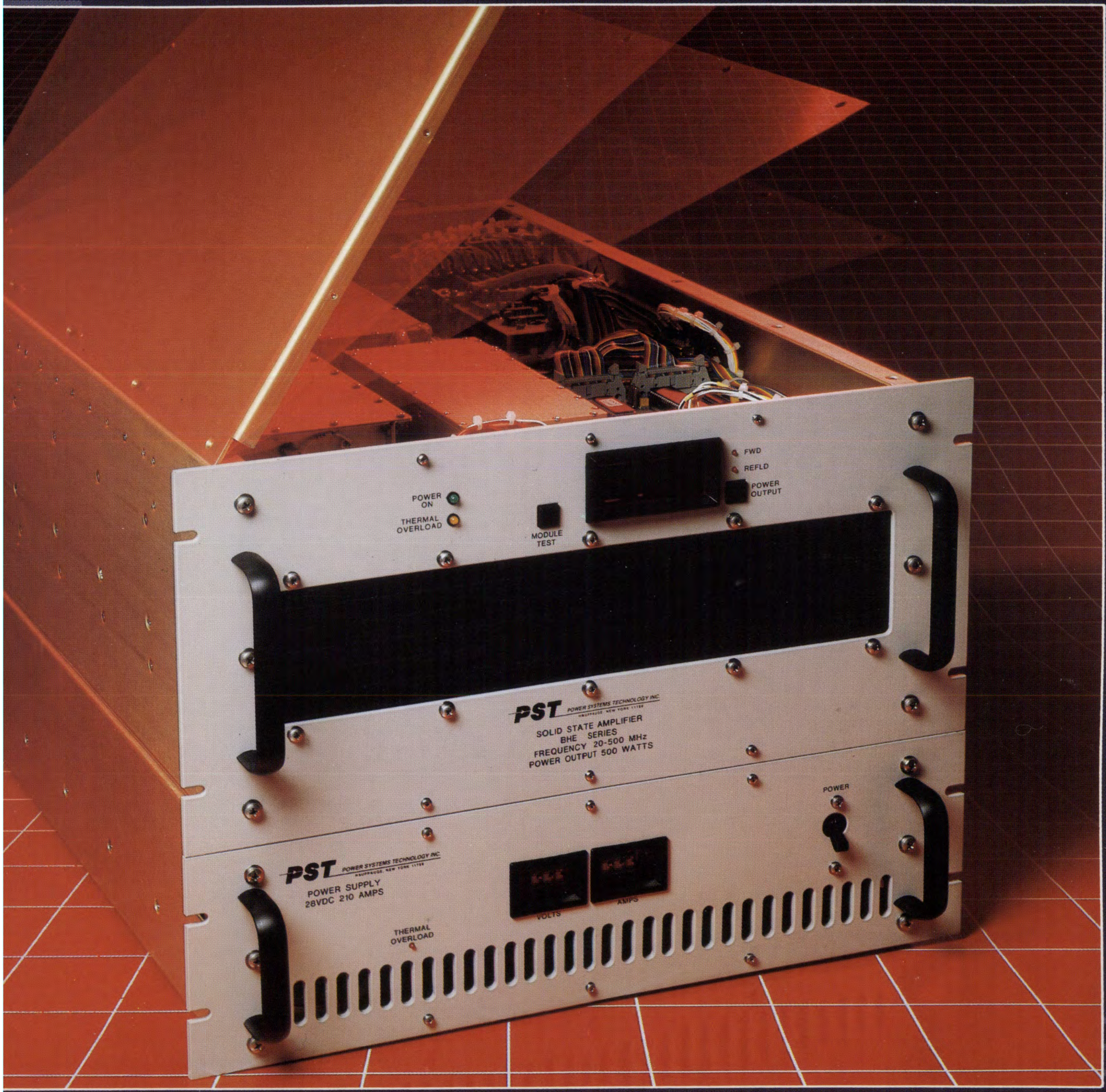
# RF design

engineering principles and practices

January 1992

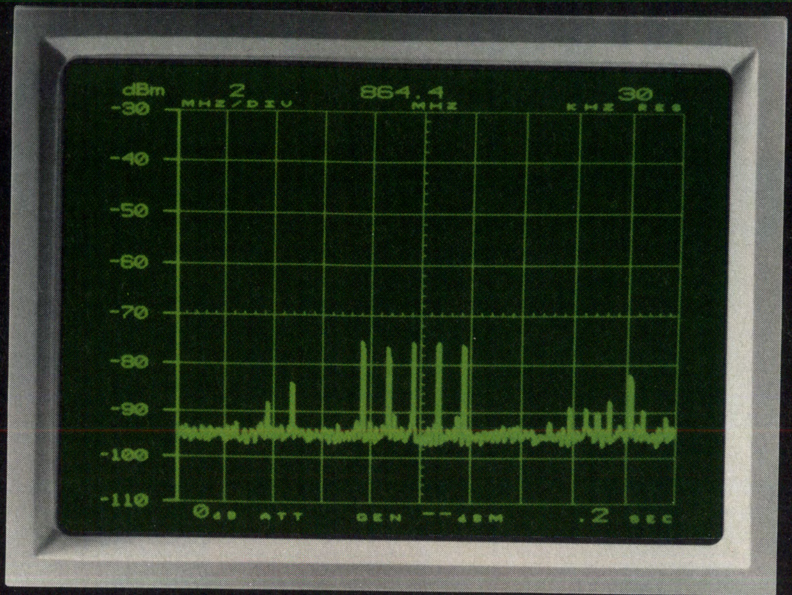



*Cover Story*
**Inside a 500-watt Amplifier**

*Featured Technology*
**Antenna Design**

*Plus—*
**New Tutorial Series**

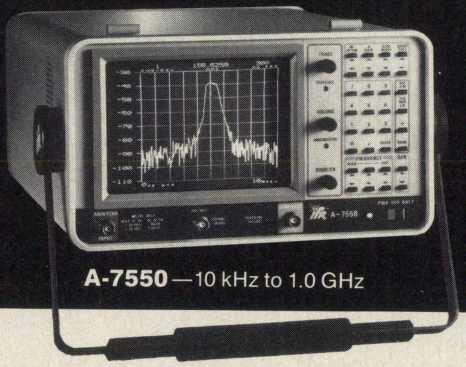
# If you're not using a spectrum analyzer...



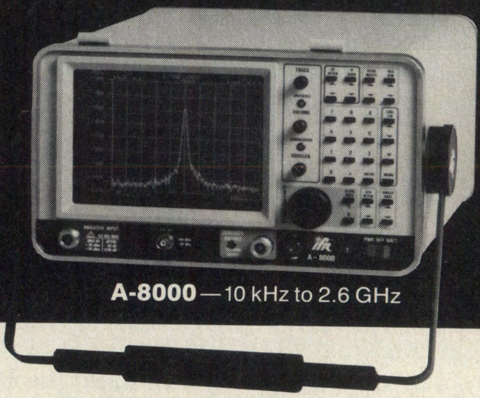

Spectrum analyzer display of cellular telephone transmissions.

# maybe it's time to take a closer look.

## IFR Spectrum Analyzers



**A-7550** — 10 kHz to 1.0 GHz



**A-8000** — 10 kHz to 2.6 GHz

You can't hear them or see them, but there are probably thousands of electromagnetic signals being transmitted through the air around you at this very moment.

Many of these signals originate from radio and television transmission. However, many other signals are emitted from computers, CRT display terminals, and other electrical devices.

Each of these signals can be a potential source of harmful interference to sensitive electrical equipment or critical systems you are operating.

The IFR A-7550 and A-8000 Spectrum Analyzers provide a full set of features to speed the identification and measurement of signals over a wide frequency range.

Optional built-in features including a rechargeable battery, tracking generator, sensitive AM/FM/SSB receiver, IEEE-488 interface, RS-232 interface, and quasi-peak detector allow either instrument to be configured to your unique testing requirements at a surprisingly affordable price.

*For more information or a demonstration of the A-7550 or the A-8000, contact your local IFR representative or call IFR at (316) 522-4981.*

Ing. Frans C. de Haan
Postbus 5156
2000 GD Haarlem NL

**IFR SYSTEMS, INC.**
10200 West York Street
Wichita, Kansas 67215-8935 U.S.A.
FAX 316/524-2623

INFO/CARD 2

# RF design

January 1992

## featured technology



## cover story

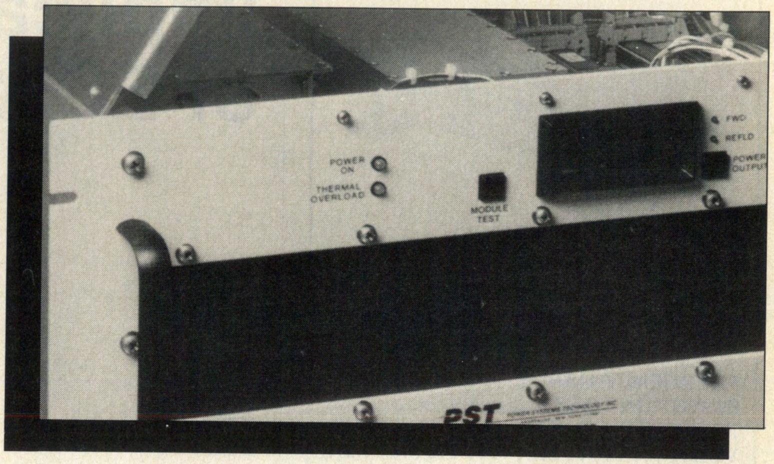


## tutorial



## design awards






## departments

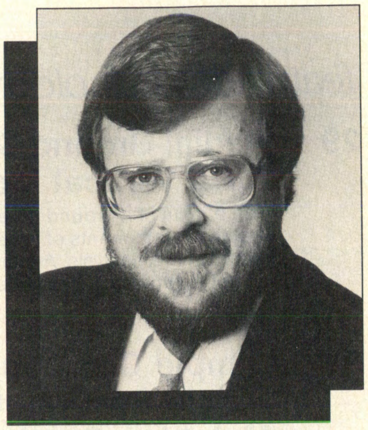



R.F. DESIGN (ISSN: 0163-321X USPS: 453-490) is published monthly plus one extra issue in September. January 1992. Vol. 15, No. 1. Copyright 1992 by Cardiff Publishing Company, a subsidiary of Argus Press Holdings, Inc., 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111 (303) 220-0600. Contents may not be reproduced in any form without written permission. Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: *RF Design*, P.O. Box 1077, Skokie, IL 60076. Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $38 per year in the United States; $48 per year in Canada and Mexico; $52 (surface mail) per year for foreign countries. Additional cost for first class mailing. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $5.00 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 Zeeb Road, Ann Arbor, MI 48106 USA (312) 761-4700.

**SUBSCRIPTION INQUIRIES: (708) 647-0756.**

POSTMASTER & SUBSCRIBERS: Please send address changes to R.F. Design, P.O. Box 1077, Skokie, IL 60076.

# Implications of EC92



*By Gary A. Breed*
*Editor*

This year marks the official beginning of an economically unified Europe; with that union to be completed by December 31, 1992.

Is this as much of a "big deal" as we have been led to believe? Yes, it is! Is it something we should fret, worry, and lose sleep over? Only for a while.

A few analysts claim that Europe will not be able to achieve their goal of economic unity. I disagree. The implementation of common trade and monetary standards may see some roadblocks and detours, but I am firmly convinced that Europe has come to the clear realization that they can wield tremendous worldwide economic power through cooperation. That power will be sufficient to place Europe in the same league as the U.S. and Japan in all matters, not limited to the industrial base of Germany, the influential traditions of Great Britain, or the international marketing expertise of France and Italy.

How will this affect you and me? Well, it already has taken up plenty of our planning and research time. As the EC92 plan is implemented, it will become somewhat more difficult to sell U.S. goods in Europe, partly because new European regulations will require re-certification for such things as EMC and product safety. We will see greater competition from other European nations, since trade among EEC member states will be much simpler.

In the near-term, we will see a degree of confusion as new standards and procedures are implemented. This will make marketing products a real adventure in some cases. We will certainly see some protectionist attitudes develop in Europe, and some kind of response from the U.S. Hopefully, this will be minor and short-lived. The EC92 plan will change the way Europe does business with the rest of the world, but it is not designed to be protectionist.

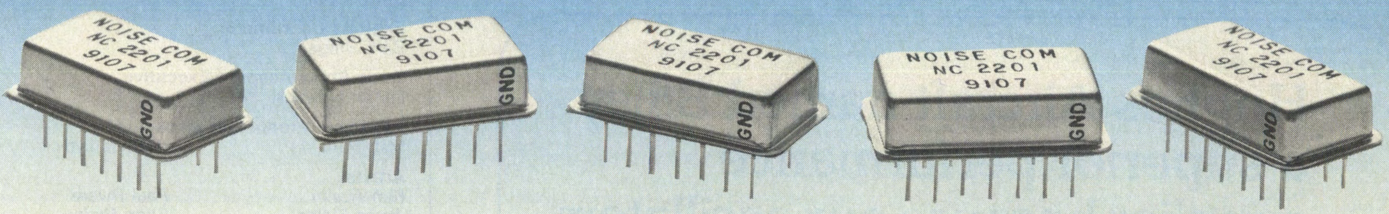
In the long run, I believe we will see benefits from this economic cooperation. A stronger European economy will have a positive worldwide impact. With Eastern Europe and the dissolving Soviet Union in economic disarray, it is essential that they have strong, stable neighbors. Once the plan is complete, it may actually be easier to sell into Europe, because one set of rules will apply to all countries, eliminating the need to deal with them one at a time.

My analysis is intentionally generalized, because the situation will be different for each company selling into Europe or buying European goods. Those companies which have established good trade relationships are not likely to be suddenly faced with closed markets! It may be more difficult to generate new business, but that will depend on the particular products involved.

There is one thing that could change my sanguine attitude toward EC92 — politics! My cynical side keeps reminding me that all of this depends on the people in power. Although it appears that even the most reluctant European leaders see the value of a unified economy, the delicate balance could be upset if any of the major nations has a dramatic shift in leadership. U.S. politicians could make life miserable for all of us by implementing anti-European trade policies before all of the bugs are worked out of the system.

Let's give it a fair chance. The Europeans are committed to making things work, and we should help them achieve their goals rather than fight them. After all, EC92 is all about cooperation, isn't it?

# Up to 1000 MHz
# Up to +5 dBm
# 14-pin DIP




## Noise Com introduces high-power drop-in noise sources...from stock.

When you need the finest high-output noise sources in a 14-pin package for PC board mounting – and you need them fast – look to Noise Com, the leader in noise source technology.

Our NC 2000 amplified noise sources deliver up to +5 dBm output from 1 to 100 MHz. They're available in +15 VDC or +12 VDC models, as well as with TTL control, MIL-E-5400T performance, and with other custom features.

And if you need them fast, we'll ship them to you the same day. Just give Noise Com a call at (201) 261-8797, and ask for Gary Simonyan.

**NC 2000 Series Specifications**

| | NC 2201 | NC2301 | NC2401 | NC2501 |
|---|---|---|---|---|
| Frequency range (MHz) | 1 to 100 | 1.5 to 300 | 1 to 500 | 1 to 1000 |
| Output power (dBm) | +5 | 0 | 0 | –5 |
| Flatness (dB) | +/–1 | | | |
| Load impedance (ohms) | 50 | | | |
| Operating voltage (VDC) | 12 or 15 | | | |
| Operating temperature (°C) | –0 to +85 | | | |
| Temperature coefficient | 0.025 dB/°C | | | |
| Package | 14 pin DIP | | | |

NOISE/COM

*Number One in Noise Sources.*

E. 49 Midland Avenue, Paramus, New Jersey 07652
(201) 261-8797 • FAX: (201) 261-8339

***Noise Com now offers noise source calibration traceable to NIST too!***

INFO/CARD 5

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

### The Right Tool

Editor:

I agree with Susan F. Smith's comments, Letter to the Editor, October 1991, that engineering should be done using the most cost-effective and reliable solutions available. I am not convinced she has come to the proper conclusions. In any event, I would like to present my view of engineering tools to your readers.

One must choose the proper tool for the proper job. I would no sooner use a steam shovel to plant a rose bush, than I would use BASIC to find the spectrum of a pn sequence.

There are many software tools available to the engineer. Each has its strength and weakness. The engineer whose task it is to solve a problem, must have knowledge of these tools.

To solve the problems that I routinely encounter in the design of RF communications equipment, I resort to a number of tools. These include a linear "S" parameter package such as Touchstone or Super Star, a circuit simulation program such as PSpice, a communications simulator such as Tess, a mathematical analysis program such as Mathcad, and a collection of analysis and synthesis software written in BASIC, Fortran, Pascal and C.

As an example, I recently had the problem of squeezing the spectrum of a spread spectrum signal into the FCC's mask. To analyze the proposed solution, one engineer used Mathcad and one used PSpice. Not satisfied with the results, I set up the analysis using Tess. It took less time to program than the other approaches (to be fair I had previously created a file to generate the pn sequence).

It is sometimes difficult to decide what tool to use to solve a problem. To make such a decision we must be familiar with the tools. We must decide if it is worthwhile to acquire and become proficient with a tool. Another possibility is to enlist the help of a colleague who is proficient with the proper tool.

Gerald S. Harrison
Syosset, NY



*RF design*

a Cardiff publication — Established 1978

Main Office:
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111 • (303) 220-0600
Fax: (303) 773-9716

**Publisher**
Kathryn Walsh

**Editor**
Gary A. Breed

**Associate Editor**
Liane Pomfret

**Consulting Editor**
Andy Przedpelski

**Associate Sales Manager**
Bill Pettit

**Account Executive**
Maryanne Averill
Main Office

**Account Executive**
Cindy Wieland
Main Office

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

**Advertising Services**
Tisha Boberschmidt Hill

**Secretary**
Theresa Maier

**Convention Manager**
Kristin Hohn

**Registration Coordinator**
Dawn Keith

**Exhibits Coordinator**
Barb Binge

**Trade Show Account Executive**
LeAnn Nowacki

**Associate Production Managers**
Matt Park, Maurice Lydick

**Artists**
Kim Austin, Joyce Fields, Brad Fuller, Paul Rivera, Sheri Ryder

**Composition**
Mike C. Moore, Marcie Tichenor

**Creative Director**
Bob Stewart

Published by

CARDIFF PUBLISHING COMPANY, INC — BPA

**President**
Robert A. Searle

**Vice President — Production**
Cherryl Greenman

**Vice President — Convention Management**
Kathy Kriner

**Treasurer**
Jennifer Burger

**Circulation Director**
Patricia Shapiro

**Credit Manager**
Tim Gleason

Please address subscription inquiries to:
RF Design
P.O. Box 1077, Skokie, IL 60076-9931
Postmaster: send form 3579
to the above address.

# *RF* calendar

## January

**13-16** **ATE & Instrumentation Conference**
Anaheim, CA
Information: Miller Freeman Expositions, 1050 Commonwealth Ave., Boston, MA 02215-1135. Tel: (800) 223-7126. Fax: (617) 232-0854

**27-31** **Communications Networks '92**
Washington, DC
Information: World Expo Corp., Barbara Inglese, PO Box 9107, 111 Speen Street, Framingham, MA 01701-9107. Tel: (800) 545-EXPO. Fax: (508) 872-8237.

## February

**18-20** **International Mobile Communications Expo/Spring**
Las Vegas, NV
Information Cardiff Publishing, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600. Fax: (303) 770-0253.

## March

**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

**1-8** **Hannover Fair Industry '92**
Hannover Fairgrounds, Hannover, Germany
Information: Hannover Fairs USA Inc., 103 Carnegie Center, Princeton, NJ 08540. Tel: (609) 987-1202.

**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

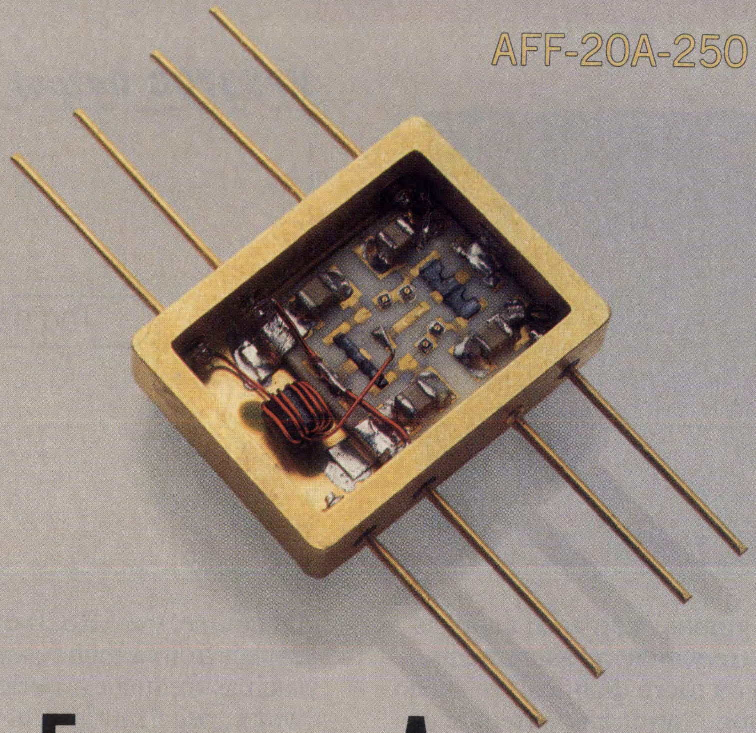
**4-8** **InfoCom '92**
Florence, Italy
Information: Maurizio Decina/ Vittorio Trecordi, Consorzio Cefriel, Viale Sarca 202, 20126 Milan, Italy. Tel: (39-2) 66-100083. Fax: (39-2) 66-100448.

**12-14** **IEEE Instrumentation and Measurement Technology Conference**
Meadowlands Hilton, NJ
Information: Robert Myers, 3685 Motor Avenue, Ste. 240, Los Angeles, CA 90034. Tel: (310) 287-1463. Fax: (310) 287-1851.

Merrimac

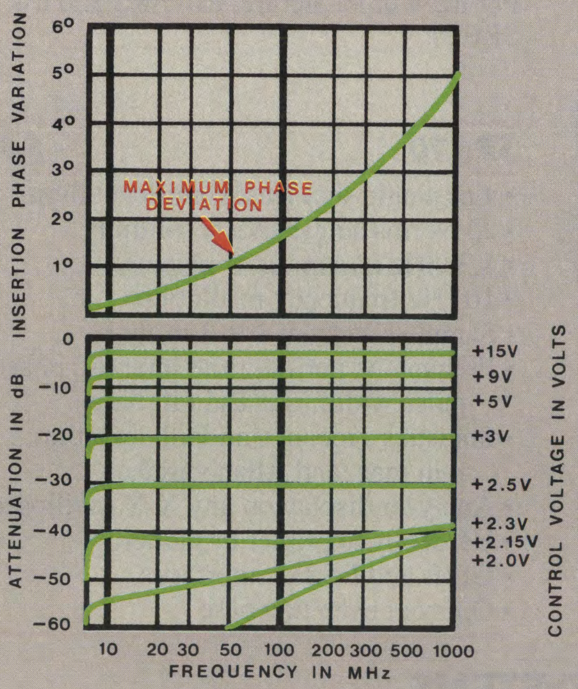
# CONSTANT-PHASE

AFF-20A-250



## ELECTRONIC ATTENUATOR

### Multi-Octave, Pin Diode Control, Flatpack




- Constant Phase
- 20dB Min. Attenuation Range
- Low Profile (0.15″) HiRel Package
- Delivery From Stock


Merrimac Industries Inc.
41 Fairfield Place
West Caldwell, NJ 07006

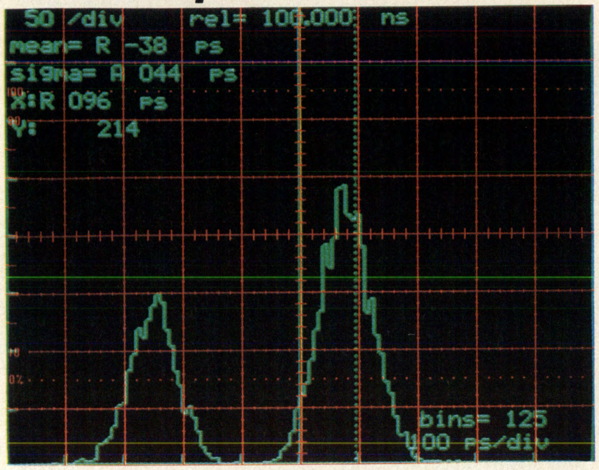

**FOR ADDITIONAL INFORMATION:**

CALL – 201-575-1300
FAX – 201-575-0531

INFO/CARD 9

# A picture is worth a thousand points in a time interval measurement.

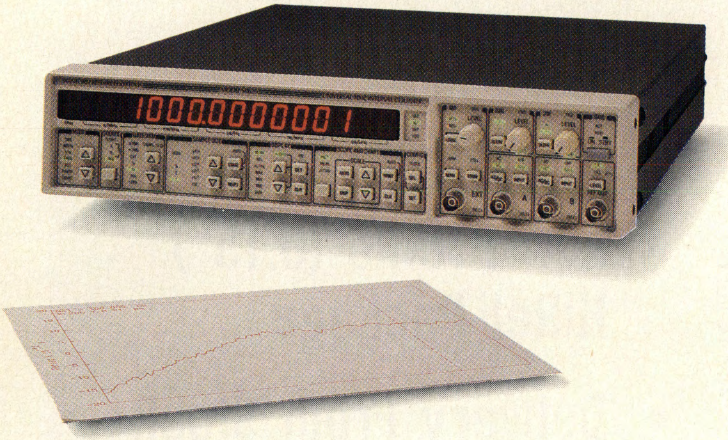
### SR620 Output




### HP5370B Output

100.038 ns

The SR620 brings graphic statistical analysis to time interval and frequency measurements. The SR620 shows you more than just the mean and standard deviation - multimode frequency distributions or systematic drift for example. Histograms or time variation plots are displayed on any X-Y oscilloscope, complete with Autoscale, Zoom, and Cursor functions. Hardcopy to plotters or printers is as easy as pushing a button.




Of course, the SR620 does everything else you'd expect from a high resolution universal counter, such as frequency, period, time interval, pulse width, rise / falltime, and phase measurements. The SR620 offers 25 ps single-shot time and 11 digit frequency resolution and complete statistical analysis, all for a fraction of the cost of comparable instruments.

For the whole picture, call SRS and ask about the SR620.

| SR620 | $4500 |
|---|---|

- 4 ps single shot least significant digit
- 25 ps rms single shot resolution
- 1.3 GHz maximum frequency
- $10^{-9}$ Hz frequency resolution
- Sample size from 1 to 1 million
- Frequency, period, time interval, phase, pulse width, rise and fall time
- Statistics - mean, standard deviation, min max, and Allan variance
- Analyzer display on any X-Y oscilloscope
- Hardcopy to printer or plotter
- GPIB and RS232 interfaces
- Optional oven timebase

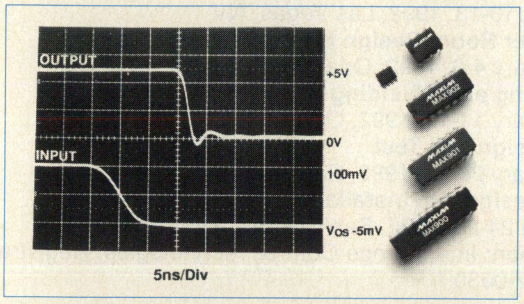
SRS STANFORD RESEARCH SYSTEMS

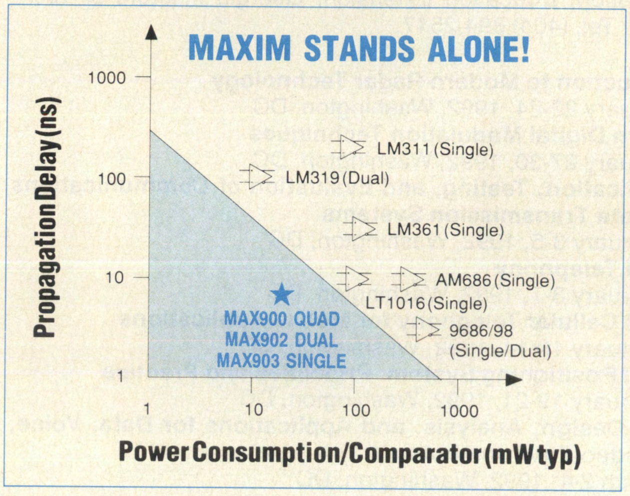
1290 D Reamwood Avenue, Sunnyvale, CA 94089 TEL (408) 744-9040 FAX 4087449049 TLX 706891 SRS UD

INFO/CARD 75

# WORLD'S LOWEST POWER HIGH SPEED COMPARATOR– 18mW, 8ns!

Maxim now offers you a selection of the fastest low-power single, dual and quad TTL comparators. For example, the new MAX903 can deliver an 8ns response time, while drawing only 3.6mA (18mW) per comparator from a +5V supply (enabling signals in excess of 100MHz to be processed). Although other comparators may operate from a single supply, the MAX900 series are the only high-speed comparators with an input voltage range that extends down to ground. In many applications this eliminates the negative supply, saving board space, power consumption and cost!



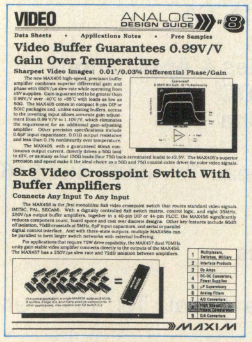




- **Separate Analog and Digital Supplies Allow:**
  **Single +5V to +10V Analog Supply**
  **Split ±5V for Bipolar Operation**
- **Input Range Includes Ground and Eliminates Need for Negative Supply**

## Select A High Speed Comparator For Your Low Power Application

| Device | # Comps | Prop Delay (ns) Typ | Prop Delay (ns) Max | Power Consumption (mW) | Single +5V Operation | Input Voltage (Single +5V Supply) | TTL Outputs | Price† |
|---|---|---|---|---|---|---|---|---|
| MAX900 | 4 | 8 | 10 | 70 | YES | -100mV to +2.5V | Single Ended | $7.01 |
| MAX901 | 4 | 8 | 10 | 70 | YES | -100mV to +2.5V | Single Ended | $5.98 |
| MAX902 | 2 | 8 | 10 | 35 | YES | -100mV to +2.5V | Single Ended | $4.01 |
| MAX903 | 1 | 8 | 10 | 18 | YES | -100mV to +2.5V | Single Ended | $3.15 |
| MAX912[1] | 2 | 8 | 10 | 40 | YES | -100mV to +2.5V | Complementary | $4.00 |
| MAX913[1] | 1 | 8 | 10 | 25 | YES | -100mV to +2.5V | Complementary | $3.13 |
| LT1016[1] | 1 | 10 | 14 | 125 | YES | +1.25V to +3.5V | Complementary | $3.13 |

1: Upcoming new products—available after March, 1992




## *FREE* High Speed Comparator Design Guide

**Includes: Application Notes ♦ Data Sheets ♦ Cards For Free Samples**

To receive your design guide, simply circle the reader response number, or contact Maxim Integrated Products, 120 San Gabriel Drive, Sunnyvale, CA 94086, (408) 737-7600, FAX (408) 737-7194.

