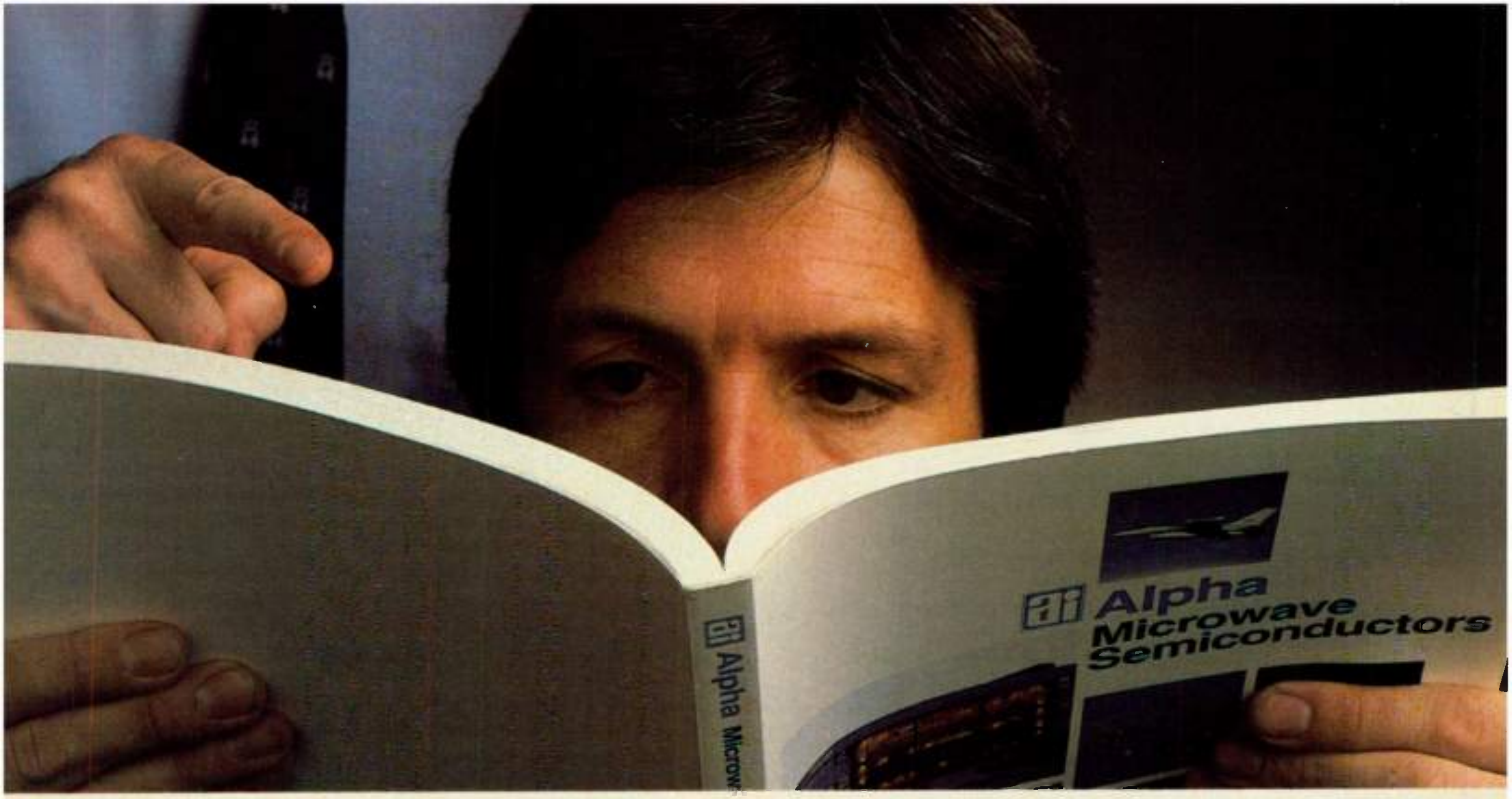
rf design

ideas for engineers

March 1986

Special Report —

New Network Analyzers For Lower Frequencies: Wiltron and Hewlett-Packard Announce RF Instruments



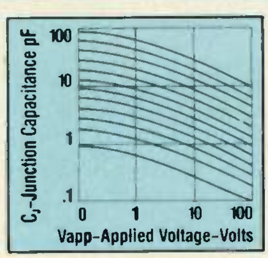
"Look...high Q GaAs Tuning Diodes that are Passivated."

As a major developer of GaAs abrupt tuning varactors, Alpha offers a wide range of devices in passivated chip form. These devices combine the advantages of "high Q" with a wide capacitance range, to accommodate any segment of the microwave spectrum, from low frequencies to millimeter waves. In addition, they offer square-law, broad-band tuning characteristics... and they demonstrate some of the lowest post-tuning drift levels available.

Alpha varactors can be used in conjunction with Impatt, Gunn, FET and bi-polar oscillators, as well as analog phase shifters, resonant filters and upconverters. Furthermore, they are compatible with microstrip, finline or suspended stripline circuits (for millimeter wave applications). And while they are able to meet a wide range of technical requirements and specifications, an extensive *custom design* capability is offered, to accommodate customers whose specifications do not match our standard components.

Electrical Specifications

Model Number			CVE 7800	CVE 7900
GaAs Abrupt High Q Chips			25 Volt Series C_0/C_{VB} = 3.7/1	45 Volt Series C_0/C_{VB} = 6/1
Suffix	C_0	C_4	Q_4 (50 MHz)	Q_4 (50 MHz)
A	.4-.6	.20	15,000	10,000
B	.6-.8	.35	13,000	9,000
C	.8-1.0	.45	12,000	8,000
D	1.0-1.5	.60	10,000	7,000
E	1.5-2.0	.90	7,500	6,000
F	2.0-2.5	1.10	6,500	5,500
G	2.5-3.0	1.40	5,500	5,000
H	3.0-4.0	1.75	4,300	4,200



Features and Specifications

☐ Passivated... Alpha's nitride oxide process is unique.

☐ High Q... typically 2 to 3 times better than equivalent silicon chips.

☐ Post-tuning drift meets ± 1.5 MHz from 60 to 200 microseconds in an X-band oscillator.

☐ Capacitance at zero volts is from 0.3 to 4.0 pF... higher upon request.

☐ Operating range is X through Ka-Band.

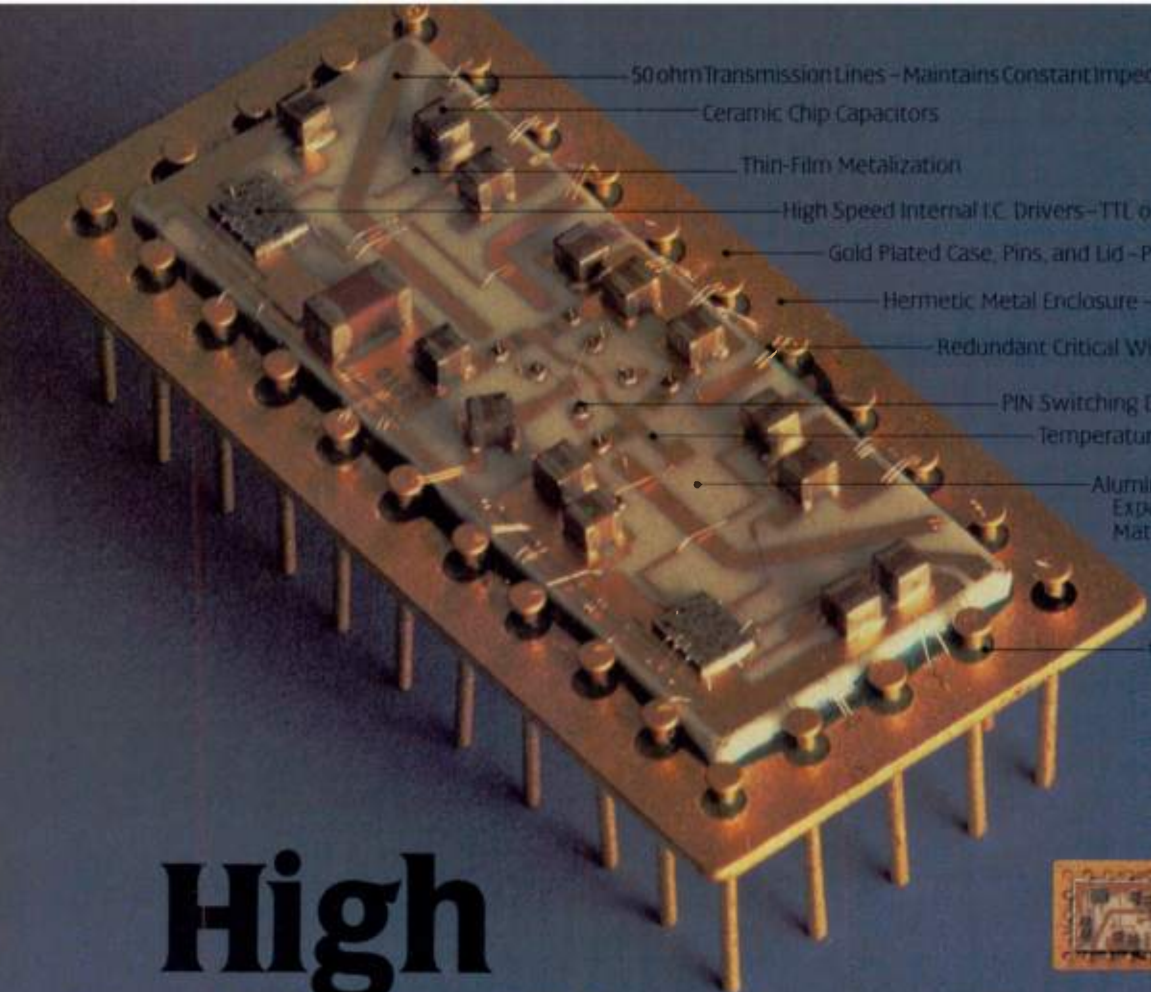
Alpha semiconductors... Our added dimension of flexibility means you don't have to compromise. Send for more information today!

Alpha

The Microwave People

Alpha Industries, Inc., 20 Sylvan Road, Woburn, MA 01801, 617-935-5150, TWX 710-393-1236, TELEX 949436.

INFO/CARD 2



Actual size

High Reliability RF MICs

DAICO High Reliability RF Microwave Integrated Circuit Components

are products of state-of-the-art thin-film technology. Quality screened components, manufactured and tested to rigid Daico standards and numerous in-process quality tests, assures each device meets applicable MIL STD Specifications. Quantitative 100% final electrical tests are made with HP8505 Analyzers and HP9825 Computer controlled automatic systems. These data assure Daico High Reliability RF MIC components meet all critical design parameters, thus saving costly incoming testing.

MIC SWITCHES
- Thin-film MIC construction.
- DC – 4GHz
- SPST – SP24T
- Speeds < 5nS (10-90% RF)
- Internal TTL or CMOS drivers
- Internal 50 ohm terminations
- PC Board mount, Stripline or Connectorized

MIC VOLTAGE CONTROLLED ATTENUATORS
- Thin-film MIC construction
- Linear attenuation to 60dB
- Linearity to ±0.75dB
- Internal drivers
- Constant 50 ohm impedance
- PC Board mount, Stripline or Connectorized

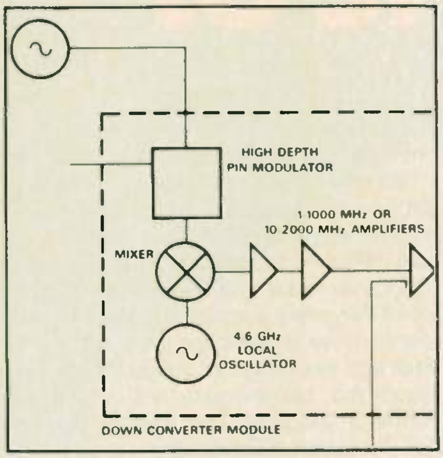
MIC STEP ATTENUATORS
- Thin-film MIC construction
- Steps – 1 through 7
- Attenuation to 63.5dB
- Speeds < 5nS (10-90% RF)
- Internal TTL or CMOS drivers
- PC Board mount or Connectorized

DAICO INDUSTRIES, INC.
2351 East Del Amo Blvd., Compton, Calif. 90220
Telephone: (213) 631-1143 · TWX 910-346-6741

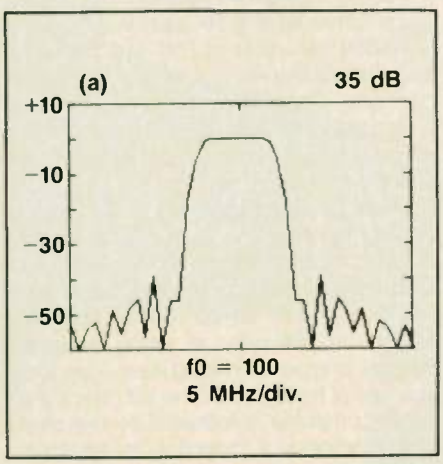
INFO/CARD 3

rf design

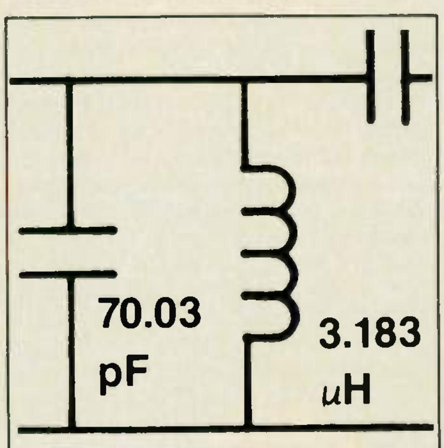
March 1986



Page 33 — Special Report



Page 43 — The Saw Filter



Page 54 — Simple Bandpass Filters

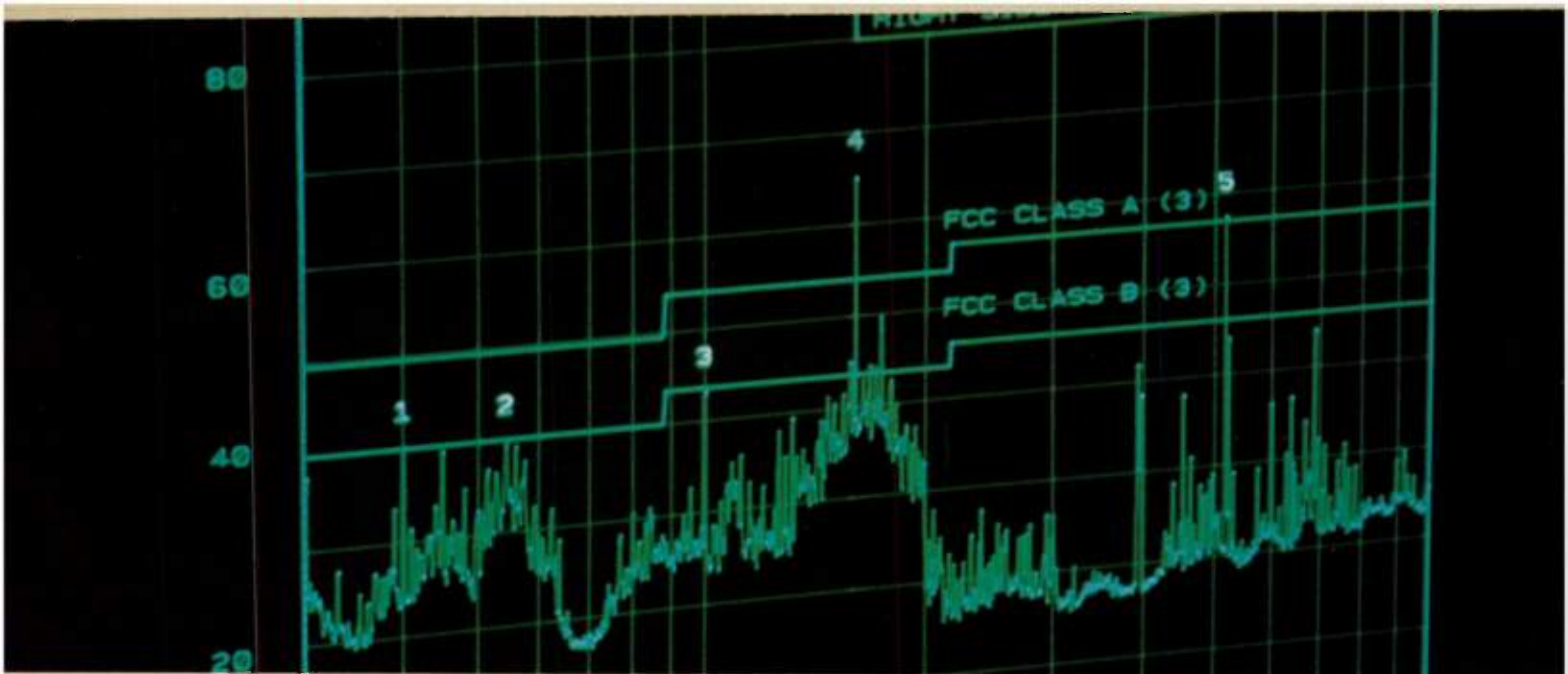
Cover

On this month's cover is Wiltron's new 6400-series Scalar Network Analyzer, a new low-cost instrument for the 1 to 200 MHz frequency range. These units represent the renewed attention being paid to RF instrumentation by test equipment manufacturers.

Features

Departments

R.F. DESIGN (ISSN: 0163-321X USPS: 453-490) is published monthly plus one extra issue in August. March 1986, Volume 9, No. 3. Copyright 1986 by Cardiff Publishing Company, a subsidiary of Argus Press Holdings, Inc., 6530 S. Yosemite Street, Englewood, CO 80111 (303) 694-1522. Contents may not be reproduced in any form without written permission. Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: 1 East First Street, Duluth, MN 55802, (1-800-346-0085). Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $22 per year in the United States; $29 per year in Canada and Mexico; $33 (surface mail) per year for foreign countries. Additional cost for first class mailing. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $5.50 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 N. Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700.
POSTMASTER & SUBSCRIBERS: Please send address changes to: R.F. Design, P.O. Box 6317, Duluth, MN 55806



CONFIDENCE

From design through compliance testing, HP's Spectrum Analyzer/EMI Receivers deliver unprecedented versatility and CISPR receiver accuracy.

Your complete EMI measurement solution.

HP's new Spectrum Analyzer/EMI Receivers deliver fast, accurate EMI compliance measurements *and* complete EMI diagnostic capabilities—all for the price of an EMI receiver alone.

Featuring the new HP85685A RF Preselector—with improved sensitivity and overload protection—these versatile spectrum analyzer-based EMI receivers are designed to CISPR* Publication 16 recommendations and meet the measurement requirements for military and commercial standards, including FCC and VDE. Which makes them the ideal instruments to conduct your final open-site EMI compliance tests with complete confidence.

And unlike EMI receivers that are dedicated solely to compliance testing, the HP Spectrum Analyzer/EMI

Receivers are also indispensible EMI diagnostic aids throughout your product's design and evaluation stages.

The ideal EMI diagnostic tool.

Using the HP8566B, 8567A or 8568B Spectrum Analyzer and the HP11940A Close-Field Probe, you can quickly locate problem emissions and evaluate potential solutions. These powerful analyzers sweep quickly over a broad frequency range, from 100 Hz to 22 GHz, 10 kHz to 1.5 GHz or 100 Hz to 1.5 GHz, instantly displaying measurement results on the easy-to-read CRT, or as hard copy plots. Built-in capabilities include: multiple-trace digital storage for instant A vs. B comparison, frequency and amplitude markers, maximum hold for capturing elusive intermittents, and direct plotter control—to name just a few.

Perform open-site tests with confidence.

When it's time for final compliance testing, the same HP spectrum

analyzer used during the design and evaluation stages can be combined with the HP85685A RF Preselector and the HP85650A Quasi-Peak Adapter. The result is an EMI receiver system with the sensitivity, overload protection and ±2 dB amplitude accuracy you'll need for both indoor and outdoor compliance testing.

System features include multiple detection modes with peak detection for the fastest possible measurement time, quasi-peak detection for compliance with CISPR Publication 16 recommendations, and average detection for discrimination between narrowband and broadband signals.

Automate your EMI measurements for increased productivity.

With the HP85864B EMI Measurement Software, featuring an easily understood menu structure, you'll be able to quickly automate your commercial and military emission measurements. Choose from a library of FCC, VDE and MIL-STD emission tests, or design your own. Test results can be annotated and notes generated as part of the test documentation.

Consider the HP advantage.

Now is the time to discover the distinct advantages of HP's Spectrum Analyzer/EMI Receivers, total solutions for EMI measurements. After all, why invest in both an EMI receiver for compliance testing *and* an additional spectrum analyzer for design/evaluation, when you can accomplish both tasks confidently with a single, versatile system that costs far less?

For more information, call us toll-free at 1-800-556-1234, ext. 515. In California, call 1-800-441-2345, ext. 515. Or write Hewlett-Packard, 1820 Embarcadero Road, Palo Alto, CA 94303.

*CISPR (Comite International Special Des Perturbations Radioelectriques) Publication 16 is the "CISPR specification for radio interference measuring apparatus and measurement methods."

HEWLETT PACKARD

5301500

A New Dimension in Portable, Digital Spectrum Analyzers!

The A-7550 Spectrum Analyzer

The A-7550 Spectrum Analyzer by IFR is the most advanced, low cost, portable spectrum analyzer on the market today.

Two powerful microprocessors, menu driven display modes and single function keyboard entry aid the user in the operation of all analyzer functions.

To further enhance the operational simplicity of the A-7550, the microprocessor system automatically selects and optimizes the analyzers bandwidth, sweep rate, center frequency display resolution and the rate of the frequency slewing keys. An operator override is also provided when non-standard settings are required.

Features...Performance...Dependability... The A-7550 portable Spectrum Analyzer by IFR—innovative accomplishments in design.

A Subsidiary of Regency Electronics Inc

Impressive Standard Features Include:

▪ 100 kHz to 1 GHz frequency coverage ▪ VRS™ (Vertical Raster Scan) CRT display ▪ Single function keyboard entry ▪ Menu driven display modes ▪ Automatic amplitude calibration ▪ Selectable linear/log display modes ▪ Digital storage of all displayed parameters ▪ 70 dB dynamic range ▪ 300 Hz resolution bandwidth ▪ 16 selectable scan widths ▪ Accurate center frequency readout ▪ Direct center frequency entry ▪ Automatically scaled electronic graticule ▪ Variable top scale reference (+30 to −95 in 1 dB steps) ▪ IF gain in 1 dB steps ▪ Line, bar, average and compare display modes ▪ 300 Hz and 30 kHz video filters

Optional Features Include:

▪ Internal rechargeable 5 APH battery for portable operation ▪ Tracking generator with 10 dB step attenuator ▪ Tracking generator with 1 dB step attenuator ▪ FM/AM/SSB receiver ▪ IEEE-488 interface bus ▪ RS-232 interface bus ▪ 75Ω adaptor ▪ Quasi-peak detector

Contact your local IFR authorized distributor for a demonstration.

IFR INC

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

INFO/CARD 8

rf calendar

March 11-13, 1986
Automated Design for Engineering for Electronics West
Moscone Convention Center, San Francisco, California
Information: Show Manager, ADEE WEST, Cahners Exposition Group, Cahners Plaza, 1350 E. Touhy Ave., P.O. Box 5050, Des Plaines, IL 60017-5060; Tel: (312) 299-9311

March 18-20, 1986
Southcon/86 High Technology Electronics Exhibition and Convention
Orange County Convention Center, Orlando, Florida
Information: Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045; Tel: (213) 772-2965

March 25-27, 1986
IEEE Instrumentation and Measurement Technology Conference
University of Colorado Events/Conference Center
Hilton Harvest House, Boulder, Colorado
Information: Robert Myers, 1700 Westwood Blvd., Los Angeles, CA 90024; Tel: (213) 475-4571

April 7-10, 1986
International Conference on Frequency Control and Synthesis
University of Surrey, Guilford, England
Information: Institution of Electronic and Radio Engineers, 99 Gower St., London, WC1E 6AZ; Tel: 01-388-3071

April 8-10, 1986
Test and Measurement World Expo
San Jose Convention Center
San Jose, California
Information: Meg Bowen, Conference Director, Test and Measurement World Expo, 199 Wells Avenue, Newton, MA 02159.

April 9-16, 1986
World Market for Electronics and Electrical Engineering '86
Hannover Fairgrounds
Hannover, West Germany
Information: Hannover Fairs USA Inc., P.O. Box 7066, 103 Carnegie Center, Princeton, NJ 08540; Tel: (609) 987-1202.