MAXIM

**Distributed by Arrow, Bell/Graham, Elmo, Hall-Mark, Nu Horizons, Pioneer, and Wyle.** Authorized Maxim Representatives: Alabama, (205) 830-0498; Arizona, (602) 730-8093; California, (408) 248-5300, (619) 278-8021, (714) 261-2123; (818) 704-1655; Colorado (303) 779-8060; Connecticut, (203) 384-1112; Delaware, (609) 778-5353; Florida, (305) 426-4601, (407) 830-8444; Georgia, (404) 447-6124; Idaho, (503) 292-8840; Illinois, (708) 358-6622; Indiana, (317) 844-8462; Iowa, (319) 393-2232; Kansas, (816) 436-6445; Louisiana, (214) 238-7500; Maryland, (301) 644-5700; Massachusetts, (617) 329-3454; Michigan, (313) 352-5454; Minnesota, (612) 941-9790; Mississippi, (205) 830-0498; Missouri, (314) 839-0033, (816) 436-6445; Montana, (503) 292-8840; Nebraska, (816) 436-6445; Nevada, (408) 248-5300; New Hampshire, (617) 329-3454; New Jersey, (201) 428-0600, (609) 778-5353; New Mexico, (602) 730-8093; New York, (516) 351-1000, (607) 754-2171; N. Carolina, (919) 851-0010; Ohio, (216) 659-9224, (513) 278-0714, (614) 895-1447; Oklahoma, (214) 238-7500; Oregon, (503) 292-8840; E. Pennsylvania, (609) 778-5353; W. Pennsylvania, (614) 895-1447; S. Carolina, (919) 851-0010; Tennessee, (404) 447-6124; Texas, (214) 238-7500, (512) 835-5822, (713) 789-2426; Utah, (801) 561-5099; Virginia, (301)644-5700; Washington, (206) 823-9535; W. Virginia, (513) 278-0714; Wisconsin, (414) 476-2790; Canada, (416) 238-0366, (613) 225-5161, (604) 439-1373, (514) 337-7540.

† 1000-up FOB USA, suggested resale



INFO/CARD 10

**RF/Microwave Circuit Design: Linear/Nonlinear Theory and Applications**
January 27-31, 1992, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (213) 825-3344. Fax: (213) 206-2815.

**Coherent Radar Performance Estimation**
January 14-16, 1992, Atlanta, GA
**Antenna Engineering**
February 4-7, 1992, Atlanta, GA
**Infared/Visible Signature Suppression**
April 28-May 1, 1992, Atlanta, GA
Information: Education Extension, Georgia Institute of Technology. Tel: (404) 894-2547.

**Introduction to Modern Radar Technology**
January 22-24, 1992, Washington, DC
**Modern Digital Modulation Techniques**
January 27-30, 1992, Washington, DC
**Specification, Testing, and Evaluation of Communications and Data Transmission Systems**
February 3-5, 1992, Washington, DC
**Digital Telephony**
February 3-7, 1992, Washington, DC
**Digital Cellular Telephony for Mobile Applications**
February 10-14, 1992, Washington, DC
**Global Positioning System: Principles and Practice**
February 19-21, 1992, Washington, DC
**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
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.

**How to Meet EMI/TEMPEST Shielding Requirements for Rooms & Facilities (Includes an Intro to Theory and a Review of the New NSA 89-02 and NTISSI 7000)**
February 3-6, 1992, San Diego, CA
**Physical Security Standards for Sensitive Compartmented Information Facilities (SCIF)**
February 7, 1992, San Diego, CA
Information: Praxis International. Tel: (215) 524-0304.

**ESD Design and Testing**
January 23, 1992, Novi, MI
Information: S.E. Michigan IEEE EMC Society. Tel: (313) 597-3950 or Jastech. Tel: (313) 553-4734.

**DSP Without Tears**
February 12-14, 1992, Scottsdale, AZ
March 24-26, 1992, Seattle, WA
Information: Right Brain Technologies. Tel: (800) 967-5034. Fax: (404) 975-0642.

**Practical EMI Fixes**
January 13-17, 1992, San Francisco, CA
March 9-13, 1992, Washington, DC
**Introduction to EMI/RFI/EMC**
January 28-31, 1992, Orlando, FL
March 10-13, 1992, Las Vegas, NV
**Computer Room Design for Interference Control**
February 4-6, 1992, Orlando, FL
**Grounding and Shielding**
February 11-14, 1992, Orlando, FL
**EMC Design and Test**
February 24-28, 1992, San Francisco, CA
**Cable Design and Installation**
March 24-26, 1992, San Diego, CA
Information: Interference Control Technologies, Registrar. Tel: (703) 347-0030.

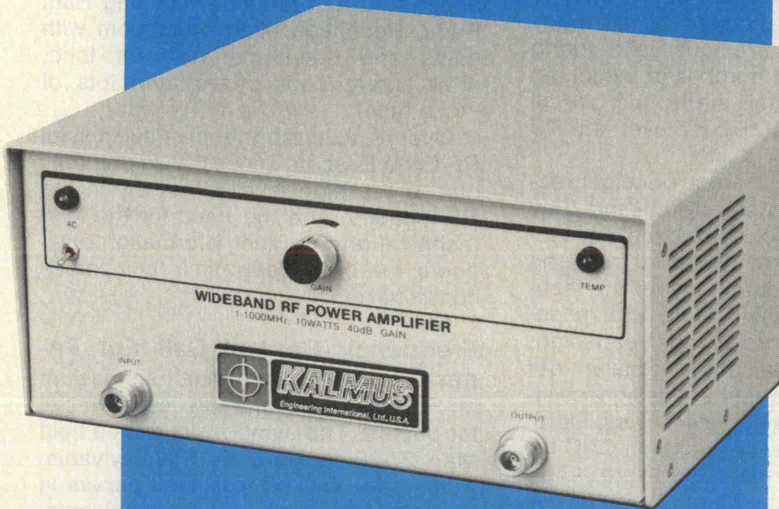
**Understanding Data Converter Frequency Domain Specifications**
January 20, 1992, Bellevue, WA
January 22, 1992, Sunnyvale, CA
January 23, 1992, Van Nuys, CA
January 24, 1992, Goleta, CA
Information: Datel. Tel: (508) 339-3000 ext. 240.

**Introduction to Telecommunications**
January 21-24, 1992, San Diego, CA
January 28-31, 1992, Vancouver, BC
February 11-14, 1992, Washington, DC
February 25-28, 1992, Toronto, Canada
March 17-20, 1992, Los Angeles, CA
**Introduction to Datacomm and Networks**
January 28-31, 1992, Washington, DC
February 4-7, 1992, San Francisco, CA
February 25-28, 1992, Washington, DC
**Hands-On Datacomm Troubleshooting**
January 21-24, 1992, Los Angeles, CA
February 11-14, 1992, Washington, DC
February 25-28, 1992, San Francisco, CA
March 17-20, 1992, Boston, MA
**Digital Signal Processing: Techniques & Applications**
January 21-24, 1992, Washington, DC
January 28-31, 1992, Ottawa, Canada
February 4-7, 1992, San Diego, CA
Information: Learning Tree International. Tel: (800) 421-8166, (703) 893-3555, (203) 417-8888.

**The Smith Chart and Its Applications**
March 16,1992, San Diego, CA
Information: Besser Associates, Eva Koltai. Tel: (415) 949-3300.

**Digital Signal Processing Control**
January 27, 1992, Dayton, OH
January 29, 1992, Minneapolis, MN
January 31, 1992, Denver, CO
Information: Texas Instruments. Tel: (800) 336-5236 ext. 700.

# NEW from KALMUS...



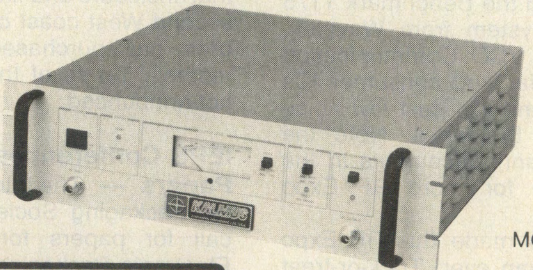

**Model 710FC**
- ★ 10 Watts Output
- ★ 1-1000 MHz Broadband
- ★ 40 dB Gain
- ★ 10 dB Gain Adjust
- ★ Only 16 Pounds
- ★ MOS-FET Efficiency
- ★ 19" Rack Adapters Included

UP TO
# 200W/1000MHz LINEAR RF AMPLIFIER SYSTEMS

| MODEL | POWER OUT | FREQUENCY RANGE | GAIN | SIZE (CM) | WEIGHT | AC LINE | U.S. PRICE $ |
|---|---|---|---|---|---|---|---|
| 700LC | 1.5W CW | .003-1000 MHz | 33dB | 25x28x13 | 3.3kg | 100-240V | $ 1,695 |
| 704FC | 4W CW | .5-1000 MHz | 33dB | 23x18x09 | 2.8kg | 100-240V | $ 2,195 |
| 706FC | 6W CW | .5-1000 MHz | 36dB | 25x28x13 | 3.3kg | 100-240V | $ 3,195 |
| 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.

MODEL 704FC



MODEL 707FC

KALMUS
Engineering International, Ltd., U.S.A.

21820 87TH SE
WOODINVILLE, WA 98072

(206) 485-9000
FAX: (206) 486-9657

INFO/CARD 12

## RF Expo East Draws 1400 to Orlando

The activity of the RF industry was reflected in the sixth RF Expo East, held this past October 29-31. Despite the sluggish economy, this trade show and conference was attended by as many engineers as the previous year. Along with an increased number of exhibiting companies and their staffs, the overall attendance was the best ever for RF Expo East.

Technical papers are a principal reason for engineers to attend, and they had another collection of excellent topics to choose from. Support from the RF engineering community for the technical papers remains high, with especially popular papers on receiver design, CDMA spread-spectrum, cellular design, consumer equipment design, oscillators, filters, and power amplifiers. Three-hour tutorial sessions on CAD for RF design (Compact Software engineers, organized by Murat Eron), power amplifiers (Nathan Sokal), and low noise amplifier design (Richard Webb) were presented to overflow audiences.

The formal short courses saw their best RF Expo East attendance, as well. An updated Filters and Matching Networks class, taught by Randy Rhea saw the biggest increase, with his Oscillator Design popular, as well. Fundamentals of RF Circuit Design, Parts I and II, taught by Les Besser each had 100 engineers in attendance. This also represents an increase. The demand for this kind of formal instruction is an indication that RF expertise is in high demand.

Exhibiting companies brought a tremendous number of new and recently-developed products to the show. The slow overall economy seems to have stimulated many RF manufacturers to speed up development time and to push hard on new technologies and manufacturing methods. A few of the many new products included the Benchmark 1175 Bench Sweep System from Wavetek, new VCOs from VCO Communication Corp., new cellular and consumer ICs from Signetics, and low cost low noise transistors from Bipolarics. Note the special product announcements in the November issue for more RF Expo introductions.

Special events made this RF Expo East more fun than ever. Trick-or-treat food and drink was provided in the exhibit hall on the 31st, with a special final-day prize drawing held at the end of the Expo. During the three-day exhibition, at least 20 prize drawings were held for everything from golf putters to CD players, a special bonus for a few attending engineers. The opening hors d'oeuvres and cocktail party for speakers and exhibitors was a good way to begin, and a Wednesday evening Ham Radio Reception filled a ballroom with hams and non-hams alike for food, drink, great door prizes, and lots of "tech talk."

Overall, this was the most successful RF Expo East. Its success was primarily due to the high level of activity in the RF industry, and the need for the kind technical and product information engineers need to keep their companies competitive.

**Frequency Control Call For Papers** — The 46th Annual Symposium on Frequency Control has issued a call for papers. The symposium will be held May 27-29 in Hershey, Pennsylvania. Authors are invited to submit papers in the following areas: fundamental properties of piezoelectric crystals, theory and design of piezoelectric resonators, filters, SAW devices, applications, measurements and specifications, quartz crystal oscillators, microwave and millimeter wave oscillators, synthesizers, frequency and time coordination and distribution, noise phenomena and aging, sensors and transducers, synthesizers, and atomic and molecular frequency standards. A 500 word summary should be sent by January 10 to Mr. Jack Kusters, 52U/07, Hewlett-Packard Co., 5301 Stevens Creek Blvd., PO Box 58059, Santa Clara, CA 95052-8059. Tel: (408) 553-2041.

**Lindgren Acquires Lectromagnetics** — Lindgren RF Enclosures recently announced the acquisition of the assets of LectroMagnetics. LMI's primary market is composed of government, defense and commercial/industrial enclosure and filter sales. This is the second West coast operation that Lindgren has purchased in the last six months. Terms of the acquisition were not announced.

**IEPS Conferences Issues Call For Papers** — The International Electronics Packaging Society has released a call for papers for the International Electronic Packaging Conference to be held in Austin, Texas on September 27-30, 1992. Abstracts are being sought in the following areas: device packaging, chip on board, packaging for surface mount, ceramic technology, interconnects for packaging, modeling and simulation, design for test and more. A eight copies of a 300 word abstract must be submitted before February 1, 1992. They may be sent to 1992 IEPS Program Committee, 114 N. Hale Street, Wheaton, IL 60187. Tel: (708) 260-1044.

**MCC Devices Moves** — MCC Devices, a manufacturer of microwave control components and assemblies, has moved to a larger facility. Their new address is 27 Brookfield Drive, RD 1, Box 798, Lafayette, NJ 07848. Their telephone is: (201) 383-5888.

**RF Identification Joint Venture** — Ramtron International recently announced that they have received a multi-million dollar payment from Racom Systems for a worldwide license allowing the use of Ramtron's ferroelectric RAM technology in RF based automated electronic identification systems. Recom is a joint venture company owned by Racom Systems and INTAQ International Ltd.

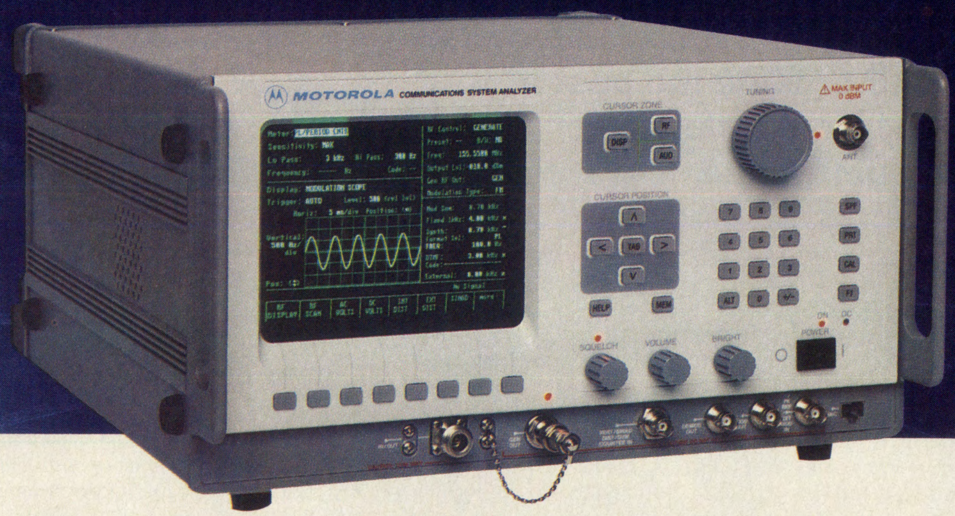
**Regional EMC Symposium Issues Call For Papers** — A call for papers has been issued for the 1992 Regional Symposium on EMC to be held in Tel-Aviv, Israel on November 2-5, 1992. The main topic of the symposium is "Europe 1992 EMC Directive - Its Applications and Implications." Authors are invited to submit papers on the current state of EMC technology. Four copies of a 50-75 word summary and a 500-700 word extended abstract in English should be sent to EMC '92 Symposium Secretariat, Ortra Ltd., PO Box 50432, Tel Aviv, 51500, Israel, by February 15.

**HP Completes Acquisition** — Hewlett-Packard has announced completion of their $82.8 million acquisition of Avantek Inc. The combined organization will target the worldwide communications market, which includes telecommunication and data-communication products such as cellular radios, cordless telephones, high-speed fiber-optic systems and direct-broadcast satellite receivers.

**MIC Workshop Requests Papers** — A call for papers has been issued for the 1992 MIC Workshop, scheduled for April 26-29, 1992 in Carlsbad, Calif.

# FUTURE SHOP

## NAMPS CELLULAR TEST




## AVAILABLE TODAY.

All that test equipment you've been using, with its endless cabling and "we mean business" knobs and switches, has served you well over the years. But some day you're going to need to replace it.

That someday is today.

Digital testing is a reality. Cellular testing is big business. Software driven testing is the future, and it's available now...In one box.

The R2600 from Motorola.

The R2600 handles NAMPS high capacity cellular systems, autotest, inbound and outbound calling, and full diagnostic capability while on cellular channels; full screen spectrum analyzer, 50MHz wideband tracking generator, sensitive "off-the-air" receiver - comprehensive total test capability not offered by any other manufacturer.

There's no need to replace old equipment one-for-one when you can have dozens of test functions in one box. Easy to use, easy to set up, transportable, intuitive to operate, economical, and upgradeable.

With the R2600, your shop will always be *future shop.*

For information on establishing your ***future shop,***
Call **1-800-424-0052**
or call (602) 441-8676, or write:
P.O. Box 2606 M/D H3170 Scottsdale, AZ 85252

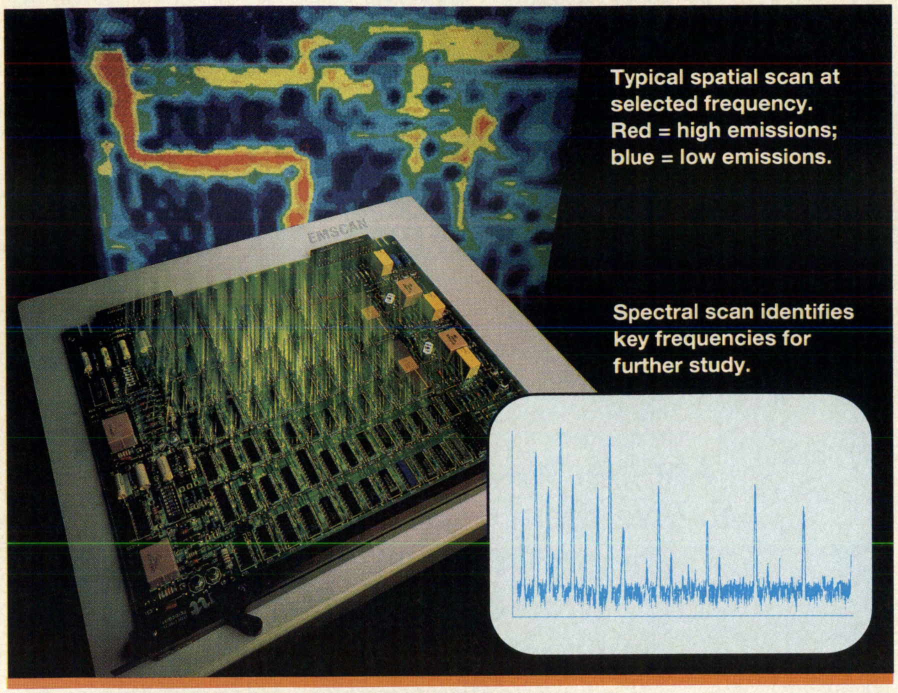
**MOTOROLA**



INFO/CARD 14


1,628 reasons to call
APPLIED ENGINEERING PRODUCTS
The reason we have so many customers is that we have so many *satisfied* customers. All of our efforts to provide the best in customer service, prompt delivery, second-to-none quality, and competitive pricing are aimed at keeping our customers by keeping them happy.
AEP SUBMINIATURE COAXIAL CONNECTORS: SMA • SMB • SMC • MIL-C 39012 QPL • SSMB
AEP


If that's not enough, here are 14,421 more.
Another way to keep customers happy is to give them what they want. Our product line growth has been based on making what our customers need, often by engineering less-expensive variations of standard parts, saving them time and money. Wouldn't it be nice to deal with a connector company that works for *you*?
"Performance, not promises"
AEP
APPLIED ENGINEERING PRODUCTS
P.O. Box 510 • New Haven, Connecticut 06513 • USA
Telephone: 203/776-2813 • Fax: 203/776-8294
SSMC • 75 OHM • ADAPTERS • AEP CABLE ASSEMBLIES: FLEXIBLE • SEMI-RIGID
AEP
INFO/CARD 15






## RF news *continued*

Three session tracks will be offered on design, quality and test, and fabrication. Topics encompass microwave, RF, and HS/HF for advanced military, commercial and consumer product applications. Abstracts of technical papers are due by January 31 and may be sent to Mark G. Carlson, Arlon, Microwave Materials Division, 1100 Governor Lea Road, Bear, DE 19701. Tel: (800) 635-9333.

**Voltronics Moves to New Facility** — Voltronics Corporation is moving its two East Hanover, NJ plants into a new much larger facility in Denville, NJ. The new address is 100-10 Ford Road, Denville, NJ 07834. The telephone number is (201) 586-8585 and the Fax number is (201) 586-3404.

**GEC and Daico Announce Joint Venture** — Daico Industries has announced a joint marketing venture with GEC Marconi Materials. Under the agreement, Daico will provide customer service, technical and application sales support, standard and custom product design, and testing and assembly.

**Maury Microwave Relocates** — Maury Microwave Corporation has relocated its corporate headquarters including their marketing, engineering and manufacturing operations to 2900 Inland Empire Blvd., Ontario, CA 91764. Their phone and fax number remain unchanged.

**Radar Technology Awarded Contract** — Radar Technology, Inc. was recently awarded a $113,000 contract from the U.S. Army Armament, Munitions and Chemical Command for improved amplifiers. The amplifiers will be used in the Army's Vulcan Air Defense System, a light weight weapon for close-in defense against low flying aircraft and ground targets.

**Motorola to Supply Uruguay's Cellular System** — Motorola Inc.'s Radio-Telephone Systems Group has announced that Movicom has initiated the commercial service of a new cellular system in Montevideo, Uruguay. Movicom is the name of a multi-national consortium, whose major partners are Bellsouth Corp. and Motorola, Inc., that is marketing cellular services and products in Uruguay. The Advanced Mobile Phone Service 800 MHz cellular system has been supplied by Motorola and is the first to go into service in that country.

Before year's end, cellular service coverage will be extended to the resort center of Maldonado/Punta del Este, and roaming will be implemented between Uruguay and Argentina's Greater Buenos Aires area.

**U.S. Electronics Sales Up** — U.S. factory sales of electronic equipment, components and related products totaled $201.6 billion for the first three quarters of 1991, resulting in a 1.5 percent increase over last year's nine month sales of nearly $198.5 billion, according to preliminary data released today by the Electronic Industries Association. It was a mixed year, however, with components, consumer electronics, telecommunications, and electromedical equipment sales all showing an increase in sales, while computers and peripherals, industrial electronics and other communications all showed a decrease.

**Penstock Franchised by M/A-COM Anzac** — M/A-COM and Penstock have announced that Penstock will distribute the Anzac product line throughout most of North America. The Anzac product line includes conventional discrete component devices as well as a line of GaAs control devices. The addition will substantially increase Penstock sales which are projected at over $25 million for 1991.

**Phase-Noise Problem Resolved** — NIST researchers have helped resolve an important phase-noise problem for a new, fiber-optic telecommunications system called SONET. Members of an American National Standards Institute subcommittee were having difficulty defining the amount of phase noise to be tolerated by SONET. Researchers from NIST analyzed noise data collected from SONET, made recommendations on useful phase-noise measures, and served as the focal point for clarifying new network phase noise specifications.

**Globalstar System Under FCC Review** — Globalstar, a new concept for mobile satellite-based phone service that would reach even the most remote areas of the world, is in the public notice period of the FCC approval process. Globalstar is a low earth orbit satellite system that would off reliable low-cost voice and data service, as well as radio-determination services to users around the world. Loral Qualcomm Satellite Services, formed by Loral Corporation and Qualcomm Inc., plans to begin satellite construction immediately following FCC application approval, projected for April 1992. Service could begin in early 1997, and Loral Qualcomm estimates that the cost of Globalstar will be $850 million.

**Semiconductor Vendors Focus on Global Market** — According to a recent report released by Market Intelligence Research Corporation, most semiconductor production equipment vendors are focusing their attention on global markets, particularly those in Asia and Europe. The market is expected to grow at a compound annual growth rate of 11.7 percent for the 1990-1997 period and will be in excess of $17 billion by 1997. Revenue growth is expected to be driven by a number of factors such as increased use of semiconductor devices in industries other than the computer industry, increase in demand for faster devices and demand for megabit memory chips.

**New Antenna Dish Design Developed by Georgia Tech** — Engineers at the Georgia Institute of Technology have found that adding serrations shaped like flower petals to the outer edges of radar, telecommunications and satellite dishes can significantly improve their performance. The serrations gradually reduce the electrical fields reflected at the edges of the dishes, which reduces unwanted sidelobe radiation and improves control over the resulting signals. Though some experimental measurements have been done, researchers have so far relied primarily on computer simulations to study the performance of the flower petal serrations. Georgia Tech has applied for a patent covering the edge treatment, and it is believed that it would add little to the manufacturing cost of the dishes.

**RF EXPO WEST '92**

**March 18-20, 1992**

**San Diego, Calif**

# RF expo

# WEST WEST WEST WEST WEST WEST WEST WEST WEST

## TECHNICAL SESSIONS AND KEYNOTE PRESENTATION

**Top industry professionals share their knowledge on today's most important topics. RF Expo West presents the best RF-specific seminar series available. Here are a few of this year's program highlights:**

### 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

**March 18-20, 1992**
**San Diego Convention Center • San Diego, California**

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

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

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

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

SSION D-4: RF and Computers
ilding 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
vice Modeling and Harmonic Balance Simulation of RF/UHF High Power DMOS Transistor Amplifiers • Steve Hamilton and Octavius Pitzalis

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

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

SSION E-2: Frequency Synthesis
iderless Phase Locked Loops • Dr. Scott Wetenkamp
ign 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. rtinez, John Brewer

SSION 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

SSION E-4: RF Systems
dict 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** |
| **er and Matching Network Design: L-C and tributed Circuits—HF to Microwaves** | **March 17** |
| **cillator Design Principles** | **March 19** |
| **m Radio Reception** | **March 19** |

EXPO WEST is sponsored by *RF Design* magazine.

## The industry's foremost RF technology conference.

Sponsored by *RF Design* magazine, RF Expo West will be in San Diego March 18-20 at the San Diego Convention Center. And special rates are being offered for early registration.

**SEE** demonstrations of the newest equipment the industry has to offer.

**HEAR** top industry professionals share their knowledge on today's most important topics.

**JOIN** electronics engineers, engineering managers, engineering service professionals, owners and consultants at the Ham Radio Reception.

**PROFIT** by choosing from among more than 50 technical sessions.

**MEET** more than 200 industry exhibitors with the latest and best in electronic design services and equipment.

**LEARN** new skills or reinforce present knowledge by signing up for one or more of the four full-day special courses. (Fundamentals of RF Circuit Design: Parts I and II; Filter and Matching Network Design: L-C and Distributed Circuits—HF to Microwaves; Oscillator Design Principles.)

**DISCOVER** new sources for answering questions about your particular needs.

**WIN** one of several big prizes being awarded by sponsors of the Ham Radio Reception.

**COME** to RF Expo West '92 sponsored by *RF Design* magazine.

The best minds in RF Design are yours for three days, March 18-20, at the San Diego Convention Center. Register now by calling (800) 525-9154.

## Plan Now To Attend

RF Expo West is attended by electronics engineers and engineering managers working in the RF frequencies. Engineers new to high frequency circuits benefit from the numerous fundamental and tutorial programs offered. Senior engineers receive valuable updates on the latest developments in high frequency technology. In 1991, attendance was as follows:

| | |
|---|---|
| Engineers | 58% |
| Engineering Managers | 16% |
| Engineering Service Professionals | 6% |
| Owners or Officers | 11% |
| Others (including reps, buyers, consultants) | 9% |

**Call:** **1-800-525-9154 or 1-303-220-0600**
**Fax:** **1-303-770-0253**
**Write:** **RF Expo West**
**6300 S. Syracuse Way, #650, Englewood, CO 80111**

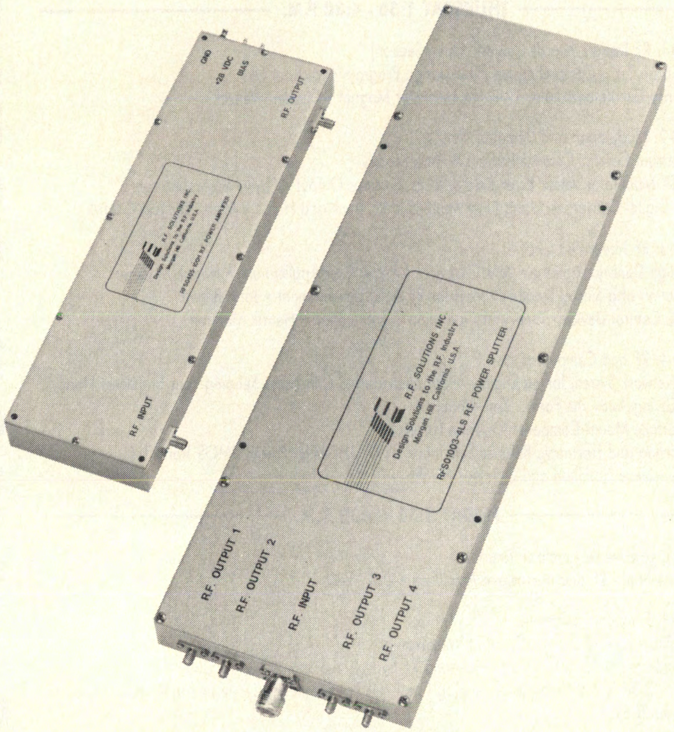
**• REGISTER NOW •**

*OFF THE SHELF*

# RF AMPLIFIERS

☐ **YES You Can Have EXPRESS DELIVERY**

| MODEL NUMBER | POWER Watts | GAIN dB | SUPPLY Volts | PRICE |
|---|---|---|---|---|
| **FREQUENCY RANGE 5 – 50 MHz** | | | | |
| RFP0550-100 | 100 | 44 | 50 | $2,100.00 |
| RFP0550-1000 | 1000 | 16 | 50 | $5,040.00 |
| **FREQUENCY RANGE 50 – 100 MHz** | | | | |
| RFP0800-100P50 | 50 | 30 | 50 | $1,485.00 |
| RFP0800-100P100 | 100 | 30 | 50 | $1,660.00 |
| RFP0800-100P200 | 200 | 30 | 50 | $2,200.00 |
| RFP800-100 | 600 | 16 | 50 | $2,424.00 |
| **FREQUENCY RANGE 1 – 100 MHz** | | | | |
| RFP01100-300 | 300 | 46 | 50 | $3,150.00 |
| **FREQUENCY RANGE 76 – 108 MHz** | | | | |
| RFP0810-600 | 600 | 16 | 50 | $1,780.00 |
| **FREQUENCY RANGE 75 – 150 MHz** | | | | |
| RFP0800-150P50 | 50 | 30 | 50 | $1,485.00 |
| RFP0800-150P100 | 100 | 30 | 50 | $1,660.00 |
| RFP0800-150P200 | 200 | 30 | 50 | $2,200.00 |
| RFP800-150 | 500 | 14 | 50 | $2,424.00 |
| **FREQUENCY RANGE 100 – 200 MHz** | | | | |
| RFP0800-200P50 | 50 | 30 | 50 | $1,660.00 |
| RFP0800-200P100 | 100 | 30 | 50 | $2,900.00 |
| RFP800-200 | 400 | 13 | 50 | $3,636.00 |
| **FREQUENCY RANGE 225 – 400 MHz** | | | | |
| RFP0204-4 | 4 | 20 | 28 | $ 484.00 |
| RFP0204-10 | 10 | 30 | 28 | $ 685.00 |
| RFP0204-25 | 25 | 30 | 28 | $1,140.00 |
| RFP0204-50 | 50 | 40 | 28 | $1,695.00 |
| RFP0204-100 | 100 | 40 | 28 | $2,200.00 |
| **FREQUENCY RANGE 400 – 500 MHz** | | | | |
| RFP0405-4 | 4 | 20 | 28 | $ 435.00 |
| RFP0405-10 | 10 | 30 | 28 | $ 616.00 |
| RFP0405-25 | 25 | 30 | 28 | $1,026.00 |
| RFP0405-50 | 50 | 40 | 28 | $1,525.50 |
| RFP0405-100 | 100 | 40 | 28 | $1,980.00 |
| **FREQUENCY RANGE 1 – 500 MHz** | | | | |
| RFP00105-4 | 4 | 20 | 28 | $1,450.00 |
| RFP00105-10 | 10 | 30 | 28 | $2,300.00 |
| RFP00105-25 | 25 | 30 | 28 | $2,800.00 |
| RFP00105-50 | 50 | 40 | 28 | $3,752.00 |
| RFP00105-100 | 100 | 40 | 28 | $5,600.00 |
| **FREQUENCY RANGE 500 – 1000 MHz** | | | | |
| RFP0510-4 | 4 | 20 | 28 | $2,610.00 |
| RFP0510-10 | 10 | 30 | 40 | $3,800.00 |
| RFP0510-25 | 25 | 30 | 40 | $4,900.00 |
| RFP0510-50 | 50 | 40 | 40 | $6,800.00 |
| RFP0510-100 | 100 | 40 | 40 | $9,800.00 |




## OTHER PRODUCTS

- Power splitters and combiners
- Directional couplers
- Standard or custom microwave amplifiers
- Filters

**R.F. SOLUTIONS INC.**

*16055 Caputo Drive, Morgan Hill, CA 95037, Phone (408) 778-9020, FAX (408) 779-4832*

INFO/CARD 19

# RF Designers Discover ASICs

By Gary A. Breed
Editor

Application-Specific Integrated Circuits (ASICs) are on the threshold of becoming viable options for many routine RF applications. Manufacturing processes and software design tools are just getting to the "real-world" stage. If you add recognition by both chip makers and design engineers that ASICs are needed for the next generation of RF products, then the obvious conclusion is that RF ASICs will be common in the future.

Digital designers have used ASICs for many years to meet specific processing or interface requirements. Low frequency analog functions were added a few years ago, especially to cover data acquisition and instrumentation requirements. Most of the early direct digital frequency synthesis products began as digital ASICs. In the microwave range, gallium arsenide (GaAs) MMICs have been developed that have similarities to both monolithic silicon chips and printed circuits. The military MIMIC program accelerated GaAs MMIC development, especially in the area of software design tools and the translation of circuit design into working devices.

In between these ranges lies RF, along with very high-speed analog and digital circuits. Silicon IC processes have been developed that can handle complex circuits operating in the 100s of MHz. Some of these processes are used for general purpose RF ICs, such as those available from Motorola and Signetics. Other companies — Analog Devices, Linear Technology, National Semiconductor and Harris Semiconductor, for example — have developed products best characterized as high-speed analog, but with some RF applications. Standard products from these companies were developed in much the same way as an RF circuit designer would approach a project.

RF engineers now have the choice of developing an ASIC instead of adapting standard parts or building a circuit with discrete components. The considerations are those already familiar to engineers: size, performance, development time, development cost, manufacturing cost, and so on. When size, manufacturing, and performance are the highest priorities, ASICs may be the best option.

### Development Tools

Key to the acceptance of ASICs by RF designers are accurate software design tools which allow circuits to be configured like familiar discrete or standard IC designs. For example, Harris Semiconductor's new HTA3000 Tile Array ASIC system has models for an operational amplifier, current feedback amplifier, Gilbert-cell mixer, and an RF transconductance amplifier. Their HDI3000 full-custom ASIC system can implement similar functions, as well as other user-defined functions.

Tektronix' ASIC group has similar capabilities in their high-speed analog/digital process. Reported customer applications include data acquisition and specialized analog-to-digital conversion circuitry. A few specific RF applications have been provided, as well. One observation within the Tektronix group is that engineers' unfamiliarity with ASIC design procedures and ASIC capabilities is a much greater problem than its cost.

Software companies are also just beginning to address the issue of ASICs. In general, these firms have specialized in either general digital/analog or GaAs microwave circuits. Recently, a few efforts were begun that will eventually bring these techniques together under a single software system. Cadence Design Systems has developed a system to support various microwave design and analysis systems, primarily for GaAs MMIC applications. Work is underway to include the analog capabilities of Cadence's existing products and those of Valid Logic, which was recently acquired. This will allow a single system to support both RF/microwave and traditional analog device design. Jim Solomon, President of the Analog Division at Cadence noted that the traditional analog semiconductor vendors now have processes with typical NPN $F_T$ of 10-15 GHz, performance that fits RF IC requirements quite nicely.

One more factor in the acceptance of ASICs as an option for product implementation is the reliability of the design tools. Discrete and standard IC designs are readily verified "on the bench," and easily modified if unexpected problems are found. In general, RF engineers do not yet have sufficient confidence in software models to risk the chance of multiple attempts at a successful ASIC design. This should change soon, as the linear/non-linear models and analytical methods become mature, and their users become used to designing with them.

The advantages of ASICs are size and performance. For example, in new consumer spread-spectrum applications, ASICs may be the *only* way to achieve the required circuit complexity and maintain a low finished product cost. For products that may not be produced in the millions, ASICs offer exact functions in a small footprint, which may also minimize EMI problems and reduce power consumption. For these reasons, ASICs will inevitably become a significant part of the RF engineer's arsenal of design weapons. ***RF***

*For reprints of this report, contact Cardiff Publishing Company at (303) 220-0600. Ask for the Circulation Department.*

# Radial Ground Screen Design for a Vertical Monopole

By Michael A. Rupar
Naval Research Laboratory

*The characteristics of vertical monopole antennas are generally well defined. However, one factor that is not easily understood is the influence of the ground constants (the conductivity, $\sigma$, and relative dielectric constant, $\varepsilon_r$) on the input impedance of a vertical monopole. Considering that the input impedance of a monopole less than a quarter-wavelength in height may have a resistive part less than one ohm, the change in the antenna's input impedance caused by an imperfect ground can be significant.*

To improve the antenna's $\Delta Z$ (the change in impedance of an antenna over perfect ground to one over an imperfect ground), one must reduce both the resistive contribution of the ground losses plus the change in reactance, which affects the antenna matching. This can be accomplished through the use of a radial ground screen at the base of the antenna. Using the theory developed by Wait and Pope (1), a program in Mathematica has been written that predicts $\Delta Z$ for cases with and without a ground screen present. One can examine the tradeoffs in choosing the best ground screen for an application by generating plots in Mathematica to illustrate how the impedance changes with respect to various parameters.

## Theory

Two factors detrimentally affect the input impedance of a short vertical monopole over an imperfect ground: its limited height and the less than ideal conductivity of the earth beneath it. The current distribution on a short monopole results in a very large input capacitive reactance.

The earth ground causes an increase in the input resistance of a vertical monopole due to the ground currents induced by the radiated fields. This contribution in resistance can be much greater than the original radiation resistance of the monopole, resulting in a significant loss of radiated power in the ground and severely reducing the antenna efficiency. The situation can be improved by the use of a radial ground screen, which provides a low-loss return path for the antenna base current.

To develop an expression for the input impedance of a vertical monopole over an imperfect ground, one starts with a simple vertical element along the z-axis of height, h, situated above a ground half-space, as shown in Figure 1.

The propagation constant ($\gamma$) and the characteristic impedance ($\eta$) of the imperfect ground are given as:

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} \tag{1}$$

$$\eta = \sqrt{\frac{j\omega\mu}{j\omega\varepsilon + \sigma}} \tag{2}$$

For normal soil with little inherent magnetization, one can assume $\mu = \mu_0$. For free space (and air), the above quantities are defined as:

$$\gamma_0 = j\omega\sqrt{\mu\varepsilon_0} \equiv j\beta = j\,\frac{2\pi}{\lambda} \tag{3}$$

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{4}$$

The antenna's self-impedance is separated into two parts,

$$Z_T = Z_O + \Delta Z_T \tag{5}$$

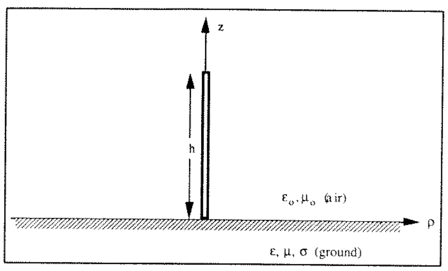



**Figure 1. The representation of a vertical monopole over an imperfect ground. The monopole is just above the ground plane.**

where $Z_T$ is the total input impedance, and $Z_O$ is the input impedance of the same antenna over a perfect ground. $\Delta Z_T$ represents the difference between the perfect and imperfect ground cases. One may think of the perfect ground case as an infinite ground screen.

Wait's paper (1) focused on the definition of $\Delta Z_T$, and then applied this factor to both the lossy ground and the imperfect ground screen problems. A detailed development of $\Delta Z_T$ can be found in Reference 2.

The expression for $\Delta Z_T$, written in cylindrical coordinates is:

$$\Delta Z_T \cong \eta\int_0^\infty [H_\phi(\varrho,0)]^2 2\pi\varrho\, d\varrho \tag{6}$$

Where $H_\phi(\varrho, 0)$ is the tangential magnetic field at the surface, defined below as:

$$H_\phi(\varrho,0) = -\frac{j}{2\pi\sin\alpha}\left[\frac{e^{-j\beta r}}{\varrho}\cos(\beta h - \alpha) - \frac{e^{-j\beta\varrho}}{\varrho}\cos\alpha - \frac{jh}{\varrho}\,\frac{e^{-j\beta r}}{r}\sin(\alpha - \beta h)\right] \tag{7}$$

with

$$r = (z^2 + \varrho^2)^{1/2} \tag{8}$$

$$\alpha = \beta(h + ht) \tag{9}$$

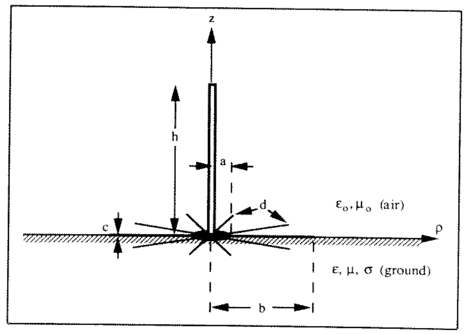



**Figure 2. The representation of a vertical monopole with a radial ground screen over an imperfect ground.**

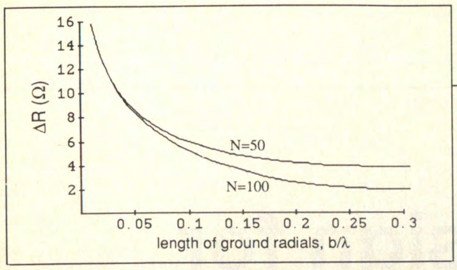



**Figure 3a. The change in input resistance of s quarter-wave vertical monopole over a perfect ground to one over an imperfect ground with a radial ground screen (ΔR) vs. the screen radius b/λ, for 50 and 100 radials.**

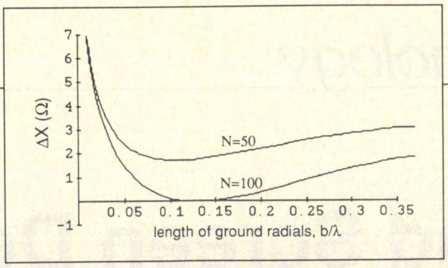



**Figure 3b. The change in input reactance of a quarter-wave vertical monopole over a perfect ground to one over an imperfect ground with a radial ground screen (ΔX) vs. the screen radius b/λ, for 50 and 100 radials.**

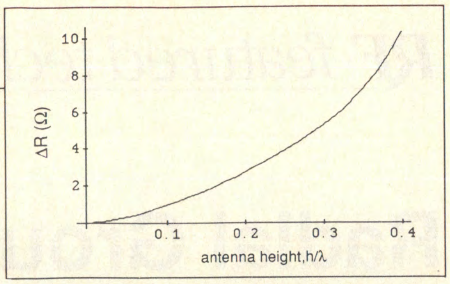



**Figure 4a. The change in input resistance of a vertical monopole over a perfect ground to one over an imperfect ground with a radial ground screen. (ΔR) vs. the antenna height, h/λ The number of radials, N, is 50.**

$\beta$ = free space propagation constant
h = height of monopole
ht = effective contribution to monopole height from top loading

For the case where there is no top loading, (ht = 0), $\alpha = \beta h$, and $\Delta Z_T$ can be reduced to

$$\Delta Z_T = \frac{-\eta}{2\pi \sin^2\beta h}\left[\int_0^\infty \frac{e^{-j2\beta r}}{\varrho}\,d\varrho - 2\cos\beta h\int_0^\infty \frac{e^{-j\beta(r+\varrho)}}{\varrho}\,d\varrho - \cos^2\beta h\int_0^\infty \frac{e^{-j2\beta\varrho}}{\varrho}\,d\varrho\right] \qquad (10)$$

These expressions are valid only when $|\gamma| >> \beta$, which limits one to cases where the displacement currents (changes in the electric field with respect to time, rather than free electron flow) in the ground are negligible. This condition is expressed as:

$$\left|\sqrt{j\mu\omega\sigma - \omega^2\mu\varepsilon}\right| >> \omega\sqrt{\mu_o\varepsilon_o} \qquad (11)$$

With $\varrho$ in the denominator of each term of Equation 7, there is a singularity at $\varrho$ equal to zero. Since the object is to calculate the change in impedance from a perfect to imperfect ground, one assumes that a base plate made of a good conductor would not contribute to the expression for $\Delta Z$. Therefore, one can substitute the value "a" for the lower limit of $\varrho$, where "a" is the radius of the "perfect" base.

### Adding a Radial Ground Screen

The inclusion of a radial ground screen at the base of the antenna has a significant effect on the impedance expression for the monopole. Although Equation 6 still applies for the region beyond the ground screen ($\varrho$ > b), a separate expression must be formulated to account for the screen's effect on the surface magnetic and electric fields. The

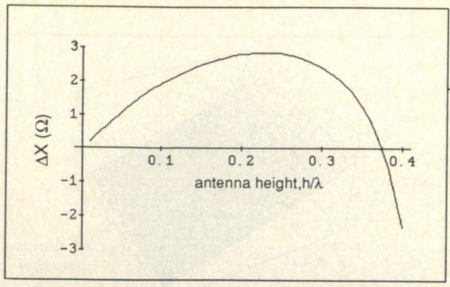



**Figure 4b. The change in input reactance over a perfect ground to that over an imperfect ground with a radial ground screen.**

vertical monopole with a ground screen is shown in Figure 2.

For the region $\varrho > b$, the impedance of the ground is just the characteristic impedance, $\eta$, but when the ground radials are present ($\varrho < b$), the impedance is the parallel combination of the screen imped-

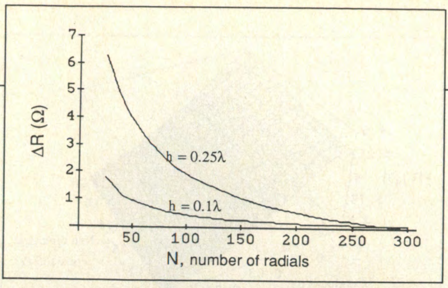



**Figure 5a. ΔR vs. number of ground radials for a uniform radial length of 0.3λ, for monopole heights of 0.1λ and 0.25λ.**

ance, $\eta_e$, and the surface impedance, $\eta$. This is called the equivalent impedance, $\eta_x$.

$$\eta_x(0 < \varrho < b) = \frac{\eta \eta_e}{\eta + \eta_e} \tag{12}$$

where

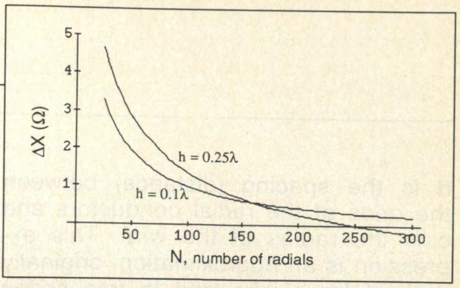



**Figure 5b. ΔX vs. number of ground radials for a uniform radial length of 0.3λ, for monopole heights of 0.1λ and 0.25λ.**

$$\eta_e = \frac{i \eta_o d}{\lambda} \ln \frac{d}{2\pi c} \tag{13}$$

and

$$d = \frac{2\pi\varrho}{N} \tag{14}$$

d is the spacing (distance) between the ends of the radial conductors and c is the radius of the wire. This expression is an approximation, originally derived for a wire grid in free space (3), and assumes that the wires are electrically close enough to approxiate a grid.

For the case of a radial ground screen, we break $\Delta Z_T$ into two parts.

$$\Delta Z_T = \Delta Z + \Delta Z_S \tag{15}$$

where $\Delta Z$ is the change in the input impedance of the antenna due to the influence of the imperfect ground outside the ground screen, and $\Delta Z_S$ is the change due to the imperfect ground screen system. The two expressions for $\Delta Z_T$ are:

$$\Delta Z \cong \eta \int_b^{\infty} [H_\phi(\varrho,0)]^2 2\pi\varrho d\varrho \tag{16}$$

$$\Delta Z_S \cong \int_a^b \frac{\eta\eta_e}{\eta + \eta_e} [H_\phi(\varrho,0)]^2 2\pi\varrho d\varrho \tag{17}$$

with $H_\phi(\varrho,0)$ remaining as defined in Equation 7.

Equation 16 is identical to Equation 5, except that the lower limit of integration is now b, representing the radius of the ground screen. Equation 17 differs in that the equivalent impedance term $\eta_x$ is now a function of the radial distance $\varrho$, and can no longer be moved outside of the integral. The lower limit "a" still represents the radius of the conducting base plate.

To more concisely illustrate how the ground characteristics of the antenna site affect the $\Delta Z$ calculations, the ground constants of conductivity and relative dielectric constant were combined into a single function, $\delta$. (This was done in Maley, et al, in Reference 4). The relation between the ground impedance and the constant $\delta$, referred to as the "ground factor," is shown below:

$$\eta = \sqrt{\frac{j\mu\omega}{\sigma + j\omega\varepsilon}} = \sqrt{j}\,\eta_o\,\delta \tag{18}$$

where $\delta$ is defined as:

$$\delta = \delta' \sqrt{\frac{1}{1 + j(\delta')^2\varepsilon_r}} = |\delta|e^{-j\psi} \tag{19}$$

with

$$\delta' = \sqrt{\frac{\omega\varepsilon_o}{\sigma}} \tag{20}$$

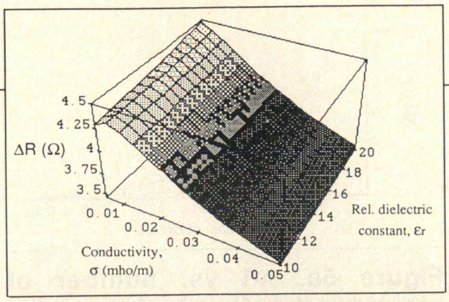



**Figure 6a. ΔR for a λ/4 monopole vs. the ground constants of the ground plane, the conductivity and relative dielectric constant. A ground screen of 50 radials 0.3λ in length is assumed.**

$$\psi = \frac{1}{2}\tan^{-1}[(\delta')^2\varepsilon_r] \tag{21}$$

with $\varepsilon_r$ being the relative dielectric constant for the ground plane. $\psi$ is referred to as the phase of the ground factor. Use of $\delta$ allows one to present calculated $\Delta Z$ results without specifying a particular frequency or ground constants.

## Mathematica

Figure 7 shows the expressions based on Equations 7, 11, 12, 16, 18 that were used in a Mathematica program (or "notebook") to calculate $\Delta R$ and $\Delta X$. The equations are for calculating $\alpha$, $H_\phi(\varrho, 0)$ (normalized), and the ground impedances for the earth, the ground screen, and their combination in parallel respectively. "no" is the free space impedance term $\eta_o$, and is entered into Mathematica as a constant.

The final expression is defined and calculated in a "Block" expression, which allows one to define variables temporarily ("locally") to a particular procedure. The examples given above are functions of the normalized ground screen radius, b/λ. dZ corresponds to Equation 16 and dZs to Equation 17. The local variables are enclosed in curly brackets {} and **NIntegrate** performs numerical integration on the enclosed expression. All values of length and height entered are normalized with respect to wavelength.

## Results

The following plots were generated with Mathematica using the equations given above. The values for "$\delta$m" and "psi" ($\delta$ and $\psi$) for Figures 3-5 are taken from a conductivity and relative dielectric constant representative of "average land" in the HF band (5). The conductivity was assumed to be 0.0278 mho/m, and the relative dielectric constant was 15. The top loading parameter, ht, was left equal to zero for all examples. The lower limit a was chosen to be 0.001λ.

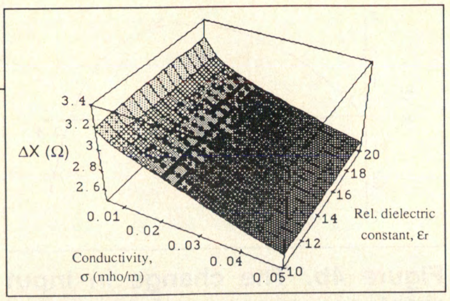



**Figure 6b. ΔX for a λ/4 monopole vs. the ground constants of the ground plane, the conductivity and relative dielectric constant. A ground screen of 50 radials 0.3λ in length is assumed.**

Figures 3a and 3b show $\Delta R$ and $\Delta X$ for a quarter-wave monopole as a function of the normalized screen radius, b/λ. As the screen radius increases, the effects of additional radials becomes more pronounced. The response in Figure 3b appears to indicate that, after a certain value of b/λ, the radials themselves contribute to the antenna's total reactance.

The next set of figures illustrate how the monopole height itself affects the imperfect ground's effect on impedance. Assuming a ground screen of 50 radials, each 0.3λ long, Figures 4a and 4b show the change in input impedance as the height of the monopole increases. After passing the quarter-wavelength in height, the reactive contribution of the imperfect ground changes dramatically.

Figures 5a and 5b illustrate how the input impedance is affected as the number of radials is increased.

In Figures 6a and 6b, the convention of $\delta$m and psi are dropped, and $\Delta R$ and $\Delta X$ are shown as functions of the ground conductivity ($\sigma$) and relative dielectric constant ($\varepsilon_r$). A frequency of 5 MHz was assumed for both figures. Except for cases of extremely poor ground, which violate Wait's conditions in (5), $\varepsilon_r$ appears to have little effect on the antenna's impedance.

In general, the following guidelines can be used when designing a ground screen for a vertical monopole:

1. A practical radial length is 0.3λ for monopoles less than λ/4 in height, as suggested by Figures 3a and 3b. In general, the radial length should exceed the monopole height.

2. Although not illustrated here, it has been demonstrated that increasing wire radius contributes little to the effectiveness of the ground system (4).

3. The number of radials can have a profound effect on $\Delta R$, $\Delta X$ when the ground is poor (i.e., low conductivity). In general, using the largest number of radials possible is recommended, although one suffers di-

```
al[h__,ht__]:=2 Pi (h+ht)                                                                    (22)

qQ[h__,ht__,p__]:=(Exp[-I 2 Pi Sqrt[pΛ2 + hΛ2]] (Cos[2 Pi h - al[h,ht]] - (Ih/Sqrt[pΛ2 + hΛ2])
     Sin[al[h,ht]-2 Pi h]) - Exp[-I 2 Pi p] Cos[al[h,ht]])                                   (23)

ng[δm__,psi__]:= Sqrt[I] no δm Exp[-I psi]                                                   (24)

ne[p__,nrad__]:= (I no 2 Pi p/(nrad))Log[p/(nrad c)]                                         (25)

n[p__,nrad__,δm__,psi__]:= ng[δm,psi] ne[p,nrad]/(ng[δm,psi]+ne[p,nrad])                     (26)

dZ[b__]:=Block[{h=.1,δm=.1,phi=.1,ht=0},(-ng[δm,phi]/(2 Pi Sin[al[h,ht]]Λ2))*
     NIntegrate[qQ[h,p]Λ2/p,{p,b,8}]]                                                        (27)

dZs[a__,b__]:=Block[{h=.1,nrad=50,δm=.1,phi=.1,ht=0}, (1/(2 Pi Sin[al[h,ht]]Λ2))*
     NIntegrate[-n[p,nrad,δm,psi] qQ[h,p]Λ2/,{p,a,b}]]                                       (28)
```

**Figure 7. Mathematical equations**

minishing returns after 200 radials.

4. If the ground constants do not meet the criteria in Equation 11, these expressions will not apply. A ground screen is even more essential for the case of a "poor" ground. *RF*

## References


1. J.R. Wait and W.A. Pope, "The Characteristics of a Vertical Antenna with a Radial Conductor Ground System," *Applied Sci. Res.*, Section B, Vol. 4, pp. 177-195, 1954.
2. Michael A. Rupar, "Computations and Measurements of the Input Impedance of a Vertical Monopole over Perfect and Imperfect Ground," Master's Thesis, The George Washington University, January 1991.
3. G.G. MacFarlane, *Journal of Institute of Electrical Engineers*, Vol. 93, Part IIIA, 1946, pp. 1523.
4. S.W. Maley, R.J. King and L.R. Branch, "Theoretical Calculations of the Impedance of a Monopole Antenna with a Radial-Wire Ground System on an Imperfectly Conducting Half-Space," AF Cambridge Research Lab., AFCRL-63-583, Report No. 26, 13 December 1963.
5. Shing Ted Li, et al, *Microcomputer Tools for Communications Engineering*, Artech House, Inc., pp. 177, Table 16-1.

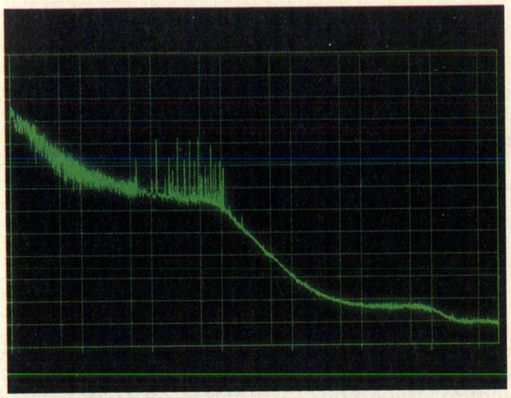


**About the Author**

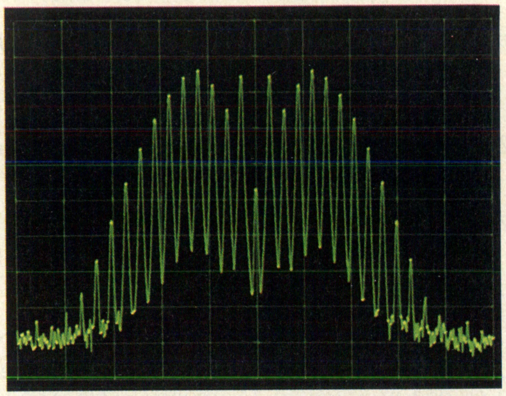
Michael A. Rupar is an electronics engineer with the Transmission Technology Branch of the U.S. Naval Research Laboratory in Washington, DC. His work is in signal propagation and in RF and antenna systems development. He can be reached at (202) 767-3155.

FLUKE AND PHILIPS – THE GLOBAL

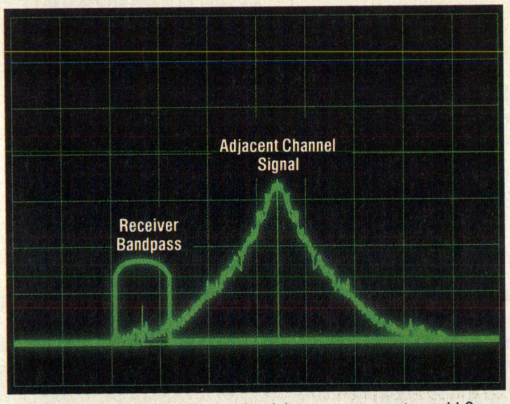
FLUKE®



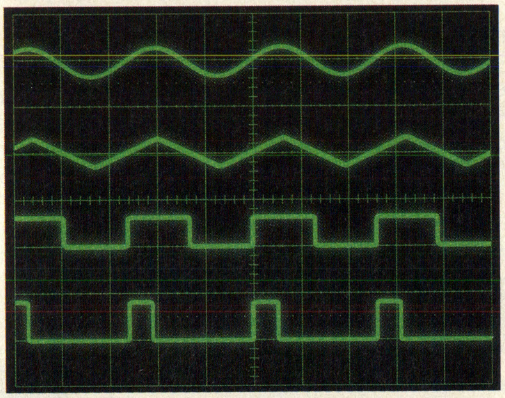
The 6080 Series is the best value today in high spectral purity RF signal generators. Phase noise at 1 GHz is -131 dBc/Hz at 20 kHz offset.



Wide FM deviation to 8 MHz for surveillance receiver testing or VCO simulation.




Low phase noise for receiver selectivity measurements and LO substitution is a definite plus.



Besides generating precise RF signals, the 6080 Series has a DDS modulation oscillator to generate multiple functions from 0.1 Hz to 200 kHz.

# Catch the perfe

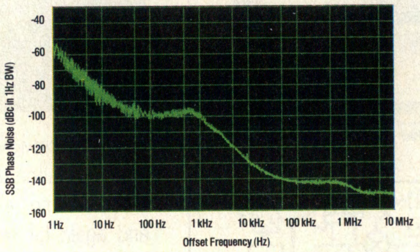
**For spectral purity, versatility and value, Fluke 6080A and 6082A Signal Generators are totally awesome.**

Short of a week off Australia's barrier reef or Oahu's North Shore, you'd be hard pressed to find more satisfying waveforms than those produced by Fluke 6080 Series 1 GHz — 2 GHz RF Signal Generators.

For the price, nothing comes close: Not Hawaii, not Australia. Not even HP.

Because with the Fluke 6080 Series you get all the performance you need for virtually all your critical receiver test, RF design, and ATE systems applications.

To begin with, the Fluke 6082A and its 1 GHz cousin, the 6080A, both offer nearly unheard of spectral purity in their price range. Phase noise at 1 GHz is -131 dBc/Hz at 20 kHz offset. Non-harmonic spurious is -100 dBc at 1 GHz. And residual FM is a low 1.5 Hz, perfect for high performance receiver testing and LO substitution.

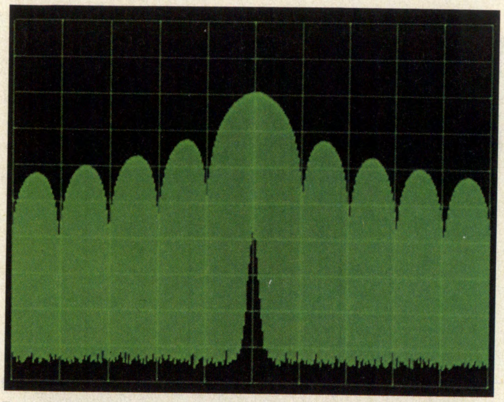



When it comes to SSB phase noise, the 6080 Series has what it takes for your tough RF communications test requirements.