May 5-7, 1986
36th Electronics Components Conference
Westin Hotel, Seattle, Washington
Information: Tom Pilcher, Electronics Industries Association; Tel: (317) 261-1592

May 13-15, 1986
Electro/86 High Technology Electronics Exhibition and Convention
Exposition Center, World Trade Center, Boston, Massachusetts
Information: J. Fossler, Electronic Conventions Management (see address above)

June 24-26, 1986
Military Microwave Conference
Metropole Convention Centre, Brighton, England
Information: Roger Marriott, Microwave Exhibitions and Publishers Ltd., Convex House, 43 Dudley Road, Tunbridge Wells, Kent TN1 1LE, United Kingdom; Tel: 0892-44027

rf courses

The George Washington University
Synchronization in Spread Spectrum Systems
April 7-11, 1986, Washington, DC

Introduction to Receivers
March 17-18, 1986, Washington, DC

Modern Receiver Design
March 19-21, 1986, Washington, DC

Antennas and Arrays
March 17-21, 1986, Washington, DC

Information: Merril Ann Ferber, Assistant Director, Continuing Education Engineering Program, The George Washington University, Washington, DC 20052; Tel: (800) 424-9773

Georgia Institute of Technology
Elements of Phased Array Radar Design
March 18-21, 1986, Atlanta, Georgia

Information: Trish Stolton, Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385; Tel: (404) 894-2547

Besser Associates, Inc.
"Principles of RF and Microwave Circuit Design" Theory and Applications
March 19-21, 1986, Santa Clara, California

Information: Jenifer Jacobs, Besser Associates, Inc., 3975 E. Bayshore Road, Palo Alto, CA 94303

Virginia Polytechnic Institute and State University
Antennas: Principles, Design and Measurements
March 19-22, 1986, St. Cloud, Florida

Information: Ann Beekman, 1101 Massachusetts Ave., St. Cloud, FL 32769; Tel: (305) 892-6146

Interference Control Technologies
Grounding and Shielding
March 18-21, 1986, San Diego, California
April 15-18, 1986, Atlanta, Georgia

Tempest Facilities Design, Installation and Operation
April 8-10, 1986, Washington, DC

EMC Design and Measurement for Control of EMI
April 21-25, 1986, Philadelphia, Pennsylvania

Practical EMI Fixes
March 24-27, 1986, Atlanta, Georgia

Information: Penny Caran, Registrar, Interference Control Technologies, State Route 625, PO Box D, Gainesville, VA 22065; Tel: (703) 347-0300

University of Mississippi
Dielectric Oscillators
April 9-11, 1986, Oxford Campus

Information: Bruce Bellande, Continuing Education, University of Mississippi, University, MS 38677; Tel: (601) 232-7282

rf letters *Continued*

But the issue is not as simple as one might infer from your response to Mr. DeZube. The Antenna Factor of a tuned dipole antenna is severely affected by: the dimensions of the antenna, the balance of the antenna, the loss of the BALUN, the height above the ground plane, the polarization, and the mismatches in the system. The actual Antenna Factor for a practical antenna used for EMI measurement on an open area test site *will* vary from the calculated value — up to several decibels in some cases! I have copies of several detailed papers written on this subject which I will be glad to send to Mr. DeZube, or others, if requested.

One last thought: If any of your readers are really interested in learning about the science of EMC, including the measurement and mitigation of EMI, they should join the IEEE EMC Society. The EMC Society publishes the EMC Transactions, an EMC-S Newsletter, and symposia records; all dedicated to the technology of EMC.

Please publish this letter in your next available letters column.

Edwin L. Bronaugh
Technical Director
Electro-Metrics
100 Church St.
Amsterdam, NY 12010

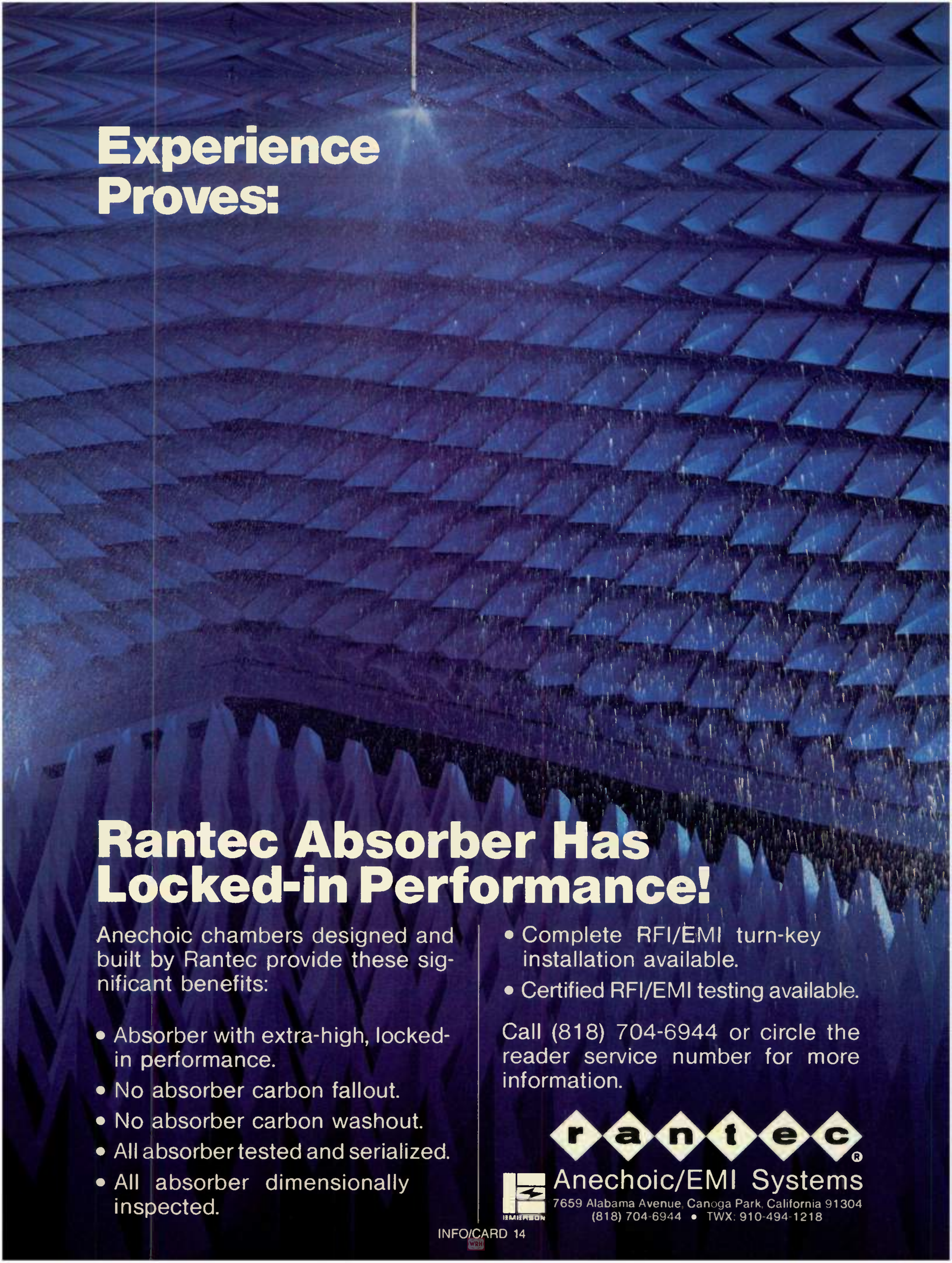
Editor:

I read with interest the article entitled "Microstrip-line High Power Amplifier Design" in the December issue, and I was interested in Mr. Tam's application of stub matching; but there is one thing that troubles me about his design technique. In the first example of input matching, he is using a 19 ohm stub (C1) to match an impedance of 9.5 + J19.5 (point B, figure 1). As a result of this, he ends up with a rather wide stub which possesses a distributed series inductance that I feel must be dealt with. As I examined figure 3 of the article, I couldn't help but think that what Mr. Tam calls the width "W," I would have called the length of some transmission line whose ZO would be determined by a width which he called "L."

I decided to examine "C1" as a transmission line instead of two shunt stubs. Using a width "L" of .580 inches, I came up with a ZO of approximately 10.8 ohms. At 1600 MHz, a length "W" of .300 inches corresponds to .0575 wavelengths which transforms 9.5 + J19.5 ohms to 51.35 + J20.51 ohms.

This is not a very bad match, but the point needs to be made that the transmission line effect must be taken into account. May I suggest for stub matching, to minimize this effect, a short, high ZO line be used in series with the stub to attach the stub at more of a point instead of attaching the stub along the line as Mr. Tam has done.

Joseph J. D'Agostino
Thomson-CSF Components Corp.
Montgomeryville, PA


Experience Proves:
Rantec Absorber Has Locked-in Performance!
Anechoic chambers designed and built by Rantec provide these significant benefits:
• Absorber with extra-high, locked-in performance.
• No absorber carbon fallout.
• No absorber carbon washout.
• All absorber tested and serialized.
• All absorber dimensionally inspected.
• Complete RFI/EMI turn-key installation available.
• Certified RFI/EMI testing available.
Call (818) 704-6944 or circle the reader service number for more information.
rantec®
EMERSON
Anechoic/EMI Systems
7659 Alabama Avenue, Canoga Park, California 91304
(818) 704-6944 • TWX: 910-494-1218
INFO/CARD 14

SIGNAL PROCESSING?

Merrimac
now there is one… in signal processing

Drop-In Isolators and Circulators

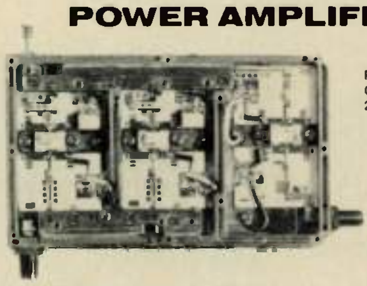
Merrimac
now there is one… in signal processing

L-BAND AMPLIFIER

Merrimac
now there is one… in signal processing

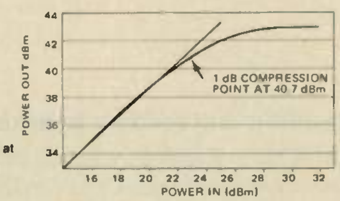
S-BAND POWER AMPLIFIER

10 WATT S-BAND POWER AMPLIFIER

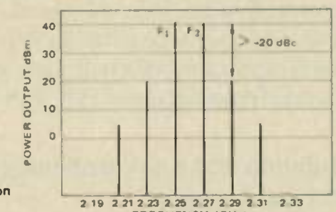


This new GaAs FET linear amplifier is specially designed, manufactured and tested for S Band Telemetry and point to point radio applications operating in the 2.2 to 2.3 GHz band. Key operating characteristics are: low intermodulation distortion, low noise and excellent linear power transfer. Packaged in a 2.5" x 4.0" x 0.75" case, these amplifiers are capable of being hermetically sealed to meet applicable MIL specifications.

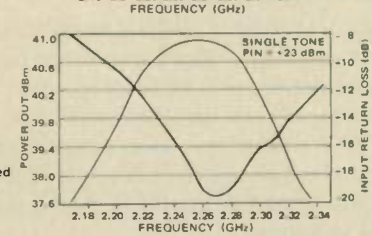
Power Transfer Characteristics at 2235 MHz



Two Tone Intermodulation



Input Return Loss and Bandwidth Measured at Nominal Power Output



Model No. AMP-10-2.25 G Minimum Performance Specification

CHARACTERISTICS	TYPICAL
FREQUENCY RANGE	2235 MHz — 2285 MHz
GAIN	16dB
GAIN FLATNESS (MAX.)	0.3dB
POWER OUTPUT AT 1 dB COMPRESSION (MIN.)	+40.7 dBm
VSWR (MIN) INPUT/OUTPUT	1.5:1/1.25:1
DC CURRENT (MAX.) AT +10 VOLTS	5.3 AMP.
THIRD ORDER TWO TONE INTERCEPT POINT	+50.7 dB

Merrimac P.O. BOX 986, 41 FAIRFIELD PLACE, WEST CALDWELL, N.J. 07007-0986
201-575-1300 · TWX 710-734-4314 · TELEX 6853128
FAX 201-575-0531

CALL US!

We have many more answers.

Merrimac P.O. BOX 986, 41 FAIRFIELD PLACE, WEST CALDWELL, N.J. 07007-0986
201-575-1300 • TWX 710-734-4314 • TELEX 6853128 • FAX 201-575-0531

INFO/CARD 15

The best system ever developed for FCC Part 15.

FSK transmitter and receiver hybrids.

Announcing the first realistic solution for demanding UHF low-power applications such as wireless security and alarm systems, commercial remote control, wireless data terminals and rf telemetry systems. RF Monolithics' FSK transmitter and receiver hybrids will allow you to get the maximum service potential out of FCC Part 15, Subpart D and E.

FSK modulation and SAW technology. The perfect combination.

Because our hybrids use FSK modulation, they afford excellent immunity to impulse noise and background AM transmissions, plus the sharp receiver "capture" characteristic of wide-band FM modulation.

And SAW technology makes them easy to use, highly reliable and surprisingly cost effective. That saves you from a protracted rf design effort. And it assures almost textbook performance.

FSK transmitters.

With our FSK hybrid transmitters, you just add a 9V battery, a simple printed-loop or coil antenna, and a digital input. Our hybrid transmitters do the rest. Transmitter output can be easily adjusted to achieve full legal radiated power (operating range) for your particular choice of antenna, transmission duty cycle, and operating authority (Subpart D or E). Quartz SAW resonator frequency control assures that our transmitters will never drift out of your receiver's bandpass—or into a military "forbidden band."

FSK receivers.

With our superheterodyne receiver "front end" hybrids, all you add is a standard 10.7 MHz FM radio i-f. The hybrids' 6.5 dB noise figure and 27 dB conversion gain assures excellent receiver sensitivity. The local oscillator is SAW resonator stabilized. A third-generation quartz SAW filter provides both image and LO-beat rejection, plus superb intermodulation performance. The filter also suppresses LO leakage to the antenna, allowing a high gain receiver antenna to be used with full compliance to Part 15 regulations.

RF Monolithics. We're behind you all the way.

Whether you need transmitters, receivers or both, you'll find our rf engineers ready to help you integrate SAW technology into your product. And you can count on innovative, cost-effective solutions.

RFM

THE NEW WAVE IN RF

RF Monolithics, Inc. • 4441 Sigma Rd. • Dallas, Texas • 75244 U.S.A.
Phone: (214) 233-2903 • Telex: 795022 • FAX: (214) 387-8148 • TWX: 910-860-5474

INFO/CARD 16

RF Power, CAD Dominate Technology Expo

Power amplification and computer aided design seemed to attract the most interest at the RF Technology Expo '86, held Jan. 30-Feb. 1, in Anaheim, Calif. Ten of the 73 technical papers presented at the Expo dealt with high power amplifier design and all were well attended. Two sessions, with six papers, were devoted to computer aided design, and several papers in other sessions described CAD techniques used by the authors.

In the exhibit hall, 32 companies showed some type of RF amplifying device. This dominance by amplifiers reflected one of the primary efforts in the industry — broadband amplification to meet today's military and commercial needs. Among the new products introduced at the show were a MOSFET Class A linear amplifier with a 7 kHz to 230 MHz bandwidth at a minimum power output level of 10 watts, by Kalmus Engineering International, a DMOSFET offering 100 watt output up to 400 MHz, by M/A-Com PHI, a 600 watt bipolar transistor for operation from 2 to 30 MHz, by Motorola Semiconductor Products, and an L-Band bipolar with a long-pulse output up to 125 watts, by Microwave Semiconductor Corp. New amplifiers by Microwave Modules and Devices and Signetics featured at the show were described in the February and December issues of *RF Design*, respectively.

This year two new RF computer software companies were at the Expo along with the established leaders, EEsof and Compact. SPEFCO Software featured revised versions of CIAO and DESIGN, developed by Stephen E. Sussman-Fort, SUNY-Stony Brook. Summit Technology introduced Optimic, an optimization program for microwave and RF circuits that operates on the Apple II and IBM PC.

EEsof demonstrated a software link that allows a personal computer running Touchstone to interact with a VAX mainframe. The Touchstone/VAX Connection™ operates on the IBM PC-XT, PC-AT and compatibles, including the HP Vectra. The VAX Connection offers a transparent connection to the mainframe. The user can optimize complex circuits on the VAX while using the PC for local simulation and optimization. Measurement data can be transferred to the VAX from an HP 8510 network analyzer.

EEsof introduced Touchstone 1.4™ at the show. Among the new elements in this version are assymetric coupled-microstrip transmission lines, six and eight-finger interdigital (Lange) couplers, a proprietary via-hole model, a linear taper and slit and gap models and three additional microstrip bend models. The program offers the ability to include equations among circuit element values, an advanced gradient optimizer, a mouse interface for tuner and editor functions, facility to include permeability and dielectric and magnetic loss in waveguide and transmission line physical models and single monitor operation with IBM's Enhanced Graphics Adapter and Display™.

EESof also introduced Touchstone Sr.™ and Microwave SPICE™ at the Expo. Touchstone Sr. allows engineers to construct circuit models and incorporate them into Touchstone while ensuring security for proprietary design techniques. Each model can be accessed as a permanent part of Touchstone's library. Microwave SPICE relates active device characteristics to process related parameters and performs frequency or time domain analysis. Microwave elements, models and analysis tools have been added to SPICE to make the program particularly useful to microwave/RF design engineers. Single transistor or complex networked models are analyzed in terms of S-parameters. One to four-port Y-parameters can be isolated and extracted.

Compact Software, recently purchased by Communications Consulting Corp., announced Super Compact PC, version 3, at the show. Version 3 offers all the features of the mainframe-based Super Compact software. Communications Consulting featured CADEC-4™ for HP series 9000 computers. This software offers expanded microwave modules with com-

New Wave of RF Engineers

Smith

Standley

Barker

In spite of driving rains in Southern California, the new wave of RF engineers poured into Anaheim's Hilton Convention Center last month just as it had the year before at the first RF Technology Expo. This year, as last, almost half the attendees had been practicing engineers less than five years. Interviews with three youthful attendees revealed some striking things in common: perhaps most notably, all are involved with digital techniques in their work as well as analog, and regard a merger of the two disciplines as essential to successful design.

Although **Shelby Smith** earned her BSEE less than two years ago at the University of Michigan, she has worked for ERIM — the Environmental Research Institute of Michigan, in Ann Arbor — for a total of four years. Like many of today's engineering students, she was part of a co-op program which allows her to work while completing her studies. She encountered no RF technology while in school, but finds it a major requirement in her work: development of synthetic aperture radar (SAR) systems. One reason for coming to RF Expo '86 was to investigate SAW filters and delay lines for application in such systems. She was "awed and surprised" to see all the resources available. One of a small but growing number of women engineers, she thinks the number will increase but will "never" be half the engineering population — "as a result of childhood conditioning." Her own conditioning as a child was unusual, she thinks, in that she spent much of her time with her father, who was an engineer.

Ian Standley earned his BA in physics from Cambridge University in 1981, an MS from London University in 1983, and an MSEE from Cal Tech in 1985. Clearly a professional student, right? Wrong. He has also been working full time since 1981 for Systron-Donner Corp., a division of Thorn EMI. For all his schooling, Standley never dealt with RF technology until it was required of him in a work assignment. As he says with a characteristic shrug: "It was what they needed me to do." The current assignment has him investigating the use of SAW devices as sensors. Like Smith, he was impressed by the number of exhibitor companies at RF Technology Expo that were relevant to his investigation. To Standley, RF technology is a means to an end. He is equally involved with digital logic and computer graphics, and considers his real specialty the interrelationships between the disciplines.

Richard Barker, unlike Smith and Standley, has been involved with RF for a long time, having "tinkered" with radio as a boy. He earned his BSEE from Penn State in 1977, and has worked since then at the National Radio Astronomy Observatory in St. Augustine, N.M., as a "front end" engineer on VLA antennas which receive signals from remote galaxies. While this work has involved L, Ku and C bands in the past, recent developments have brought an emphasis on X band and megahertz frequencies. Barker's assignments are mainly design of low noise amplifiers. Everything at the observatory is computer-controlled, Barker says, so his work too involves a melding of digital and analog techniques. He came to RF Technology Expo to find three things: new products, new instrumentation, and CAD/CAM software. He found them all.

rf design

a Cardiff publication
Established 1978

Publisher
Keith Aldrich
Editor
James N. MacDonald
Technical Editor
Gary A. Breed
Consulting Editor
Andy Przedpelski

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

Sales Supervisor
Kate Walsh

Eastern Sales Manager
Douglas Markhouse
Eastern Sales Office
167 South Broadway
Hastings on the Hudson, NY 10706
914-478-0909
914-478-4349

Advertising Services
Elizabeth Van Brocklin

Circulation Director
Pam Greenberg

Circulation Manager
Trish Shapiro

Circulation Assistant
Michelle Schwinghammer

Production Manager
Madeline Price

Assistant Production Manager
Mary Barr Felker

Artists
Carol Bates
Sarah Brown
Maurice Lydick
Matt Park
Bill Schmitt

Composition
Jay Jarrett
Ellen Wilson

Published by
CARDIFF PUBLISHING COMPANY, INC.
6530 S. Yosemite St.
Englewood, CO 80111
(303) 694-1522

BPA

President
Robert A. Searle
Vice President
Judy L. Rudrud
Controller
Marvin Laut
Operations Manager
Cherryl Greenman

Member of Business Publications Audit of Circulations, Inc.

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

plete nodal circuit noise analysis at twice the speed of previous versions.

RF Fundamentals Course Draws 300 Before Show

The all-day course in the fundamentals of RF design was one of the main attractions at this show as it had been at RF Technology Expo '85 a year earlier. The course was taught by Les Besser, president of Besser Associates, Inc., Palo Alto, Calif. Besser conducts many seminars and workshops during the year for RF and microwave designers, managers and technicians.

Called *Introduction to RF Circuits*, the course was offered twice. Almost 300 Expo attendees came the day before the conference to attend the course. Nearly 100 more attended the second offering on the first day of the show. Show organizers had scheduled one session of the course before the Expo so attendees would not have to miss any technical papers.

The course began with an introduction to two-port network characterization using Z, Y and ABCD parameters, then went into the development of S-parameters for two-port networks. Basic transmission line theory was discussed with emphasis on coaxial and microstrip forms. Besser also covered the effects of frequency on lumped elements and the development and use of the Smith Chart. Small signal amplifier design was illustrated in a step-by-step procedure for a 70 MHz IF amplifier.

Press Conference Ignored

In contrast to the interest generated by every other segment of the Expo, none of the high frequency publications except *RF Design* were represented at the press conference, scheduled the afternoon of

the first day. Editors contacted in advance had said they would not attend, causing two of the companies to cancel their scheduled briefings, but show organizers held the conference for any unexpected publications that might want to attend. Organizers said there probably would not be a press conference at future shows. Free press registrations are available so representatives can conduct interviews one-on-one at the Expo.

Sawtek, Inc. had planned to use the press conference to introduce two new oscillators at the Expo designed to operate at the fundamental IFF frequencies of 1030 MHz and 1090 MHz. The oscillators use L-band SAW resonators to obtain low SSB phase noise, spurious content and power consumption. They include interstage isolation and output buffer amplifiers to minimize load pulling.

Attendance Up By One Fourth

Conference organizers reported at least 1,566 attendees at Expo '86, a 24.8 percent increase over the year before. Exhibitor attendance, which included many engineers who attended the technical sessions, added 817, almost double the year before, bringing the total attendance to more than 2,383. Based on pre-registration compared to the year before, show organizers expected a higher total attendance. Approximately 200 who had exhibit-only passes did not show up, probably because of the steady and sometimes heavy rain all three days of the conference. It also appeared that a higher percentage had pre-registered than the previous year.