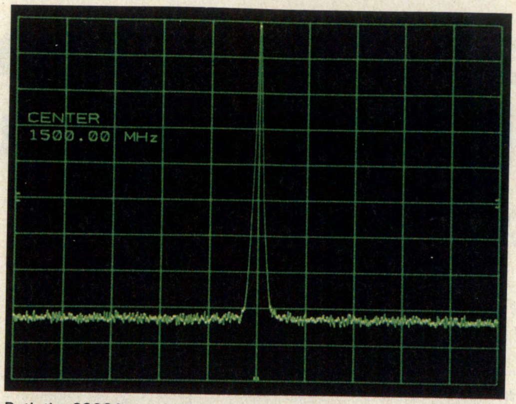
Output level of +16 dBm provides the oomph you need for receiver overload test and driving high level mixers. Level accuracy is ±1 dB. A special user-defined level correction register allows you to

ALLIANCE IN TEST & MEASUREMENT

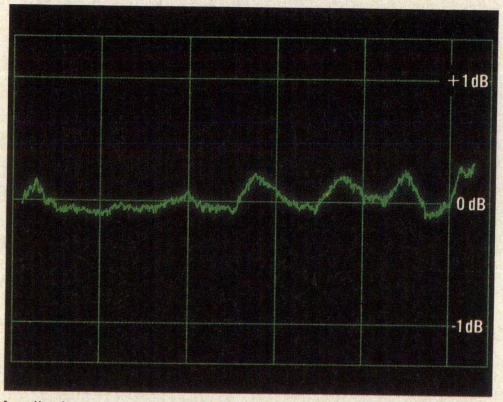
**PHILIPS**



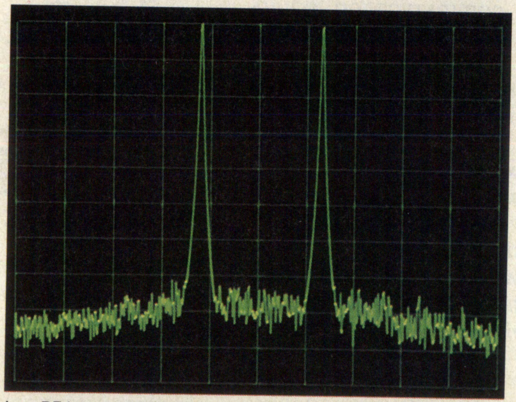
Fast pulse modulation: 15 ns edges, up to 80 dB on/off ratio. Perfect for radar component testing.




Both the 6080A and 6082A have the performance you need for even your toughest RF test applications.




Amplitude accuracy is spec'd to ±1 dB at -127 dBm over the entire frequency range, but typical performance is actually much better.



Low RF intermodulation distortion is ideal for receiver sensitivity testing in mobile, cellular, and military applications.

# ct wave, dude.

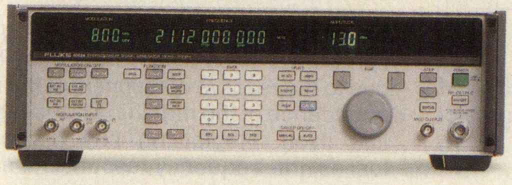
compensate for external cable losses.

Flexibility is a major plus, too. Whether you're testing mobile, cellular, military communications, surveillance receivers, or doing RF design work, the Fluke 6082A is ready to go.

Modulation versatility is standard. So is HP 8642A/B software and rack space compatibility. AM, FM, phase and pulse modulation are all included, and can be combined for complex signal simulation.

Pulse rise time is <15 ns (7.5 ns typical). And the 6082A's on/off ratio is 80 dB, ideal for radar applications.

Sound too good to be true? Take a peek at the Fluke 6082A and see for yourself what the new wave in high performance signal generators is all about.



Fluke 6080 Series high performance signal generators. U.S. List Prices: 6080A $15,950; 6082A $21,950.

Call **1-800-44-FLUKE** for the whole picture. And in the meantime, hang loose.

John Fluke Mfg., Inc., P.O. Box 9090, M/S 250E, Everett, WA 98206-9090. U.S. (206) 356-5400. Canada (416) 890-7600. Other countries: (206) 356-5500. © 1991 John Fluke Mfg. Co., Inc. All rights reserved. Ad no. 00156. HP® is a registered trademark of Hewlett-Packard Co. Information subject to change without notice.

RF SIGNAL GENERATORS

**FLUKE**®

INFO/CARD 28

# Simple Compensation of the Single-Section, Quarter-Wave Matching Section

By Ernie Franke
E-Systems, ECI Division

*This article examines several methods for improving the performance of the simple quarter-wave transmission line matching circuit, which is widely used in communication equipment today. The techniques of using a quarter-wave short-circuit or a half-wave open-circuited transmission line are compared for compensation. The use of an LC network as a lumped constant approximation to a transmission line compensation network is then examined. The Wilkinson RF splitter/combiner, which is composed of two simple quarter-wave transmission lines, is then compensated using these techniques to achieve an improved response.*

To serve as a broadband matching network, a transmission line must transform a load impedance to a value close to that of the generator impedance. The input impedance ($Z_{in}$) looking into a lossless transmission line, Figure 1a, terminated with a load impedance ($Z_L$) is given by:

$$Z_{in} = Z_o \left[ \frac{Z_L + jZ_o \tan\theta}{Z_o + jZ_L \tan\theta} \right] \qquad (1)$$

$$\theta = 360° \left( \frac{L}{\lambda} \right) \qquad (2)$$

where $Z_o$ is the matching transmission line characteristic impedance in ohms, $\theta$ is the electrical line length in degrees, and $L/\lambda$ is the line length expressed as a fractional wavelength. The input impedance is a complex quantity, even for a purely resistive load impedance. Solution of the above equation for a quarter-wave, impedance-matching transmission line yields:

$$Z_{in} = \frac{Z_o^2}{Z_L} \qquad (3)$$

and

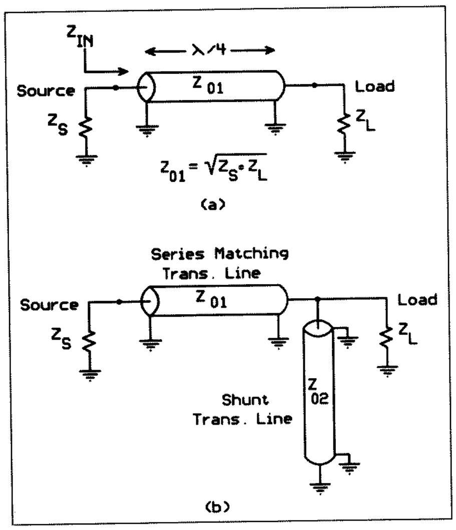



**Figure 1. Simple quarter-wave matching element with shunt transmission line added for compensation.**

$$Z_o = \sqrt{Z_{in} Z_L} \qquad (4)$$

A quarter-wave section of lossless transmission line has the property of being an inverter of impedance. Thus

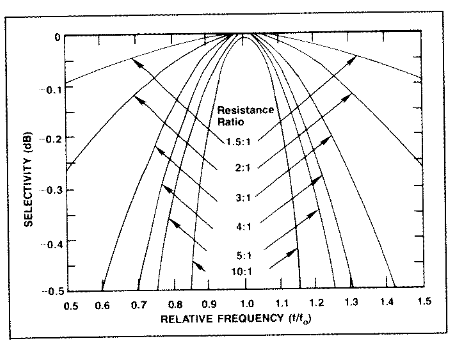



**Figure 2. Relative bandwidth of single quarter-wave matching section for various $R_G$ to $R_L$ or $R_L$ to $R_G$ ratios.**

a low value load impedance is transformed into a high value impedance at the input. The input VSWR is given as:

$$VSWR = \frac{1 + \dfrac{Z_{in} - R_g}{Z_{in} + R_g}}{1 - \dfrac{Z_{in} - R_g}{Z_{in} + R_g}} \qquad (5)$$

Where $R_g$ is the source impedance, typically 50 ohms.

The input return loss is given as: (6)

$$\text{Return Loss} = 10 \log \left( \frac{\text{forward power}}{\text{reflected power}} \right) \text{dB}$$

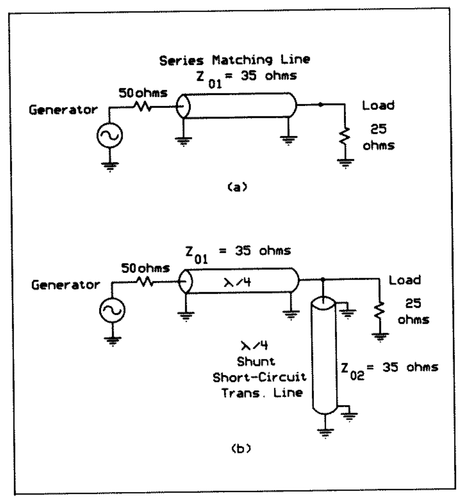



**Figure 3. 2:1 impedance transformer with quarter-wave shunt added for increased frequency response.**

$$\text{Return Loss} = 20 \log \left( \frac{VSWR + 1}{VSWR - 1} \right) \text{dB} \qquad (7)$$

Thus the input VSWR to a matching section will vary across the frequency band due to the reactive component of the input impedance of the matching transmission line itself. Neglecting any dissipative losses, the frequency response or selec-

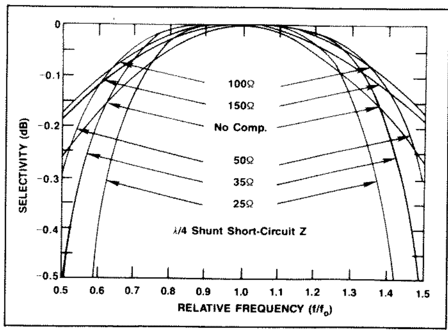



**Figure 4. Simple quarter-wave, short-circuit compensation of single quarter-wave matching section.**

tivity is determined by the input VSWR.

$$\text{Selectivity} = -10 \log \frac{1}{1 - \left[\frac{VSWR - 1}{VSWR + 1}\right]^2} \text{ dB} \quad (8)$$

For instance, an input VSWR of 2:1 will yield a selectivity of −0.51 dB due to input signal reflection.

$$\text{Selectivity} = 10 \log (1 - 10^{-R_L/10}) \text{ dB} \quad (9)$$

Thus frequency compensation to broaden the response of a matching network amounts to improving the input match over a specific operating frequency range.

The Q of a matching network is a measure of relative bandwidth and is given as:

$$Q = \sqrt{Z_{Ratio} - 1} \quad (10)$$

where $Z_{Ratio}$ is the ratio of the source to load, or load to source, resistive component of impedance. The Q is the same whether transforming up or down by the same resistance ratio. The selectivity as a function of impedance transformation for a single-section transmission line matching section is shown in Figure 2. To broaden the response of an impedance matching network, it is possible to increase the number of matching sections or to use a method of adding shunt compensation networks.

## Shunt Compensation

In a simple quarter-wave transformer,

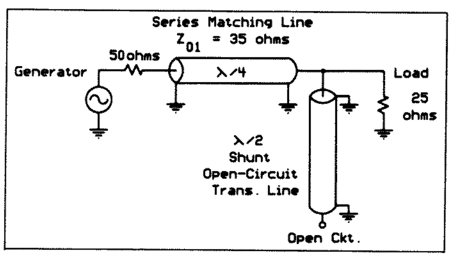



**Figure 7. A half-wave open-circuited transmission may laso be used for compensation.**

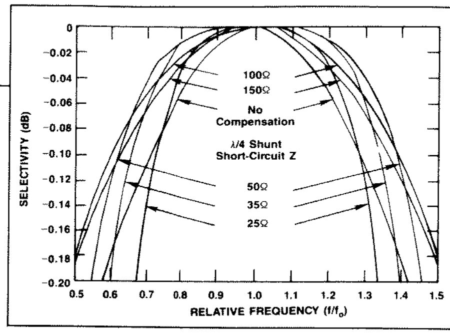



**Figure 5. Simple quarter-wave, short-circuit compensation of single quarter-wave matching section.**

the input admittance locus spread due to the frequency dependence of the matching transmission line length may be compensated by a shunt (1), short-circuited quarter-wave stub placed at the load, Figure 1b. The input impedance ($Z_{SC}$) to this lossless, shunt transmission line is given as:

$$Z_{sc} = +jZ_o \tan\theta \quad (11)$$

where $\theta$ = 90 degrees ($f/f_o$) for a quarter-wave transmission line and f is the actual frequency of operation and $f_o$ is the frequency at which the line is quarter-wave length.

Thus a lossless, short-circuited, transmission line looks like a pure reactance with a value dependent on both the line length and line impedance and with the polarity dependent on line length. For frequencies less than a quarter-wavelength, the transmission line appears as an inductor. For frequencies greater than λ/4, the input impedance looks capacitive. Thus, the designer has the choice of characteristic impedance and line length to control the reactance value and slope with respect to frequency.

A short-circuited transmission line, $Z_{02}$, placed in shunt with the load, may be used as a simple compensation network as it adds the required compensating reactance, Figure 1b. A specific example of the simple quarter-wave, transmission matching line is shown in

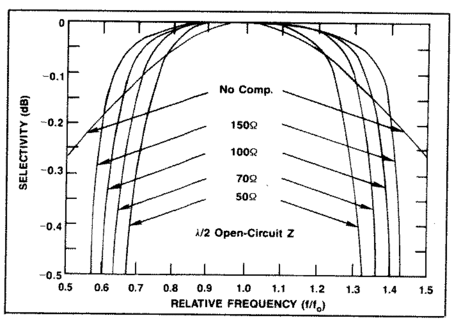



**Figure 8. Simple half-wave, open circuit compensation of single quarter-wave matching section.**

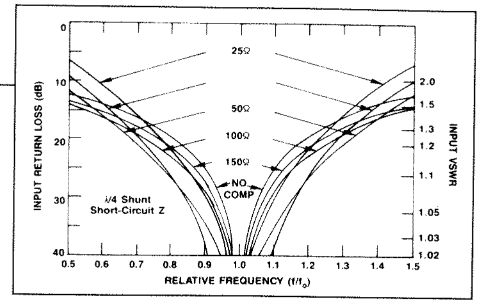



**Figure 6. Simple quarter-wave, short-circuit compensation of single quarter-wave matching section.**

Figure 3a. If it is desired to transform a load resistance of 25 ohms to match the generator source resistance of 50 ohms, a quarter-wavelength of 35 ohm transmission line is used. The response of the simple quarter-wave 2:1 impedance transformer is shown in Figure 4 (No Compensation Curve) over a relative frequency range of 0.5 $f_c$ to 1.5 $f_c$, where $f_c$ is the center design frequency. It is desirable to broaden the response over the expected operating frequency range. A matching network is typically useable with a relative selectivity less than 0.2 dB, as opposed to the commonly specified 3 dB bandwidth. This same amplitude response of the matching network is expanded in Figure 5 for easier examination. The use of a 50 ohm shunt transmission line for example improved the matching network response at the 0.1 dB response from 54 percent relative response (No Compensation Curve) to 76 percent (50 ohm Compensation Curve). The corresponding input match presented to the source generator using each of these matching networks is shown in Figure 6. An input return loss of better than 15 dB is typically needed to ensure a stable match. Increased frequency response may be achieved with the higher impedance transmission lines.

## Half-Wave, Open-Circuit Stub Compensation

An alternative to using a quarter-wave, short-circuit transmission line

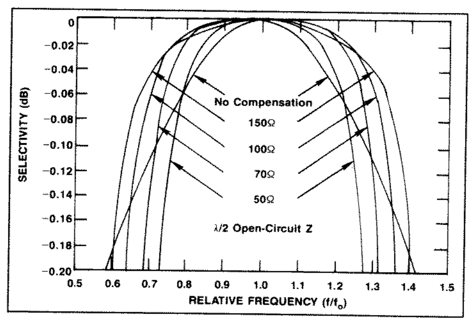
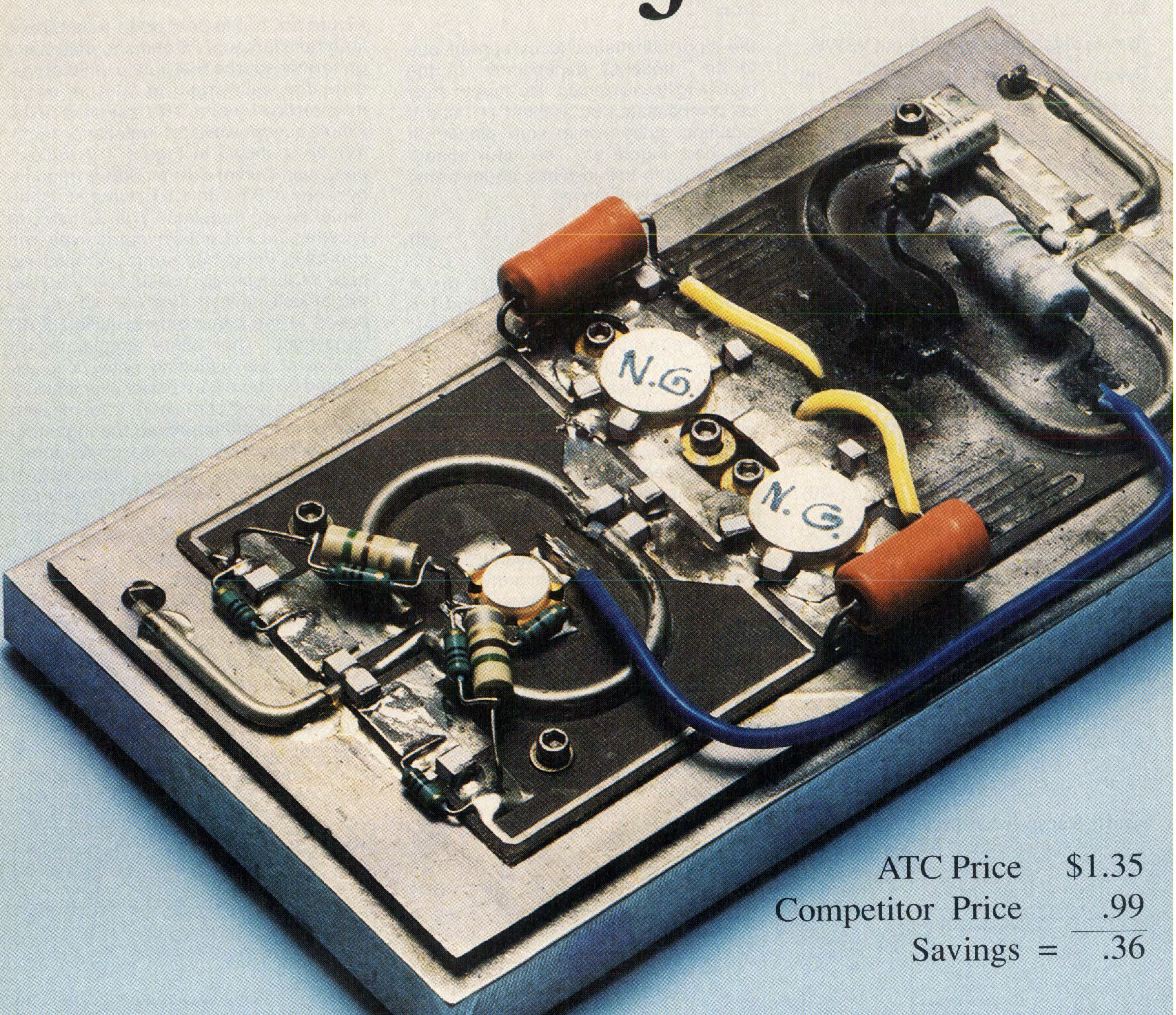



**Figure 9. Simple half-wave, open circuit compensation of single quarter-wave matching section.**

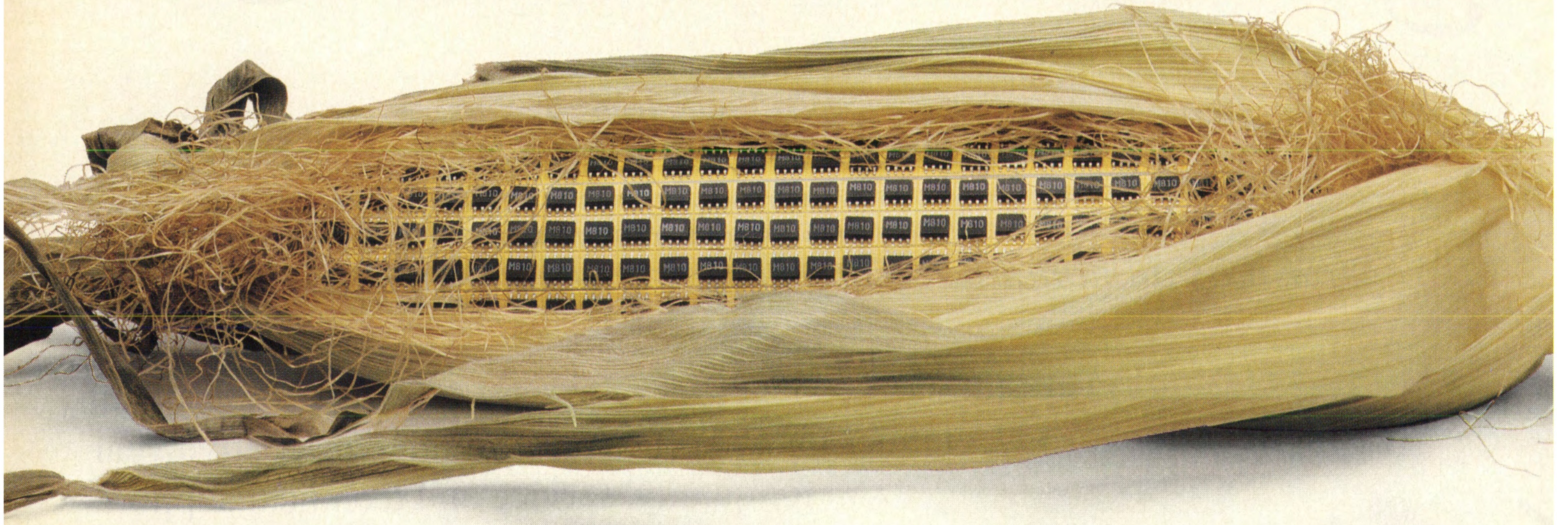
# . . . "But they just as




| | |
|---|---|
| ATC Price | $1.35 |
| Competitor Price | .99 |
| Savings = | .36 |

| | |
|---|---|
| Amplifier Module Cost | $1,800.00 |
| Amplifier Replacement Costs | 2,600.00 |
| Minus Savings — | .36 |
| Total Loss = | $2,599.64 |

# AVANTEK MMICs NATURE, AT A NATURAL PRICE



### High Performance RF/ Microwave Circuits in Tiny SMD Packages

Fresh idea. A growing family of DC to 5.0 GHz amplifiers, active mixers, and other high performance monolithic microwave ICs (MMICs), at design conscious prices—as low as $0.95 each in 10,000 piece quantities. Avantek's new ISOSAT™ process yields a harvest of silicon MMICs in plastic SMD packages for portable, handheld, and low-power high-volume designs, where size and cost are as critical as RF performance.

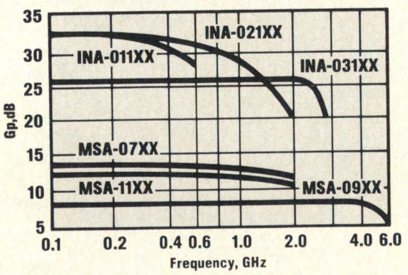
### Cellular, Spread Spectrum, Fiber Optics, GPS—Any RF/ Microwave Application

Avantek, the pioneer of commercial and defense RF/microwave solid-state, offers the ISOSAT family of plastic MMICs in bulk, tape and reel. High-volume, low-cost circuits that meet your highest requirements for low power consumption, bandwidth, low noise (as low as 1.7dB), high gain, stability and cascadeability. ISOSAT products make your linear design goals easy and efficient.

### Get a Little Help from Your Friends

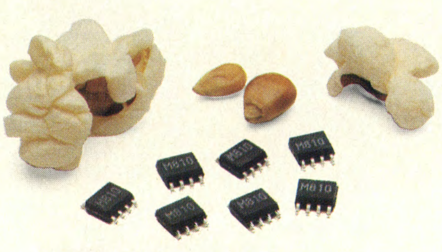
Avantek has over 50 field specialists around the world to assist in developing your RF/ microwave designs. And, Avantek ISOSAT amplifier product data is available for use in all major CAE libraries, such as EEsof Touchstone.™

**Power Gain vs. Frequency**




With over 20 major stocking locations, and a worldwide trans-shipment operation, Avantek has the largest RF/microwave semiconductor distribution network in the world. We meet the demands of the most demanding JIT programs, or supply critical prototypes with the same matchless service and support.


**Call Your Local Distributor or 1-(800) AVANTEK for Fast Delivery**



*Putting Microwave Technology to Work for You*

**AVANTEK**

INFO/CARD 50

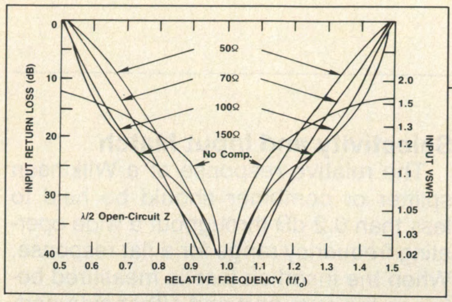



**Figure 10. Simple half-wave, open circuit compensation of single quarter-wave matching section.**

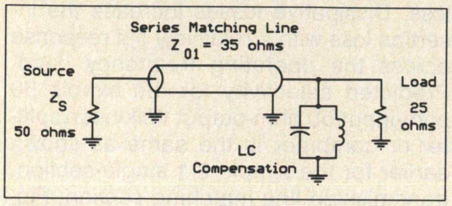



**Figure 11. LC compensation of quarter-wave transmission line matching section.**

as an equivalent parallel resonant circuit, a half-wave, open-circuit transmission line may be used, Figure 7. The input impedance ($Z_{OC}$) to a lossless, open-circuited, transmission line is given as:

$$Z_{oc} = -jZ_o \cot\theta \qquad (12)$$

The selectivity is shown in Figures 8 and 9 for various shunt, half-wave compensation transmission line impedances. This compensation technique is not as effective as the quarter-wave shorted stub, but it does remove the presence of a DC short. The input match response is shown in Figure 10. Because the transmission line is half-wave, the reactive component varies twice as fast with frequency as it does for the quarter-wave case.

## LC Compensation

A simple, parallel LC network placed in shunt with the load, Figure 11, behaves similar to a shorted quarter-wave transmission line. The compensation for the simple series, quarter-wave matching network is shown in Figures 12 and 13 for various values of inductive and capacitive reactance at the center design frequency, with the corresponding input match response shown in Figure 14. The value of the inductance and capacitance can be varied to cancel the input reactance above and below the center frequency to yield an even flatter response.

## Wilkinson Splitter/Combiner

The Wilkinson (2) splitter/combiner, Figure 15a, is composed of two series quarter-wave, transmission lines with

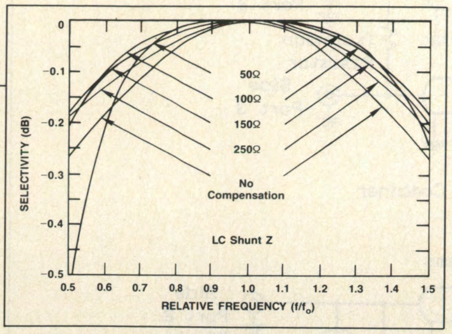



**Figure 12. Simple LC-compensation of single quarter-wave matching section.**

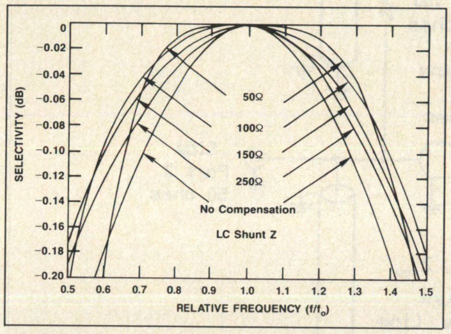



**Figure 13. Simple LC-compensation of single quarter-wave matching section.**

an isolation resistor between side ports 2 and 3. Input power applied to the sum port (port 1) is equally divided between the side ports, ports 2 and 3. Each transmission line transforms the 50 ohm impedance of the side ports to a value of 100 ohms at input port 1. The parallel combination of the input impedance to each of these transmission line matching sections thus provides a 50 ohm input match at the sum port. The Wilkinson splitter or combiner thus effectively parallels two 2:1 impedance transformers with an internally terminated balance port, the isolation resistor. The Wilkinson may be used to either split or combine power as shown in Figure 16 for a typical receiver or transmitter amplifier. Shunt, short-circuited transmission lines may be added across each side port to provide wide bandwidth, Figure 15b.

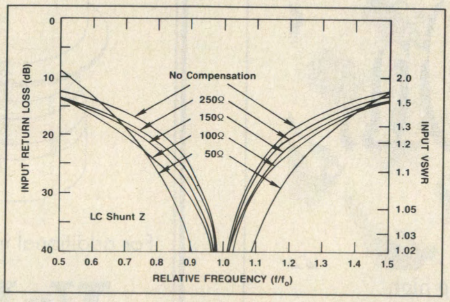



**Figure 14. Simple LC-compensation of single quarter-wave matching section.**

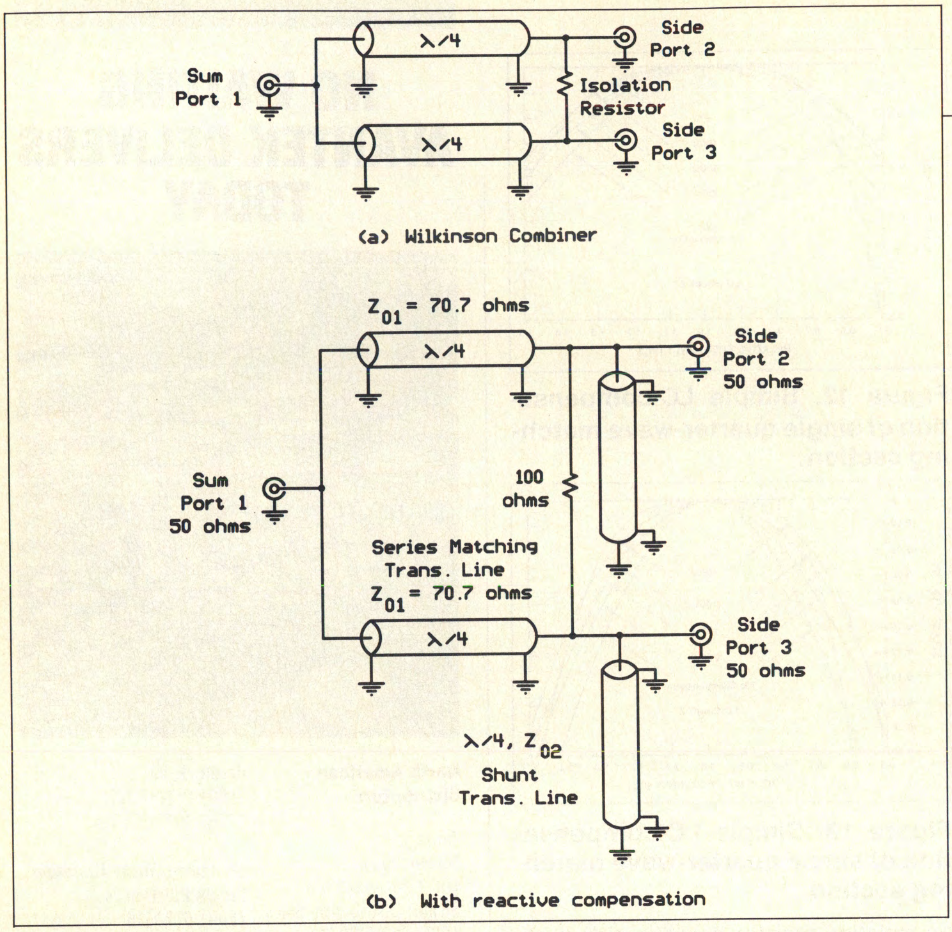



**Figure 15. (a) A simple Wilkinson may be used as an RF power splitter or combiner, (b) The use of shunt short-circuited transmission lines provide reactive compensation.**

### Selectivity and Input Match

The relative response of a Wilkinson splitter or combiner should be held to less than 0.2 dB throughout a wide operating frequency range for a flat response. When the insertion loss is measured between the sum port and either side port, the ideal indicated insertion loss will be the equal-power splitting loss (3.01 dB) plus the frequency-selective matching loss. Dissipative losses increase the insertion loss with a relatively flat response across the operating frequency band. Predicted selectivity for the simple 50 ohm-input/50 ohm-output Wilkinson splitter or combiner is the same as shown earlier for the simple 2:1 single-section, transmission line matching section, Figures 4 and 5. The input match response at the sum port was also shown in Figure 6 for the Wilkinson. These same compensation techniques may be used on a Wilkinson splitter/combiner that is also used to transform impedances.

### Construction and Measurement

The series matching transmission line and shunt compensation transmission line may be realized in several forms; semi-rigid coaxial cable, stripline or microstrip. Semi-rigid coax is readily

# The 48 cent solution.

## Wideband Amplifiers – From $.48 each

| | | | | |
|---|---|---|---|---|
| **UPC1653**<br>To 1300MHz<br>18dB $G_P$ | **UPC1654**<br>To 1100MHz<br>19dB $G_P$ | **UPC1655**<br>To 900MHz<br>18dB $G_P$ | **UPC1656**<br>To 850MHz<br>19dB $G_P$ | **UPC1658**<br>To 1100MHz<br>17dB $G_P$<br>2.0dB NF | |
| **UPC1659**<br>600MHz to 2300MHz<br>23dB $G_P$ | **UPC1675**<br>To 2100MHz<br>12dB $G_P$ | **UPC1676**<br>To 1300MHz<br>20dB $G_P$<br>4.0dB NF | **UPC1677**<br>To 1700MHz<br>24dB $G_P$<br>$P_{out}$ = 19.5dBm | **UPC1678**<br>Up to 1900MHz<br>23dB $G_P$<br>$P_{out}$ = 18dBm | **UPC1688**<br>Up to 1000MHz<br>21dB $G_P$<br>4.0dB NF |

## Prescalers – From $2.20 each

| | | | | | | |
|---|---|---|---|---|---|---|
| **UPB581**<br>÷ 2<br>500MHz to 2.8GHz | **UPB582**<br>÷4<br>500MHz to 2.8GHz | **UPB584**<br>÷2<br>500MHz to 2.5GHz | **UPB585**<br>÷ 4<br>500MHz to 2.5GHz | **UPB586**<br>÷ 512/256<br>500MHz to 2.5GHz | **UPB587**<br>÷ 2/4/8<br>50MHz to 1.0GHz<br>$V_{cc}$=2.2 to 3.5V | **UPB588**<br>÷64/128<br>500MHz to 2.5GHz |

## Freq. Convertors – From $1.58 each

| | | |
|---|---|---|
| **UPC1685**<br>DC to 890MHz<br>14dB GAIN<br>Double Balanced Mixer Applications | **UPC1686**<br>DC to 890MHz<br>22dB GAIN | **UPC1687**<br>DC to 890MHz<br>28dB GAIN<br>$I_{cc}$ of 38mA |

## IF Amplifiers – From $3.50 each

| | | |
|---|---|---|
| **UPC1668**<br>10 to 170MHz<br>$G_L$=14.5dB<br>60dB Isolation | **UPC1669**<br>10 to 180MHz<br>$G_L$=10.5dB<br>55dB Isolation | **UPC1670**<br>10 to 150MHz<br>$IM_3$ of 56dBc<br>60dB Isolation |

## Transistor Arrays From $2.40 each

| | |
|---|---|
| **UPA101**<br>$F_T$=9GHz<br>Double Balanced Mixer Applications | **UPA102**<br>$F_T$=9GHz<br>Differental Amplifier |
| **UPA103**<br>$F_T$=9GHz<br>Differental Amplifier | **UPA104**<br>$F_T$=9GHz<br>OR/NOR Functions |

## Special Function MMICs From $1.08 each

| | |
|---|---|
| **UPC1684**<br>LED DRIVER<br>150mA<br>Drive Current<br>300 Mbits NRZ | **UPC1663**<br>VIDEO AMPLIFIER<br>170MHz @ $A_{VOL}$=100<br>1.6ns Propagation Delay |

Note: MMIC prices based on 25K quantities

Want to make life simpler? Reduce the parts count in your design with silicon MMICs from NEC. They're the low cost, no-hassle way to achieve your design goals.

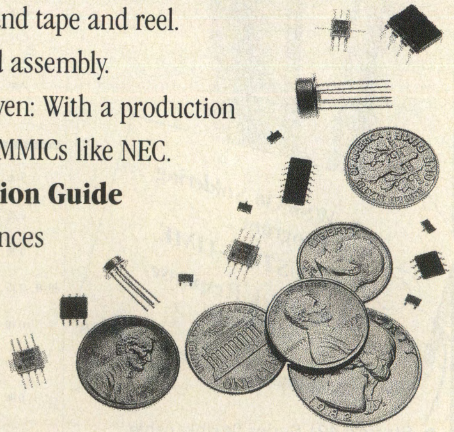
But be aware of the side effects!

Reducing your parts count can also make your QC easier. Your overall circuit more reliable. And your assembly, whether manual or automated, faster and more efficient.

NEC MMICs come in chips and a variety of packages, including hermetic, low cost plastic, surface mount and tape and reel. So they're ideal for high volume automated assembly.

And their quality and reliability is proven: With a production rate of *7 million a month,* no one knows MMICs like NEC.

Our **Silicon MMIC Product Selection Guide** lists specifications for dozens of parts. Chances are good it has just what you need. To get a copy, call your nearest CEL Sales Office or circle the number below.



NEC®

**California Eastern Laboratories**

CEL Headquarters, 4590 Patrick Henry Drive, Santa Clara, CA 95056-0964; (408) 988-3500 FAX (408) 988-0279 □ Santa Clara, CA (408) 988-7846 □ Los Angeles, CA (213) 645-0985
Bellevue, WA (206) 455-1101 □ Scottsdale, AZ (602) 945-1381 □ Richardson, TX (214) 437-5487 □ Shawnee, KS (913) 962-2161 □ Woodridge, IL (708) 241-3040 □ Cockeysville, MD (410) 667-1310
Peabody, MA (508) 535-2885 □ Hackensack, NJ (201) 487-1155 or 487-1160 □ Palm Bay, FL (407) 727-8045 □ Snellville, GA (404) 978-4443 □ Nepean, Ontario, Canada (613) 726-0626

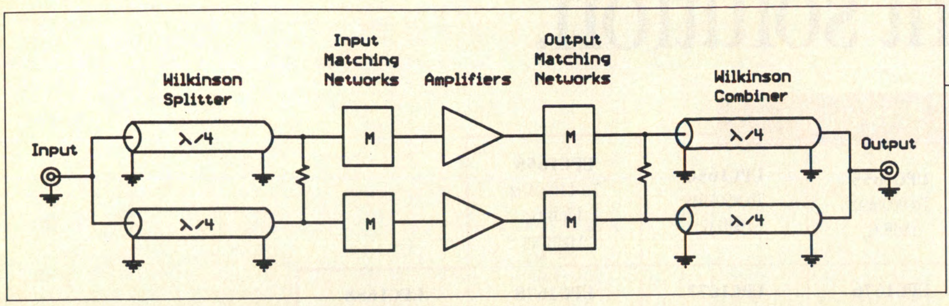



**Figure 16. The Wilkinson hybrid is used as an RF splitter/combiner to effectively parallel two amplifiers.**

available with characteristic impedances from 50 to 95 ohms. Realization of high impedance shunt compensation transmission lines is simplified using stripline or microstrip. Etching tolerance for line widths is easier because the actual

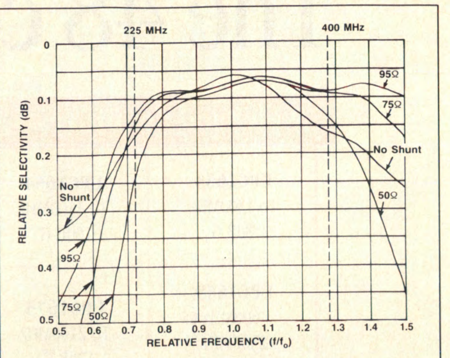



**Figure 17. Selectivity of a UHF Wilkinson hybrid using 0.141" semi-rigid coax.**

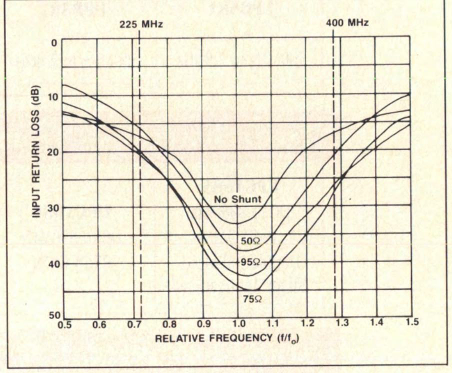



**Figure 18. Input match of a UHF Wilkinson hybrid using 0.141" semi-rigid coax.**

value of the shunt transmission line is not critical. Lumped L and C elements may also be etched on a circuit board for a broadened response.

Experimental 50 ohm Wilkinson splitters were constructed using 0.141" outside diameter, PTFE dielectric, semi-rigid coax for the 225 to 400 MHz military UHF band. The measured results, Figure 17, show an improved bandwidth when using 95 ohm, quarter-wave, shunt transmission lines at the side ports. The input match at the sum port, Figure 18, also shows an improvement when this compensation is added. ***RF***

## References


1. E. A. Franke and R. M. Savage, R. M., "EMP Protection of VHF/UHF Radio Equipment Using Compensated Splitters and Combiners," *EMC Technology*, Vol. 10, No.2, March/April 1990, pp. 25-30.
2. E. J. Wilkinson, "An N-Way Hybrid Power Divider," *IRE Trans. on Microwave Theory and Techniques*, Vol. MTT-8, January 1960, pp. 116-118.


### About the Author


Ernie Franke is a Senior Staff Engineer with E-Systems, ECI Division. He may be reached at PO Box 12248, 1501 72 Street N., St. Petersburg, FL 33733-2248. Tel: (813) 381-2000.

# Designing an Amplifier for 500 Watts, 20 to 500 MHz: The Inside Story

By Richard J. Sheloff
Power Systems Technology

*Applications requiring instantaneous frequency coverage from 20 to 500 MHz with linear operation can boost their power levels from 1 milliwatt to 500 watts with the amplifier described in this article (see general specifications in Table 1). These applications may include linear amplifications for EMI/RFI testing, communications systems, electronic warfare (EW) and electronic countermeasures (ECM) systems.*

The key design challenges facing the engineers at Power Systems Technology were in the design of broadband transformers for both RF transistor matching and combiner/divider schemes. The transformer designs had to be of minimum loss for high power uses. A combination of ferrite material selection and unique coaxial designs were used along with low thermal resistance paths for heat removal from heat dissipators.

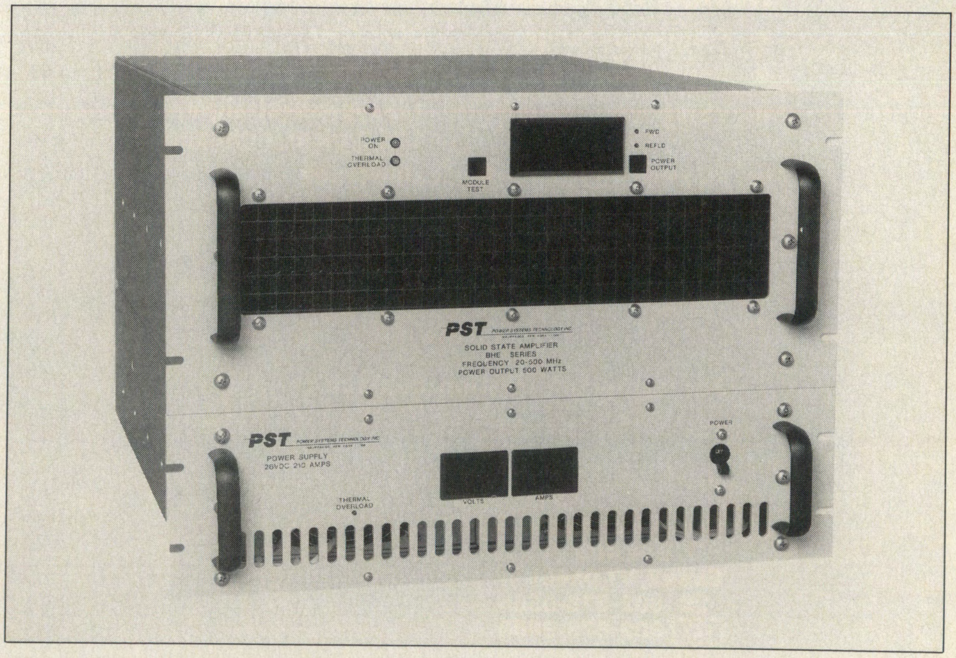
The architecture for the 500 watt amplifier is shown in Figure 1. The input signal passes through a bandpass filter, protecting the amplifier from any out of band drive signals. The signal then passes through a pin attenuator which is used as part of the feedback loop via an ALC control circuit and a dual directional coupler. This feedback loop protects the amplifier from being overdriven by excessive signal input drive. It also allows for graceful degradation or overcurrent protection in the event of an RF transistor failure, output load VSWR protection and output power adjustment for remote programming.

The signal from the pin attenuator is then amplified to greater than 12 watts through the driver amplifier. The output of the driver amplifier feeds the signal through a two-way quadrature divider. Each of these signal paths is then amplified by an RF power transistor in the intermediate power module. Both paths are then recombined using a two-way quadrature combiner arranged opposite in phase from the divider so that the two signal paths combine in phase to a power level of 50 watts.

| MODEL BHE 2758-500 AMPLIFIER SPECIFICATIONS IN GENERAL | |
|---|---|
| Frequency Range | 20 MHz to 500 MHz |
| Output Power | ⩾ 500 watts into 2.0:1 load VSWR |
| Output Power Flatness | ±0.6 dB |
| Harmonics | ⩽ −20 dBc even<br>⩽ −15 dBc odd |
| AM Distortion | < 10% maximum at 85% DOM |
| Spurious | < −60 dBc |
| Operating Temperature | 0°C to 50°C |
| Size | |
| Amplifier | 19" × 8.75" × 26.25" |
| Power Supply | 19" × 5.25" × 24" |
| Weight | 180 lbs. |

**Table 1. Amplifier specifications**

From the two-way combiner the signal is split into four additional signal paths by four-way quadrature divider. Each of these signal paths is amplified by an RF power transistor in the power module. The four amplified signal paths are




*20-500 MHz, 500 Watt amplifier.*

then recombined in phase by a four-way combiner. Each of these signal paths is once again split into four additional signal paths by four-way quadrature dividers resulting in a total of 16 signal paths. Each of these signal paths is amplified by an RF power transistor located on power modules, to approximately 51 watts. The 16 amplified signal paths are then combined by four-way quadrature combiners.

The four combined signal paths are then recombined by a four-way in-phase combiner to a total power level of 524 watts. The combined signal passes through a dual directional coupler for signal sampling before exiting the amplifier at the final output connector at a power level of 500 watts. The dual directional coupler has built-in detectors for rectifying forward and reflected RF signals. The detected signals are processed through the ALC circuit for forward power leveling, reflected power turndown and monitoring. Forward and reflected power monitoring is sent from the ALC circuit to the microprocessor where it is digitized and displayed on the front panel. Each RF transistor is constantly being monitored for faults by the fault boards. This information is also processed by the microprocessor for display and corrective action should a fault occur.

The power amplifier is all connectorized and of modular construction for ease of maintenance. The modules are fastened to a 3-inch finned aluminum heatsink for maximum heat transfer using forced air cooling. Thermal switches strategically located will shut down the amplifier when a thermal overload is present and will automatically return to full power when the temperature returns to normal.

DC power supplied to the power amplifier is derived by a 28 VDC at 210 amps, 100 kHz switching power supply. The power supply consists of two 105 amp modular power supplies which are operated in parallel with capability of load share under all extremes. A digital voltage and current meter monitors the overall output. Internal individual fault indicators guide the user to the faulty module for minimal down time.

The performance of the amplifier over the 20 to 500 MHz band, operating at full power in a pulse mode, showed rise times of less than 200 nanoseconds and fall times of less than 50 nanoseconds. When operated with an audio modulated (AM) RF input signal, distortion measurements were less than 10 percent at

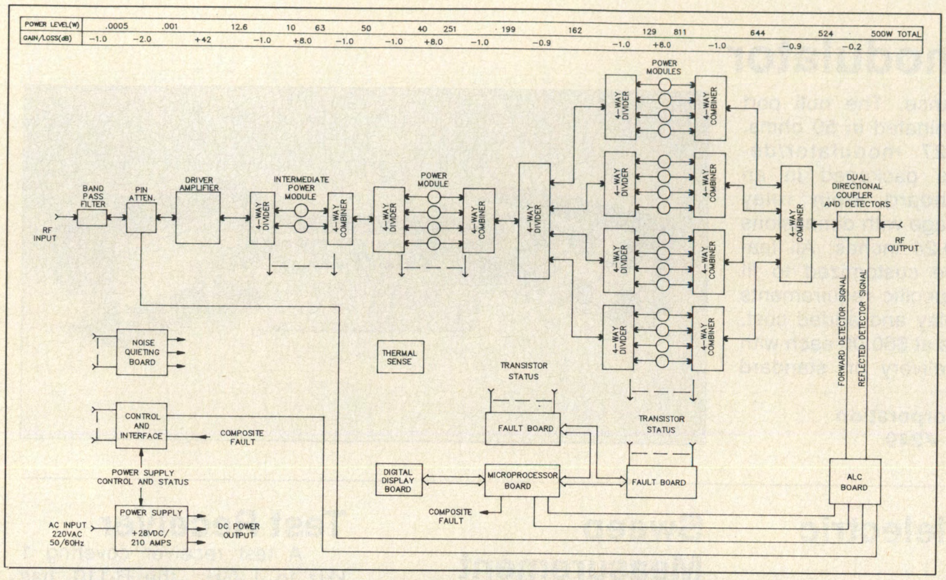



**Figure 1. Block diagram of 20-500 MHz 500 W amplifier.**

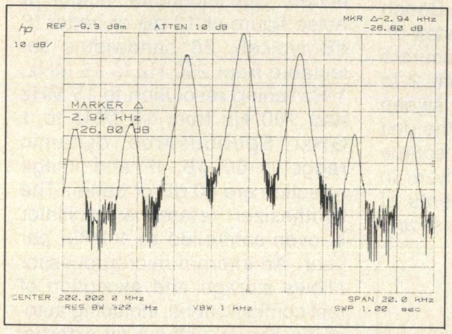


**Figure 2. Amplitude modulation distortion.**

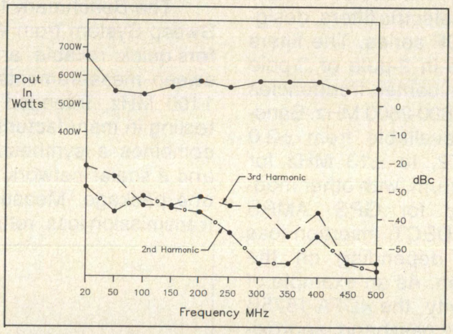



**Figure 3. Output power and harmonics versus frequency.**

85 percent depth of modulation (see Figure 2). Measurements made while using a CW signal yielded an overall flatness across the full 20 to 500 MHz band of ±0.6 dB. Harmonic content was typically less than −20 dBc for all harmonics (see Figure 3). Noise quieting circuits within each PA module reduced noise power to −145 dBm/Hz within 15 microseconds. Third-order, two-tone intermodulation distortion with test signals separated by 1 kHz, operated at 500 watts PEP, was −30dBc (see Figure 4).

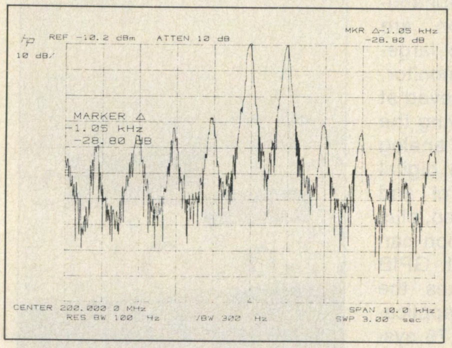


**Figure 4. Intermodulation distortion measurement.**

Optional extras than can be readily incorporated into the Model BHE 2758-500 amplifier are IEEE-488 and RS232 type interfaces, audio input for amplitude modulation, power level control, harmonic filtering via switched filters, and special interfaces, to name a few.

Power Systems Technology, Inc. considers the design of this versatile high performance amplifier to be a significant state-of-the-art product and it believes that will be extremely useful in a wide range of both military and industrial applications. *For more information on this unit, circle Info/Card #250.* ***RF***

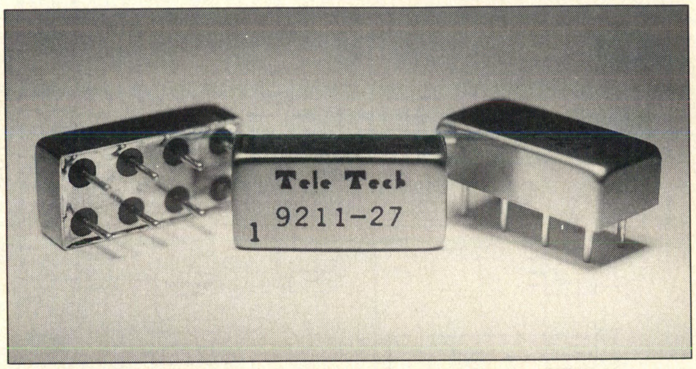
## About the Author

Richard J. Sheloff is the Director of Marketing for Power Systems Technology. He may be reached at 63 Oser Avenue, Hauppauge, NY 11788. Tel: (516) 435-8480.

# QPSK Modulator/Demodulator

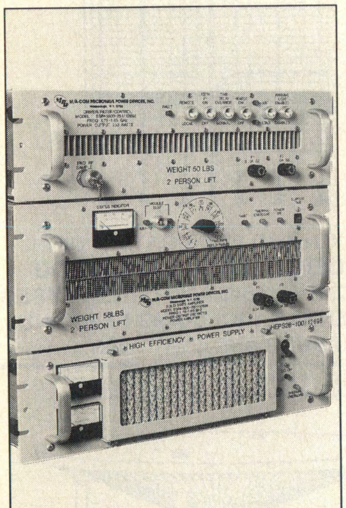
Tele-Tech Corp. introduces the 9211-27 QPSK Modulator/Demodulator for the 800-900 MHz band. The unit requires a reference power of +10 dBm, and handles signal power to 0 dBm. Output voltage (typical) is specified at 75 mV peak. Amplitude balance of the unit is ±1 dB maximum, and phase balance is ±3 degrees maximum. Signal rise time is less than 10 nsec. Required sin/cos inputs are ±20 mA maximum. All signal and reference ports have a 50 ohm impedance. The null port must be terminated in 50 ohms. The 9211-27 modulator/demodulator is packaged in an industry-standard 8-pin relay header package with dimensions of 0.4×0.8×0.24 inches. All features can be customized to fit the user's specific requirements with little delay and added cost. Pricing starts at $60.00 each with 4-6 week delivery on standard parts.

**Tele-Tech Corporation**
**INFO/CARD #249**




## Transportable Satellite Uplink Amplifier

Microwave Power Devices has developed a solid-state high power amplifier with 250 watts CW output, minimum, over the 1750-1850 MHz frequency range. The amplifier, model SSPA 1800-251/12698, is intended for communications to an orbiting satellite using frequency or phase modulated signals. Critical uplink transmitters will benefit from its high reliability and graceful degradation of power in the event of single device failure. The unit supports an RS-232 control interface. Additional features include harmonics and spurious signals at −70 dBc or better, built-in status selectors and panel meters, and built-in forced-air cooling.



**Microwave Power Devices, Inc.**
**INFO/CARD #248**

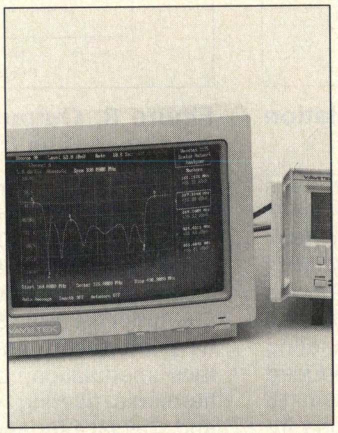
## SMT Dielectric Filters

Toko America announces a new line of miniature surface mountable dielectric filters, designated the 4DF series. The filters are available in 2-pole or 3-pole designs with center frequencies ranging from 800-2500 MHz. Bandwidths are available from ±2.0 MHz for CT2, to ±13 MHz for spread spectrum, with other models intended for GPS, AMPS cellular and DECT. Insertion loss is 2-3 dB, depending on the model chosen. As an example of filter selectivity, the 4DFA-1575B has a ±5 MHz passband, approximately 10 dB loss at ±35 MHz, and 35-45 dB at ±140 MHz. 2-pole filters are 12.5×14.5×5.0 mm and 3-pole units are 17.5×14.5×5.0 mm. Pricing starts at $6-7 in 100-piece quantities.

**Toko America, Inc.**
**INFO/CARD #247**


## Sweep Measurement System

The Benchmark 1175 Bench Sweep System from Wavetek offers quick, reliable, and accurate sweep measurements from 2 to 1100 MHz. Intended for sweep testing in manufacturing, the unit combines a synthesized source and a scalar network analyzer in one package. Measurements of transmission loss, return loss and absolute power, with alphanumeric marker information, are displayed on a separate large-screen super VGA color monitor. A 500-point sweep is achieved at 8 sweeps per second, giving the same "real-time" feel as analog sweep systems, but with digital precision. Flexible control and display options are provided, plus setup and trace information can be stored for easy recall. GPIB interface capability makes the unit compatibie with ATE applications. The Benchmark 1175 system is priced at $11,000.

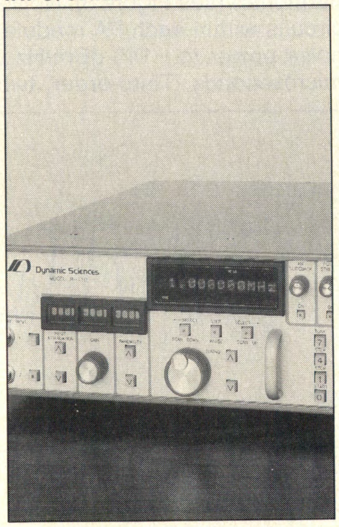


**Wavetek Communications Div.**
**INFO/CARD #246**

## Test Receiver

A test receiver covering 1 kHz to 1 GHz, the R-110, has been introduced by Dynamic Sciences. Specifications include a noise figure of 12 dB or better (8 dB typical), 26 bandwidths selectable from 200 Hz to 15 MHz, 1 Hz tuning resolution to 15 MHz and 100 Hz from 15 MHz to 1 GHz. Spurious-free dynamic range is 60 dB, IF and image rejection are 80 dB or better. The synthesizer reference oscillator is oven-controlled to 1 PPM per year. An internal microprocessor allows storage and execution of test configurations, including automatic sweep, without an external computer. An IEEE-488 interface allows full control, if required. Optional modules provide additional demodulation, DVM, tracking preselection, frequency extension, pulse stretching, wide-bandwidth, and other specific capabilities.

**Dynamic Sciences**
**INFO/CARD #245**



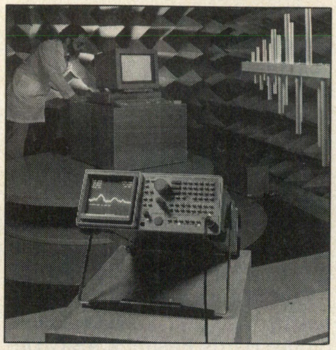
## TEST EQUIPMENT

### Multitone Signal Generators

Teslatronics introduces a line of multitone RF signal generators that greatly simplify IMD measurement of linear power amplifiers. Standard models combine 3 to 16 individual carriers into a single output. Applications include CATV, cellular, GSM and other services. Prices start at $5900.
**Teslatronics, Inc.**
**INFO/CARD #244**

### Spectrum Analyzer With EMC Options

Tektronix announces the 2712 low cost spectrum analyzer covering 9 kHz to 1.8 GHz with excellent frequency accuracy and high dynamic range. The portable unit performs EMC prequalification testing using its quasi-peak detector and EMC filters option. A number of transducer products



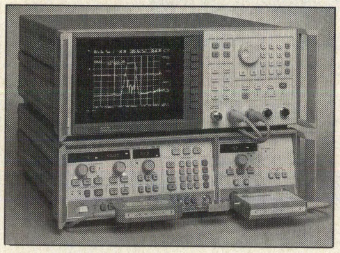
are available to facilitate EMC testing. Full performance features and standard GPIB interface allow automated testing in all applications. The 2712 is priced at $11,950; an optional internal tracking generator is $3150.
**Tektronix, Inc.**
**INFO/CARD #243**

### Modulation Analyzer

Racal-Dana now offers the 4150 Modulation Analyzer, a message based, single-slot, C-size VXI module. Consisting of an RF receiver/downconverter and audio analyzer, the unit accepts RF inputs from 1.5 to 2000 MHz. Values of FM deviation, AM depth and phase deviation may be read over the bus. On-card digital signal processing resolve the signal into magnitude and phase components. The digitized audio is available over the bus for further processing and analysis. Price of the 4150 is $6900.
**Racal-Dana Instruments, Inc.**
**INFO/CARD #242**

### Scalar Network Analyzer

The HP 8757D is the latest in a family of scalar network analyzers introduced by Hewlett-Packard. All models can be configured to cover 10 MHz to 110 GHz, measuring transmission and reflection,



insertion loss and gain, absolute power, and return loss of RF and microwave components. Optional new precision detectors with EEPROM correction factors and an internal calibrator allow power measurement nearly equal to a separate power meter. Limit testing, external disk SAVE and RECALL, four display channels and a color display are other new features. The HP 8757D is priced at $9300, an 18 GHz detector is $1750, and the optional internal calibrator is $2500.
**Hewlett-Packard Co.**
**INFO/CARD #241**

## SEMI-CONDUCTORS

### Low Noise GaAs FET

A GaAs FET chip with a typical optimum noise figure of 0.7 dB and gain of 11 dB at 12 GHz is announced by Microwave Technology. In a broadband 6-18 GHz balance gain module, performance is typically 9 dB gain and

under 3 dB noise figure. The device is available in 19 IDSS "bins" from 9 to 66 mA.
**Microwave Technology**
**INFO/CARD #240**

## ASIC Process Technology

Harris Semiconductor announces the UHF-1 process with 8 GHz NPN FT and 4 GHz PNP FT, using silicon-on-insulator technology. The process is available on the Harris Fastrack ASIC Design System, which has accurate models and analysis tools. Designers can optimize tile array (HTA3000) or device-level (HDI3000) designs for either extreme high speed or low power consumption. The tile array library includes a mixer, current feedback amplifier, comparator, references, video amplifiers, sample and hold, and current output multiplier.
**Harris Semiconductor**
**INFO/CARD #239**

## 1 GHz RF Switch

A bidirectional SPDT switch with low ON resistance, wide bandwidth, and very low power consumption has been introduced by Signetics. The NE/SA630 uses BiCMOS technology to achieve a DC-1 GHz bandwidth, 25 ns switching time, CMOS/TTL drive compatibility, and just 140 microamps current consumption from a 5 V supply. Unused inputs are terminated in 50 ohms to prevent oscillations in the OFF channel. The 1 dB compression point is +18 dBm allows its use as T/R switch in low power applications. Pricing is $2.79 in 100s.
**Signetics Company**
**INFO/CARD #238**

## Chips for Spread Spectrum

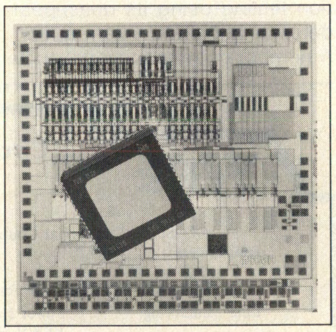
Stanford Telecom has introduced four ASICs performing necessary functions for wireless data communications and other spread spectrum applications. The STEL-2120 is a differential PSK demodulator which handles both DBPSK and DQPSK; the STEL-2130 is a digital downconverter/carrier tracking IC with SSB downconversion, an on-chip NCO, and IF processing; the STEL-3310 is a digital matched filter for quadrature channels, with 22 MHz sampling rate and 64 taps per channel; and the STEL-1179 is a low cost numerically controlled oscillator (NCO) with up to 25 MHz clock rate and 12 bit digital output.
**Stanford Telecom**
**INFO/CARD #237**

## Digital Cellular Chip Set

Qualcomm announces two sets of ASICs for manufacturers licensed to produce their CDMA digital cellular systems; one set for subscriber equipment and one set for cell site equipment. Each has three chips, with one chip common to both. Work is in progress to shrink the chip sets to a single ASIC.
**QUALCOMM, Inc.**
**INFO/CARD #236**

## 12-Bit High Speed DAC

Tektronix Microelectronics announces the TKDA30, a 12-bit multiplying DAC operating up to 100 MHz for video, direct digital synthesis and signal reconstruction applications. Spurious-free dynamic range is 65 dB at 100 MSPS and a 10 MHz output. The device dissipates 900 mW and uses a single −5.2 V supply. Price of the TKDA30 is $118.00 in 100s.