Exhibitors Fill Next Show

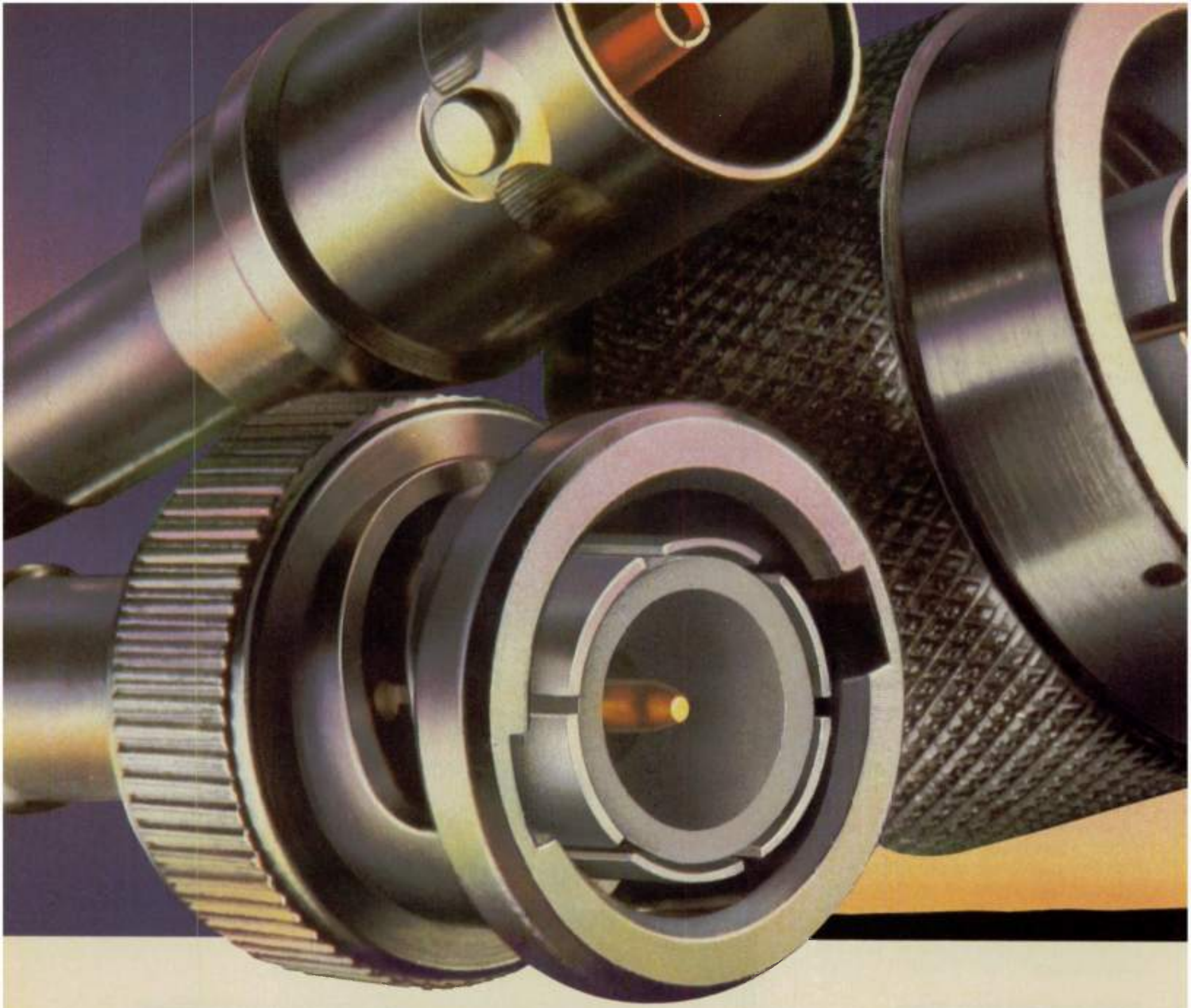
Exhibitors at this show contracted for nearly all the 136 booths available at RF Expo East, to be held Nov. 10-12 in Boston, and other company representatives present took the rest. Two-thirds of the booths available at RF Technology Expo '87, to be held Feb. 11-13, 1987, in Anaheim, were also taken. Booth space at each show was made available on a point system, with companies receiving points based on previous contracts. Exhibits at this show were as popular as the technical sessions. Exhibitors always knew when one of the papers finished by the wave of attendees entering the exhibit hall.

Speakers, Session Chairmen Sought For Next Two Shows

Conference organizers have called for papers to be presented at RF Expo East and RF Technology Expo '87. Approximately 75 papers will be presented at each conference. A few of the most popular papers at this show will be repeated at Expo East, organizers said, and some from that show will be repeated at RF Technology Expo '87.

Program Chairman Jim MacDonald is also calling for session chairmen for both shows. MacDonald said session chairmen will have a much larger role in future shows. He said he will ask session chairmen to help select topics and work with authors. He said he is especially looking for experienced speakers who can advise authors about preparing and presenting their papers.

"The technical sessions are a very important part of the show," MacDonald said. "The average attendance for all sessions was 91, with a high of 300 in one session. There is obviously a need for this kind of information exchange and we want to present the best quality of work we can." rf



MMD™

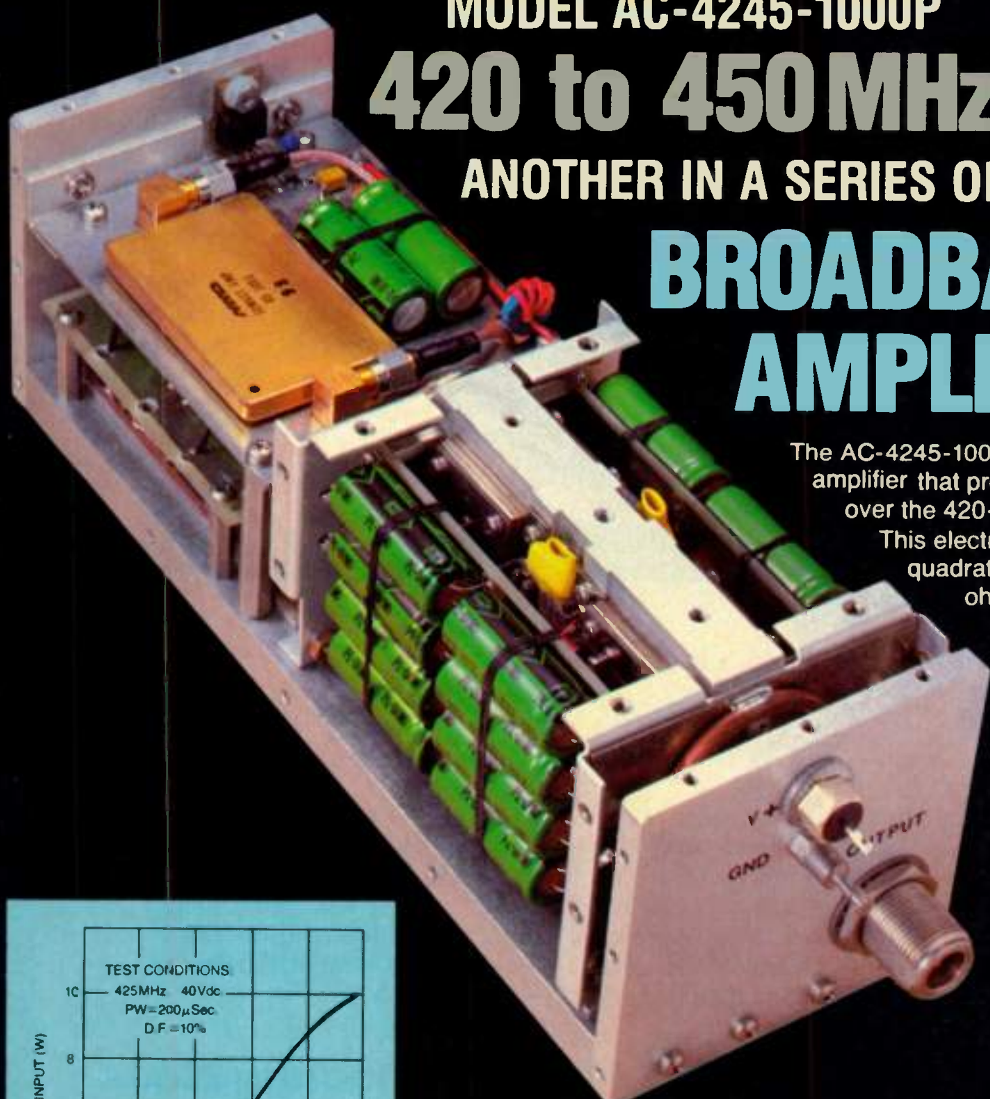
1 KW POWER

MODEL AC-4245-1000P

420 to 450 MHz

ANOTHER IN A SERIES OF

BROADBAND AMPLIFIERS

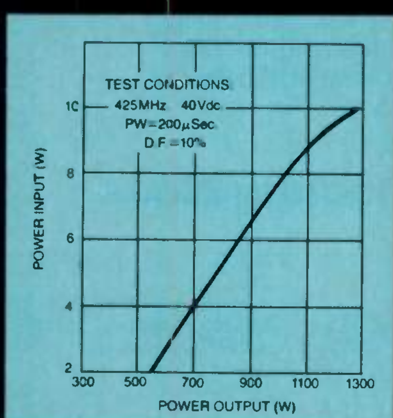


The AC-4245-1000P is a modular, wideband power amplifier that provides 1000 watts of pulsed power over the 420-450MHz frequency range.

This electrically stable unit incorporates 90° quadrature combiners for predictable 50 ohm system interfaces and superior performance into mismatched loads.

Multiple units can easily be combined for multi-kilowatt applications.

AC-4245-1000P constitutes a rugged, reliable building block for a variety of military and commercial high power VHF applications.



GAIN: 20dB min. PULSE WIDTH: 200μSecs.

VOLTAGE: 40VDC. DUTY FACTOR: 10%

- 1000W pulsed output into 1.5:1 VSWR.
- 50 ohm input/output.
- Efficient (45% min.)
- Excellent stability.
- Compact, lightweight, only 3″×3″×9″ and 4.25 pounds. (76×76×229mm, 2KG)

Call for additional information.

MMD
MICROWAVE MODULES & DEVICES, Inc.
550 Ellis St., Mountain View, CA 94043 (415) 961-1473 TWX 508746

INFO/CARD 21

New Network Analyzers Bring Price/ Performance to Lower Frequencies

Hewlett-Packard and Wiltron Recognize Growth in RF Applications Below 2-3 GHz, Introducing New Vector and Scalar Network Analyzers.

RF engineers have new design tools with the introduction of new RF network analyzers by Wiltron and Hewlett Packard. The Hewlett-Packard HP 8753A is a vector network analyzer for the 300 kHz to 3 GHz frequency range, providing magnitude and phase analysis of RF circuits. Wiltron has introduced two scalar analyzers, Model 6407 for 1 to 1000 MHz and Model 6409 for 10 to 2000 MHz, providing precision amplitude analysis capabilities. This Special Report provides a look into the design of these instruments and their measurement capabilities.

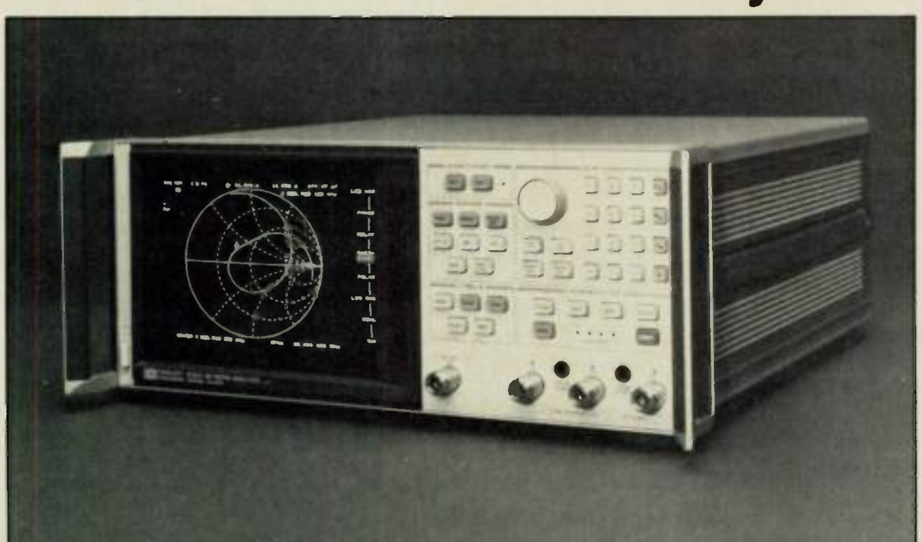
Both companies' instruments represent excellent price/performance value, but they also make clear the difference between scalar and vector analysis, both in price and performance. Scalar analyzers provide amplitude measurement capabilities that will satisfy many RF engineers' requirements for design, development and production. However, when phase information is needed in addition to magnitude, only the vector analyzer will do the job.

The greatest benefit represented by these instruments is their direct application in the RF spectrum below microwaves. The manufacturers have been able to implement significant cost savings in the production of these instruments by eliminating the complexity of microwave circuitry and by using the design techniques just developed in the recent past.

As you read the following descriptions of the featured network analyzers, note the design techniques used to make each one the best possible value to their respective end-users.

— Gary A. Breed
Technical Editor

The Hewlett-Packard 8753A RF Vector Network Analyzer



By Tom Phillips
Hewlett-Packard Co.

High-performance network analyzers have traditionally provided accurate transmission and reflection measurements of components and other networks. The new HP 8753A network analyzer has incorporated novel design techniques to achieve excellent accuracy, while reducing cost.

Recall that network analyzers can characterize a device under test (DUT) by measuring the magnitude and phase of the transmitted and reflected signals from each of the DUT's ports. Therefore, a network analyzer consists of a source that provides the test signal to the DUT; a signal separation device that separates the incident, transmitted, and reflected signals; and a receiver that processes and displays the measurement results (Figure 1).

Previous-generation network analyzers typically used open-loop sweep oscillators to provide the input signal to the DUT. With frequency accuracy and repeatability on the order of 1 MHz, these simply were not accurate enough for measuring narrowband devices. The HP 8753A has a synthesized source that provides 1 Hz resolution throughout its 300 kHz to 3 GHz frequency sweep range. The design challenge for the HP 8753A source was to provide this level of performance at a low cost.

Synthesized Sweeper Design

The design goals for the source used in the HP 8753A were:

- broadband frequency coverage (300 kHz to 3 GHz)
- synthesized stability and accuracy
- high resolution
- phase-continuous frequency sweep capability
- high output power (100 mW)
- inexpensive to manufacture
- easy to repair

As an integral part of the network analyzer, the source and receiver are controlled by a common microprocessor. Tracking between the source and receiver is easier when the two are integrated, and achieves high dynamic range.

To achieve its accuracy and resolution

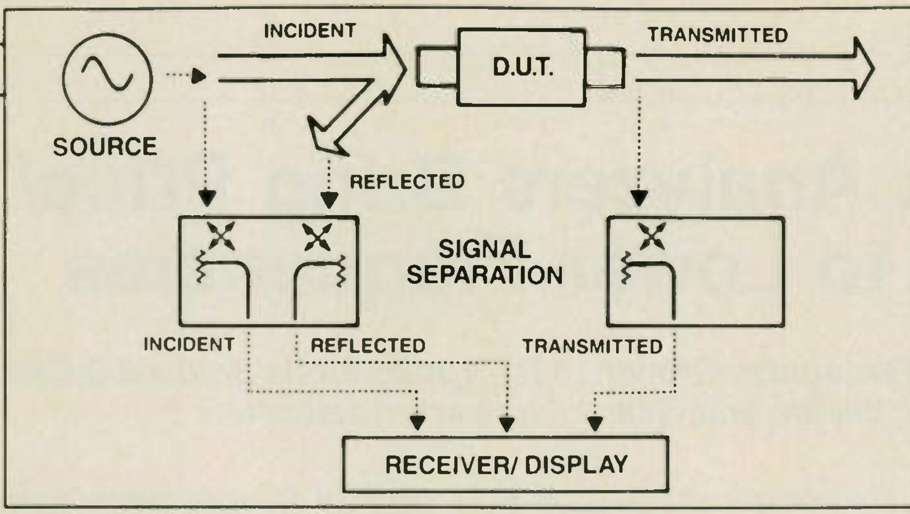


Figure 1. Simplified network analyzer block diagram

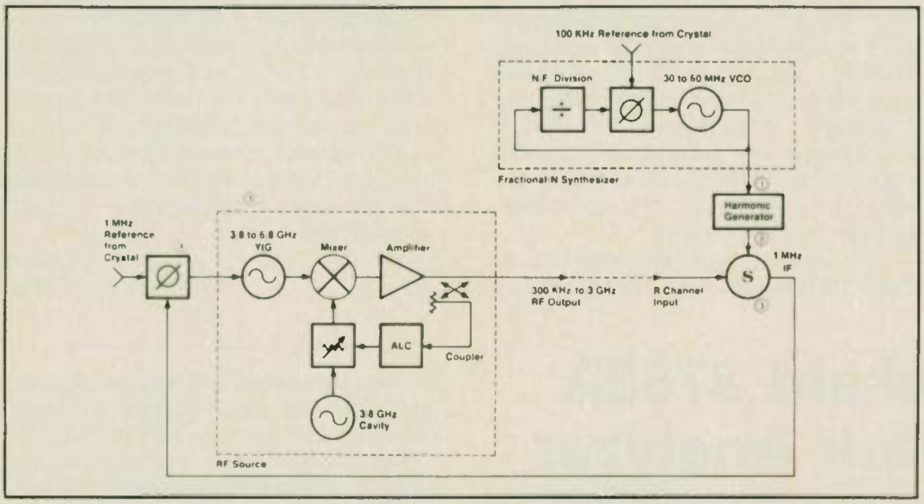


Figure 2. Synthesized source used in the HP 8753A

goals, the source had to eliminate much of the analog sweep circuitry found in previous designs. To accomplish this, the HP 8753A uses a fractional-N technique to digitally control the RF output frequency to better than 1 Hertz resolution. The fractional-N synthesizer provides a 30 to 60 MHz frequency reference that very accurately controls the RF output frequency. This low frequency, low-cost synthesizer determines the overall frequency resolution of the RF output as shown in the steps below (illustrated in Figure 2):

1. The fractional-N controlled VCO delivers a 30 to 60 MHz synthesized signal to the harmonic generator circuit.
2. The harmonic generator multiplies the 30 to 60 MHz signal to a frequency that is 1 MHz lower than the desired RF output signal.
3. The RF output, as seen at the R channel input, is mixed with the output of the harmonic generator to produce an IF signal.
4. This IF signal is compared to a 1 MHz reference signal by a phase comparator.
5. The output of the phase comparator drives the RF source to the correct output frequency. The RF source was pretuned to a frequency slightly above the desired RF output frequency before phase lock.

Fractional-N Frequency Synthesis

The fractional-N synthesizer is the key to the accuracy and economy of the source. The digital circuit is able to control the 30 to 60 MHz VCO to 100 nanohertz resolution. Even after frequency multiplication by the harmonic multiplier, the resultant resolution is better than 10 millihertz. The absence of analog tuning circuitry reduces cost and increases reliability.

Fractional-N synthesis locks the 30 to 60 MHz VCO to a fractional multiple of the frequency reference. That is, the oscillator frequency is equal to the number N.F times the reference frequency, where N and F are positive integers. In the HP 8753A the VCO frequency in the synthesizer is N.F × 100 kHz where N is between 300 and 600 and F can be any 12 digit integer. The 12 digit fraction F allows the synthesizer to achieve 100 nanohertz (10^{-7}) resolution from a 100 kHz (10^5) reference.

To achieve the goal of broadband frequency coverage (300 kHz to 3 GHz) a separate scheme is used for frequencies below the fractional-N output frequency. For these lower frequencies, a fundamental mixing scheme is used where the RF output frequency is phase-locked to a derivative of the reference frequency.

The RF source contains a YIG oscillator, a cavity-tuned oscillator and source microcircuits in a single removeable assembly. The source microcircuits, a broad-band amplifier, coupler, mixer, and level modulator, are all thick-film hybrids. By means of carefully controlled processes, tight dimensional tolerances more like those associated with thin-film circuits are achieved. This dimensional control on thick-film allowed sophisticated RF components such as a 15 element low pass filter at 3.1 GHz to be made with a very high yield.

The four thick-film microcircuits are connected with conductive elastomer pressure contacts. They can be fully tested as microcircuits and just dropped in place and re-calibrated inside the instrument. By using thick-film instead of thin-film hybrids and by eliminating the wire bonding process, the HP 8753A is able to maintain excellent RF performance at a two to three times lower manufacturing cost. Figure 3 shows the four thick-film microcircuits inside the integrated source assembly.

Modular construction also makes the HP 8753A easy to service. With a calculated MTBF of greater than 8000 hours (4 years), the instrument should be very reliable. If it does need to be repaired, the modular construction makes it possible to offer the customer a choice of either on-site or return-to-HP repair. On-site service appeals to customers demanding maximum uptime. Most of the 17 independent modules in the instrument can be replaced and recalibrated using the HP 8753A's internal diagnostics, three verification standards, and an external power meter.

Localized RFI Shielding

RFI shielding is critical to the spectral purity of the RF output signal. This shielding can be an expensive manufacturing step in building a synthesized source. The HP 8753A uses local shielding around those components that are susceptible to RF interference. For example, local shielding around the fractional-N circuitry (Figure 3) keeps the digital switching noise away from the frequency reference circuitry. This technique keeps the fractional-N spurs under 70 dB and radiated emissions well below required levels.

A phase-continuous frequency sweep is important for accurate device character-

New!
Symmetrical Shielding Strips (S^3) provide bi-directional engagement at severe shear angles!

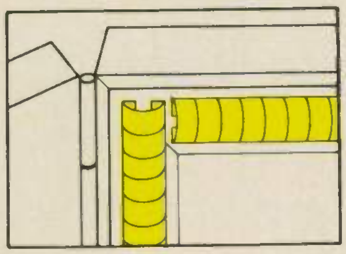
These new symmetrical slotted shielding strips of beryllium copper permit continuous spring contact throughout their length, providing the perfect answer for a variety of shielding requirements.

Three models are available: basic, rivet-mount and double-faced adhesive-mount designs. The basic design consists of low-compression, adhesive-mounted strips. A generous radius profile provides for the greatest incident engagement angle with the lowest force. As with all Sticky Fingers® shielding strips, the self-adhesive tape makes mounting easy and secure.

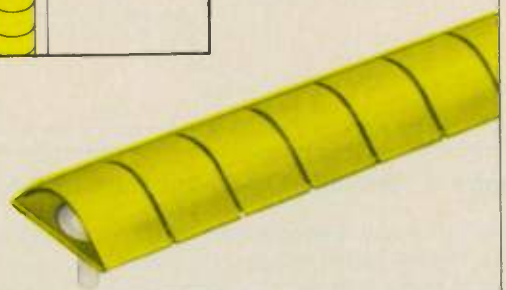
The rivet-mount design incorporates the addition of an integral track, pierced for mounting with nylon push rivets. This configuration allows bi-directional engagement, and is specially designed for slide applications, PC board connections, etc.

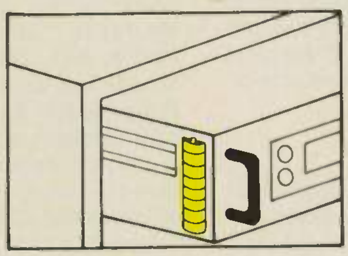
The third design also incorporates an integral track-mount design, but employs a double-faced adhesive tape instead of push rivets. This provides for fast, easy field replacement in military applications, especially where high frequencies do not permit the use of mounting holes.

For complete information, including exact specifications, dimensional drawings, etc., on these and other Instrument Specialties shielding strips, use this publication's Reader Service Card. Or write to us directly at Dept. RFD-27.

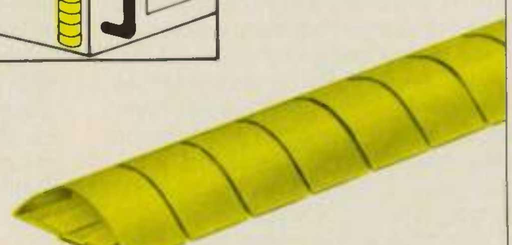


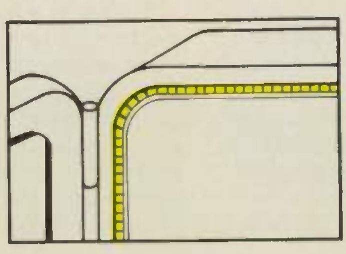
Adhesive-mounted strips for typical electronic enclosures.





Strips with integral mounting track* and nylon push rivets, for sliding drawer applications.





Strips with integral mounting track* and self-adhesive strip for fast field replacement.

*patent pending

INSTRUMENT SPECIALTIES COMPANY, INC.
P.O. Box A • Delaware Water Gap, PA. 18327
Phone: 717-424-8510 • TWX: 510-671-4526

Specialists in beryllium copper since 1938

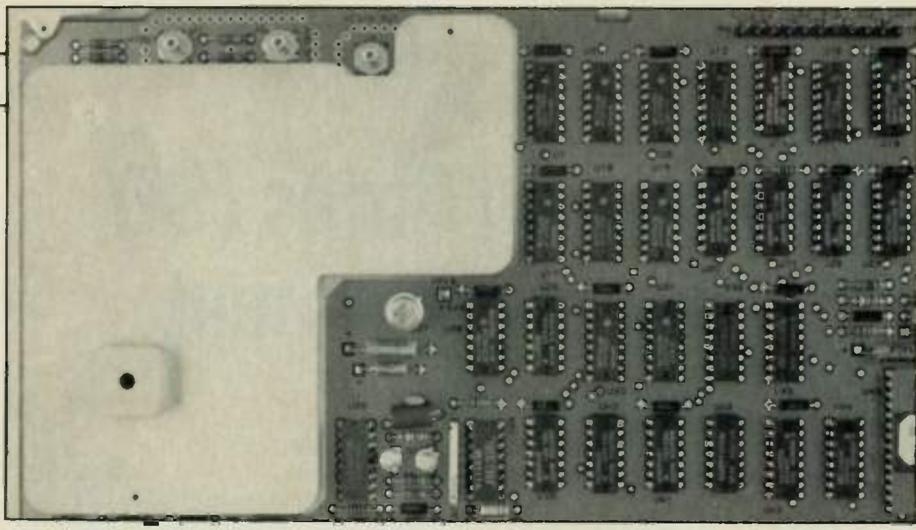


Figure 3. The fractional-N synthesizer, showing localized RFI shielding

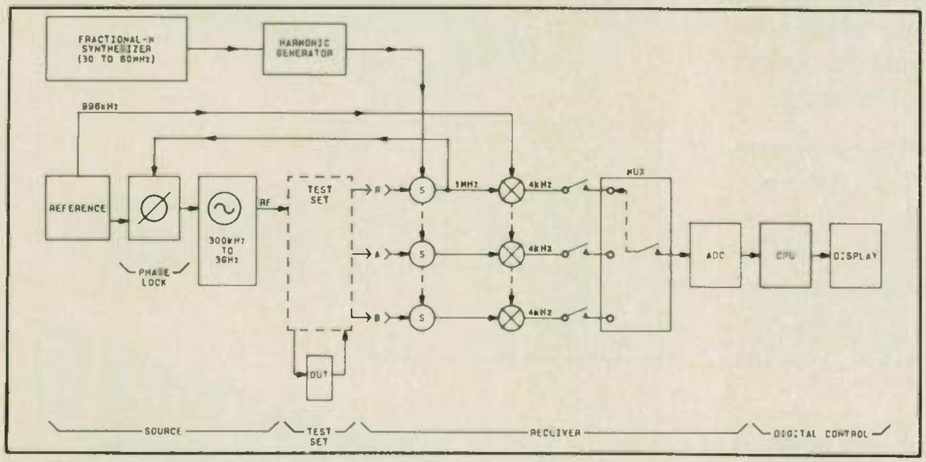


Figure 4. Simplified block diagram of the HP 8753A Network Analyzer

ization in many measurement applications. The RF output frequency is synthesized at every data point throughout the frequency sweep, yet sweeps fast enough for "real time" adjustments of components such as tunable filters and amplifiers.

Digital Receiver

The incident, reflected and transmitted signals are downconverted to a lower frequency before being digitized and displayed on the CRT. For input frequencies above 30 MHz, the input is downconverted to a 1 MHz IF using the output of the harmonic multiplier as discussed in the source section. Next, the input signal is downconverted to a 4 kHz IF using a 996 kHz derivative of the reference (crystal) frequency. Figure 4 shows the simplified block diagram of the entire instrument.

At the 4 kHz IF, the data is sampled and digitized by a 16 bit A/D converter. A dedicated signal processor (TMS 32010) digitally processes the input signal much like analog log amplifiers, blocking capacitors, synchronous detectors and video filters did in previous generation network analyzers. The processor removes DC components and spurious signals, and corrects for both IF and sampler gain and phase errors. The processor is fast enough to control the A/D, do the digital filtering and apply the hardware corrections in real time. There is no significant speed penalty for moving these functions from hardware to software. An advantage is the elimination of all potentiometers from this section of the instrument while still achieving over 100 dB dynamic range.

Some parts of the digital filter can be controlled by the user. For example, by reducing the IF bandwidth the user can increase the sensitivity by lowering the noise floor on the CRT. Smaller IF bandwidths require longer sweep times, however.

Accuracy Enhancement

The key to accurate network measurements is the removal of error signals from the measurement system (systematic errors), and displaying only the characteristics of the device under test (DUT). Examples of systematic errors are the reflected energy due to impedance mismatches at the source output and DUT ports, and the frequency response of the test set. The HP 8753A can remove these (and the other) systematic errors by measuring their magnitude and phase and vectorially subtracting their effect from the DUT measurement.

The analyzer uses a Motorola 68000 microprocessor to perform accuracy enhancement on each data point on every frequency sweep. This main CPU also allows the user to format the data to display amplitude in either logarithmic (dB) or linear units. Phase data or group delay can be displayed at the same time. Amplitude and phase of the reflected signal can be displayed on polar coordinates or as impedance on a Smith chart.

An optional feature has the CPU perform an inverse Fourier transform on the frequency-domain data. Time-domain data is very useful for locating points of high reflection (faults) along a transmission line or for determining the effects of undesired signal paths in a transmission measurement. For example, by using the time-domain feature, the user is able to identify the RF leakage and triple travel responses in the insertion loss measurement of a surface acoustic wave (SAW) device.

Several test sets have been designed for use with the HP 8753A analyzer, including an S-parameter test set, a transmission/reflection test set, and a broadband power splitter (for transmission measurements only). The test sets are offered for measurements in either 50 or 75 ohm environments. The entire system (analyzer and test set) can be operated under program control via the Hewlett-Packard Interface Bus (HP-IB).

The HP 8753A is priced under $24,000. For more information, circle INFO/CARD #160.

Acknowledgements

The author would like to thank Dave Sharrit, HP 8753A R&D manager, and Joel Dunsmore, R&D engineer, for their assistance.

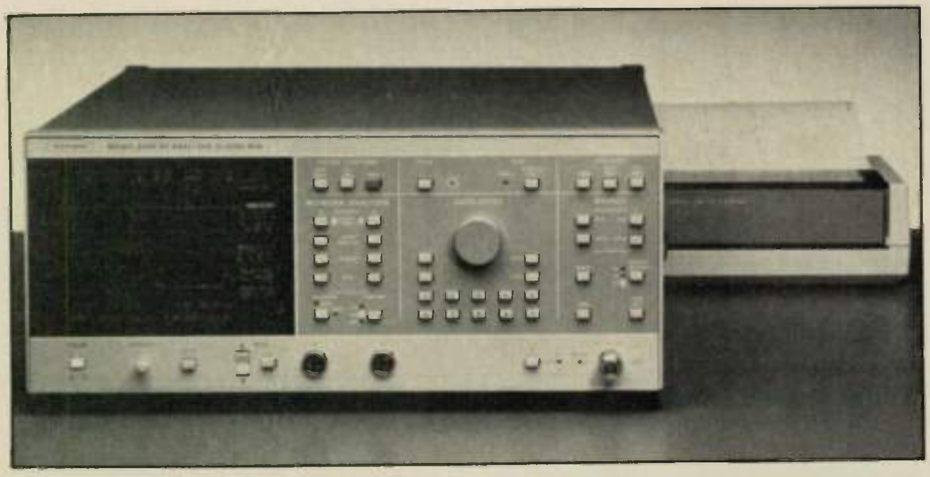
Reference

1. D. Danielson and S. Froseth, "A Synthesized Signal Source with Function Generator Capabilities," Hewlett-Packard Journal, January 1979.

About the Author

Tom Phillips is an applications engineer for RF vector network analyzers at HP's Network Measurements Division. He has a BSEE from the University of California, Berkeley and an MSEE from Cornell University.

The Wiltron 6400 Scalar RF Analyzers



By Robert Bathiany
Wiltron Company

A new family of RF analyzers from Wiltron offers improvements in price/performance ratio over previous RF measurement instruments. The Model 6407 (1-1000 MHz) and Model 6409 (10-2000 MHz) make use of thin film microelectronic technology and microprocessor enhancements to provide advanced operating and performance features. Each RF analyzer represents a measurement system containing a two channel scalar network analyzer which interfaces with a built-in signal source (Figure 1). The resident microprocessor adds operating convenience, automatic error correction, and hard copy output of measurement data.

The signal source

Traditionally, RF and microwave source users have been forced to choose between two technologies (and price levels) depending upon their requirements for frequency accuracy. At the low end, sweepers are low priced but seldom exceed a frequency accuracy of ±5 MHz, a real limitation to users requiring accurate frequencies for narrow band applications or for overall accuracy in testing.

At the other extreme, users have been able to choose an RF synthesizer with superb frequency accuracy but at a substantial price increase. Many users have selected an in-between approach, mixing frequency combs or fixed RF frequencies with the output of the sweeper to generate zero-beats or "birdie markers." These markers are displayed on the CRT along with the measurement data, while the user interpolates frequencies in between. Aside from being time consuming, this approach is error prone.

The 6400 uses the microprocessor to perform what used to be the drudgery of the operator. The processor monitors internal 25 MHz comb markers to accurately identify frequencies. Temperature drifts and non-linearities are virtually eliminated, CW frequency accuracy is ±100 kHz and drift with time or temperature is negligible. The measurement display is stable, and will be the same at turn on as when it was turned off the evening before. As a result of these techniques, the 6400 features 109 kHz frequency resolution, up to 8 frequency markers, and intelligent CRT graticule which identifies major frequency points along the sweep.

The RF chain represents microwave microelectronic technology applied to the RF measurement world (Figure 2). The heart of the unit is a 4.61 to 6.6 GHz YIG-tuned transistor oscillator. It is mixed with a 4.6 GHz fixed frequency local oscillator to produce a 10 to 2000 MHz output for the 6409. This signal is then amplified and leveled before leaving the down converter module. For the 6407 1 to 1000 MHz frequency range, the YIG-tuned oscillator stops at 5.6 GHz and narrower bandwidth amplifiers are used after the mixer.

Maximum leveled output power is specified at +12 dBm except when the optional 70 dB step attenuator is added. Output power is then +10 dBm. Harmonics are −30 dBc and spurious signals are −45 dBc.

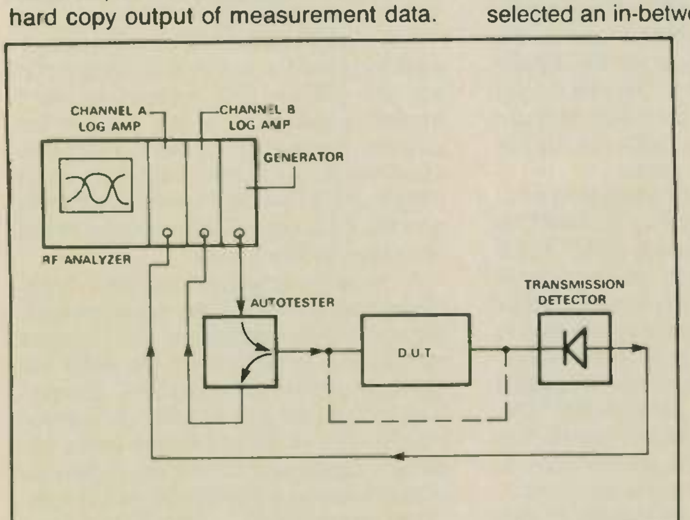


Figure 1. Typical measurement setup of a 2-channel RF analyzer system.

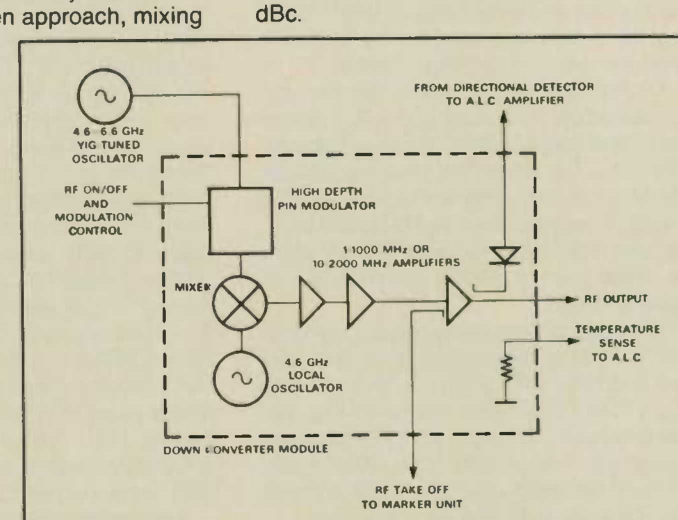


Figure 2. The 6400 RF section functional diagram. Internal 25 MHz markers are monitored by the microprocessor to eliminate drift.

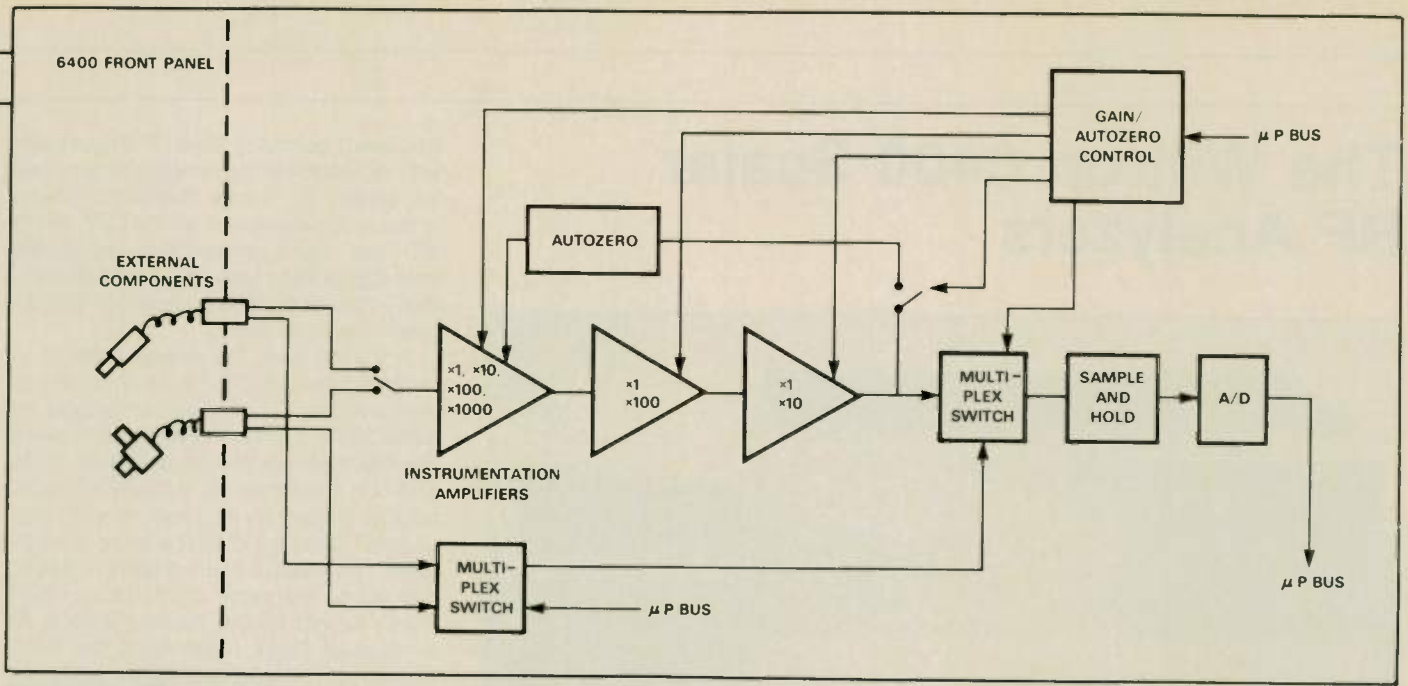


Figure 3. The 6400 signal analyzer channel. A/D conversion and digital processing eliminates analog compensating circuitry.

The Network Analyzer

The built-in two channel scalar network analyzer features 76 dB dynamic range with a low level sensitivity of −60 dBm. This specification is achieved using accurate low drift DC amplifiers which are automatically corrected for drift during retrace. The result is accurate, drift-free operation without the need for a modulated signal. The network analyzer signal channel is shown in Figure 3.

A single precision instrumentation amplifier multiplexes between the two inputs. The microprocessor then sets the gain of the amplifiers to optimize the signal at the sample and hold which will be digitized by the A/D converter. Logarithmic amplifiers and circuits that compensate for the square-law and linear response of detectors have been replaced by the accurate (and inexpensive) microprocessor.

Microprocessor control allows the unit to "autoscale" the resolution (dB/division) and offset (dB) to optimize data display on the CRT. The user can also manipulate the offset or resolution to meet his specific needs. In addition he can set limit lines — two per channel — for rapid identification of performance within predetermined specifications.

With vertical lines as frequency markers and horizontal lines as test limits, one may not need the CRT graticule at all. Pressing a front panel button removes the preset graticule allowing lines to be customized using markers and limits. With these customized limits, data can be interpreted and devices adjusted very quickly.

The SAVE/RECALL function saves time and reduces operating errors by storing and recalling up to nine complete front panel setups. Included in the stored data are marker frequencies, data limits, frequency range, and vertical scaling.

How about calibration? A scalar network analyzer must have a through-line 0 dB reference for transmission and a 0 dB return loss reference for reflection measurements. Once calibrated, the 6400 can be used over any frequency range, whether full band or a narrow 100 kHz sweep width. No recalibration for new sweep widths is required. In addition, calibration data is non-volatile, valid as long as the same measurement components (detectors and autotestors) are being used.

Additional Features

For hard copies of test results at the push of a button, the 6400 interfaces directly with dot matrix printers such as the Hewlett-Packard Thinkjet or the Epson MX-80 through a built-in parallel printer port. Either tabular or graphical data can be printed (Figure 4), with the choice made through a print menu.

For more extensive data handling or instrument control capability, the 6400 is available with an optional GPIB (IEEE 488) interface to control all front panel functions. In addition, a rapid data transfer can send complete measurement data to the controller in a matter of seconds. The bus address of the 6400 can be displayed at the push of a front panel button. Depressing the same button returns the 6400 from remote to the local mode unless local lockout has been activated.

Alternative sweep is available in two modes. The first allows two different frequency ranges to be swept while viewing the same signal input at different display scalings. This mode is ideal for a filter designer wishing to simultaneously view the passband in detail and the rejection band in high dynamic range. The other mode features two different frequency ranges with different network analyzer signal inputs. This feature is ideal for multiplexer analysis of two different output ports at different frequency ranges.

Self-test at instrument turn-on or from the front panel assures operating reliability. If a fault occurs, an explanation is displayed on the CRT rather than an error code. If the CRT circuit has failed, the information is available through the GPIB interface. Instrument operation is guided by CRT menus with a moving cursor. An up/down rocker switch moves the menu cursor and the adjacent "select" key activates the menu item.

Any of eight frequency markers can be selected as an active measurement cursor with dB or dBm readout for each measurement trace at the marker frequency. Frequency markers also allow identification of the frequency and magnitude of "glitches" in test responses, and the data readout of particular areas of measurement curves.

A network analyzer requires high-performance measurement components. Detectors and Autotesters (RF bridges with built-in detectors) for the 6400 are available with type N and BNC connectors, in both 50 and 75 ohm. Autotester directivity is 40 dB across the entire frequency range and the detectors feature ±0.5 dB flatness with 22 dB return loss.

The model 6407, 1-1000 MHz unit is priced at $9,430 and the Model 6409, 10-2000 MHz unit at $11,040. Delivery is 16 weeks. For more information, circle INFO/CARD #159. rf

rf design

needs a few good articles

RF Design is a forum where engineers share ideas. We need a few of *you*, our readers, to share your ideas and expertise on a few important subjects! Our authors are paid for their work, and enjoy the benefits of recognition among their peers. We don't need great writers, just good engineers who can communicate their ideas.

Here are a few of the subjects we would like your help to cover in *RF Design*.

RFI/EMI Corner
TEMPEST requirements
Non-ionizing radiation hazards
Spectrum management
Design techniques for EMC

Digital Connection
Digital/RF interfacing
Microprocessor controls
High-speed A/D & D/A conversion
GaAs digital applications

Designer's Notebook
Short notes on circuit design, computer programs, application of a device, or design hints.

Feature Articles
Surface-mount design
Spread-spectrum
High power diode switching
LF and VLF communications
Modulation & demodulation
Upgrading existing designs
New components
P.C. board design & layout
Receiver front-end design
Very high power amplifiers

This is only a small portion of the topics our readers need to know about. For more information, or to obtain an author's guide, call or write:

Gary A. Breed
Technical Editor
RF Design
6530 South Yosemite St.
Englewood, CO 80111
(303) 694-1522

Grounding Techniques to Reduce RFI Susceptibility

By Gary A. Breed
Technical Editor

It is a safe wager that everyone has experienced radio frequency interference (RFI) of one form or another. It may have been an FM radio overloaded by a police radio as the squad car passed by, a personal computer causing an AM radio to hear only bleeps and whistles, or a CB operator being picked up on a hi-fi system. These are certainly nuisances, but there are much more serious forms of RFI, too. Computer systems might have outside interference alter data, emergency communications can be disrupted, or laboratory research can be severely hampered.

These are not hypothetical situations; all of the problems noted have been personally witnessed by the author in 15 years as a broadcast engineer and 24 years as an amateur radio operator. What is an inconvenience to a private individual can be costly and dangerous to public or commercial facilities. Protection of these facilities from RFI starts with a properly designed and constructed master ground system.

A review of electromagnetic field theory reminds us of Gauss' Law and its derivative principles. The fundamental principle of shielding was proven by Gauss, who showed that a field will not penetrate a volume enclosed by a conducting surface. However, since no conductor is perfect, and since there are usually gaps which prevent the shield from being a continuous enclosure, leakage of external fields into any practical shielded enclosure will always exist to some degree.

A partial remedy to imperfect shielding is a reduction of the field intensity surrounding the circuitry by reducing the potential induced on the outer surface of the shielded enclosure. This can be done through grounding. Grounding can be defined as: *Reducing to zero the potential difference between objects in proximity to one another.* In practice, there are two components of a ground system: an "infinite" current sink (earth ground), and a low impedance path from equipment to the sink (ground connections).

Earth Grounds

The configuration of a good earth ground is a subject of some controversy among proponents of "deep" grounds and "wide" grounds. Deep grounding methods usually suggest a system of ground rods which are long enough to penetrate into soil that is permanently moist, and provide a low impedance path to this relatively high conductivity region. This concept has been well-established, and has survived for some time as the best method. The use of well casings, water supply pipes, and other underground utilities as all or part of a "deep" ground system has been recommended often for commercial or home earth grounds.

A development of recent research into lightning behavior is the "wide" ground system, which relies on a large number of ground connections over a very large area, with little concern over the depth. The principle of this technique is that localized current densities in lightning discharge situations are too high in "deep" grounds that do not have a large area over which to distribute the charge. Spreading the charge over a wide area reduces the concentrated current densities, reducing the possibility of damage.

For RFI protection, there appears to be no distinct advantage of either earth ground method. Practical considerations of available space, soil conditions, and installation convenience may dictate the type of system used at a given location.

Equipment Grounding Connections

There is only one rule to follow in connecting equipment to the earth ground: *Minimize the inductance (and impedance) of the connection.* As an example of this rule, consider a ground connection requiring 30 feet of #6 copper wire. DC resistance of the wire is .012 ohms, but it has an inductance of 10 μH, which results in 63 ohms reactance at 1 MHz. At 100 MHz, the connection might as well be an open circuit, or worse, could act as an antenna to increase RFI in the "grounded" unit!

Keeping in mind that inductance per unit length is approximately in inverse proportion to surface area, here is a list of some conductors that might be used in a ground connection, and their surface areas:

#6 Copper wire = 0.51 in²/in
#12 Copper wire = 0.25 in²/in
RG58A/U shield = 0.38 in²/in
1" Copper strap = 2.0 in²/in
2" Copper strap = 4.0 in²/in
4" Copper strap = 8.0 in²/in

From this list, it is clear that flat copper strap will provide lower reactance ground connections than even large-gauge wire.

The broadcast industry has long known of the low inductance properties of strap, with 2", 4" and even 6" wide strap used to interconnect equipment which must operate in the vicinity of multi-kilowatt transmitters. With the spread of many urban areas, it is not unusual for homes, offices and factories to be located adjacent to radio and television transmitter facilities which were once in rural areas. These facilities will experience the same severe RFI problems as exist within those broadcast stations, and will have to solve the RFI problems in a similar manner.

We hope this note will encourage those who experience troublesome RFI problems to attack the problem with some fundamental understanding of grounding techniques. Readers are encouraged to share their experiences and analysis of RFI difficulties by contacting the author at *RF Design*.

The Surface Acoustic Wave Filter: Window Functions

By Jeff Schoenwald
Contributing Editor

This article explains what window functions can do for surface acoustic wave (SAW) filter design and what they cannot do. Simply stated, the objective of the ideal window function is to eliminate the passband ripple and stopband sidelobes. Although it would be very nice, we will not require the ideal window to produce perfect transition skirts, i.e., having zero bandwidth. Practicality forces us to examine window functions that can only approach these objectives, and to compare the relative advantages and limitations of several of them.

In the last article on surface acoustic waves (August 1985, *RF Design*) the reader was introduced to the fundamental technique of weighting the electrodes of the SAW interdigital transducer (IDT) to obtain a rectangular bandpass response in the frequency domain. By examining a succession of sin(x)/x weighted transducers of increasing length, we observed the interplay of the stopband sidelobe level and passband ripple. The one characteristic that seemed to improve reliably was the sharpness of the band edge cutoff, increasing as the device lengthened. We call this the transition bandwidth, and it seems to vary in an inverse relationship with the length of the transducer. No matter how long the transducer gets, the first sidelobe will settle in near the −40 dB level, while the passband ripple only gets worse.

Remember that we took the Fourier transform of a rectangular transducer (one with uniform electrode overlap) and found the frequency response had a sin(x)/x behavior. The peaks of the successive frequency sidelobes trailed off at a rather leisurely pace. Truncating the transducer is equivalent to multiplying an infinitely long device by a finite length "window," which has a fixed "aperture," but is closed elsewhere. In fact, we may use the term "window" appropriately, because the window function determines how much of the impulse response we can "see," (William D. Stanley should be credited for this apt analogy.) It is natural, then, to expect that multiplication of any transducer by a rectangular window will impose its characteristics on the net frequency response. In mathematical jargon, the product of two or more window and weighting functions in one domain (frequency or time) corresponds to convolution in the other domain. Thus, when the desired frequency response is convolved with the Fourier transform of a rectangular window, the final frequency result will converge no better than that of the rectangular window.