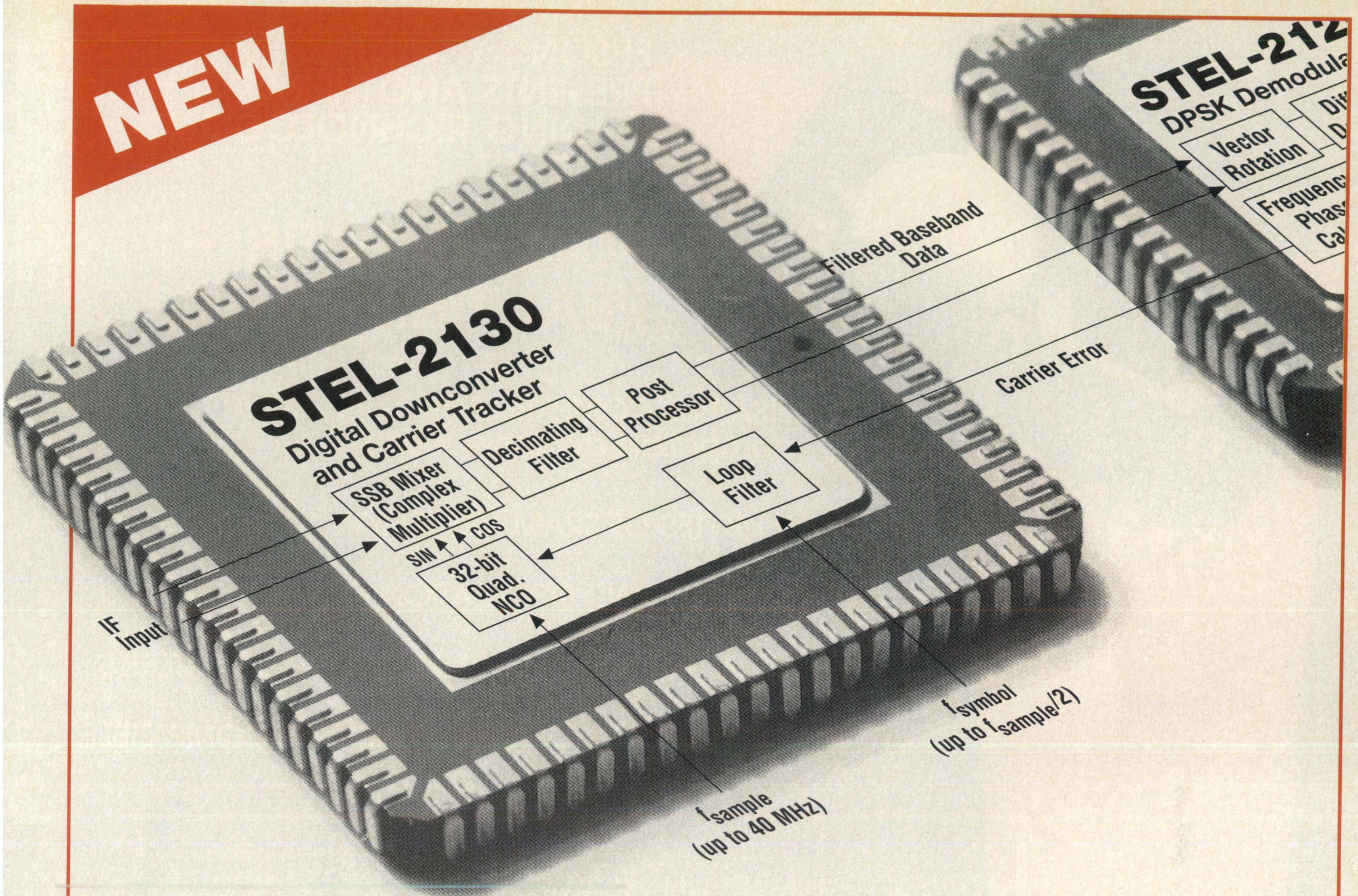


**Tektronix Microelectronics**
**INFO/CARD #235**

# DISCRETE COMPONENTS

## DIP Relays

CP Clare announces a new series of HGZM miniature wetted reed relays with form C contacts. The relays provide bounce-free operation for up to 1 billion cycles at loads up to 50 W, 350 V and 1 A. The relays have very low contact resistance for low signal levels. Input power is 550 mW, and coil voltages are available in standard 5, 12, 24 and 48 V ratings.
**DP Clare Corporation**
**INFO/CARD #234**




# Digital Wireless ...at a low cost

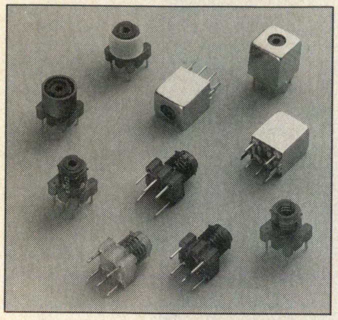
The STEL-2130 Digital Downconverter and Carrier Tracking ASIC combines several essential receiver functions for digital communications receivers and demodulators. Designed for IF sampling in both conventional and Spread Spectrum receivers the STEL-2130 brings the digital interface and processing one step closer to the antenna. The STEL-2130 is an ideal communications solution for **cellular radio, Wireless LANs and other transportable equipment.** To find out how you can simplify your designs and improve performance at the same time, call Stanford Telecom today...

**STANFORD TELECOM®** ASIC & Custom Products Division

ASIC & Custom Products Division
2421 Mission College Blvd.
Santa Clara, CA 95056-0968
Tel: (408) 980-5684
Fax: (408) 727-1482

INFO/CARD 41

### 7mm Inductors
The "Slot Seven" line from Coilcraft provides inductance values from 100 nH to 220 uH with up to 25 percent tuning range using a slotted ferrite adjustable

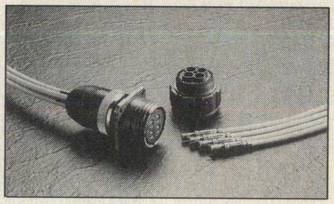


core. A variety of magnetic and electrostatic shielding options are available. A Designer's Kit with 39 shielded values is available for $60. Typical 1000 quantity pricing is 70 cents per coil.
**Coilcraft**
**INFO/CARD #233**

### Ultraminiature Crystal
The SX-2 AT-strip crystal is now available from KDS America. This SMT device features a glass-sealed ceramic case measuring 4.5×9.5 mm and only 1.8 mm high. Fundamental mode frequencies range from 3.579545 to 25.0 MHz with ±100 ppm tolerance over 0 to +70C. In 100s, prices range from $1.00 to $1.50.
**KDS America**
**INFO/CARD #232**

## CABLES & CONNECTORS

### Multiport Connectors
M/A-COM Adams-Russell has enhanced MIL-C-38999 multiport connectors which maintain stable RF/microwave electrical paths. The Mul-T Port EIS[tm] save panel space and offer performance to 18.5 GHz.



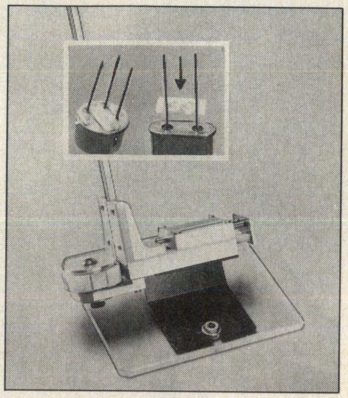
These cylindrical connectors are available in several pin configurations for DC, RF and microwave.
**M/A-COM Adams Russell**
**INFO/CARD #231**

### Subminiature Connectors
Coaxial contacts for use in any D connector are announced by RETCONN. The new RDM connectors have low VSWR in both 50 and 75 ohm systems, and feature a one-piece body to reduce leakage. Installation is with standard crimping tools.
**RETCONN**
**INFO/CARD #230**

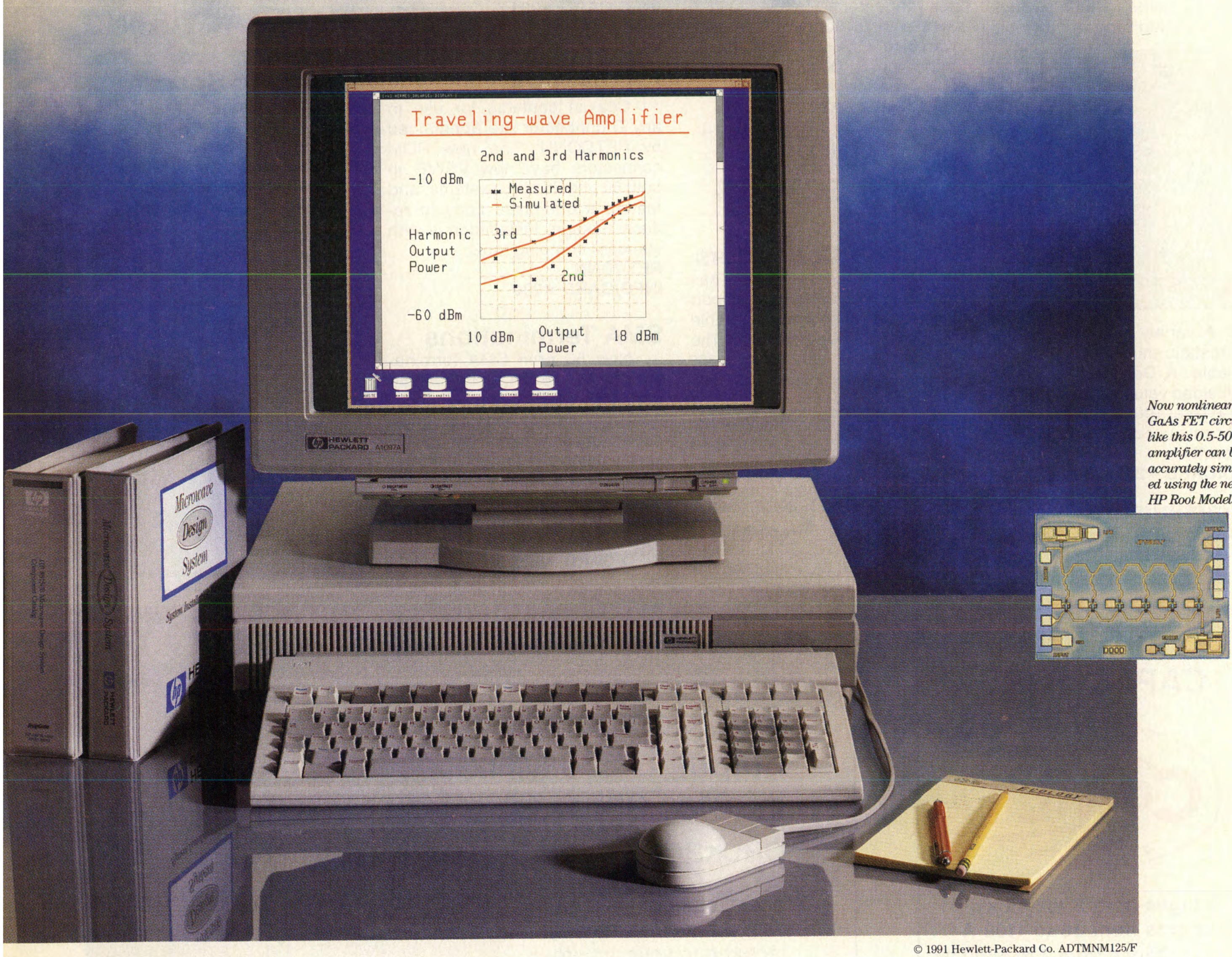
### SMA Terminations
New 50 ohm SMA terminations for DC-18 GHz are available form M/A-COM Control Components Div. These low cost terminations have a minimum VSWR specification of 1.05 + 0.01f(GHz) and meet or exceed requirements of MIL-D-39030.
**M/A-COM Control Components Div.**
**INFO/CARD #229**

## TOOLS, MATERIALS & MANUFACTURING

### Mounting Spacer
Nine versions of SNAPTITE, a spacer which provides easier cleaning and strain relief, are available for crystals, transistors, ICs, capacitors, resistors, inductors, and other components. The spacers are made of flat or dim-



# 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.

To help you get started, popular GaAs FET devices characterized using the HP Root Model are already included in the HP MDS nonlinear libraries—ready to go.

It doesn't require optimization or specialized modeling expertise to add your own, either. Because the HP Root Model computes device parameters directly from measured data.

And the HP MDS software runs on HP, Apollo, Sun, DEC or 386-based platforms.

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.

## There is a better way.

**HEWLETT PACKARD**

United Kingdom (0344) 369 369 • Germany (06172 ) 16 0 France (1-69) 82-65-00 • Italy (02) 95.300.134 • Singapore (65) 291 8554 • Taiwan (886-2) 714 8740 • Hong Kong (852) 848 7070 • Korea (82-2) 784 2666

pled mylar and fit a manual or air-operated applicator.
**Polaris Electronics Corp.**
**INFO/CARD #228**

## UHF Substrate

NTK Technical Ceramics has developed a high purity (99.7 percent) alumina substrate with dielectric loss of only 0.00003 at 8 GHz. The material is designed for thin film microwave components.
**NTK Technical Ceramics**
**INFO/CARD #227**

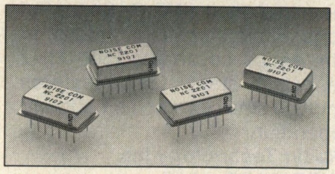
# SIGNAL SOURCES

## ACMOS Oscillators

The MA Series from M-Tron offers TTL and CMOS compatible outputs in the 80.0 to 135.0 MHz range. ACMOS circuitry offers high drive capability plus fast rise and fall times. Applications include HDTV, DSP, ultrasound, digital recording, and MRI.
**M-Tron Industries, Inc.**
**INFO/CARD #226**

## Noise Modules

Noise Com introduces the NC 2000 Series high power noise sources, mounted in 14-pin packages for p.c. mounting. Four models cover 1 to 1000 MHz with powers from +5 dBm (1-100 MHz



model) to −5 dBm (1-1000 MHz model) with flatness of ±1 dB. Power requirements are +12 or +15 V., and load impedance is 50 ohms.
**Noise Com, Inc.**
**INFO/CARD #225**

## 2.5 GHz Synthesizer

The VDS-6000 from Sciteq covers 1.75× bandwidths up to 2.5 GHz, for a variety of applications including L-band satellite systems. Improved phase noise (−85 dBc/Hz) is achieved with a proprietary Arithmetically Locked Loop technique. Spurious responses are better than −60 dBc, switching speed is 10 ms, and power consumption is under 5 watts. Price of the VDS-6000 is under $800 in unit quantities.
**Sciteq Electronics, Inc.**
**INFO/CARD #224**

## VHF VCO Line

A new line of voltage controlled oscillators is available from Bluestem Electronics. An example unit is the V135-10 with a 3-15 volt tuning range of 136-146 MHz, −5 dBm output, and 17 mA current with a +12 V supply. Prices start at $175, dropping to $50 in 1000 quantities.
**Bluestem Electronics, Inc.**
**INFO/CARD #223**

## Ovenized Oscillators

The 815 crystal oscillator is designed for fast warmup and ruggedness. The unit features excellent time and temperature stability and low aging rate. 0.0 dBm power output is standard, with spurious responses −80 dBc. Phase noise is −85 dB at 1 Hz, −145 dB at 1 kHz. the operating temperature range is −55 to +85C.
**McCoy Electronics Co.**
**INFO/CARD #222**

# AMPLIFIERS

## Cellular LNAs

A family of cellular LNAs covering the 820-915 MHz range is available from Microdata. Models include the following features: 12 to 44 dB gain with up to 6 outputs, 2 dB maximum noise figure, +0.2 to −0.4 dB gain flatness, and 24 to 47 dBm third order intercept points.
**Microdata Innovation AB**
**INFO/CARD #221**

## High Intercept Amplifier

The Model PA1214-20L is a class AB linear amplifier operating in the 1.2 to 1.4 GHz range, with an IP3 of 51 dBm, minimum. The amplifier achieves an output of +41 dBm at 1 dB compression,

and has up to 38 dB gain with ±1 dB flatness. The unit will withstand an infinite output VSWR at all phase angles.
**Frequency Products, Inc.**
**INFO/CARD #220**

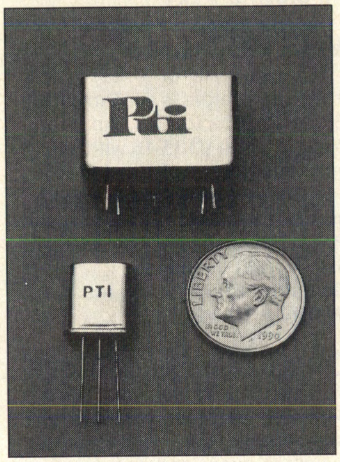
## Cellular Base Amplifiers

Motorola introduces three linear amplifier modules for operation in the cellular radio base station bands of 850-900 MHz. The PA900 Series includes the PA900-19-60L with 60 watts output, 19 dB gain and a price of $1010; the PA900-19-100L offering 100 watts and 19 dB gain at $1230; and the PA900-19-10LGC with 10 watts, 45 dB gain, and a price of $1120 (prices are all for 10-24 units).
**Motorola, Inc.**
**INFO/CARD #219**

# SIGNAL PROCESSING

## Single-Wafer Filter

A new single-wafer four-pole filter has been introduced by Piezo Technology. Offered in the 40-50 MHz range, the filter has a minimum 3 dB bandwidth of ±48 kHz with a 3:40 dB




shape factor of 2.8:1. Ultimate attenuation is 60 dB. Package options include a HC-18/U with the natural impedance (3300-4300 ohms).
**Piezo Technology Inc.**
**INFO/CARD #218**

## Log Amplifiers

Radar Technology announces their RTL-7 Series of logarithmic amplifiers. Models in the series cover 200-1500 MHz in octave steps. Major features include small size and broadband operation.
**Radar Technology Inc.**
**INFO/CARD #217**

## Directional Detectors

Directional couplers are now available for monitoring VHF or UHF transmitter power or antenna VSWR, providing a DC output for measuring equipment. The PR50 series have either one or two internally terminated coupled ports and detector ports are negative ground. Reverse polarity is optional, as is remote, isolated diodes.
**Antenna Engineering Ltd.**
**INFO/CARD #216**

## 10-watt Transformer

Model TR-50-5.6-B-HP from Lorch Electronics is a 50 to 5.6 ohm transformer designed for power amplifier matching from 20-200 MHz. Typical insertion loss is 0.7 dB with VSWR of 1.4:1 or better. Available packaging includes a flatpack and a PC plug-in case.
**Lorch Electronics**
**INFO/CARD #215**

## Clock Oscillators

A selection of clock oscillators is available 50 MHz to 120 MHz. The oscillators are available in several different packages including 4 pin model in 14 pin metal DIP, 4 pin model in 8 pin metal MINI-DIP, surface mount 0.3" × 0.5× plastic package with J-leads or Gull-Wing leads. Prices range from $3.00 for 50 MHz to $8.00 for 120 MHz in 1000 piece lots.
**Pletronics Inc.**
**INFO/CARD #200**

# Intermodulation Distortion

*By Gary A. Breed*
*Editor*

*This is the first edition of our new monthly column featuring "nuts and bolts" tutorials on key RF topics. These lessons will be very basic, intended for engineers without extensive experience in RF. Future topics include a variety of basic RF circuits, components, measurements and design methods.*

Intermodulation distortion (IMD) can be defined as: "The presence of unwanted signals which are caused by interactions among two or more desired signals." The results of excessive IMD in a transmitting system are unwanted signals which may cause interference. In a receiver, internally-generated IMD can hinder reception of the desired signals.

The term distortion means that this is a deviation from ideal performance. Therefore, IMD measurements are a useful figure of merit for the linearity of an RF system or subsystem; equally important for both transmitting and receiving equipment.

### Intermodulation Mechanism

Nonlinearities in a circuit can cause it to act like a mixer, generating the sum and difference frequencies of any two signals which are present. These same imperfections generate harmonics of the signals, which can then be mixed with other fundamental or harmonic frequencies. Figure 1 shows these relationships in the frequency domain, as they would be displayed on a spectrum analyzer.

The *order* of a particular product of IMD is defined as the number of "steps" between it and a single fundamental signal. Harmonics add steps. For example, the second harmonic = $2f_1 = f_1+f_1$, which is two steps, making it a second-order product. The product resulting from $2f_1-f_2$ is then a third-order product. Some of the IMD products resulting from two fundamental frequencies are:

Second Order $= 2f_1$
$= 2f_2$
$= f_1+f_2$
$= f_1-f_2$

Third Order $= 2f_1+f_2$
$= 2f_1-f_2$
$= 2f_2+f_1$
$= 2f_2-f_1$
...etc.

The order is important because, in general, the amplitude of IMD products falls off as order increases. Therefore, low-order IMD products have the greatest potential to cause problems if they fall within the band of interest, or on frequencies used by nearby equipment. Odd-order IMD products are particularly troublesome, since they fall closest to the signals which cause them, usually within the operating frequency band.

### IMD Measurements

The worst-case situation for IMD occurs when strong signals are very close together in frequency, since many distortion products fall within the band of operation. Widely separated signals will still generate distortion, but the products are more likely to be eliminated by filtering already in place in the system.

With this in mind, most IMD testing uses closely-spaced test signals, perhaps 1 kHz, 20 kHz, 100 kHz, or 1 MHz apart, depending on the frequency of operation and the particular application.

*Receiver Dynamic Range*: The measurement format most commonly used compares the level of a specific IMD product (3rd order, 5th order, etc.) to the level of the test signals. A two-tone test of a mixer might look like Figure 2. This hypothetical display shows a mixer with third order IMD products 80 dB below the level of the test signals.

A rule of thumb is to use test signals separated by five to ten times the IF bandwidth, to ensure that they are completely outside the filter passband. Either the receiver or the test signal generators are tuned to place the target IMD product (e.g. third order product $2f_1-f_2$) in the receiver passband. The conventional test method will have first determined the noise floor of the receiver, the minimum discernible signal (MDS) level. The test signals are then adjusted in amplitude until the IMD product being measured is equal to the MDS. The difference between the amplitude of the test signals and the MDS is the dynamic range. Third-order IMD dynamic range is often referred to as the Spurious-Free Dynamic Range (SFDR).

SFDR specifications indicate the ability of a receiver to handle weak signals in the presence of nearby strong signals. The acceptable SFDR number will vary with system bandwidth and test signal separation. Modern narrowband receiving equipment for SSB, NBFM, or FSK communications can achieve SFDR better than 100 dB, as measured with test signals spaced ten times the bandwidth.

In virtually all mixers and amplifiers, square-law relationships determine the IMD levels as the test signals (or real-world signals) increase above the threshold which causes detectable IMD products. This means that dynamic range

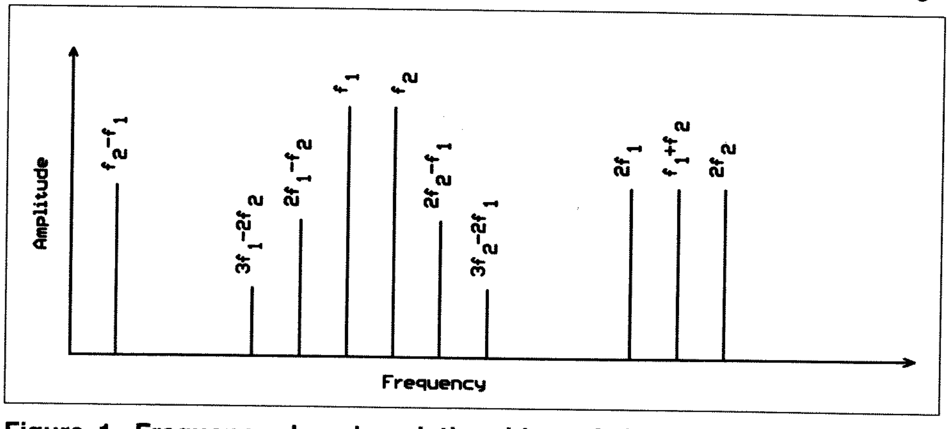



**Figure 1. Frequency-domain relationships of the desired signals and low-order IMD products.**

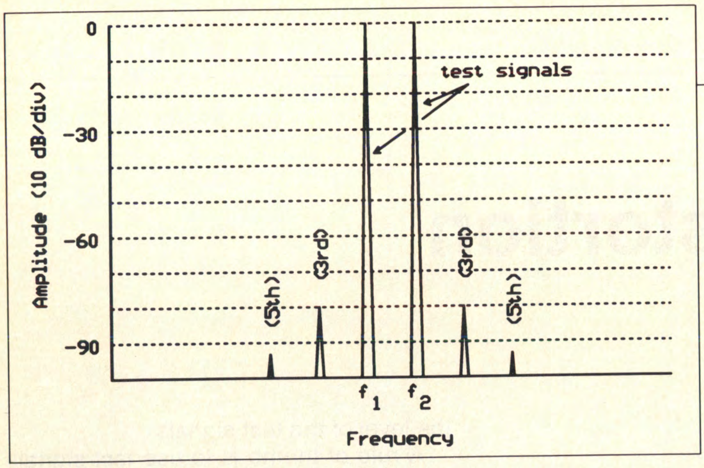



**Figure 2. Typical two-tone test display of a mixer (observed at the IF output). A small-signal amplifier test would be similar.**

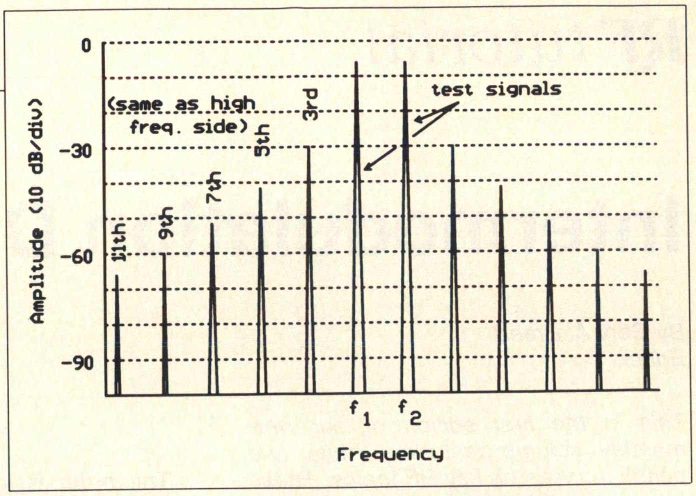



**Figure 3. Two-tone IMD testing of a Class AB linear amplifier would look similar to this display.**

which have essentially random modulation characteristics. Reference (5) covers this and other transmitter testing. Reference (6) has practical data on both transmitter and receiver IMD testing.

## Summary

Intermodulation distortion is an important specification in both receiver and transmitter performance, particularly in high-performance or crowded-band applications. This brief introduction has only identified the basic IMD mechanism and standard test methods. With the growing use of spread-spectrum systems, increasing utilization of cellular radio systems, and many new RF applications coming soon, IMD performance will become an even more critical specification for RF equipment. *RF*

## References

1. M. Bartz, "Designing Effective Two-Tone Intermodulation Distortion Test Systems," *RF Design*, November 1987, pp. 59-69.
2. N. Ayrandjian, "Simple Computation of Spurious-Free Dynamic Range," *RF Design*, January 1987, pp. 65-66.
3. W. Sabin and E. Shoenike, Editors, *Single-Sideband Systems & Circuits*, McGraw-Hill, 1987, Chapter 17, "Receiver Measurement Techniques."
4. U. Rohde and T. Bucher, *Communications Receivers,* McGraw-Hill, 1988, Chapter 2, "Radio Receiver Characteristics."
5. (Sabin and Schoenike), Chapters 12, 13 and 14, on various types of power amplifiers.
6. K. Kleinschmidt, Editor, *The ARRL Handbook for the Radio Amateur,* 67 Edition, ARRL, 1990, pp. 24-34 to 25-45.

# High Performance Active Double Balanced Mixer

By Bruce Hubbard
British Aerospace (Australia) Ltd.

*This entry in the 1991 RF Design Awards contest was the result of the author's personal interest in an amplifier design by Dr. David Norton using advanced negative feedback techniques.*

The performance of a superheterodyne receiver is largely determined by the characteristics of its RF amplifier and mixer. Presented here is a high performance double balanced mixer, which offers low noise figure, high dynamic range, good isolation and excellent impedance matching properties.

It has been shown (1,2) that by using transformers to provide negative feedback an amplifier can be produced with a noise figure and dynamic range which is substantially that of the active device, and an input impedance which is that of the load.

It has also been shown (3) that the noise figure of a common base transistor mixer with RF feedback is equal to the noise figure of the corresponding amplifier. The circuit presented here is an active double balanced mixer employing these principles.