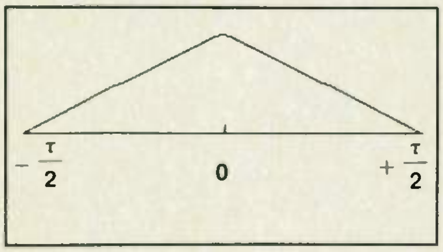


Figure 1a. Triangular window function

Clearly, a rectangular window, which has poor frequency convergence (has significant energy outside the passband) requires improvement. By looking at the results produced by sin(x)/x weighted IDTS truncated at successively increasing lengths, it becomes obvious that the addition of more lobes adds more energy back into the filter response just above and below the center frequency, squaring up the response. The first set of sidelobes, which are phase reversed with respect to the central lobe, appear to reduce the efficiency of the overall device at center frequency relative to the passband level just above and below band center, as seen in Figure 5d of the previous article. Truncating an IDT midway through a complete lobe will temper the ripple in the passband, but aggravate sidelobes in the stopband.

An additional degree of freedom that we can exercise is in tailoring the relative weighting of the sidelobes. The first reasonable deduction would be to taper the sin(x)/x weighting smoothly toward zero to suppress the effect of truncation. However, if the tapering is too severe, and tapers the strength of the main lobe in the time domain, then we will observe that the frequency passband broadens unacceptably, and we lose control of the filtering characteristics we wanted in the first place.

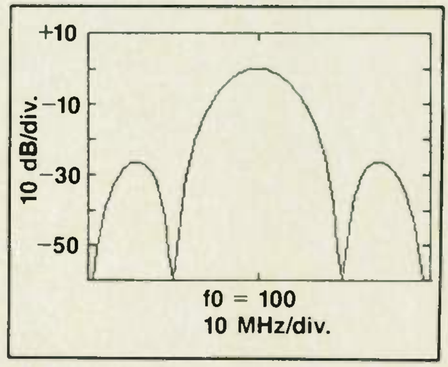


Figure 1b. Frequency response of an IDT (N = 40) with the triangular window in 1a.

Window Function Choices

In many texts on digital signal processing the frequency response of the window function is examined separately (1). Here, we will examine the effect of some windows on the frequency behavior of a single SAW interdigital transducer and make some observations about the relation between the properties of a window and its effect on a filter which is composed of two transducers. There are a number of window functions to choose from, including:

1) Rectangular
2) Triangular
3) Hanning
4) Hamming
5) Blackman
6) Gaussian
7) Kaiser
8) Dolph-Chebyshev

The first one, the rectangular window, is the trivial case. The triangular window is a linear taper from unity at the geometric center of the transducer to some value between unity and zero at the truncated ends, and is descriptive of windows that broaden bandwidths or degrade the sharpness of the transition skirt.

The Hanning, Hamming and Blackman windows consist of a constant plus one or more cosine terms (arranged symmetrically about the center of the transducer structure). They have simple, closed form expressions that allow for easy implementation, but they do have their penalties.

The Kaiser function is a ratio of two Bessell functions of the first kind, whose arguments contain a parameter that controls the details of the window and, therefore, of the frequency response.

The Gaussian window is appealing because the Fourier transform of a Gaussian is again a Gaussian. It can be expressed in simple closed form.

The Dolph-Chebyshev function is controlled by a parameter which is determined by the requirement for stopband sidelobe level. It is considered optimum in the sense that the main-lobe width is as small as possible for the specified sidelobe level.

We will only examine some of these window functions. For all the cases we shall examine, please note that the Greek letter τ (tau) refers to the length of the transducer, in units of time.

Triangular Window

The triangular window function (Figure 1a) is:

$$W(t) = 1 - \frac{2|t|}{\tau}, \text{ when } |t| \leqslant \frac{\tau}{2} \quad (1)$$

$$W(t) = 0 \text{ elsewhere}$$

τ is the total time length of the window, centered around $\tau = 0$. We may describe the weighting effect this has on the apodization of a previously unwindowed IDT by expressing time in terms of the number of half wavelengths (i.e., the electrode spacing) from the center of the transducer to the edge. For convenience, if we assume an IDT of (2N + 1) electrodes, with the center one as n = 0, then the IDT is N wavelengths long. The equivalent expression for equation (1) is then:

$$W(n) = 1 - \frac{|n|}{N}, \text{ where } |n| \leqslant N$$

$$W(n) = 0 \text{ elsewhere} \quad (2)$$

Taking the Fourier transform of equation (1), we get:

$$W(f) = \frac{\tau}{2}\left[\frac{\sin\left(\frac{\pi f \tau}{2}\right)}{\frac{\pi f \tau}{2}}\right]^2 \quad (3)$$

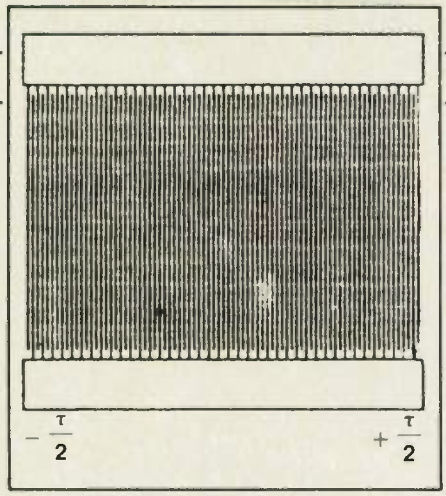


Figure 2a. An unweighted IDT (N = 40)

Note the following:

1) The triangle function is always positive. By itself, it will never induce phase reversal in the IDT pattern. As has been pointed out such tapering has the effect of broadening the 3 dB bandwidth relative to that of a rectangular IDT pattern. Furthermore, nulls, or zero values of the amplitude occur when the sine function is zero, except for f = 0, when the limiting value of A(f = 0) is unity. Thus nulls occur when:

$$f = 2m/\tau, \ m = 1, 2, 3, \ldots \quad (4)$$

2) A rectangular IDT of length (N) wavelengths will have nulls at:

$$f = m'/\tau, \ m' = 1, 2, 3, \ldots \quad (5)$$

or twice as often as the triangular window.

3) We have not modulated the triangular window function by the sign reversal that occurs between adjacent electrodes. Remember that adjacent electrodes have opposite polarity by connection to two buss bars (wire bonding pads) which are excited by a biphase voltage. To do this, we only have to replace f by $f - f_o$, or the distance from the synchronous (center) frequency of the transducer. (In this context, f by itself is the offset frequency from the passband center.) Figure 1b shows the frequency response of an IDT with a triangular window.

In the examples to follow, we will always illustrate the case for which the original, unweighted, IDT is 40 wavelengths long (N = 40), designed for operation at 100 MHz. Thus, the nominal 3 dB bandwidth is 100 MHz/40, or 2.5% fractional bandwidth, with the first null occuring at 100 +/− 2.5 MHz. Figure 2a is the original unweighted IDT. Its frequency response is shown in Figure 2b, and for completeness, the rectangular window is shown in Figure 2c.

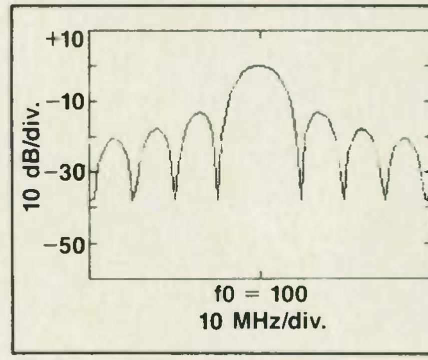


Figure 2b. Frequency response of a single unweighted IDT (N=40)

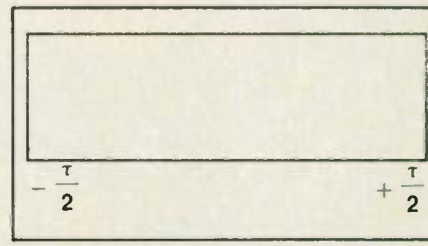


Figure 2c. Window function of an unweighted IDT

For all subsequent illustrations we will design for a sin(x)/x apodized transducer with a desired bandwidth of 2.5% at the 3 dB points. As a consequence, the length of the transducer becomes a variable parameter. For the sake of consistency, all examples will be for transducers 240 wavelengths long, to produce a fairly square response. This way, when comparing the effects of different windows, we will keep all other parameters fixed. We also choose the convention of examining a single IDT to simplify the tutorial objective of this article. In practice, it is the filter response that is specified, not that of a single IDT. There have been design cases where the response of each transducer is synthesized separately to enhance the net (passband, skirt and stopband) performance of the total filter. The reader will easily see how to modify his/her design strategy for the total filter response.

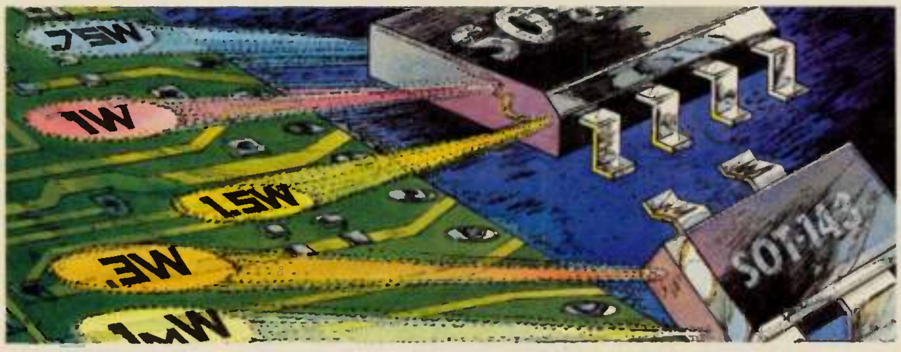
Hanning, Hamming and Blackman Windows

We will treat the next three window functions as a group, because they all consist of a truncated series of cosine functions, with coefficients determining the relative weight of each term.

The **Hanning window** is just a cosine-squared function:

$$W(t) = \cos^2\left(\frac{\pi t}{\tau}\right) = \frac{1}{2}\left[1 + \cos\frac{2\pi t}{\tau}\right]$$

Motorola RF Design News



Take your choice of surface-mount power.

Superb 8 GHz performer even more so in SOT-143.

None finer and now in SOT-143. It's the popular MRF571 and it's now MRF5711 in 4-leaded SMD for reduced common-element inductance and higher gain.

Leading-edge die technology, identical to its MACRO-X counterparts, provides 1.7 dB NF and 12 dB gain at 1 GHz.

Available in standard and low profile, this high-performer is ideal for high-gain, low-noise, small signal amplifiers: satellite TV receivers (TVRO), wide dynamic range front end amplifiers and low-noise VCOs. Plus instrumentation applications where high-gain to high-frequencies are required, or in fast switching designs. $1.00, 100-up. Samples now.

Your best resolution—RF CRT drivers.

NPN/PNP symmetry, f_T more than 1 GHz, $V_{(BR)CBO}$ greater than 100 V and common-emitter or common-base characterization make the MRF542-549 units ideal for high-resolution color monitors.

They offer low output capacitance to aid wideband amplifier design and emitter ballasting for ruggedness.

The medium-powered TO-39 units are common-emitter characterized. The low-cost, PowerMacro and up-to-800 mA TO-117 types are common-base. By assembling the SOB parts with two base leads, you can apply them in voltage gain and signal transfer circuits in the preferred common-base amplifier configuration.

Prices start at only $2.90, 100-up.

900 MHz SO-8 grabs 1 W honors.

Providing 1 W and more P_D, equal to or exceeding that of MACRO-X and SOE packaging, the MRF8372 is the SMD version of the popular, 6 GHz f_T MRF837 used in wideband, large-signal, pre-driver, 900 MHz, land-mobile stages.

No sacrifices in technology: 2-micron geometry, gold top metal, ion-implanted emitters and silicon nitride passivation.

Typical performance is 10 dB gain at 870 MHz, 12.5 V, in a broadband circuit delivering 3/4 W RF power with 60% efficiency. It's also characterized at 7.5 V and at 512 MHz.

Little price, too: $1.65, 1K-up.

600 W, MRF430 bipolar unit not for the timid.

At 600 W P_{out}, the MRF430 is the most powerful bipolar RF transistor of its kind. It's for those who want to have it all in one potent package without water-cooling for linear amplifiers from 2 to 30 MHz, base station equipment, nuclear magnetic resonance, sputtering equipment or in 1 KW SSB amplifiers.

You replace up to eight lower-powered units plus associated parts and circuitry.

Low, 0.2° C/W thermal resistance keeps die temperature cooler for a given P_D, improving reliability and allowing direct, heat sink mounting. It's basically four MRF429s in a single package with all the ruggedness and low IMD of the '429.

And 50-up is only $315—30% less than MOSFETs.

GHz gain, miniscule drain.

Operating at less than 1 mA I_C with a V_{CC} of only 1 V, the MRF9331 offers 13 dB typical gain at 1 GHz and 2 dB NF at 500 MHz in SOT-143. A single emitter finger of a 1.25 micron die design achieves state-of-the-RF-art, 6 GHz f_T.

Applications are pagers, portable radios, hearing aids, remote controlled door openers and any equipment operating on batteries you want to last. Wide dynamic range is possible with 100 μA to 2 mA I_C.

And SOT-143s provide dual emitters for best performance in common emitter configurations.

Price: just $1.50, 1K-up.

One-on-one design-in help.

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

1-800-521-6274

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

We're on your design-in team.

MOTOROLA

To: Motorola Semiconductor Products, Inc.
P.O. Box 20912, Phoenix, AZ 85036

Please send me the latest information on these Motorola RF Semiconductors: ☐ MRF430 ☐ MRF8372 ☐ MRF542-549 ☐ MRF5711 ☐ MRF9331

26RFD030086

Name ____________________

Title ____________________

Company ____________________

Address ____________________

City ____________ State ____________ Zip ____________

Call me (______) ____________________

INFO/CARD 26

is the nearly imperceptable broadening of the passband and slower roll-off in the transition region. This very often makes the Dolph-Chebyshev window the one of choice. (The Kaiser window also shares some of the same flexibility in design, but will not be discussed here.)

Summary

It is now clear that window function techniques can improve the performance of a symmetric SAW passband filter. A variety of window types are available, and have been presented here for comparison. Some are quite simple, others more involved. All have the same basic features: The time domain sidelobes are always tapered in such a way as to fool nature into thinking the IDT is infinite, in order to suppress frequency sidelobes below what results for a truncated sine function without a window. The price paid is the more gradual transition bandwidth roll-off. Passband ripple is another feature that benefits from windowing. It is possible to reduce or eliminate those unsightly Gibbs phenomena ripples at the passband edge of sharp cut-off filters.

The filters discussed here are all symmetrical, in the time domain about the center of the IDT, and in the frequency domain about the center frequency. This symmetry corresponds to a linear change in phase with frequency across the passband. Another class of SAW filters is the linear FM chirp, where the periodicity of the IDT fingers varies in such a manner that the local center frequency changes linearly with distance from one end of the IDT to the other. The phase response of one of these IDTs is decidedly nonlinear. Interesting games can be played by designing two IDTs with up-chirp or down-chirp electrode patterns and feeding swept frequency signals into filters consisting of combinations of up- and down-chirped IDTs. That will be the subject of another article. rf

References

1. William D. Stanley, "Digital Signal Processing," Reston, VA: Reston Publishing, 1975.

2) Charles E. Cook and Marvin Bernfeld, "Radar Signals," New York: Academic Press, 1967.

Figure 3a. Hanning window.

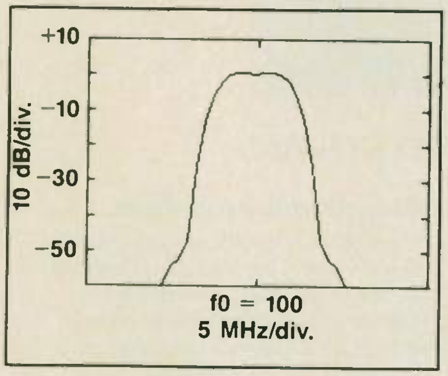


Figure 3b. Frequency response for 2.5% bandwidth IDT with Hanning window.

where $|t| \leq \tau/2$ (6)

and $h(t) = 0$ elsewhere

In terms of the electrode index number this becomes:

$$W(n) = \cos^2\left(\frac{\pi n}{2N}\right) = \frac{1}{2}\left(1 + \cos\frac{\pi n}{N}\right)$$

where $|n| \leq N$ (7)

and $W(n) = 0$ elsewhere

The window function is shown in Figure 3a. The frequency response of this window applied to an IDT is shown in Figure 3b. Note the usual broadening in the pass bandwidth.

The **Hamming window** is a simple extension of the Hanning:

$$W(t) = 0.54 + 0.46\cos\left(\frac{2\pi t}{\tau}\right); \quad (8)$$

where $|t| \leq \tau/2$

and $W(t) = 0$ elsewhere

Again, in terms of the electrode index:

$$W(n) = 0.54 + 0.46\cos\left(\frac{\pi n}{N}\right);$$

where $|n| \leq N$ (9)

and $W(n) = 0$ elsewhere

The effect of a Hamming window on an unweighted IDT is shown in Figure 4b. The advantage of this function is suppression of the first stopband sidelobe below −43 dB. The drawback is the broadening of the 3 dB bandwidth. The Hamming window is shown in Figure 4a.

The **Blackman window** is a further refinement beyond the Hamming window. It is given by the series:

$$W(t) = 0.42 + 0.5\cos\left(\frac{2\pi t}{\tau}\right) + 0.08\cos\left(\frac{4\pi t}{\tau}\right)$$

where $|t| \leq \tau/2$ (10)

$$W(n) = 0.42 + 0.5\cos\left(\frac{\pi n}{N}\right) + 0.08\cos\left(\frac{2\pi n}{N}\right)$$

where $|n| \leq N$

$W(t)$, $W(n) = 0$ elsewhere

This window, shown in Figure 5a, with its judicious choice of constants, reduces the sidelobe level below −80 dB relative to the main lobe (in a single IDT!), but triples the width of the passband of rectangular, unweighted IDT. Figure 5b shows the effect of this window on our sin(x)/x apodized IDT.

Gaussian Window

This window is interesting for the following reason: The Fourier transform of a Gaussian function is a Gaussian function. Therefore, a simple unapodized IDT weighted by a Gaussian window will produce a transducer with a Gaussian amplitude response. It is a relatively simple window/apodization to implement. It has properties that distinguish it from all other windows. The only two parameters that are needed for its design (apart from center frequency) are the normal distribution ("standard deviation") and the length of the IDT. Both parameters are given in wavelengths, as R and N. This window may be expressed as:

$$W(t) = e^{-\left(\frac{t}{t_o}\right)^2}$$

where $|t| \leq \tau/2$ (11)

and $t_o = \dfrac{R_o}{f_o}$

and $W(t) = 0$ elsewhere

Once more, in terms of the electrode index:

$$W(t) = e^{-\left(\frac{n}{R}\right)^2}$$

where $|n| \leq N_2$ (12)

and $W(t) = 0$ elsewhere

Another property that distinguishes it is that the sidelobe level of the frequency response continues to decrease as the ratio N/R increases, as the IDT gets longer relative to the spreading parameter R. This is not a general property of other windows.

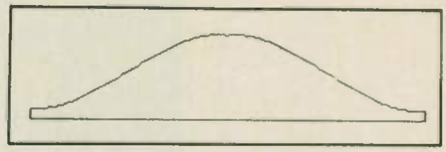


Figure 4a. Hamming window

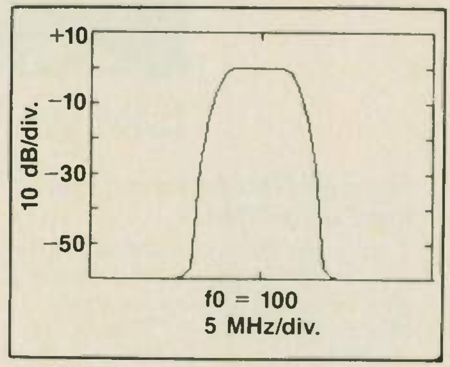


Figure 4b. Frequency response of sine(x) IDT with a Hamming window

Of course, there is a trade-off: The Gaussian window, applied to an unweighted IDT, produces a Gaussian response; it does not have a sharp band edge cutoff. We diverge momentarily from our pattern of windowing a 240 wavelength sine IDT to illustrate these properties. The Fourier transform of equation (11), when we let τ go to infinity, yields:

$$W(f) = \frac{\sqrt{\pi}R}{2f_o}\, e^{-\left(\frac{\pi R\,(f-f_o)}{f_o}\right)^2} \quad (13)$$

This is what was meant by the Fourier transform of a Gaussian function producing another Gaussian function. Strictly speaking, a true Gaussian extends to ± infinity in its variable. When we truncate the function to finite length, in effect we are multiplying a rectangular function times a Gaussian. In the transformed domain (in this case frequency) the result is the convolution of a Gaussian function and a sine function. After thinking about this for a moment, it seems natural to expect that the result of this procedure (truncation) will result in a frequency domain behavior in which sidelobes occur in some relation to the length of the rectangular window.

The set of frequency responses shown in Figure 6 correspond to a set of successive transducers in which the parameter R is always set equal to 40, with the length of the transducer N = 60, 80, 100. R is the parameter which determines the bandwidth of the filter, but the definition of bandwidth is different for a Gaussian passband. A perfect Gaussian response (which implies a transducer of

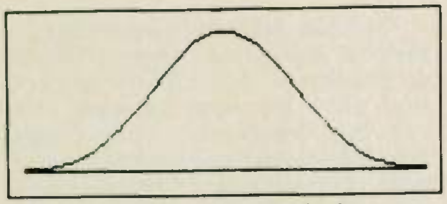


Figure 5a. Blackman window

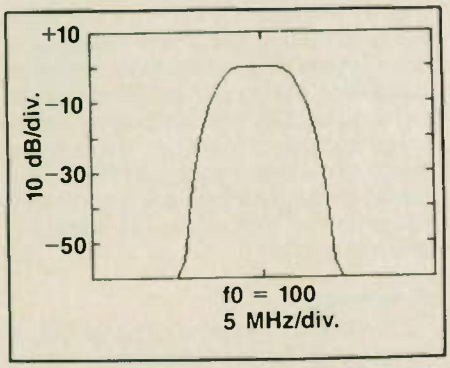


Figure 5b. 2.5% bandwidth sine apodized IDT with Blackman window.

infinite length) has a 1/e decrement in amplitude and power at:

$$f = f_o\left(1 \pm \frac{1}{\pi R}\right) \quad (14)$$

The bandwidth, then, is given as

$$\Delta f_e = \frac{2f_o}{\pi R} \quad (15)$$

and is not the 3 dB bandwidth. The 3 dB bandwidth is defined for the single transducer amplitude as:

$$BW_{3dB}\ \text{amp} = \frac{f_o}{\pi R}\ \ln 2 \quad (16)$$

and for the single transducer power as:

$$BW_{3dB}\ \text{pwr} = \frac{f_o}{2\pi R}\ \ln 2 \quad (17)$$

and for the two IDT amplitude and power response the 3 dB bandwidths are half of those quoted for the single transducers.

Filters designed this way can have very smooth properties and are easy to specify. Unfortunately, they do not have a flat bandwidth and fall off rather slowly for many critical applications. Of course, it is always possible to apply a Gaussian window to a sine apodization. The rule of thumb in this case is that we may expect the filter to look (1) Gaussian-like when the Gaussian parameter R is larger than the sine bandwidth parameter f_o/B, (2) rectangular when R is smaller, and (3) a blend of the two when the parameters are comparable.

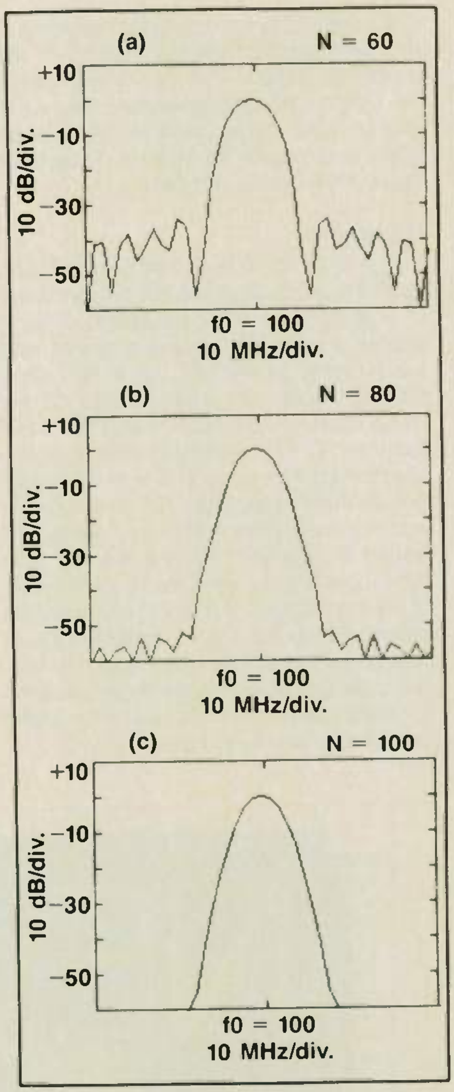


Figure 6. Gaussian filters, R = 40. (a) N = 60, (b) N = 80, (c) N = 100.

Dolph-Chebyshev Window

This window function is optimum in the sense that the passband width has a minimum tendency to expand beyond the design parameter for a given sidelobe level. The specification is stated this way: For a given sidelobe level, we can predict by what percentage the passband will grow relative to the theoretical value of an infinite sine apodized transducer without a window function.

We will not go into the details of this calculation, since Cook and Bernfeld give an excellent discussion(2). Figure 7 is an example of a 2.5% design bandwidth IDT with a Dolph-Chebyshev window successively specified at 35, 40, 45 and 50 dB in power per IDT. The striking feature about this series of predicted responses

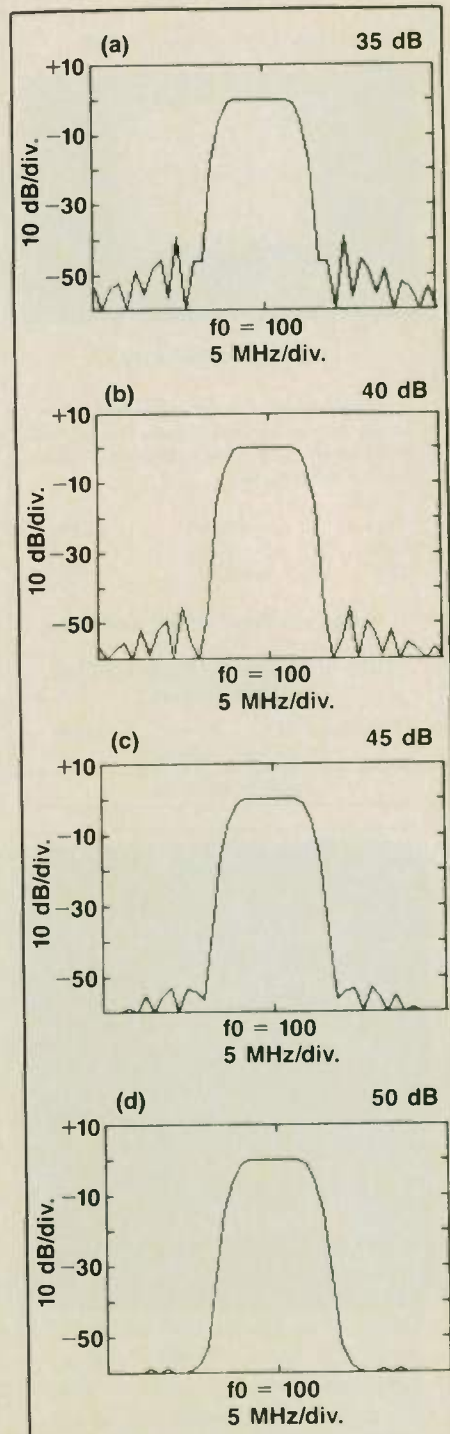


Figure 7. 2.5% bandwidth sine apodized IDT frequency response with Dolph-Chebyshev weighting. (a)-(d) IDT sidelobe level set at 35, 40, 45 and 50 dB.

is the nearly imperceptable broadening of the passband and slower roll-off in the transition region. This very often makes the Dolph-Chebyshev window the one of choice. (The Kaiser window also shares some of the same flexibility in design, but will not be discussed here.)

Summary

It is now clear that window function techniques can improve the performance of a symmetric SAW passband filter. A variety of window types are available, and have been presented here for comparison. Some are quite simple, others more involved. All have the same basic features: The time domain sidelobes are always tapered in such a way as to fool nature into thinking the IDT is infinite, in order to suppress frequency sidelobes below what results for a truncated sine function without a window. The price paid is the more gradual transition bandwidth roll-off. Passband ripple is another feature that benefits from windowing. It is possible to reduce or eliminate those unsightly Gibbs phenomena ripples at the passband edge of sharp cut-off filters.

The filters discussed here are all symmetrical, in the time domain about the center of the IDT, and in the frequency domain about the center frequency. This symmetry corresponds to a linear change in phase with frequency across the passband. Another class of SAW filters is the linear FM chirp, where the periodicity of the IDT fingers varies in such a manner that the local center frequency changes linearly with distance from one end of the IDT to the other. The phase response of one of these IDTs is decidedly nonlinear. Interesting games can be played by designing two IDTs with up-chirp or down-chirp electrode patterns and feeding swept frequency signals into filters consisting of combinations of up- and down-chirped IDTs. That will be the subject of another article. rf

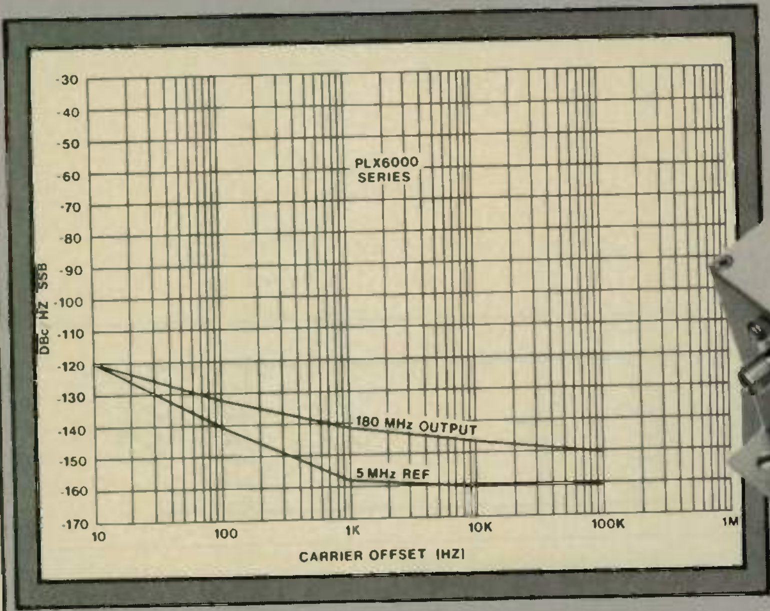
References

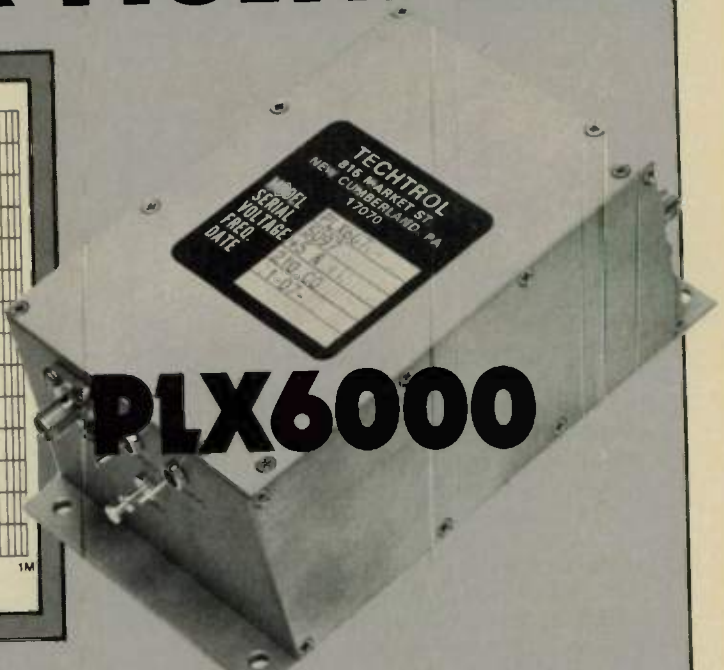
1. William D. Stanley, "Digital Signal Processing," Reston, VA: Reston Publishing, 1975.

2) Charles E. Cook and Marvin Bernfeld, "Radar Signals," New York: Academic Press, 1967.

NEW PRODUCT

LOW NOISE SYNTHESIZER-MULTIPLIER





PLX6000

The PLX6000 series provides low noise multiplication by application of digital and analog synthesis techniques. This method provides an output signal with the lowest possible noise.

FEATURES:

- **Low Noise Degradation**
- **Programable Loop Bandwidth**
- **Integer or Fractional Multiplication**
- **Single or Multiple Frequency**

TCI

THE SOURCE SOURCE

Techtrol Cyclonetics Inc.

815 Market Street New Cumberland, Pennsylvania 17070

(717) 774-2746

INFO/CARD 28

Simple Bandpass Filters

A Review of Fundamentals and a BASIC Design Program

By Alex J. Burwasser,
Electronics Engineer Consultant, and
Earl F. Bossaller Jr.,
RF Products

Simple bandpass filters have been employed by RF design engineers since the beginning of radio. In those early days, the absence of modern filter design models forced designers to use an approach that was intuitive and straightforward. Although simple bandpass filters might seem crude and unsophisticated compared to the filters that can be designed using today's models, the simple bandpass filter is still a powerful building block for many design requirements. Yet many of today's RF engineers have only a fleeting acquaintance with this family of circuits, and therefore fail to use simple bandpass filters to their full potential.

This article reviews the fundamentals of simple bandpass filters and their implementation, and describes a user-interactive BASIC program to simplify and accelerate the design process for the RF design engineer, whatever his level of experience.

Obviously, the simplest LC bandpass filter is a series or parallel resonant tuned circuit. We might also consider the 14 impedance transformation networks discussed in reference (1) as simple bandpass filters. For the purpose of this article, we will define simple bandpass filters as any pair of *coupled resonant circuits.* The configuration most familiar to designers is two top-coupled identical parallel resonant tanks (Figure 1).

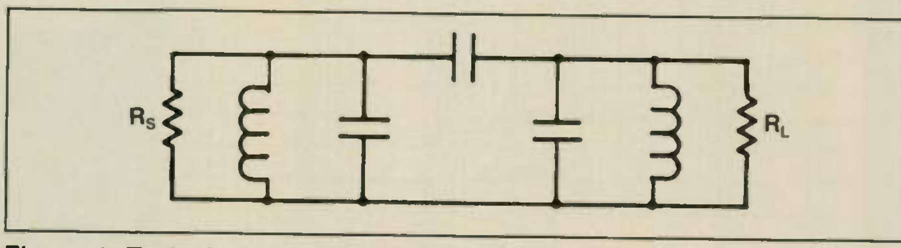


Figure 1. Typical simple bandpass filter.

The frequency response of the filter of Figure 1 depends upon the resonant circuit Q and the coefficient of coupling K. When the product of K and Q is less than unity, circuits are said to be *under-coupled.* This results in a non-dissipative mismatch loss at all frequencies, including the peak amplitude center frequency. If the KQ product is increased to unity, the resonant circuits are said to be *critically-coupled,* and the filter will be lossless at the peak-amplitude frequency only. If the KQ product exceeds unity, the circuits are said to be *over-coupled,* and there will be two frequencies at which the filter will be lossless (the familiar double-peaked response characteristic). These responses are shown in Figure 2. Higher values of KQ will result in even more pronounced peaks. By the appropriate selection of K and Q, the designer has considerable latitude to influence the filter passband characteristics.

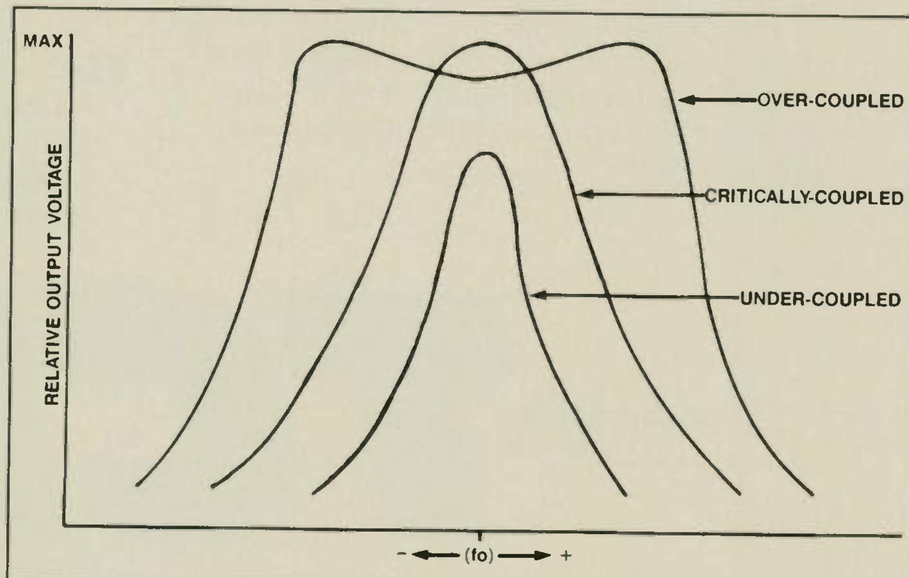
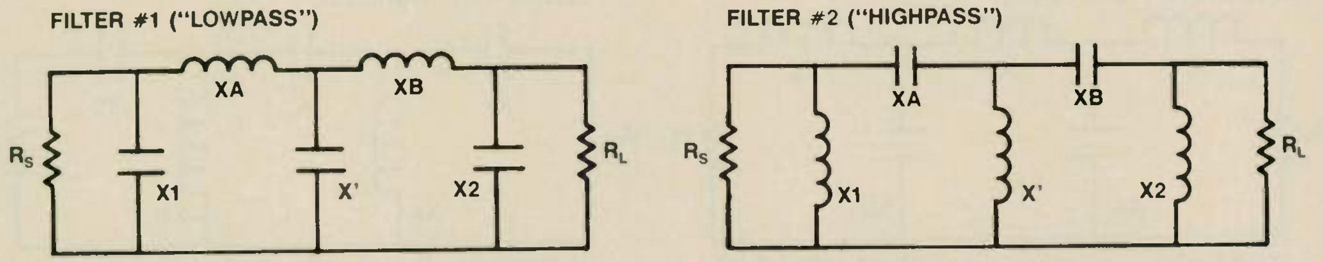


Figure 2. Curves illustrating effects of degree of coupling on simple bandpass filter response.



X1=−RS/Q
X2=−RL/Q
X'=−K•$\sqrt{X1•X2}$
XA=−X1−X'

"HIGHPASS" VALUES ARE NEGATIVES OF CORRESPONDING "LOWPASS" VALUES

Figure 3. Coupled standard PI network simple bandpass filters.

Simple Bandpass Filter Configurations

Most references discuss the simple bandpass filters of Figure 1 plus two or three other common configurations and provide design equations for equal termination resistances. However, there are many more ways that these filters can be realized. First, the filter in Figure 1 employs capacitive top-coupling with equal termination resistances, but an inductive coupling element, bottom-coupling, series resonant circuits or unequal termination resistances could be employed.

Figures 3 through 10 illustrate 16 more simple bandpass filter configurations and their respective design equations. These configurations were derived from equations for coupled *three-reactance impedance transformation networks,* using standard conventions for K and Q. These are the same networks described in reference (1). For example, bandpass filters #1 and #2 (Figure 3) are coupled pairs of standard Pi networks. The other bandpass filters are simply couped pairs of mixed Pi, standard Tee, mixed Tee, series enhanced-Q, L, or shunt enhanced Q L impedance transformation networks. Using these networks, it is a simple matter to incorporate impedance transformation in the filter synthesis algorithms, easily accommodating unequal termination resistances.

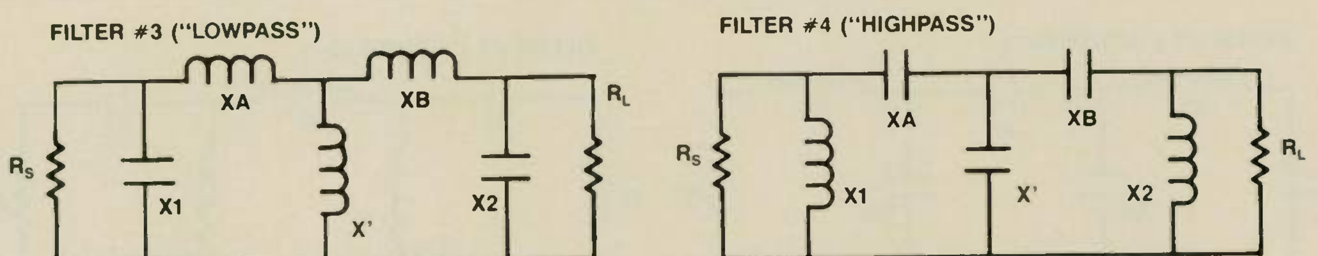
In order to use these equations, the designer must select the filter source resistance (RS), load resistance (RL), K and Q. Although source and load resistances can be different, their selection limits the maximum value of K. This limitation can be expressed as:

$$K(max) = \sqrt{RS/RL}$$

where RS < RL. (This will seldom be a practical limitation.)

Notice that the filter equations provide the element reactance values with positive and negative values indicating inductance or capacitance. Reactance values can then be converted to specific component values for the desired center frequency.

With so many filters to select from, what should the selection criteria be? For a given value of K and Q, the passband responses of the 16 different filters will be very similar, but the stopband responses can differ greatly. Filter #1, for example, is an all-pole network and therefore provides an excellent lowpass characteristic above resonance. This filter might therefore be considered where harmonic suppression is a major design goal. In addition to stopband response, another selection criterion should be component realization. It often happens that a particular filter selection results in component values that are impractical at the frequency of interest. A different filter configuration can result in more practical component values. Of course, flexibility in the selection of the termination resistances can also help mitigate this problem. In any case, a large number of available filter configurations should allow the designer to reach a satisfactory compromise between stopband response and component values.



X1=−RS/Q
X2=−RL/Q
X'=K•$\sqrt{X1•X2}$
XA=−X1−X'
XB=−X'−X2

"HIGHPASS" VALUES ARE NEGATIVES OF CORRESPONDING "LOWPASS" VALUES

Figure 4. Coupled mixed PI network simple bandpass filters.

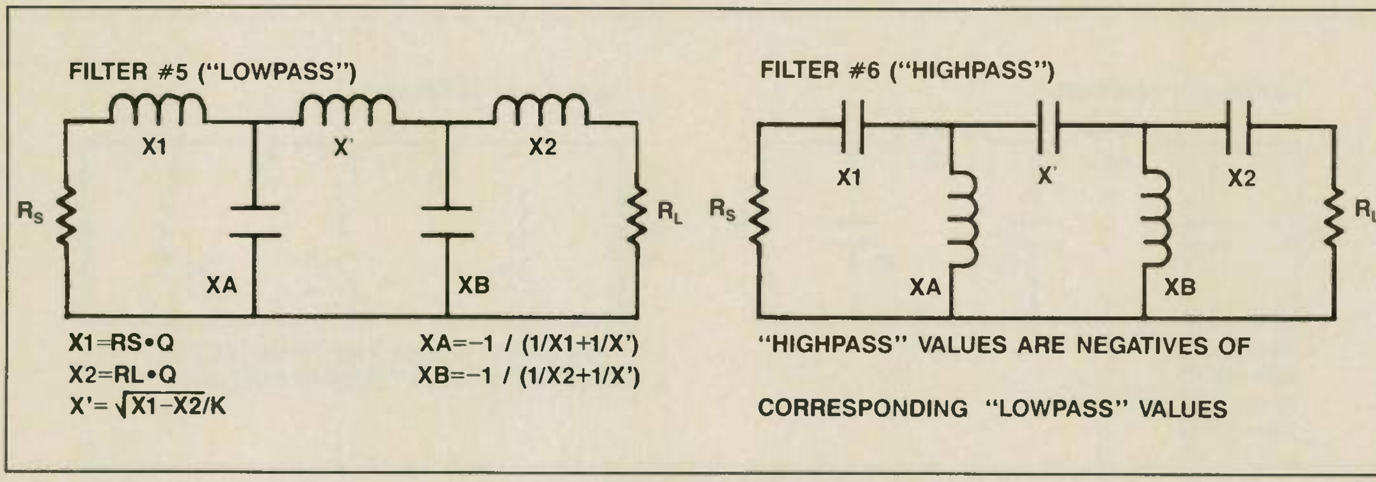


Figure 5. Coupled standard TEE network simple bandpass filters.

Using the Basic Program

With the help of the BASIC program offered with this article, the filter synthesis process can be easy and rapid. The program accepts user inputs for source/load termination resistances, K, Q, and center frequency, and can display any one of the 16 filters along with element reactance and component values. Since the user can select any of the 16 filters, it is a simple matter to scan the results to determine the most suitable configuration. The user can also select a printout of the input data and any or all of the 16 filters and their element values. Input data can be easily modified if the user desires to change parameters. A sample CRT display from the synthesis program is shown in Figure 11. The program is written in IBM PC-compatible BASIC, although the commands are as "generic" as possible for the program to run in most versions of microcomputer BASIC with little or no modification.

A copy of the program is available from the authors (see note at the end of this article).

Simple bandpass filters have some serious limitations that the designer must recognize and take into account. One shortcoming is that the designer must select K and Q values rather than bandwidth. This requires the designer to infer the bandwidth from the K and Q values. This is quite possible to do, but is far less straightforward than the remainder of the filter synthesis procedure.

This difficulty can be overcome by graphical techniques. Figure 12 is a reproduction of a graph for this purpose from reference (2). The use of this graph is best explained by example. Suppose that we wish to design a simple bandpass filter with a center frequency of 50 MHz and a 3 dB bandwidth of 5 MHz. First, select one of the five curves corresponding to simple bandpass filter frequency response using desired bandpass ripple as the criterion. If we can live with .5 dB of ripple, we select the curve labelled "P=2," which means that if the product of K squared and Q squared is 2, the passband ripple will be .5 dB. Next, find the point where this curve is down 3 dB from the peak value (on the vertical axis), and find the corresponding value on the horizontal axis. This value is close to 1.95, and represents the quantity:

$$Q \times \frac{(bw)}{f_o} = 1.95,$$

$$Q \times 5/50 = 1.95$$

Solving the equation for Q, we find that we need a Q of 19.5. Since:

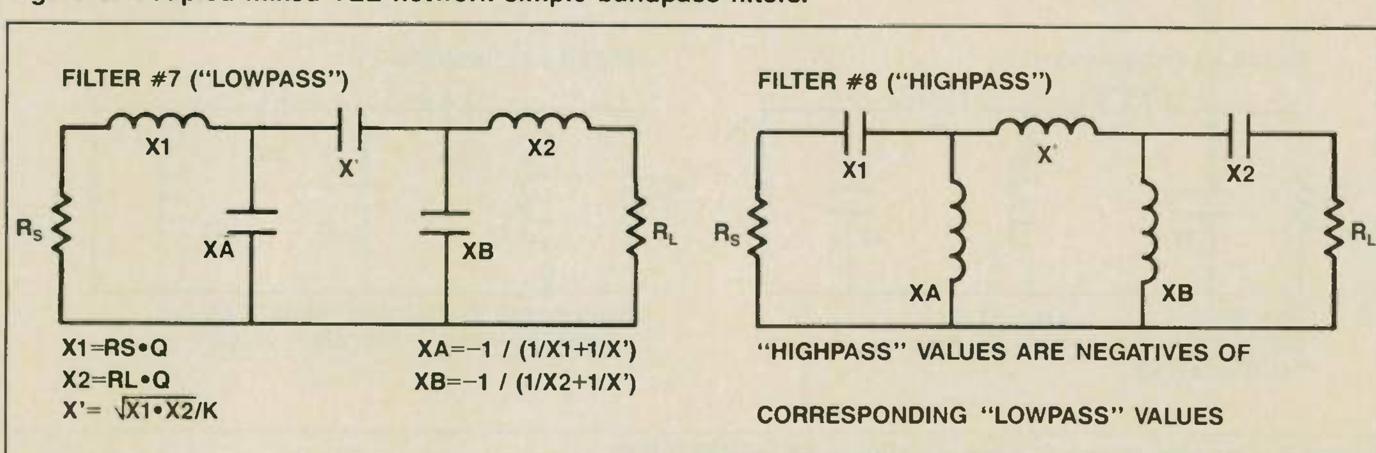
$$p = K^2 \times Q^2 = 2,$$

then $K \times Q = 1.414$, and

$$K = 1.414/Q, = 1.414/19.5 = .073.$$

To synthesize this filter then, we enter K as .073, Q as 19.5, and 50 MHz as the center frequency. The resulting passband characteristics for all 16 filters will be very

Figure 6. Coupled mixed TEE network simple bandpass filters.