### The Noiseless Feedback Amplifier

Referring to Figure 1, a transistor operating as a common base amplifier has a broadband transformer connected between its output and input as shown. Figure 2 shows the equivalent circuit. The transistor is biased for an emitter current of several milliamps and has an input impedance $R_e \approx 26/I_e$ (mA) which is of the order of a few ohms and may be ignored. The input voltage $V_a$ therefore appears across the input winding and

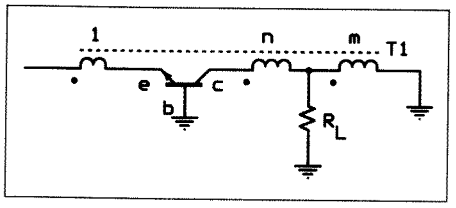



**Figure 1. Common base amplifier with transformer feedback.**

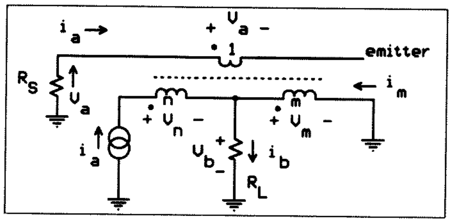



**Figure 2. Equivalent circuit.**

the following relationships now apply.

$$v_n = nv_a \quad (1)$$

$$v_b = mv_a \quad (2)$$

Therefore:

$$A_v = m \quad (3)$$

For a common base amplifier $i_e \approx$ ic, therefore $i_a$ flows through the single primary turn and n secondary turns. By auto-transformer theory:

$$i_a + ni_a = mi_m \quad (4)$$

And:

$$i_b = (i_a + i_m) \quad (5)$$

Therefore:

$$i_m = i_a\left(\frac{n+1}{m}\right) \quad (6)$$

And:

$$i_b = i_a + i_a\left(\frac{n+1}{m}\right) = i_a\left(1 + \frac{n+1}{m}\right) \quad (7)$$

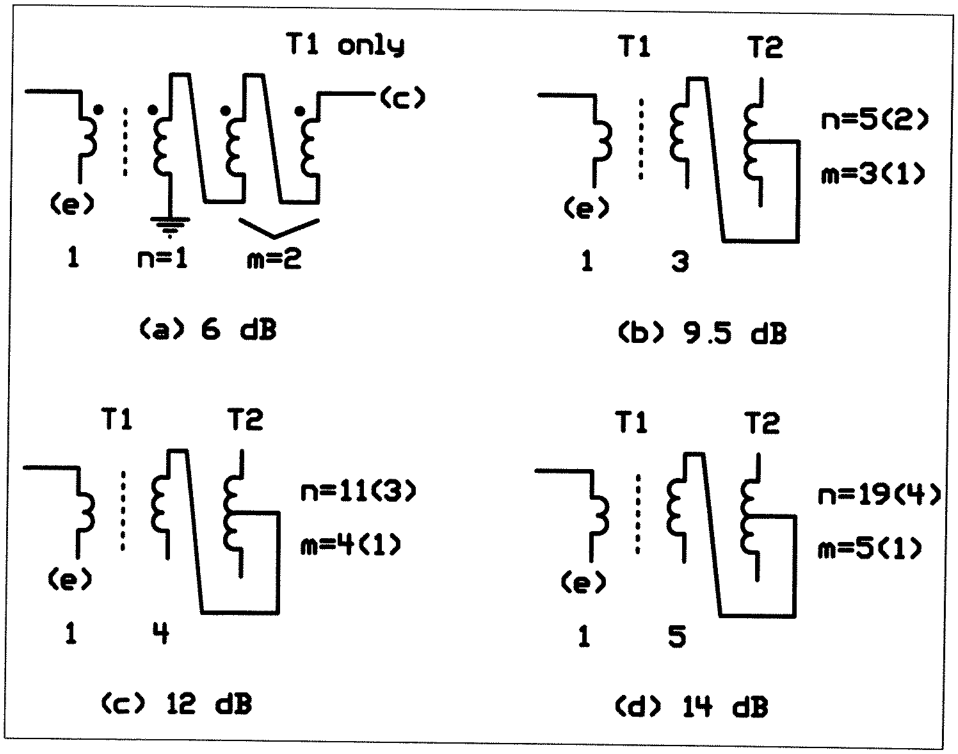



**Figure 3. Transmission line transformers (a) 6 dB, (b) 9.5 dB, (c) 12 dB, (d) 14 dB.**

Therefore:

$$i_b = i_a \left(\frac{m + n + 1}{m}\right) \tag{8}$$

Hence:

$$v_b i_b = v_a i_a (m + n + 1) \tag{9}$$

From Equations 2 and 8

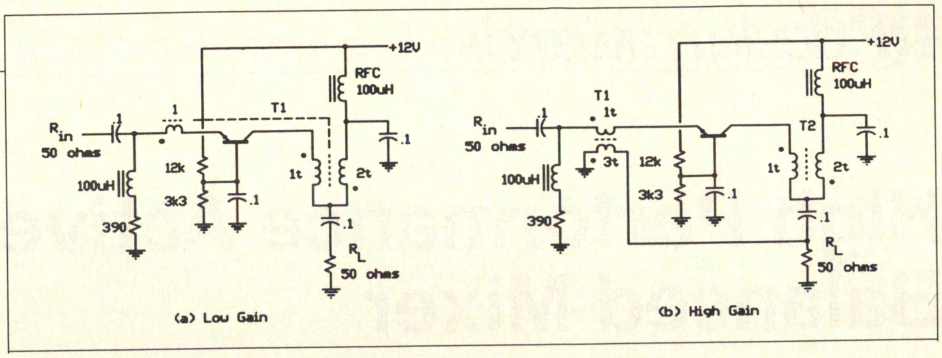



**Figure 4. Practical circuits (a) low gain, (b) high gain.**



And:

$$\frac{v_b}{i_b} = \frac{v_a}{i_a}\left(\frac{m^2}{m + n + 1}\right) \tag{10}$$

From Equations 2 and 8

But:

$$R_L = \frac{v_b}{i_b} \tag{11}$$

And:

$$R_{in} = \frac{v_a}{i_a} \tag{12}$$

Therefore:

$$R_{in} = R_L \left(\frac{m + n + 1}{m^2}\right) \tag{13}$$

Rearranging Equation 13 for $R_{in} = R_L$:

$$n = m^2 - m - 1 \tag{14}$$

Transducer gain:

$$G = \frac{P_b}{P_a} = (m + n + 1) = m^2 \tag{15}$$

From Equations 10 and 14

Collector Load Voltage:

$$v_c = v_a(n + m) \tag{16}$$

Therefore Collector Load Impedance:

$$R_{Lc} = v_a \frac{(n + m)}{i_a} = (n + m)R_L \tag{17}$$

As $R_s = R_{in}$ the emitter-source impedance $R_{se} = 2R_S$

In summary

Voltage gain: $A_V = m$
Power gain: $G = m^2$
Turns Ratio: $n = m^2 - m - 1$
Collector Load: $R_{Lc} = (n+m)R_L$
Emitter Source Impedance: $R_{se} = 2R_s$

In practice, a transmission line transformer is connected as shown in Figure 3a. The windings are parallel twisted wires, with all windings including the "single turn primary" having 3 or 4 turns through the core.

For high gain versions, this arrangement is better achieved by two cores connected as show in Figures 3b, c, d with practical turn ratios given in brackets. Figure 4a shows a practical circuit arrangement for 6 dB gain, while the higher gain versions are given in Figure 4b.

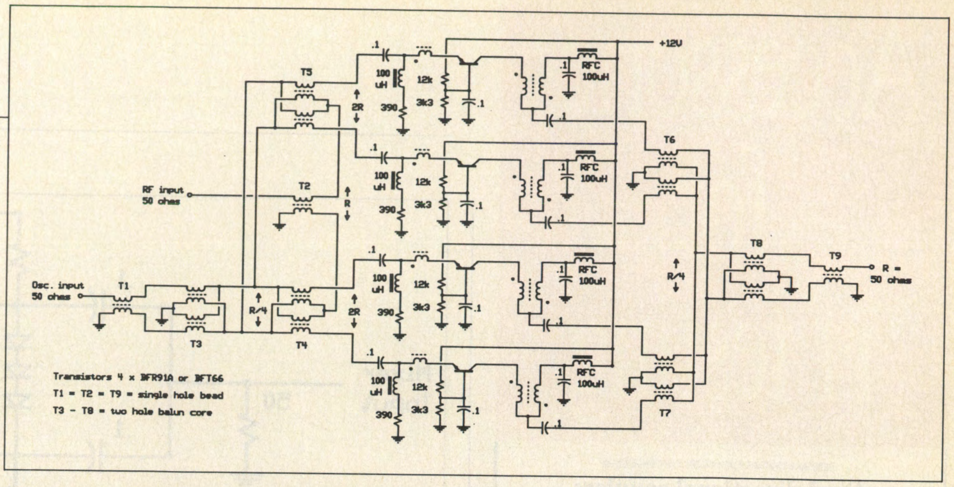



**Figure 5. Active double balanced mixer.**

### The Double Balanced Mixer

Figure 5 shows the circuit of the double balanced mixer. Balance is achieved by using four identical noiseless feedback amplifiers. Transistor types BFT66 or BFR91A are suitable with noise figures less than 2 dB, and third order intercepts around 40 dBm. As they have an $f_T$ around 5 GHz, it is recommended that a ferrite bead be placed over each lead to ensure stability.

Each amplifier is isolated by an arrangement of transmission line hybrids (5,6) which provides 50 ohm termination at the input and oscillator ports. For the lower frequencies, the hybrids are wound with twisted pairs through two hole baluns for good balance and low loss. Input and output isolation transformers are wound with single hole beads. With an LO drive of 1 V RMS (+13 dBm), RF and LO rejection is 60 dB.

For cases where the mixer output termination is reactive, such as a crystal filter, a buffer may be required. Figure 6 shows a suitable circuit which is a complementary emitter follower (7). The mixer is thus loaded with 50 ohms and the filter also sees 50 ohms or other required load by adjustment of the emitter current.

### A High Performance Preamplifier

Two noiseless feedback amplifiers operating in push-pull as shown in Figure 7, provide an excellent RF preamplifier, which when used before existing receivers will present the characteristic impedance of the receiver at the input to the preamplifier.

### Summary

The preamplifier and mixer circuits presented here would be useful for any part of the RF spectrum, if implemented accordingly. What is significant, is that negative feedback may be used as a very effective tool at RF to control stage

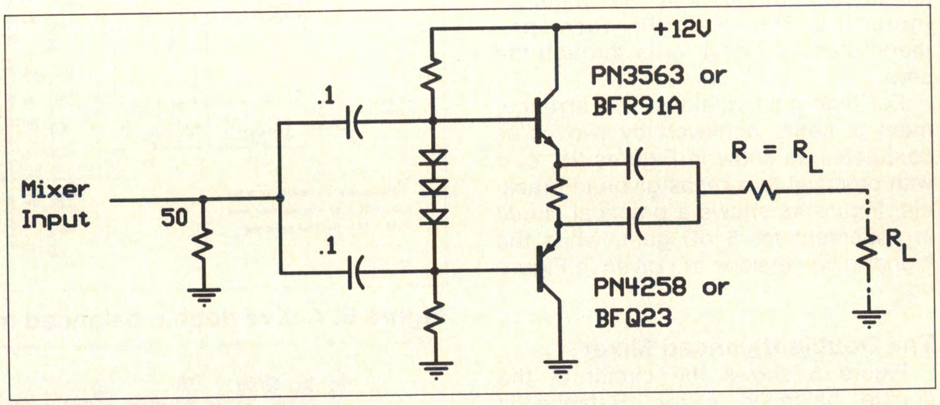



**Figure 6. Buffer.**

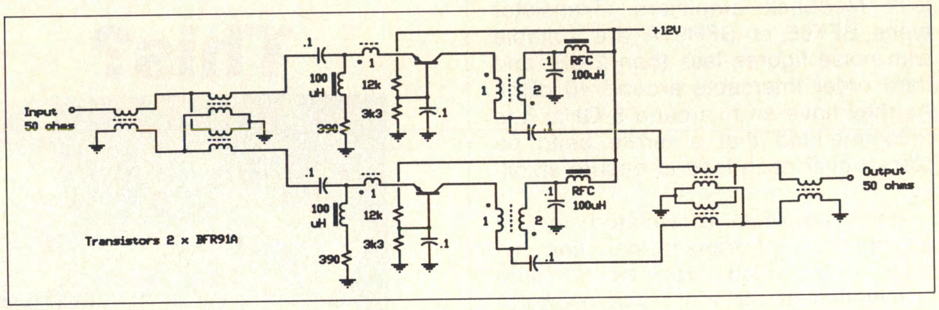



**Figure 7. Broadband push-pull RF pre-amp.**

gain, and provide closer to idealized noise figure, linearity and impedance match characteristics. *RF*

## References


1. David Norton, Transistor Amplifier with Impedance Matching Transformer, US Patent 3,891,934 June 1975.
2. David Norton, "High Dynamic Range Transistor Amplifiers Using Lossless Feedback," *Microwave Journal*, May 1976.
3. A. Van Der Ziel, M. Okamato, Correspondence, *IEEE Journal of Solid State Circuits*, September 1968.
4. Ulrich L Rohde, "*High Dynamic Range Active Mixer*," Ham Radio, November 1977.
5. C.L. Ruthroff, "*Some Broadband Transformers*," Proc. IRE, August 1959.
6. H.O. Granberg, "Broadband Transformers and Power Combining Techniques for RF," Motorola Application Note AN-749.
7. U. Tietze, C.H. Schenk, *Advanced Electronic Circuits*.


### About the Author


Bruce Hubbard has worked for the Civil Aviation Authority (Australia) in their Communications Engineering Section on airways engineering projects including modifications to receiving equipment. He is presently working for British Aerospace (Australia) Ltd, at Technology Park, South Australia. He may be reached at 13 Surf St., South Brighton, Adelaide, South Australia 5048.

# A VCO Tuning Range Calculation Program

By Marshall H. Hollimon
Hollimon, Inc.

*VCOCALC is a utility program which was entered in the 1991 RF Design Awards Software Contest. It will calculate the tuning characteristics and the necessary tuned circuit inductance for voltage-controlled oscillators using certain popular tuning varactors which are chosen from a menu presented by the program. The following notes should help the user to maximize the utility of the program in simplifying VCO design and in greatly reducing bench iteration time in realizing the actual circuit.*

The circuit analyzed by VCOCALC consists of two nodes coupled by a fixed capacitor. One node contains the tuning varactor plus any stray (or deliberate) parallel capacitance. The other node contains the circuit fixed inductance plus any stray (or deliberate) parallel capacitance. A schematic of the circuit is presented in Figure 1.

The program prompts the user for values of the varactor parallel capacitor (CP), the coupling capacitor (CS), and the inductor parallel capacitor (CT); it also asks for a value for maximum or highest tuned frequency, and finally for the necessary tuning voltage information: minimum voltage, maximum voltage, and voltage step size.

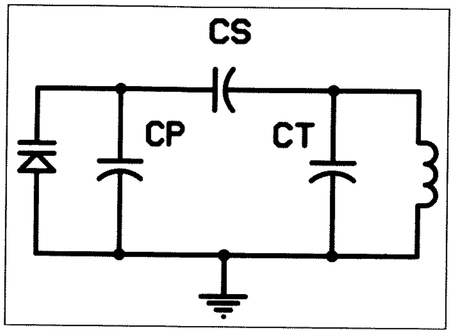



**Figure 1. Circuit example to be analyzed by VCOCALC.**

There is no restriction on any of the values entered except for tuning voltage. In this latter case, the program is designed around several popular hyperabrupt tuning varactors for which considerable experience indicates that the useful range of the tuning voltage is between 3 volts and 25 volts. Accordingly, any attempt to enter a voltage below 3 or above 25 will result in an error message and a request for new voltage information.

When all requested data has been entered, the program runs several subroutines which calculate a matrix of result data including, for each step: varactor junction capacitance, total effective capacitance across the inductor, and tuned frequency. It does this by first calculating the varactor capacitances for all tuning voltages, as well as the total effective circuit capacitance for each step. It then adds 0.01 volt to each tuning voltage step, and calculates the corresponding pair of delta-C capacitances. When this step is complete, a matrix of capacitance information is available for frequency calculation.

The next step is to calculate the circuit inductance, which is done using the total effective circuit capacitance at the highest tuning voltage.

The program then steps through the matrix, calculating a frequency for each total effective circuit capacitance and for each such capacitance in the delta-C column. Those frequencies corresponding to non-incremented capacitances are the tuned frequencies of the VCO; the incremented values are used to obtain tuning slopes for each step from the formula $100(F_{inc}-F_{std})$. Finally, the slope matrix is then searched for its maximum and minimum values, and the ratio of these is calculated.

When calculations are complete, an options menu is presented for the user to choose several methods of presentation of the results, including screen or printer output and a simple graph of frequency versus tuning voltage so that gross linearity may be visually estimated. A

MV104 TUNING VARACTOR
BACK-TO-BACK

| VT VOLTS | CJ PF | CE PF | FREQ MHz | SLOPE MHz/V |
|---|---|---|---|---|
| 4 | 17.81678 | 15.6594 | 42.62671 | .4084 |
| 4.5 | 17.02997 | 15.51538 | 42.82409 | .3816 |
| 5 | 16.32628 | 15.38276 | 43.00829 | .3556 |
| 5.5 | 15.69563 | 15.26071 | 43.17993 | .3308 |
| 6 | 15.12889 | 15.14836 | 43.33976 | .308 |
| 6.5 | 14.6178 | 15.0448 | 43.48867 | .2872 |
| 7 | 14.15493 | 14.94911 | 43.62764 | .2684 |
| 7.5 | 13.73365 | 14.8604 | 43.75765 | .2516 |
| 8 | 13.34809 | 14.77783 | 43.87973 | .2368 |
| 8.5 | 12.99307 | 14.70061 | 43.99483 | .2236 |
| 9 | 12.6641 | 14.628 | 44.10389 | .2128 |
| 9.5 | 12.35728 | 14.55935 | 44.20774 | .2028 |
| 10 | 12.06932 | 14.49409 | 44.30715 | .1948 |
| 10.5 | 11.79746 | 14.43173 | 44.40278 | .1876 |
| 11 | 11.53941 | 14.37184 | 44.49519 | .182 |
| 11.5 | 11.29337 | 14.31411 | 44.58484 | .1764 |
| 12 | 11.05793 | 14.25827 | 44.67205 | .172 |
| 12.5 | 10.83203 | 14.20415 | 44.75708 | .168 |
| 13 | 10.61496 | 14.15162 | 44.84007 | .164 |
| 13.5 | 10.40629 | 14.10064 | 44.92105 | .16 |
| 14 | 10.20579 | 14.05121 | 45 | .156 |

VARACTOR PARALLEL CAPACITY = 12 PF
VARACTOR COUPLING CAPACITY = 22 PF
INDUCTOR PARALLEL CAPACITY = 3 PF
INDUCTANCE = .8911319 uHY
SLOPE RATIO = 2.617949

**Figure 2. Tabular output data of a sample 45 MHz VCO.**

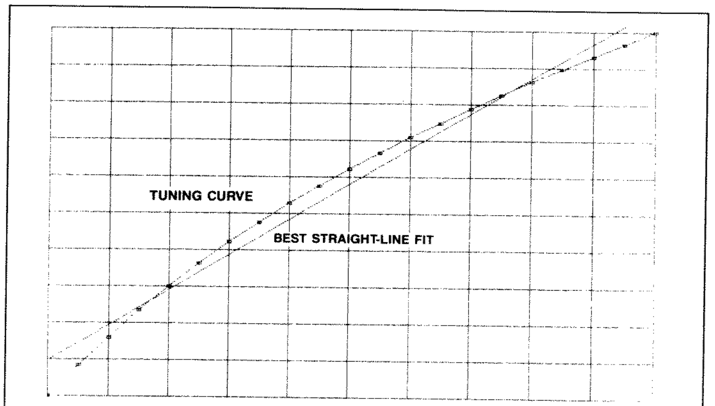



**Figure 3. Plot of frequency vs. voltage with best straight-line fit.**

capability is provided for changing input data and rerunning calculations, so a design can be iterated on the computer until a satisfactory result is obtained.

When the design begins to appear satisfactory, a linear regression tuning linearity analysis sub-routine may be selected from the results menu; this routine will perform a standard least-squares best-straight-line fit to the frequency versus voltage data points. This routine has its own results menu, including screen or printer data output plus two types of graphs. The first of these is another plot of the frequency/voltage characteristic, upon which is superimposed the fitted straight line calculated by the regression. The second graph is a simple histogram showing magnitude of the percentage tuning error versus tuning step. This latter graph may be used to estimate the quality of the straight line fit to the data. The main program may be re-entered from the regression routine for further iteration of the design.

The program requires an EGA-compatible graphics adaptor in order to display the graphs. If a dot matrix printer with graphics capability is connected to the computer, print-outs of the graphics screens may be obtained using an EGA screen dump utility program. Such a program must be loaded before VCOCALC was run.

### Notes on Accuracy

The two main sources of error between calculated performance and real circuits will be errors in the estimated values of circuit capacitances, and in departures from the calculated varactor capacitances by individual tuning varactors. Each of these error sources are discussed below.

The two parallel capacitances in the equivalent circuit analyzed by the program are present so that the user may account for stray circuit capacitance due to leads, PC mounting pads, etc., to the maximum accuracy possible. This in turn means that the better the estimate of these values, the better the overall accuracy of the calculation. Some care in the measurement or estimate of these capacitances will be amply rewarded by the close agreement between the computer result and real circuit behavior. These elements, as well as the series coupling capacitor value, may also certainly be used to restrict the control range of the varactor to suit particular applications. Fixed parallel capacitance (over and above circuit strays) and/or low values of coupling capacitance will reduce the effect of any given varactor and may be used together with the tuning voltage range to tailor the frequency swing and tuning linearity to suit the designer.

The other main source of error is any departure by actual varactors from the ideal capacitance/voltage curve used in the program. For each varactor presented by the selection menu, there is present in the program a subroutine containing equations describing the varactor junction capacitance as a function of applied tuning voltage. If the varactor has a moderate, well-behaved curve only one equation will be used; some extreme hyperabrupts such as the KV2301 require two quite different equations to obtain a good fit to the actual characteristics of the device. The breakpoint in the program is set at 6.099 volts to minimize calculated slope errors for voltage step points set on even tenths of a volt (but see further note below).

The equations for each varactor were obtained by extracting from the device data sheet tabular values for the capacitance for each tuning voltage. Since most varactor data sheets give this information in a very approximate way (via a small, imprecise graph), selected points on these graphs were read visually and replotted on good graph paper. A smooth curve was then drawn through the points and the tabular values were read from this derivative curve. The tabular values were then entered into a curve-fitting utility program. For the 6 to 25 volt range this approximation was always a least-squares polynomial fit; for those varactors requiring a different curve below 6 volts, the curve was an exponential approximation.

The approximation equations were iterated until the best degree of fit was obtained for any given segment of the data. This required in some cases as high as a fifth order polynomial. The maximum error accepted was about 1.5 percent of the value of capacitance involved, compared to the derived tabular value.

As may be deduced from the above, the mathematical description used by the program is thus quite derived in nature, and significant differences between actual varactor behavior and the calculated values may be expected. This effect will have a major component due to the fact that there is a statistical spread among varactors of a given type unless they are carefully matched (at the factory or by the user). Thus even if original factory data had been available to generate the capacitance/voltage curves, variations from the curve could be expected from randomly selected varactors of the chosen type unless well matched sets were to be used. In this latter case equations for the sets would have to be individually developed if high accuracy was to be expected.

The net result is that VCOCALC can provide a very useful tool for iterating a VCO design in its early stages, narrowing the large number of circuit variables into a manageable number of testable choices. Any final design must certainly be breadboarded and tested.

### Two Final Points.

Any tendency of the actual circuit to parametric nonlinearity effects (such as voltage variability of collector output capacitance in bipolar oscillator transistors) or other types of nonlinear feedback will modify the actual tuning curve. Similar confusion will result from any RF rectification by the varactor at low tuning voltages.

Calculated slopes at points very near the 6.099 volt equation breakpoint may suffer an accuracy degradation since there will be a mathematical inflection point right at 6.099 volts. The results from the program are nonetheless quite representative of real circuit behavior. For example, VCO's made with KV2301 varactors do display higher tuning slopes in the middle tuning voltages rather than having highest slope at lowest tuning voltage.

### Software Notes

VCOCALC was written and debugged using Microsoft QuickBASIC 4.0 and was compiled by that utility as a standalone executable program. Since the program is reasonably modular, modifications to suit user needs are simple and straightforward. In particular, the tuning varactor menu facility and capacitance-versus-voltage calculations are both in subroutines so that new varactors may be easily added.

Varactor characteristic equations may be developed using any desired mathematical curve-fitting program. Any form of equation which adequately describes the behavior of a given tuning varactor is useful; fifth-order polynomial approximations may not always be required nor be the best approximation to use. Some experimentation with the other fitted forms is usually desirable in order to obtain the best possible fit over the chosen range of tuning voltages.

### Acknowledgements

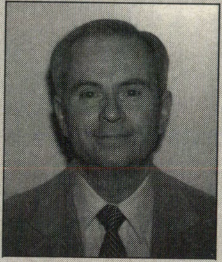
Ideas used in developing VCOCALC were obtained from studying the programming techniques in many published sources. Tabular data was converted into polynomial or other functions using Curve Fitter-PC™ from Interactive Microwave, Inc.

*This program is available from the RF Design Software Service. It is provided with a screen dump untility program for Epson or Epson-format dot matrix printers. See the advertisement on page 82 for ordering information.* **RF**

### References

1. Joseph J. Carr, *Scientific and Engineering Programs for the IBM-PC and PC-XT*, Prentice-Hall/Reston, 1985.
2. Jules H. Gilder, *BASIC Computer Programs in Science and Engineering*, Hayden, 1980.
3. C.P. Koelling and P.M. Wolfe, *BASIC Engineering and Scientific Programs for the IBM PC*, Prentice-Hall/Brady, 1983.
4. Cass Lewart, *Science and Engineering Programs for the IBM PC*, Prentice-Hall/Micro Text, 1983.
5. Alan R. Miller, *BASIC Programs for Scientists and Engineers*, Sybex, 1981.

### About the Author



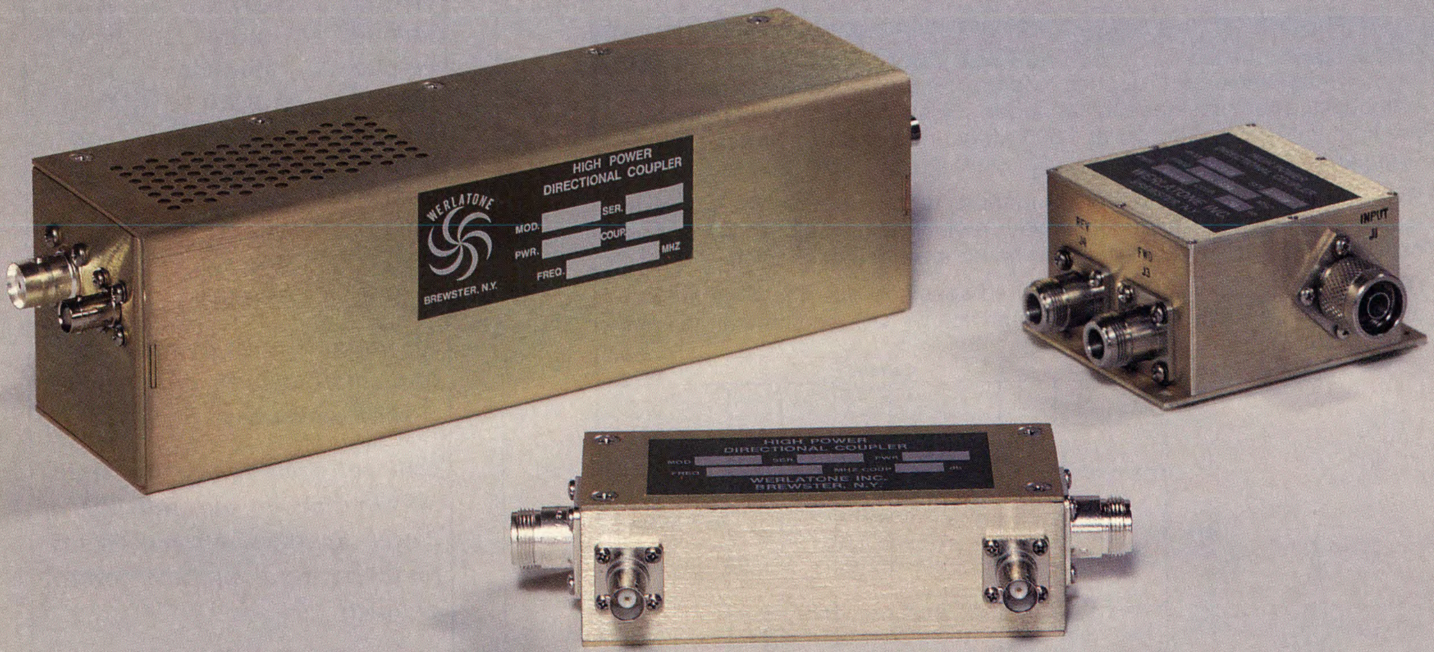
Marshall H. Hollimon is an independent consulting engineer specializing in analog and RF design. His main areas of expertise are in frequency synthesis and communications signal transmission and reception. He is the owner and president of Marshall H. Hollimon, Inc., a consulting engineering firm at 11155 La Paloma Drive, Cupertino, CA 95014. Tel: (408) 253-6078.

# HIGH POWER DIRECTIONAL COUPLERS

Werlatone offers an extensive line of broadband high power directional couplers spanning the range of 10 KHz to 2000 MHz. Both uni and dual couplers are available at power levels to 100 KW. Each coupler features **WERLATONE WIDEBAND TECHNOLOGY** which assures you of high performance, and reliability you can count on.

| MODEL | Frequency Range MHz | Coupling db | Flatness +/− db | Directivity db | Power watts |
|---|---|---|---|---|---|
| C1795 | .01-1000 | 40 | 0.5 | 20 | 100 |
| C1373 | 1.5-80 | 30 | 0.2 | 25 | 750 |
| C1487 | 100-500 | 40 | 0.5 | 20 | 1000 |
| C1460 | .01-1000 | 50 | 1.0 | 20 | 2000 |
| C1449 | 1.0-100 | 70 | 1.0 | 20 | 10000 |
| C2717 | 1.0-30 | 70 | 0.3 | 35 | 100000 |

*Over 1200 additional uni and dual couplers available.*




**An experienced WERLATONE applications engineering team is ready to answer technical questions and help with your custom designs.**

**WERLATONE INC. • P.O. BOX 47 RT 22 • BREWSTER, NY 10509**
DECADES AHEAD
**PHONE 914 279 6187 FAX 914 279 7404**

INFO/CARD 66

# HF Miniloop Antennas

By Pradeep K. Wahi
Antenna Research

*High Frequency (HF) transmission has reemerged as the choice for tactical and strategic communications. It is the sole common facility and the primary medium for continuous mutual exchange of air surveillance and early warning systems in NATO. The vulnerability of satellite relays to physical and electromagnetic disruption, has caused planners to reconsider the use of HF as mandatory for back-up, and to renew their interest in the HF spectrum.*

For an optimal HF (2 to 30 MHz) communication system, the selection of an appropriate antenna is imperative. Conventionally, the HF antennas are large and, most often, a system designer is forced to make performance tradeoffs. When multiple operational roles have to be satisfied, the restriction in size further limits the demand on system performance resulting in accepting mediocrity.

Several existing facilities must be upgraded to cope with the resurgence of HF. The lack of areas for expansion and significant increase in man-made noise, as a result of industrialization around these sites, makes the Miniloop an ideal candidate to replace current inefficient antenna systems.

For receive applications it is possible to use electrically small, but inefficient, antennas coupled with a preamplifier. For high power transmit applications, however, the choices are limited for a small size HF antenna. In the past, the commonly used antennas for transmit applications have been the horizontally polarized rotatable log periodic antennas or vertically polarized whips. Both options are unattractive because of size, complexity, cost and performance. HF log periodics require considerable real estate and have nulls in their vertical radiation patterns which restrict their suitability for short-to-medium range operations. The whips require a large ground plane and interfere with nearby antennas and metallic objects.

At the time the system designers were reconsidering the use of HF for tactical and strategic communication, the Miniloop antenna was introduced. This electrically small, tuned loop antenna represented the state-of-the-art in both performance and practicality for two way HF communication. The Miniloop occupies less vertical space, is lighter than and can withstand greater wind drag than a whip or a log periodic dipole antenna. Other characteristics which make the tuned loop antenna far superior to its rivals for ship or shore communication are described here.