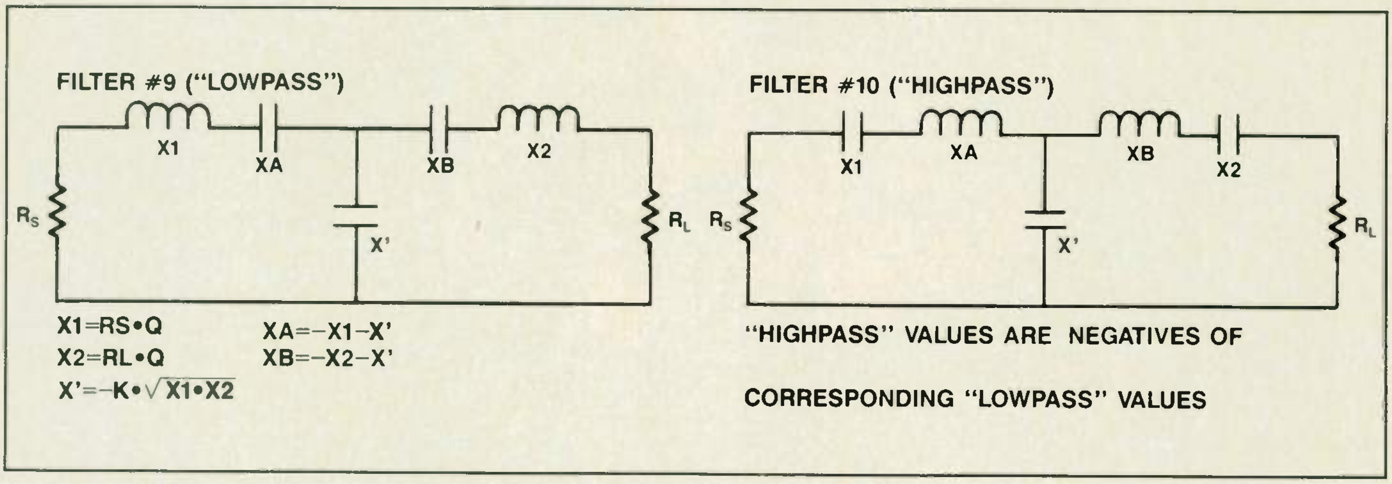


Figure 7. Coupled series enhanced-QL network simple bandpass filters.

similar to that predicted by Figure 12. Although Figure 12 also illustrates response characteristics outside the filter passband, they are not accurate for many of the 16 filters presented here.

Rather than use 3 dB down as the bandwidth criterion, any reasonable criterion can be used. For example, to use ripple bandwidth (0.5 dB) as the bandwidth criterion rather than the 3 dB bandwidth used in the above example, the required value as read from the horizontal axis would be 1.4 rather than 1.95, resulting in a Q of 14 and a K of .101.

Reference (2) also provides curves to estimate the stop-band response of simple bandpass filters, but they also are not applicable to many of the filters described here. In any case, a filter analysis program is the most appropriate tool for this task.

This leads us into another weakness of simple bandpass filters. With only two sections, these filters do not always yield adequate rejection in the stopband. Although more sections can be added, this moves us away from simple bandpass filter theory into more complex filter design models. Simple bandpass filters can be cascaded if they are isolated by an amplifier or other device (feasible in many instances), but this technique will increase the overall passband ripple. It may be necessary to design the individual sections for less ripple.

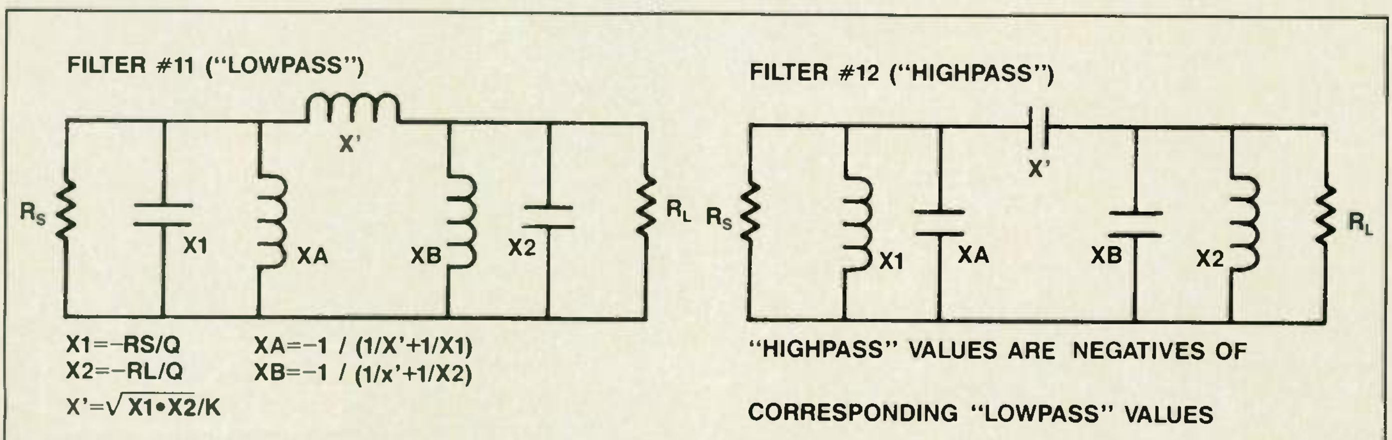
Impedance Transformations

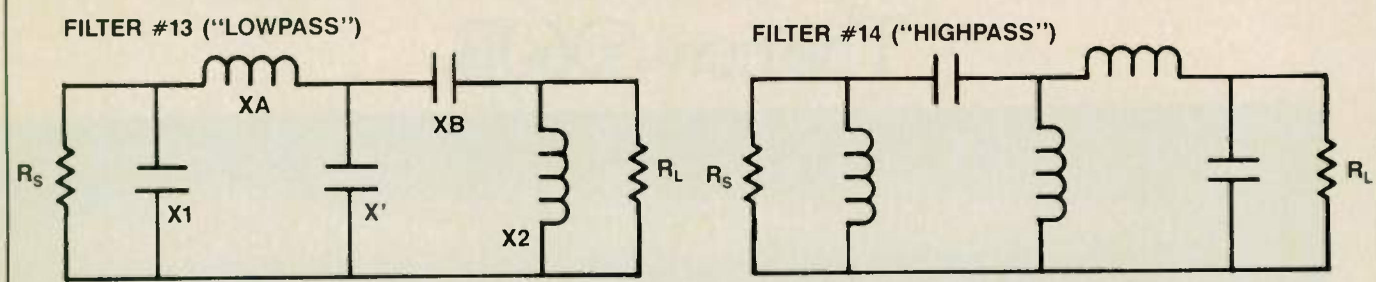
A simple bandpass filter designed for available termination resistances often yields impractical component values, regardless of the configuration. This situation can usually be remedied by designing the filter at some practical impedance, then employing the impedance transformation networks to match the available termination resistances. Broadband ferrite autotransformers of the type discussed in reference (3) could be used, provided that the impedance transformation is not too extreme.

Another method uses the three-reactance impedance transformation networks discussed in reference (1). As an example, suppose that it is necessary to design a 50 ohm filter of the type illustrated in Figure 1 for a center frequency of 10 MHz, K = .12, and Q = 10. If we attempt to design this filter directly into 50 ohm terminations we obtain unwieldy component values, with capacitors too large and inductors too small. However, if the filter is designed for 2000 ohm terminations, the resulting component values are realistic as illustrated in Figure 13a.

Figure 13b illustrates two methods of using reactive transformation networks to match a high impedance filter into lower impedance terminations. At the input of the filter, the parallel resonant tank is replaced by a highpass mixed Pi three-reactance network. Most readers will recognize this impedance transformer as the familiar "capacitance voltage divider." Although the voltage divider concept has a certain intuitive appeal, this network should be viewed as a three-reactance

Figure 8. Coupled shunt enhanced-QL network simple bandpass filters.





X1=−RS/Q
X2=RL/Q
$X'=-K\bullet\sqrt{-X1\bullet X2}$

XA=−X1−X'
XB=−X2−X'

"HIGHPASS" VALUES ARE NEGATIVES OF CORRESPONDING "LOWPASS" VALUES

Figure 9. Coupled standard PI/mixed PI network simple bandpass filters.

matching network for purposes of analysis.

To compute the reactance values of the "divider" capacitors, we first establish the following definitions:

$R1 = R'/(1+(R'/X1)^2)$

$X_s = R'^2/X1/(1+(R'/X1)^2)$

$X_o = -\sqrt{R1\times R - R1^2}$

Then $X1A = (1+X_o^2/R1^2)/(X_o/R1^2)$
$X1B = X_s - X_o$

where:
R' = filter impedance (2000 ohms in example)

R = desired termination resistance (50 ohms in example)

X1 = reactance of unmodified filter end capacitor (70.03 pF capacitor in Figure 13b)

X1A = reactance of modified filter shunt end capacitor (312 pF capacitor in Figure 13b)

X1B = reactance of modified filter series end capacitor (79.8 pF capacitor in Figure 13b)

X1, X1A and X1B are negative quantities.

The second impedance transformation method illustrated in Figure 13b is used at the output end. The series capacitor in conjunction with the parallel LC tank at the filter output actually comprises a highpass shunt enhanced −Q L network. The reactance values of the two capacitors are computed as follows:

$X1A = -R\sqrt{R'/R-1}$

$X1B = 1(1/X1+\sqrt{R'/R-1}\ /R')$

where: R', R and X1 are defined as above.

X1A = reactance of modified filter series end capacitor (50.97 pF capacitor in Figure 13b)

X1B = reactance of modified filter shunt end capacitor (20.33 pF capacitor in Figure 13b)

X1, X1A, and X1B are negative quantities.

There is a limit to the possible impedance transformation ratio that can be obtained by the above method. The following condition must be met:

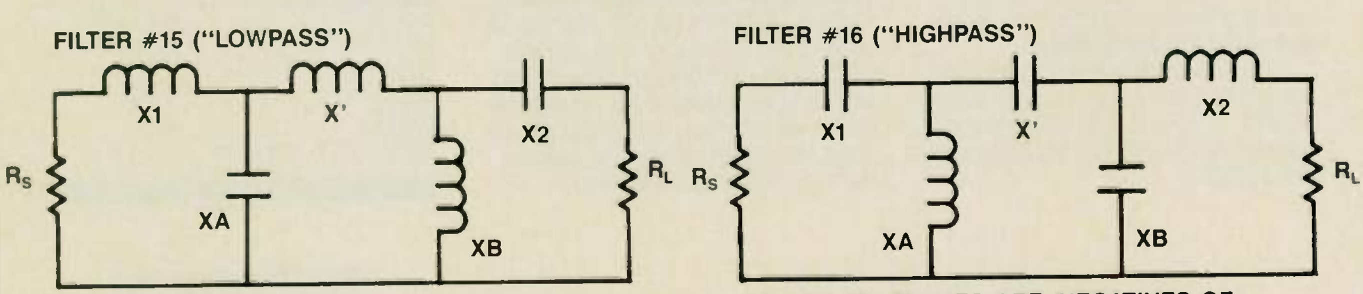
$R > R'/(1+(R'/X1)^2)$

This limitation parallels the similar limitation in three-reactance tranformation networks where high impedance transformation ratios require higher network Q. (R'/X1 in the above expression is actually a Q term.)

The above formulas were derived through network manipulations involving series-to-parallel and parallel-to-series conversions. Przedpelski performed these manipulations for the "capacitive voltage divider" impedance transformation network (see reference 4). Of course, these impedance transformers can also be used for applications other than simple bandpass filters.

Other network configurations can be used to provide these transformations,

Figure 10. Coupled standard TEE/mixed TEE network simple bandpass filter.



X1=−RS•Q
X2=−RL•Q
$X'=\sqrt{-X1\bullet X2/K}$

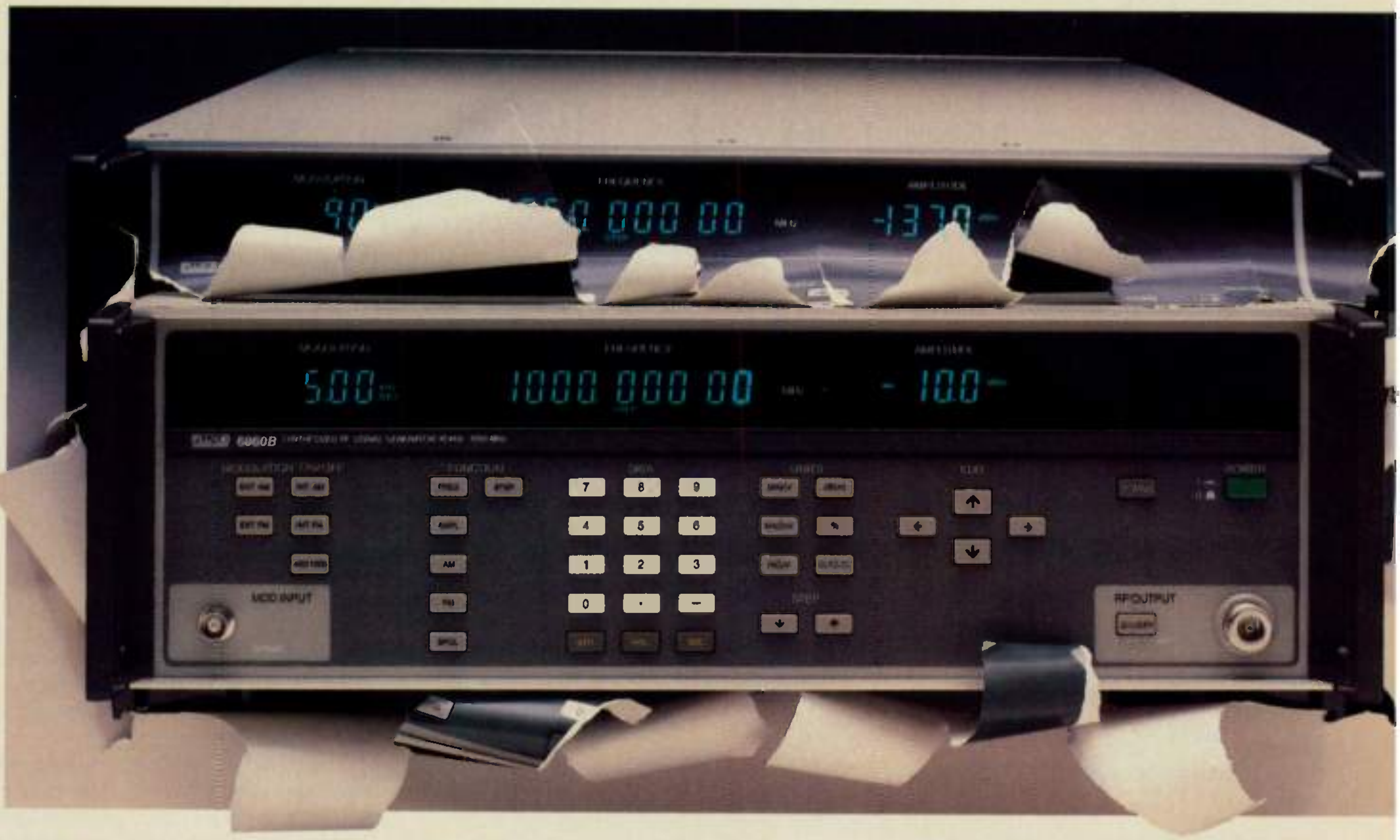
XA=−1 / (1/X1+1/X')
XB=−1 / (1/X2+1/X')

"HIGHPASS" VALUES ARE NEGATIVES OF CORRESPONDING "LOWPASS" VALUES

IEEE-488

There's only one signal generator that's a better value than the 6060A.

The new 6060B.



Price, features and performance. Judge the new 6060B by its specifications.

When we introduced the 6060A, it was without a doubt the best signal generator value on the market. With its unique architecture, this fully programmable synthesized RF signal generator offered the RF industry the performance it needed for design, testing and maintenance applications. Yet it was priced well below other generators in its class.

The new 6060B takes this remarkable signal generator another major step ahead.

New wider frequency range.

The 6060B has an even wider output frequency range. Low end coverage is extended to 10KHz for VLF and LF applications and still maintains the capability to output frequencies up to 1050MHz.

Better residual FM and amplitude accuracy.

Guaranteed amplitude accuracy is now ±1.0dB from +13dBm to −127dBm, improved from ±1.5dB. You can rely on precise amplitude control across the frequency range.

Residual FM performance specification has been improved by better than 30% in all bands. It is now guaranteed less than 10Hz rms (.3 to 3KHz) at 500MHz.

Three options now included standard.

We've added three popular options to the standard 6060B model for much less than you'd pay for each separately. Now standard are: Non-Volatile Memory that can store 50 instrument settings up to two years without power, Reverse Power Protection, and Sub-Harmonic External Reference input.

Good news on the bottom line.

Although we've boosted performance and standard features, the 6060B is still priced at a modest **$4995.*** We think that makes it an unbeatable value in general purpose signal generators. Second to none.

For more information about the 6060B, call **1-800-426-0361** or contact your local Fluke Sales Engineer or Representative.

Fluke 6060B

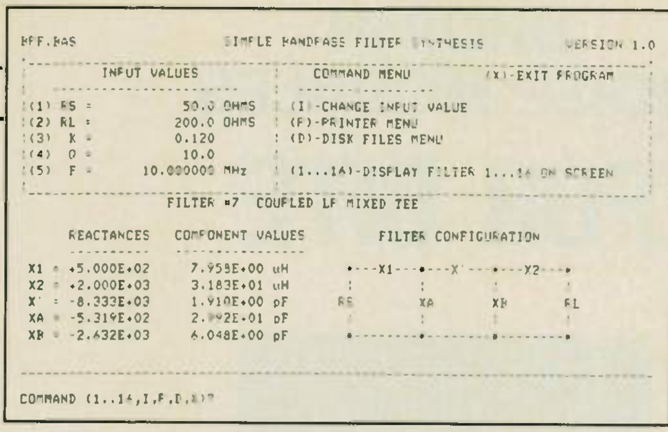
Frequency range	10KHz – 1050MHz
Amplitude range	+13dBm to −127dBm
Accuracy	±1.0dB
Harmonics	< −30dBc
Spurious	< −60dBc
Modulation	AM/FM
IEEE-488 Interface, opt. 488 switch speed	<100 ms, typ

FLUKE®

*Suggested U.S. price only

IN THE U.S. AND NON-EUROPEAN COUNTRIES: John Fluke Mfg. Co., Inc., P.O. Box C9090, M/S 250C, Everett, WA 98206, Sales (206) 356-5400, Other (206) 347-6100
EUROPEAN HEADQUARTERS: Fluke (Holland) B.V., P.O. Box 2269, 5600 CG Eindhoven, The Netherlands, (040) 458045, TLX 51846

INFO/CARD 32



```
RFF.BAS               SIMPLE BANDPASS FILTER SYNTHESIS          VERSION 1.0
-------------------------------------------------------------------------------
        INPUT VALUES           :   COMMAND MENU          (X)-EXIT PROGRAM
   ------------------------    :   ----------------
:(1) RS =          50.0 OHMS   : (I)-CHANGE INPUT VALUE
:(2) RL =         200.0 OHMS   : (P)-PRINTER MENU
:(3)  K =         0.120        : (D)-DISK FILES MENU
:(4)  Q =          10.0        :
:(5)  F =     10.000000 MHz    : (1...14)-DISPLAY FILTER 1...14 ON SCREEN
-------------------------------------------------------------------------------
                   FILTER #7  COUPLED LP MIXED TEE

      REACTANCES    COMPONENT VALUES          FILTER CONFIGURATION
      ----------    ----------------
 X1 = +5.000E+02     7.958E+00 uH        *---X1---*---X'---*---X2---*
 X2 = +2.000E+03     3.183E+01 uH        :        :        :        :
 X' = -8.333E+03     1.910E+00 pF       RS       XA       XB       RL
 XA = -5.319E+02     2.992E+01 pF        :        :        :        :
 XB = -2.632E+03     6.048E+00 pF        *--------*--------*--------*

-------------------------------------------------------------------------------
COMMAND (1..14,I,P,D,X)?
```

Figure 11. Simple bandpass filter synthesis program CRT display.

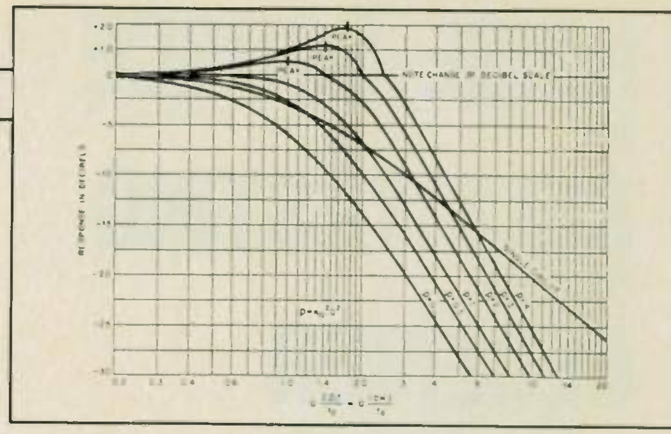


Figure 12. Simple bandpass filter passband response graph.

although many of these require the use of additional inductors. Also, the possibility of tapping or linking into the existing inductors should be considered where feasible. Although engineers may tend to shy away from taps and links, these often provide the most cost-effective approach, especially in high-volume production applications.

Modern bandpass filter design techniques

The limitations of the simple bandpass filters, we might wish to find other bandpass filter design models that overcome these shortcomings. Modern filter design theory offers sophisticated bandpass filter design models that do not rely on graphical design techniques. These models permit any number of sections to be cascaded to obtain the desired stopband rejection. They are based on precise mathematical transfer functions that have been optimized for passband flatness, stopband rejection, phase linearity, or other desireable characteristics. Through mathematical manipulations, the selected transfer function can be used to establish driving point impedances and component values for a prototype lowpass filter. This lowpass filter can then be transformed into a bandpass configuration that retains the qualities of the lowpass filter. Named after its transfer functions, a filter synthesized from the Butterworth polynominal yields a steady-state response that is maximally flat. Filters synthesized from the Chebyshev polynominal, on the other hand, have uniform ripple in the passband, but a sharper transition from the passband to the stopband and better stopband rejection with the same number of elements.

Simple bandpass filters are actually narrowband approximations of these more sophisticated filters. A filter with a KQ product equal to unity is a close approximation to a two-section Butterworth bandpass filter, provided that the Q is not too low. Similarly, filters with KQ products greater than one are actually narrowband approximations to two-section Chebyshev bandpass filters.

Bandpass filter synthesis techniques based on polynominal filters are far superior to the simple bandpass filter synthesis model presented here. This superior model is much more complicated, but there are a number of shortcuts that can be taken to reduce tedious mathematical manipulations and abstract reasoning that are required. Most RF design engineers rely upon filter design tables (references (5) and (6) are excellent sources for these tables), and with programmable calculators and personal computers filter design algorithms can be written that permit the user to select bandwidth rather than K and Q values, making synthesis programs easier to use. In a future article, we will discuss bandpass filters derived from prototype lowpass based upon modern filter design theory, and present an accompanying BASIC program.

Computer Program

For a copy of the program described in the article, send a formatted disk plus $5.00 in a stamped, self-addressed envelope to the authors at the address below. The available formats are: MS-DOS/PC-DOS, Kaypro, and Zenith Z-100 (others may be available — contact the authors). rf

About the Authors

Alex Burwasser is an electronics engineering consultant with considerable experience in RF network design and analysis.

Earl Bossaller, Jr. is senior electronics engineer at RF Products, 5022 Artesian St., San Diego, CA 92117. Both authors may be reached at that address.

References

(1) Alex J. Burwasser, "TI-59 Program Computes Values For 14 Matching Networks," *RF Design*, November/December 1983.

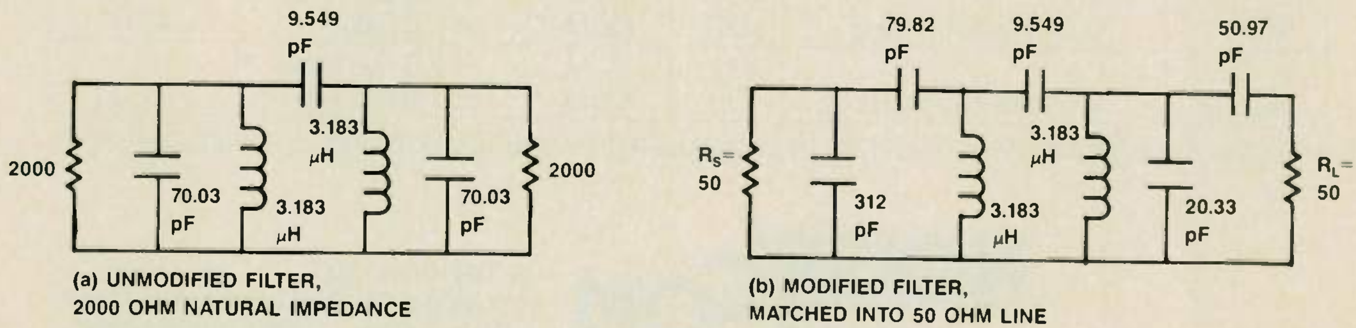
(2) ITT, *Reference Data For Radio Engineers*, 5th Edition, Ch. 9, Howard W. Sams and Co., Indianapolis, 1974.

(3) Alex J. Burwasser, "Wideband Monofilar Autotransformers," *RF Design*, January-April, 1981.

(4) Andrej B. Przedpelski, "Low Impedance Double Tuned Circuit," *RF Design*, May/June 1982.

(5) Anatol I. Zverev, *Handbook Of Filter Synthesis*, John Wiley and Sons, Inc., New York, 1967.