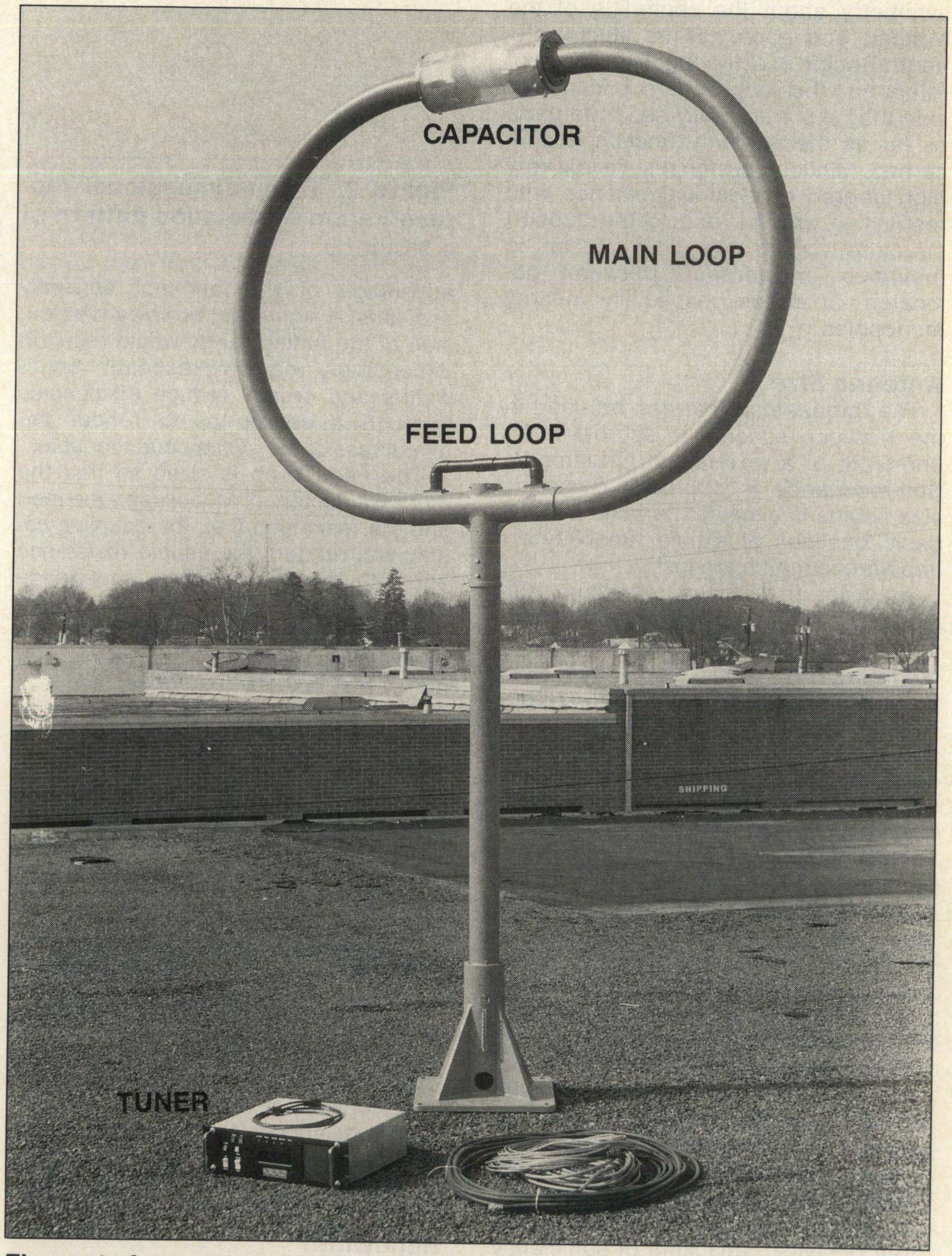



Figure 1. An example of a tuned antenna.

## The Miniloop Antenna

Essentially, a tuned antenna consists of a tunable and a non-tunable single turn loop (Figure 1). The two loops are inductively coupled and maintain a coplanar relationship. The larger loop is considered to be the radiating element because the radiation resistance of the antenna is almost entirely associated with it. The smaller loop is called the feed loop. The latter, serves as the impedance matching coupler between the transmission line and the radiating element.

Both loops are constructed to provide symmetry about the centerline of the system, and each has its electrically-neutral point exactly opposite the gap. Although, the loops share a common side they are electrically separate parts as far as the antenna function is concerned. Miniloop design results in a very high degree of electrical balance with respect to ground, and to the support structure, which are both crucial to minimize interference between co-located antennas, especially nearby monopoles.

## Antenna Size

The largest loop that can be used in the Miniloop scheme is approximately one-tenth of a wavelength in diameter. Self-resonance is approached as the size begins to exceed this value and the basic qualities of simple tunability for impedance match are lost.

In order to achieve maximum efficiency, the loop is designed approximately circular with as large an area as possible. The loop approaches one-tenth wavelength diameter at the upper limit of the frequency range, with the specified capacitor set at its minimum capacitance. The range of the variable capacitor then determines the tunable frequency range. The loop size can be varied slightly without changing its inductance by varying the diameter of the tubing from which it is formed. With a larger diameter tubing, the efficiency increases. Trade-offs must be made among size, weight, efficiency, bandwidth and cost. All things considered, the Miniloop is an optimal choice.

Frequency bands of about three octaves (8:1) are regularly achieved with an SWR less than 1.5:1 at resonance, using commercially available high-voltage vacuum variable capacitors. Although, the range over which a low SWR can be obtained is slightly greater than three octaves, capacitors of sufficiently high voltage ratings required to take

$$|E| = [\cos^2\theta\cos^2\phi + \sin^2\phi]^{1/2}\cos(\beta h\cos\theta)$$

where

$h$ = height above ground plane
$\beta = 2\pi/\lambda$
$\lambda$ = wavelength = 300/f MHz meters
= 984/f MHz feet

Small arrows show direction of E – field

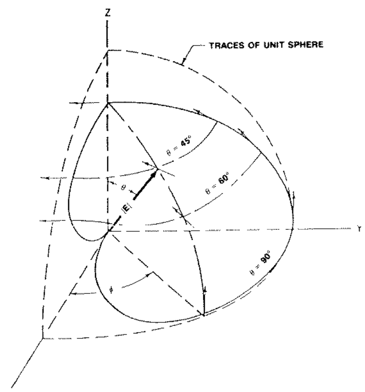



**Figure 2. Three-dimensional representation of radiation pattern of a Miniloop.**

advantage of this are not currently available. A significant downward extension of the tuning range would result in exceedingly narrow resonant bandwidths and greatly reduce efficiencies to such a degree as to render the usefulness of the system questionable.

The Feed Loop is sized so that the mutual inductance, M, between the feed and the main loop (i.e., the coupling coefficient) renders the couple resistance equal to the characteristic impedance of the coaxial feeder. Since, $R = \Omega L/Q$, one finds for a given main loop size, the coupled resistance at the input is proportional to both the area of the feed loop and the Q of the antenna. Virtually ideal impedance matching across the band could be achieved by controlling the feed loop in such a way as to optimize the mutual inductance, M, between the main loop and the feed loop. However, the high cost due to increased complexity far outweighs the small improvement in performance achieved.

The maximum current, and hence the most intense magnetic field, occurs on the main loop at a point diametrically opposite the tuning capacitor. By coupling at this point, the size of the feed loop is minimized. This also provides a very convenient and practical location for the balanced feed loop because its neutral point corresponds to the neutral point of the balanced main loop.

## Bandwidth

The narrowness of the resonant bandwidth of the Miniloop is a natural consequence of its small electrical size (compared to a wavelength) and its relatively high efficiency. It is inherent in such antennas that the bandwidth, electrical size, and efficiency are closely related. For a given size, the bandwidth tends to vary inversely with the efficiency.

The 3 dB bandwidth at the low end of HF band is only a few kilohertz. Since, the total resistance of the loop increases more rapidly than the inductive reactance, because of the radiation resistance component, the bandwidth broadens toward the high-frequency end of the tuning range. The bandwidth/frequency characteristic is essentially a straight line on logarithmic coordinate chart paper.

The 3 dB bandwidth is commonly used as a guide for receiving. However, for transmitting at kilowatt power levels, a more stringent guide is the 2:1 SWR bandwidth. The 2:1 SWR bandwidth is defined as the frequency range, centered at resonance, where the SWR is less than 2:1. During modulation it is not necessary that the modulation frequency be strictly less than this 2:1 bandwidth. But most of the transmitted power must be contained within this bandwidth.

## Power Gain

Gain is understood to mean actual power gain relative to an ideal isotrope. It is stated for the direction of maximum signal, which is in the plane of the loop at zero elevation. An ideal isotrope is a fictitious lossless reference antenna that has a spherical pattern, and a gain of unity (0 dBi) in all directions.

The gain, G, is the product of per-unit radiation efficiency, n, and the directivity, D. That is,

$$G = nD \tag{1}$$

The directivity is a pattern characteristic, determined by reckoning the ratio of the maximum to the average relative powerflow density, measured over the surface of a large sphere centered on the antenna. The free-space, or intrinsic directivity of the Miniloop is the same as that of an infinitesimal loop, namely 1.50 (1.76 dBi), because the patterns are virtually identical. In any practical installation, reflections coming off the ground cause the pattern to be very different functionally from what it is in free-space. Since the pattern varies with the frequency

and the antenna height, the gain is also a function of these parameters. As a matter of fact, a ground of good conductivity causes the gain to be anywhere from three to seven decibels higher than the free-space value, depending upon the height of the antenna and the characteristics of the ground. The maximum gain is reached when the loop is approximately 0.35 wavelength above ground, but coverage at the high elevation angles is sacrificed for gain in the horizontal direction, when these conditions prevail.

The efficiency is defined as the ratio of the radiation resistance, $R_r$, to the total resistance, $R_t$, which also includes the loss resistance, $R_l$. Specifically,

$$n = R_r/R_t \tag{2}$$

$$R_t = R_r + R_l \tag{3}$$

To accuracy within a few percent, the free-space radiation resistance of an electrically small single-turn loop, either circular or square, is

$$R_r = 20\,(2\pi/\lambda)^4 A^2 \tag{4}$$

where A is the area of the loop inside the centerline of the conductor from which it is formed, and $\lambda$ is the wavelength measured in the same units of length as the area. Interaction with surroundings, such as the ground, causes the actual radiation resistance of a Miniloop to be somewhat different from the free-space value by an amount depending on the frequency, distance from the ground and other objects, and the nature of the surroundings.

One might think of this as reflection effects, induction effects, mutual-coupling effects, or reaction effects. Whatever the cause, one result is a contribution to the overall radiation resistance which may or may not be negligible, depending largely on the circumstances. Another factor affecting the radiation resistance is the non-uniformity of the current around the loop, especially at the higher frequencies where the loop is tending toward self resonance and a standing wave of current exists. Since these variations are both relatively small, it can be concluded that the total radiation resistance varies principally as the inverse fourth power of the wavelength, $\lambda$, or directly as the fourth power of the frequency.

The loss resistance consists of the

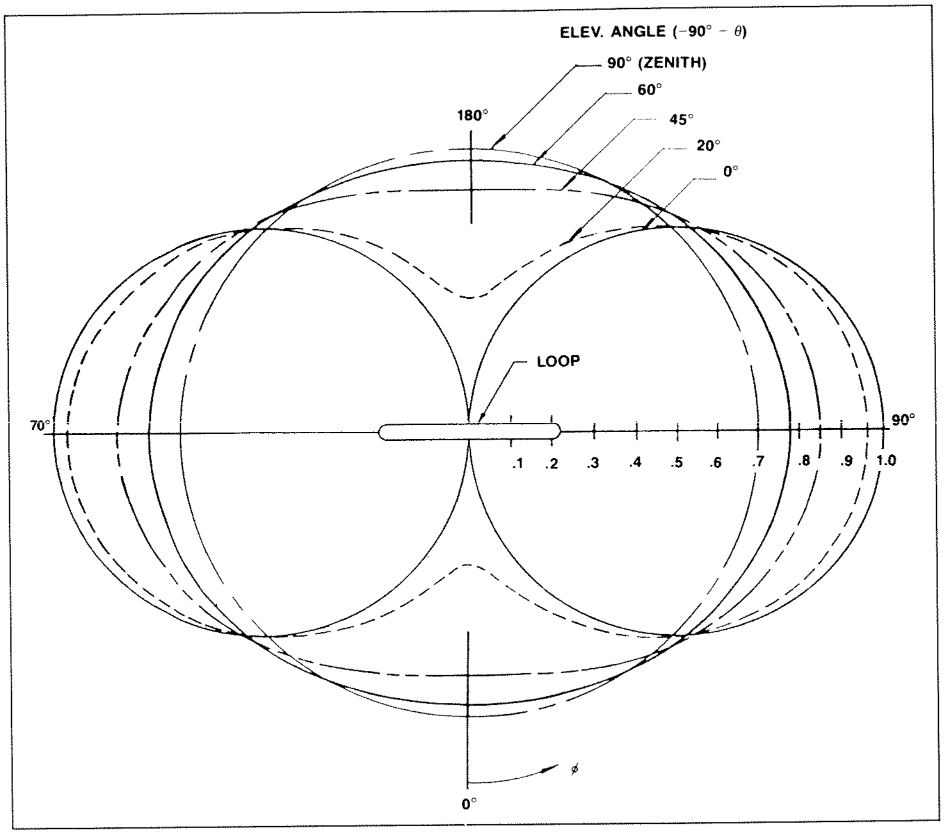



**Figure 3. Calculated relative amplitude patterns at fixed elevation angles of Miniloop centered above a good ground plane.**

RF skin resistance $R_s$, and miscellaneous resistance, $R_m$, of contacts between sections of the loop, capacitor resistance, and whatever absorption-loss resistance exists due to the presence of the ground in the induction field of the antenna. All of these resistance components work to decrease the efficiency. The ground induction losses are kept low by providing a mast for installing the antenna well away from ground. No estimate is available for the relative magnitudes of the contact, capacitor and ground-absorption resistances in calculating the total loss resistance, or even of their dependence upon frequency. The contact resistance probably varies inversely with the frequency because of capacitance bypass phenomena, while the ground absorption loss probably varies as the square root of the frequency and is a function of the electrical distance of the antenna above the ground.

The radiation resistance of the loop rises quickly to over-ride the loss resistance, causing the efficiency to increase rapidly to a high value with a correspondingly steep rise in the gain to around mid-band. The efficiency in the high end of the operating band may exceed 90 percent. The fast rise in efficiency, combined with the increase in directivity due to the array effect with the in-phase image in the ground, is the reason for the increase in gain characteristic.

## Pattern

The intrinsic pattern of the Miniloop is a closed surface having essentially the shape of a torus generated by swinging a circle about the loop axis, with the circle being tangent to the axis at the point where the loop is centered. In a typical installation, the axis of the loop is horizontal, and the pattern has a null on the horizon in each direction of the axis. The ground gives rise to reflection effects which cause the pattern to vary in complexity with the frequency, height of the antenna above ground, ground characteristics, and site conditions. The mast height above ground may be optimized for uniform coverage in the half space. For such an installation, the pattern resembles half a doughnut (with a zero diameter hole) standing on its cut ends.

The mathematical expression for the pattern of a Miniloop at any height over a perfectly conducting ground plane is given in Figure 2, where the plane of the loop is coincident with the YZ-plane of the coordinate system shown, and the loop axis coincides with the X-axis. The figure shows the pattern in three dimensions that would result from a Miniloop mounted on a mast above a large perfectly-conducting ground plane. The small arrows of the figure indicate the direction of the electric field force (polarization), which is everywhere along circles parallel to the YZ-plane and centered on the X-axis regardless of antenna height. The relative amplitude of the pattern is represented by the length of the radius vector drawn from the origin to the point on the pattern.

The patterns shown in Figure 3 are calculated from the same mathematical expression to show the azimuthal variation at various fixed elevation angles for the same conditions as for Figure 2.

### Interference Rejection

A standing problem of major proportions in HF communications is that of interference due to manmade noise and spectrum overcrowding. The Miniloop embodies a number of features which help combat this problem. One of the unique features is its relatively narrow resonant bandwidth, especially at the lower end of the operating band, which causes interference adjacent to the desired signal to be sharply rejected. Another characteristic of the Miniloop that greatly enhances reduced sensitivity to common mode interference is its high degree of electrical balance with respect to ground. That is, the currents which may exist on the mast due to common mode excitation will not produce a voltage in the antenna. Common mode excitation refers to currents running everywhere on a common ground system due to switches, sparkgaps, motors and other interference generators.

Yet another feature which tends to make the Miniloop less responsive to interference is the fact that it is a magnetic-field type of antenna. Most man-made noise is electrostatic in nature, at least in the near field. Since loops do not couple strongly to predominantly electrostatic fields, the Miniloop has a natural rejection to such interference. For example, a loop does not receive well from a radiating whip antenna in the near field region because the near field of a whip is primarily electrostatic.

Furthermore, the bidirectional character of the pattern in the plane of the earth also rejects interference. The loop can be oriented with one of its pattern nulls in the direction of an interfering groundwave to reduce or eliminate the interference with probably a weaker desired skywave signal. Not much of the skywave signal is sacrificed by this tactic, since the Miniloop is practically omnidirectional for signals arriving at elevation angles above 20 degrees.

### Applications

The various features of narrow bandwidth, pattern, polarization, electrical balance, and magnetic-dipole character associated with the Miniloop make it especially well suited for simultaneous (duplex) skywave communications using two co-located antennas. A combination of either two Miniloops, or one Miniloop and a monopole or horizontal electric dipole, is very effective. In the latter configurations, the Miniloop should be used with the receiver to achieve maximum protection from the strong fields generated by the nearby broader band transmitting antenna. In either case, it is necessary to offset frequencies only a very small amount, since relative orientation of the antennas can be utilized to obtain large additional isolation. The small frequency offsets that can be permitted between transmitter frequencies at each end of a duplex skywave communication path through the use of Miniloops favors the reliability of communication in both directions as path conditions vary. A related important result is the reduced need for spectrum space for duplex communications. ***RF***

**About the Author**
Pradeep K. Wahi is the president of Antenna Research Associates. He may be reached at 11317 Frederick Avenue, Beltsville, MD 20705-2088. Tel: (301) 937-8888.

## Advertising Index

# RF Distributors — Filling the Gap

By Liane G. Pomfret
Associate Editor

The RF component distributor fills an important niche within the RF marketplace. They pick up where the manufacturer leaves off, providing services above and beyond what the manufacturer offers. The distributor fills a number of roles — providing next day or just in time delivery, special testing, modifying and other value added service, providing technical support and especially catering to the small business who doesn't necessarily need large OEM quantities.

The fact that the RF distributors have been growing steadily over the last few years suggests that they are actively supporting a niche market requirement. Growth rates over the last several years have been impressive and even with the current recession they continue to do well. Since distributors are in the place of supplying to several different markets, they are able to weather changes in the economy better than single market companies. They are also companies who have been around for years; not fly-by-night companies without experience in the RF field. Distributors have built their business and reputations by serving the customer. Joel Levine, Senior Vice President at Richardson Electronics comments, "A niche distributor learns from his customer and understands the market, their engineering needs, manufacturing needs and purchasing needs. So they're not just a customer, they become partners." The market focus may change, perhaps from military to the broadcast, industrial, and medical industries, and these speciality distributors have evolved to serve those markets.

There is no doubt that the RF distributor serves a niche market. Several of the distributors began supplying to the broadcast industry, but have since expanded to supply to other sectors of an ever-growing market. According to Doug Gordon, Vice President of Marketing for Surcom Associates, "We're looking more now at industrial accounts, people who are doing vacuum deposition, sputtering, RF heat. We're also seeing some medical applications such as NMR, which we didn't see even 6 or 7 years ago." Joel Levine adds, "With all the new commercial applications, we've had no problem finding customer for our product lines."

Many of the distributors have been in business twenty or more years. They've built their reputations on service which is what keeps customers coming back. They have more to offer a customer in the way of value-added service and technical support than a manufacturer might. "We make the engineer's job a lot easier. We not only have the product on the shelf, so they can get it when they need it. But we also have applications and technical assistance available with our outside sales force," notes Steve Ulett, Marcom Manager at Penstock. Customer service includes a multiple of things. It can be anything from providing overnight delivery on a part to building assemblies per a customer's request. Most distributors offer value-added services of one form or another. The most common include qualifying parts to an engineer's specifications with few or minor modifications and suggesting replacements for discontinued parts. Customers who order from a distributor can virtually be assured of receiving a product off-the-shelf rather than having to wait as long as 26 weeks if they order from the manufacturer.

*"A niche distributor learns from his customer...".*

Often, manufacturers don't have the time to deal with the smaller OEM's and don't feel that it's worth it for them to court the small companies. Merit Arnold, Owner of RF Parts explains, "To buy direct you have to have a large amount of business, otherwise the manufacturer prefers to sell through a distributor. Manufacturers usually do not carry goods in stock and lead times these days are such that a user needs to have a product on a short turnaround." It can also be very hard for an engineer to get prototype numbers of a part from the manufacturer, but relatively easy to get those same parts from a distributor. This is where a distributor has a distinct advantage. By offering services and quantities that are appealing to the small company or a one man operation, they virtually guarantee that sector of the business for their own. Later on, when these small companies grow or the product goes into production, the distributor expects loyalty because of the service previously provided. But small companies are not the only ones to buy from distributors. The range of companies runs the gamut all the way up to Fortune 500 companies.

Applications and support is a service that sets the RF distributor apart from a generic electronics distributor. The service departments of RF distributors are usually staffed with degreed engineers who have experience in the field. As Doug Gordon notes, "Both of us are graduate EE's and the fellow who started this business has about 35 years of experience with these products. If someone were to call and say they needed a replacement for a part, chances are he would know what the original part was." RF engineers need this kind of experience at the other end of the phone when they're working with a new product. If an engineer works with a distributor to find a specific product, it is also easier for him to compare the different manufacturers and what their versions offer.

RF distributors do have a lot to offer the smaller company as well as the larger customers. Their value-added services, technical support and RF specialty parts availability make them an excellent alternative to dealing directly with a manufacturer. **RF**

*For reprints of this report, contact Cardiff Publishing Company at (303) 220-0600. Ask for the Circulation Department.*

# A Program for Winding RF Coils

By David M. Raley
Consulting Engineer

*Coilturn is a program for the design of single-layer solenoid inductors. It will determine the number of turns and spacing required to obtain a certain inductive reactance at a desired frequency using a given diameter, operating resistance, AWG wire size and prospective length. The program was originally written for the author's own use, with input protocols improved for submission to the RF Design Awards contest.*

The program is based on some fundamental relationships between frequency and reactance, and capacitance between adjacent turns. The terms involved include:

- XL = Inductive reactance
- F = Frequency
- L = Inductance
- XC = Capacitive reactance
- C = Capacitance
- K = Dielectric constant
- A = Area
- d = Separation of plate surfaces
- n = Number of plates or number of turns
- b = Coil length
- a = Radius of coil.

If $XL = 2\pi FL$, then $L = XL/2\pi F$ to obtain the required inductance. It at resonance XC = XL and $XC = 1/2\pi FC$ then $C = 1/2\pi FXC$, giving the required capacitance to resonate at the specified frequency. In the case of the coil,

$$n = (L(9a + 10b))/a2$$

to determine the number of turns.

If the prospective length given is too short for a single layer coil of the required number of turns, the program will increase the length and recalculate. Spacing between turns is derived from the length, number of turns and the wire diameter. The wire diameter is looked up from a list of wire diameters corresponding to the AWG wire size (from #1 to #40).

Distributive capacitance is obtained by first considering adjacent turns of wire to be a series of facing steps rather than facing cylinders. The capacitance is figured for each set of steps using $C = .224\ ((KA)/d)(n-1)$ and combining the result. The value of the external capacitor required for resonance at the given operating resistance is the difference of the required capacitance for resonance and the distributed capacitance.

```
DO YOU ALREADY KNOW THE INDUCTANCE?
WHAT IS THE OPERATING RESISTANCE?
? 200
WHAT IS THE FREQUENCY IN KILOCYCLES?
? 10000
WHAT IS THE AWG WIRE SIZE?
? 14
WHAT IS THE DIAMETER OF THE FORM?
? 2.5
YOU MAY SPECIFY <S> COIL LENGTH AND MINIMUM SPACING BETWEEN TURNS.
THE DEFAULT <D> FIRST APPROXIMATIONS ARE: SPACING = 1/2 WIRE DIAMETER
                                           LENGTH  = 1 INCH
IF YOU CHOOSE A LENGTH THAT WILL NOT ALLOW A SINGLE LAYER THE PROGRAM WILL
FIND A NEW LENGTH BASED ON THE SPACING YOU CHOOSE. ENTER  <S> OR <D>
WHAT MINIMUM SPACING, IN WIRE DIAMETERS, DO YOU WANT BETWEEN TURNS?
? 1
HOW LONG DO YOU WANT THE COIL IN INCHES?
? 2

COIL LENGTH IN INCHES                                  =    2
NUMBER OF TURNS                                        =    7.817185
FREQUENCY IN KILOCYCLES                                =    10000
OPERATING RESISTANCE IN OHMS                           =    200
INDUCTANCE IN MICRO-HENRIES                            =    3.184713
CAPACITANCE REQUIRED AT F/O IN PICO-FARADS             =    79.61
AWG WIRE SIZE                                          =    14
DIAMETER OF THE FORM IN INCHES                         =    2.5
MID-WIRE COIL DIAMETER IN INCHES                       =    2.5641
MINIMUM SPACING REQUESTED IN WIRE DIAMETERS            =    1
ACTUAL SPACING IN WIRE DIAMETERS                       =    2.991366
LENGTH OF WIRE IN ACTUAL COIL IN INCHES                =    62.97017
THE WIRE RESISTANCE IN OHMS                            =    1.324359E-02
MAXIMUM THEORETICAL Q                                  =    15101.64
THE DISTRIBUTED CAPACITY IN PICO-FARADS                =    4.247931
THE SELF RESONANT FREQUENCY IN KILOCYCLES              =    43270.97
OPERATING RESISTANCE AT SELF RESONANCE IN OHMS         =    865.8576

WOULD YOU LIKE TO DO ANOTHER?  <Y>  <N>
```

**Figure 1. Input format (top) and output data (bottom) for a coil with 200 ohms reactance at 10 MHz.**

To run the program, call the compiled program from the prompt and answer the on-screen questions. The program responds to single letter entries immediately with no ENTER keystroke; numerical inputs are ENTERed. Inputs that lead to a division by zero will cause the program to end.

## Computations Performed

The program returns the required number of turns, the inductance or inductive reactance (whichever was not specified), actual length, spacing between turns, distributed capacitance, self resonant frequency, theoretical Q, and capacitance required for resonance.

The computations assume that the coil is air-wound, and does not include dielectric effects.

*This program is available on disk from the RF Design Software Service. See the advertisement on page 82 for ordering information. A compiled version is included, along with BASIC source code. There are no special hardware or software requirements.* **RF**

### About the Author

David Raley is a self-employed consulting engineer. He can be reached at PO Box 7, Laurel Hill, NC 28351. Tel: (919) 462-2292.

## Pattern Recorder Software

JEF Consultant has released PATTERN3 Version 1.0, software for converting a PC into a flexible pattern recorder suitable for making antenna pattern or RCS measurements. It allows the user to collect data over any set of angles or dynamic range, view the data in polar or rectangular form, rescale, print and save the data to disk. The program will work with any spectrum analyzer, receiver or network analyzer that has a DC vertical output. PATTERN3 runs on PC/XT/AT/386 and compatible computers with 512K of RAM and Hercules, CGA, EGA or VGA graphics.
**JEF Consultant, Inc.**
**INFO/CARD #214**

## HP Updates

Hewlett-Packard has introduced major enhancements to, and additional libraries for its HP 85150B microwave-design system. Revision 4.0 of the system and new libraries include a system model library for simulating linear and nonlinear performance of complete systems, Monte Carlo and yield analysis, a nonlinear device library for FETs, simulation directly from layout and a TriQuint Foundry library. Prices begin at $3000 for the TriQuint and nonlinear FET libraries.
**Hewlett-Packard Company**
**INFO/CARD #213**

## Switched-Capacitor Software

DGS Associates has announced the release of version 2.0 of the SCASY program for analysis of switched-capacitor circuits. New features include 12 clock phases per sampling period, more components and more frequencies per run. It can also calculate secondary output levels, making it possible for the user to optimize the dynamic range of the circuit.
**DGS Associates, Inc.**
**INFO/CARD #212**

## Pulsed Measurements

An 8-page application note is available to aid the development of controller software for the Wiltron Model 360PS20A Pulse/CW Vector Network Analyzer. It includes a sample Microsoft[R] C program listing that is a scaled down version of the Wiltron Pulsed Measurement software operating in the VNA system.
**Wiltron**
**INFO/CARD #211**

# RF literature

## Precision Trimmer Capacitors

Voltronics Corporation has issued a new 32-page catalog of its precision trimmer capacitors and microwave tuners. In addition to descriptions of their standard product lines, custom products are also called out as well as engineering prototype kits and tuning tools.
**Voltronics Corporation**
**INFO/CARD #210**

## Radiation Test Equipment

A new catalog from Holaday Industries profiles their line of meters, monitors and calibration services including a new line of low frequency instruments. The catalog details the instruments' frequency response and sensitivity as well as other pertinent specifications.
**Holaday Industries, Inc.**
**INFO/CARD #209**

## Industrial Applications Components

An extensive list of new and hard-to-find electronic components for industrial applications is featured in Richardson Electronics' new industrial brochure. The 12-page catalog highlights power tubes, microwave magnetrons, SCRs, high voltage capacitors and resistors and more. A listing of equipment manufacturers utilizing products available from Richardson is also included to assist users with their replacement requirements.
**Richardson Electronics, Ltd.**
**INFO/CARD #208**

## Noise Product Brochure

A 10-page brochure describes the new Maury Noise Product Line including instruments and accessories designed for the measurement of noise performance factors such as noise figure and effective input noise temperature. Complete specifications and a detailed description of the MT2075B Noise Gain Analyzer are provided. The brochure also describes Maury's line of low cost system noise monitors and solid state noise generators.
**Maury Microwave Corporation**
**INFO/CARD #207**

## Connectors and Adaptors

Astrolab Inc has released its updated catalog which features comprehensive engineering information, detailed drawings and specifications of connectors and adaptors. Their microwave cable for various applications and other passive components are also described.
**Astrolab, Inc.**
**INFO/CARD #206**

## Delay Line and Filter Products Brochure

A new short form brochure describes a complete line of delay lines, LC filters, and digital delay lines for video and RF applications and is available from Allen Avionics. The new catalog features three new video product introductions: HDTV video filters, ultra-sharp brickwall filters and the AVS series video filters.
**Allen Avionics, Inc.**
**INFO/CARD #205**

## SST Power FET Notes

Three new technical notes are available to aid designers in the development of power amplifiers using the MwT Solid State Triode silicon power FETs. The notes are entitled, "Class AB Linearity," "The Solid State Triode in a Wide-Band, 100 W, 225 MHz to 400 MHz Amplifier," and "Pulsed Power Operation at 100 W, 1.3 GHz."
**Microwave Technology**
**INFO/CARD #204**

## Micro Miniature Products

Micro miniature digital and RF products for data acquisition, signal conditioning, 1553 bus monitoring, wideband/video telemetry, command control and flight termination are featured in Aydin Vector's new 4 page short form product guide catalog. Included with the product guide is a form for FAX requests for information on any or all of the products shown.
**Aydin Vector Division**
**INFO/CARD #203**

## GSM Brochure

A new brochure about GSM mobile radio is available from Wandel & Goltermann and describes the various measurements required on GSM networks. The descriptions are broken down according to system interface. The test equipment includes standard PCM instruments and special GSM devices. Besides the GSM measurement technology, the brochure also provides a general overview of the pan-European mobile radio network. This overview covers the various interfaces and signalling.
**Wandel & Goltermann Inc.**
**INFO/CARD #202**

## Antenna Sourcebook

This sourcebook describes forty CNI and EW/ECM/DF antenna types with complete specifications, gain patterns, and dimensions. In addition, 64 other antennas of interest are listed. Discussions of antenna characteristics and tradeoffs are included in addition to a series of design aids.
**M/A-COM, Adams-Russell Division**
**INFO/CARD #201**



# *RF design* MARKETPLACE

**WHEN YOU ARE READY TO BUY-SELL-TRADE CALL *RF DESIGN* MARKETPLACE**

Increase your REVENUES with ***RF Design Marketplace*** advertising! Over 40,000 prospects read and buy from this section each month. To reach this sophisticated, targeted market call today **(303) 220-0600.**



## *RF engineering opportunities*