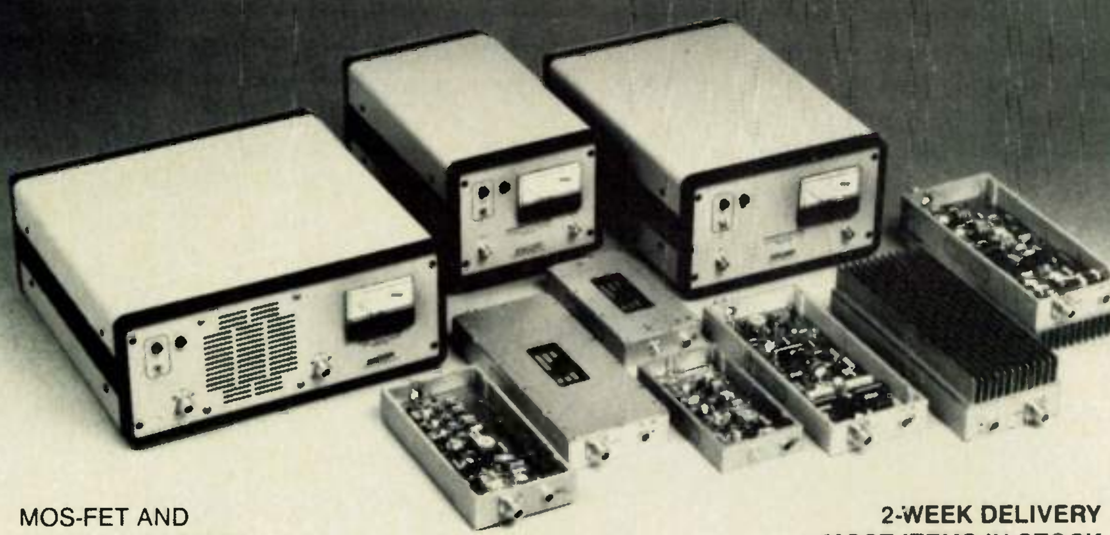
(6) Arthur B. Williams, *Electronic Filter Design Handbook*, McGraw-Hill Book Company, New York, 1981.



RF POWER

Lab Instruments & Modules

- 2 to 5000 Watts, 25Hz to 550MHz
- Innovators in Solid State Design
- Superior Quality Construction



MOS-FET AND
BI-POLAR DESIGNS

2-WEEK DELIVERY
MOST ITEMS IN STOCK

A complete line of high quality RF Power Amplifiers designed for versatility and reliability. Choose from over 30 laboratory type AC instruments, or from more than 40 state-of-the-art DC modules for OEM or special project use. All modules are housed in "one-piece" solid aluminum machined RFI-proof enclosures for reliability and low leakage performance. Over 16 years of RF POWER design and manufacturing experience enable us to supply you with a combination of the very best amplifier system for your money and provide the know-how to quote you on your special requirements. If we don't have what you need, we'll design it! Send for your free amplifier catalog.
APPLICATIONS: NMR/ENDOR/ESR, Communications, Lab Test Equipment, Ultra Sonics/Sonar, RFI/EMI Testing, Accelerators, Medical Research.

KALMUS

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

21820 87th SE, WOODINVILLE, WA 98072 **206-485-9000** • 206-823-1832 • TELEX: 24-7028

INFO/CARD 33

"SWITCH DC TO HUNDREDS OF MHz IN 8x8 to 64x8 CONFIGURATIONS"

It's easy to switch eight DC to 500Mhz inputs to any of eight outputs with our Model 4108 wide-band coaxial relay matrix shown at the left. This miniaturized matrix is completely self-contained, requiring only TTL control signals and DC power.

For larger systems, our Model 4076 can switch 64 signal sources to any of eight outputs under IEEE-488 control with a bandwidth of DC-300Mhz by packaging up to eight 4108 modules in a compact cabinet.

These miniaturized extremely wide-band matrices are perfect for Automatic Test Equipment (ATE) where fast rise time, wide bandwidth data from the unit under test must be connected to any array of test equipment, or in telecommunications where wideband data rates must be connected between modems, transceivers or satellite uplink/downlink terminals.

Experience—We Have It
No matter what kind of high frequency switching system you're buying, it pays to deal with a company who really understands the business. Matrix does. We've been designing state-of-the-art reed relay and semiconductor switching matrices for over 17 years—to the toughest electrical and packaging specs imaginable. Our customers include government agencies, defense contractors, the TV industry, ATE and telecommunications companies and more. So deal with the leader and be sure.

MATRIX
SYSTEMS CORPORATION

5177 NORTH DOUGLAS FIR ROAD
CALABASAS, CALIFORNIA 91302
(818) 992-6776 · TWX 910-494-4975

INFO/CARD 34

Radian Review

By H. Paul Shuch
San Jose City College

Radian measure is one of the most useful and misunderstood tools of AC circuit analysis. It is easy to be confused by its origin and application, especially if the use of radian was learned by rote memorization. This article de-mystifies the radian, and hopefully dispels some of that confusion.

In analyzing the amplitude and phase response of AC circuits, one has certainly converted angles between degree and radian measure. RF engineers, of course, do so with great frequency, using the conversion constant which we all have memorized:

$$\text{radians} = \frac{\text{degrees}}{57.3}$$

If you've ever wondered where the magic number came from, this discussion is for you. Don't let yourself be intimidated by the math, it's really as easy as pi.

Let's start by recalling that the circumference of a circle is related to its diameter by the constant π (a little more than three). You can approximate the value of π by measuring the diameter and circumference of any circle. But π is a transcendental number, which means its digits never end, and never repeat. Its value can be approached through the following infinite series:

$$\pi/4 = 1 - 1/3 + 1/5 - 1/7 + 1/9 - 1/11 \ldots$$

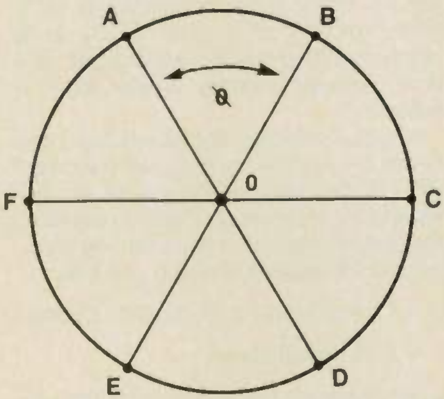
A casual glance at the above series should give you a sense of *deja vu,* with its uncanny resemblance (signs and reciprocals neglected) to the Fourier series for a square wave.

The iterative solution to π is incredibly time consuming. Just for fun, try the BASIC program below which solves the fractional series for as many terms as you care to specify. 10^6 double-precision iterations on a 64 kByte, Z-80 based PC, came up with:

$$\pi \sim 3.131593653607635$$

which is accurate to only six of its 16 significant figures, and took nearly three hours to execute! At that rate, the program will calculate π to ten significant figures (the number you can get on a cheap hand calculator) in roughly three years!

Since a circle's diameter equals twice its radius, we can as easily say that a circle's circumference is $2\pi R$, roughly six times its radius. This approximation allows us to draw the circle in Figure 1, with an origin (0) at the center, radius R, and the circumference divided into six equal arcs by points A through F.



You will note that the radii drawn from the origin to define each of the arcs conveniently divide the circle into six slices. Now for each slice the length of the arc, if we straighten it out, is roughly equal to the radius of the circle, so the circle is about six radians (which sounds better than "radiuses") around. Since a circle, like a cycle, is divided into 360 degrees, each sixth of a circle (radian) contains about a sixth of 360, or roughly 60, degrees.

Actually, the circle is divided into not six, but rather 2π, or roughly six and two-sevenths, radians. Which makes the actual angle ϕ in Figure 1, $350/2\pi$, or 57.3 degrees. It is interesting to note that the gross simplification of $\pi = 3$, though it may make a mathematician cringe, has given us an approximation of radian measure which is accurate to within better than five percent.

If you've been thinking that each segment in Figure 1 looks rather like a piece of pie, you're half right. It's actually a piece of 2π! Which brings us to the subject of angular velocity.

```
10 '         ----> PI.BAS <------
20 '                BY N6TX
30 '                (C) 1985 MICROCOMM
40 '
50 '  This program was inspired by the novel "Contact", by Cosmic Carl Sagan
60 '  (1985, New York: Simon and Schuster).  I wish I had Ellie's CRAY-21 to
70 '  run it on.
80 '
90 '
100 CLS$ = CHR$(26)
110 BEL$ = CHR$(7)
120 '  Edit the Clear Screen and Bell strings for your particular computer.
130 PRINT CLS$
140 PRINT "THIS PROGRAM CALCULATES THE VALUE OF PI FROM THE INFINITE SERIES: "
150 PRINT
160 PRINT "PI/4  =  1 - 1/3 + 1/5 - 1/7 + 1/9 - 1/11 + 1/13 - 1/15 + . . ."
170 PRINT
180 PRINT
190 DEFDBL P
200 DEFINT A, B, I, J, X
210 X = 1
220 P = 1
230 INPUT "How many ITERATIONS do you desire?    ",A
240 B = INT (A/100+.5)
250 FOR I = 1 TO B
260 FOR J = 1 TO 50
270 X = X + 2
280 P = P - 1/X
290 X = X + 2
300 P = P + 1/X
310 NEXT J
320 PRINT CLS$;P*4
330 NEXT I
340 PRINT BEL$
350 PRINT CLS$
360 PRINT "AFTER ";A;" ITERATIONS, PI ~  ";P*4
370 PRINT
380 INPUT "Do you wish to continue (Y/N)?    ";D$
390 IF D$="y" OR D$="Y" THEN 230
400 END
```

Frequency is commonly measured in the unit Hertz (Hz), which was chosen to honor our old friend Heinrich Rudolph Hertz. You may also remember a time when the unit of frequency was the Cycle Per Second, before Mr. Hertz was so honored. The point is, we specify frequency in terms of the number of repetitions (cycles) of the wave which occur in a specified time span (one second). We could just as easily have standardized on a given *fraction* of a cycle (such as a number of degrees, or radians) per unit time. Angular velocity is just such a measure.

Angular velocity, abbreviated ω (the Greek lower case omega), is an expression of the rate of change of an AC waveform, expressed in *radian measure*. Since each cycle of a wave can be divided into 2π radians, we can see that:

$$\omega = f \text{ (cycles/sec)} \times 2\pi \text{ (radians/cycle)}.$$
$$= 2\pi f \text{ (radians/sec)}$$

which explains the presence of the ubiquitous 2π factor in AC equations. Examples include the familiar expressions for resonant frequency, filter cutoff frequency, and inductive and capacitive reactance and susceptance.

Why Radians?

The chief advantage of using radian measure is that it reduces otherwise cumbersome trigonometric manipulations to a few simple steps. A related unit, the steradian (perhaps the subject of a future "Designer's Notebook") affords similar simplification in spherical trigonometry, used in antenna pattern and gain analysis and free space loss computations. And, of course, radian measure is convenient in analyzing the behavior of frequency dependent circuitry. But we should hope angular velocity never replaces the familiar units for frequency altogether. For those many *RF Design* readers who happen to be ham radio operators, how would you feel about having our 2-meter band start at 905 M rad/sec? rf

About the Author

H. Paul Shuch heads the Microwave Technology program at San Jose City College, and teaches Avionics Systems at San Jose State University. He is also an avid microwave experimenter and ham radio operator (N6TX). He can be reached at 14908 Sandy Lane, San Jose, CA 95124.

rf products

Spectrum Analyzer and Tracking Generator Make Test Combo

Swept frequency measurements can be carried out from 4 MHz to 990 MHz with up to 70 dB dynamic range on screen, using Texscan's tracking generator/spectrum analyzer combination, the NA51. The analyzer portion also has a 2 dB/division

display range enabling in-band ripple to be examined as well as skirt response. The generator portion has 0 dBm output with attenuation control up to 80 dB and ±0.5 dB flatness. A built-in 5 digit counter has a resolution of 10 kHz. U.S. list price is $7,500. **Texscan Instruments, Indianapolis, Ind. INFO/CARD #158.**

Triode Cavity Amplifiers Simplify TV Transmitters

A series of triode cavity amplifier assemblies that deliver 10 and 15 kilowatts peak-of-sync power in television service has been introduced by Varian/EIMAC. The CV-2242 and CV-2252 (54-88 MHz) cavities utilize the coaxial-based EIMAC 3CX12,000U7 power triode in a cathode-driven circuit that provides high gain. The CV-2240A and CV-2250 (170-228 MHz) cavities use the coaxial-based EIMAC 3X10,000U7 power triode in a cathode-driven circuit for up to 10 kW peak-of-sync power. **Varian EIMAC Division, San Carlos, Calif. Please circle INFO/CARD #157.**

GaAs FET Amplifiers Improve High Excess Noise Sources

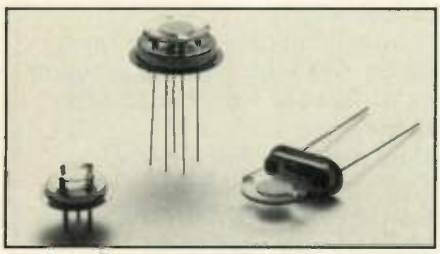
International Microwave's SERIES A solid state noise source has combined bipolar and GaAs FET amplifiers with solid state Noise Sources for applications requiring greater than 40 dB of excess noise. These units provide up to 100 dB of excess noise and operate from 1 to 16 GHz. Custom designs can be provided to meet user specifications. **International Microwave Corporation, Stamford, Conn. INFO/CARD #156.**

Acrylic Finish Provides EMI/RFI Shielding

Carroll Coatings Company offers a silver-filled acrylic coating specifically formulated for electromagnetic and radio frequency interference (EMI/RFI) shielding, or other high conductivity applications. Designated Spectraguard C-641, the new formulation provides a shielding effectiveness of 75 dB 1-3000 MHz as per ASTM D-9 12.14 for applications requiring a high-grade shield to guard against EMI/RFI emissions. With a surface resistance of 0.02 ohms/sq. at 1.5-2.0 mil., the coating is ideal for use with dielectric structures to eliminate static electricity build-up, or in ground plane applications requiring conductivity across a non-conductive seam, or in TEMPEST and FCC applications. **Carroll Coatings, Providence, R.I. INFO/CARD #136.**

SC-Cut Resonators Feature High Precision

PTI now offers SC-Cut precision resonators, available for two standard frequencies (10.00 MHz and 10.23 MHz). Designed for ovenized operation with a choice of three standard coldweld enclo-



sures, the resonators have the fast warm-up and low phase noise characteristics of SC resonators along with ±1.5 ppm frequency tolerance, low aging rates and high Q. Price is $210.00 (1-9). **Piezo Technology, Inc., Orlando, Fla. Please circle INFO/CARD #133.**

Programmable Noise Generator Gets New Options

Micronetics has extended the PNG Series of IEEE Programmable Noise Generators, with a new series of options, including output bandwidth to be selected either remotely or from the front panel. It provides up to eight selectable bandwidths in one PNG. Another option includes a signal input, which simplifies the addition of noise to a signal in noise figure testing. Alternate Signal Path options start at $300, and the signal mixers at $100.00. **Micronetics, Inc., Norwood, N.J. Please circle INFO/CARD #154.**

Conformable Coax Replaces Semi-Rigid Cable

Belden now offers high-temperature coaxial cable with a copper-tin composite shield in 50 and 75-ohm versions. Part numbers 9307 and 9308 are miniature cables with a .084" outside shield diameter. Both cables are substitutes for semi-rigid, copper-sheathed coaxial cable in applications where compact electronic packaging and tight bending radii are required. The cables can be formed by hand without the need for forming tools, and they are compatible with most non-crimp connectors. **Belden Electronic Wire and Cable, Richmond, Ind. Please circle INFO/CARD #135.**

915 MHz RF Power Source Delivers 400W

A high power, solid state 915 MHz RF power source is now available for system or laboratory requirements. The Model 1100 series provides up to 60 watts per channel of isolated RF power, or up to 400 watts single output. The sources incorporate true linear control and monitors for system interfacing. A switching supply is provided to minimize size and weight, and optimize overall efficiency. **American Microwave Technology, Inc., Fullerton, Calif. INFO/CARD #132.**

Cryogenic Refrigerator Provides 1 Watt Cooling at 77°K

A miniature closed-cycle cryogenic refrigerator is now available from Cryodynamics. Model M15 produces 1 watt net useable cooling at 77° Kelvin in only 8 minutes with less than 30 watts input power. The non-lubricated, hermetically-sealed unit exhibits low vibration and weighs only 3 lbs. Designed for infrared sensor and laser systems, low noise amplifiers, antennas and range instrumentation, it is adaptable to special functions and configurations. **Cryodynamics, Inc. Mountainside, N.J. INFO/CARD #151.**

ESD Instrument Simulates Human Discharge

KeyTek Instrument Corp. has introduced new adapters designed to simulate both the standing and collapsing E-fields associated with human electrostatic discharge (ESD). Designed for use with the KeyTek Series 2000 ESD simulation system, these new adapters provide diagnostic capability of realistically simulating ESD failures resulting from a standing E-field (Model FT-11) and a rapidly collapsing E-field (Model FT-21). The adapters can be ordered separately, or as a package for $700.00. **KeyTek Instrument Corp., Burlington, Mass. INFO/CARD #131.**

Ferrite Materials Have High Permeability, Low Loss

Krystinel Corporation is now producing a new family of high permeability and low loss materials. These improved materials were made possible by the acquisition of new, state-of-the-art equipment and newly developed chemical formulations. LT6, LT7 and LTA materials have initial permeabilities of 6,000, 7,500 and 10,000, respectively. **Krystinel Corporation, Paterson, N.J. INFO/CARD #130.**

UHF Telemetry Radio Transceiver Has 3W, Small Size

Neulink, a division of Celltronics Inc., introduces its UHF telemetry transceiver for sending and receiving telemetry data via RF, CP-403U/TM. The telemetry transceiver replaces hardwire applications for transfer of voice, tones, or FSK data. Power is selectable between 3 and 1 watts, and three frequency bands are available, 406-420 MHz, 420-450 MHz, and 450-480 MHz. Size is 4.5"x 2.3"x 1.4". **Neulink, San Diego, Calif. Please circle INFO/CARD #134.**

SOIC Devices Get ATE Handler/Sorter

Electro-Mechanical Systems has just released two new automatic handlers for testing Small Outline integrated circuits (SOICs). The model 5050 can be dedicated to any of four SOIC JDEC configurations, and can sort packages of any length, from 8 to 28 leads. The model 5050F sorts 150 and 300 mil devices interchangeably with no tool changeover. Microprocessor controls prompt operators through messages displayed on a 40-character screen. **Electro-Mechanical Systems, Inc., St. Paul, Minn. Please circle INFO/CARD #153.**

SPICE 3 Enhanced with Temperature Simulation

SPICE PLUS, a version of the SPICE 3 simulation software, enhanced to include simulation of temperature effects and op amps, has been introduced by Analog Design Tools, Inc. for its Analog Workbench engineering software package. Berkeley SPICE 3 is based on the earlier version, 2G.6, but is written in C instead of FORTRAN. SPICE PLUS adds an improved version of the Boyle operational amplifier and the temperature simulation. **Analog Design Tools, Menlo Park, Calif. INFO/CARD #152.**

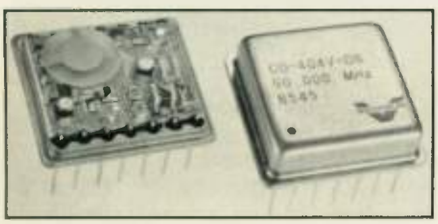
Drop-In Isolator Features .15" Height

TRAK introduces a drop-in isolator, only .75 x .50 x .15 inches in size. The isolator is easy to mount, is magnetically shielded, and capable of being supplied to high

rel specifications. Specifications are guaranteed from −54°C to +95°C. C-band versions are offered with 20 dB minimum isolation and 0.5 dB insertion loss. **TRAK Microwave Corporation, Tampa, Fla. INFO/CARD #150.**

Hybrid DIP VCXOs Designed for Phase-Lock Applications

The CO-404V Series Hybrid VCXOs from Vectron are designed specifically for phase locking applications. They provide TTL output at any specified center fre-



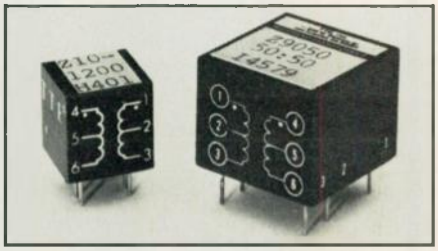
quency from 25 MHz through 70 MHz. They conform to MIL-O-55310 and are available level B screened. **Vectron Laboratories, Inc., Norwalk, Conn. Please circle INFO/CARD #149.**

System Automates SMT Assembly

The QS-34 assembler system for surface mounting of electronic components was designed from the ground up for surface mount technology (SMT), and features software based design. The system can step through the desired pick-and-place sequences with a hand-held programmer, or placement programs can be downloaded from a computer. System hardware is modular, with in-line systems made from one or more QS-34 assembler, each having one pick-and-place head with movement in four axes. Component chucks are programmed to change automatically and position each component before placement. **Quad Systems Corporation, Horsham, Pa. Please circle INFO/CARD #148.**

Wideband Baluns Ease Coupling and Matching

TTE, Inc. has introduced three series of miniature, PC-mounting baluns covering the range 30 Hz to 10 MHz. They are available in power ratings of 100 mW, ½ W and 1 W and in frequency ranges of 30 Hz to 200 kHz, 10 kHz to 5 MHz and 20 kHz to 10 MHz. The output impedance



(Z_2) can be any specified value while the input impedance (Z_1) is fixed at 50, 75, 400 or 600 ohms. The primary and secondary windings can also be reversed for any input impedance and 50, 75, 400 or 600 ohms output impedance. Both primary and secondary windings are center tapped. **TTE, Inc., Los Angeles, Calif. INFO/CARD #147.**

100 MHz Digital Scope Has 40 Megasamples/Sec. Rate

A new 100 MHz digital storage oscilloscope has 4 digital memories with post-capture manipulation capabilities. The Iwatsu DS-6121 also allows on-screen waveforms to be stored by a single key operation. Multiple waveform processing functions include high-speed equivalent sampling; waveform averaging and GO/

NOGO judgments. Cursor measurements in both digital and analog mode include voltage, voltage ratio, time and phase difference. X-Y recorder/plotter output, 7 memory set-up function and GP-IB and RS232C interfaces are available as accessories. Suggested retail price is $5,550.00. **Iwatsu Instruments, Carlstadt, N.J. INFO/CARD #146.**

Ceramic EMI Filters Are QPL Approved

Tusonix, Inc. has received QPL approval to MIL-F-15733 for 12 new ceramic EMI filter products. The newly-approved filters cover a variety of voltage, extended atten-

uation, and capacitance ranges in both solder mount and bushing mount styles. Most styles are available from stock in production quantities. **Tusonix, Inc., Tucson, Ariz. INFO/CARD #145.**

SET SAIL FOR BALTIMORE
JUNE 2-6, 1986

- IEEE/MTT-S International Microwave Symposium June 2-4
- Monolithic Circuits Symposium, June 4-5
- Automatic RF Techniques Conference, June 5-6

PLUS
Beautiful Inner Harbor Location, Outstanding Restaurants and Shops, Historic and Cultural Attractions and Legendary Chesapeake Bay Hospitality

Complete the coupon below and return it to Microwave Journal to receive the Advance Program, advance registration form and hotel reservation forms.

MICROWAVE JOURNAL • 610 Washington Street • Dedham, Massachusetts 02026

Send me additional information on attending MTT-S '86.

Name __________ Title __________

Organization __________

Address __________

City, State, Zip Code __________

Country __________ Phone __________

MTT-S Member? ☐ Yes ☐ No R

INFO/CARD 42

Take the guess out of rfi testing.

You've decided not to take chances with rfi susceptibility. Then why mix and match the tools you'll use to test for it?

Instead, you can equip your entire test loop with instruments from Amplifier Research that have been thoroughly tested and work well with our high-performance broadband rf amplifiers.

From 1W to 10kW, 10 kHz to 1,000 MHz, in 32 standard models, AR amplifiers give you optimum power, bandwidth, and versatility for your cw, sweep, and pulse requirements. Each model provides instantly available bandwidth without bandswitching or tuning, is completely immune to load mismatch, and won't shut itself down when you may need it most.

But a high-quality test presumes high-quality test equipment throughout. So we also supply specialized antennas, leveling preamplifiers, field sensor systems, fiber-optic telemetry links, TEM cells, matching transformers, and directional couplers.

With this full-system approach, equipment variables are less likely to show up in your test results. It'll pay you to talk with us about *all* your rfi test requirements.

ar AMPLIFIER RESEARCH

160 School House Road, Souderton, PA 18964-9990 USA
Phone 215-723-8181 • TWX 510-661-6094

INFO/CARD 43

Low Cost Heat Sink Saves Assembly Time

Aavid Engineering, Inc. has introduced a plug-in heat sink for TO-220 semiconductors. The Series 5933, features a patented plug-in design which cuts down on assembly time. The heat sinks also have stepped tabs, a new solder termina-

tion design which provides greater support and stablity. Three vertically-mounted styles are available in heights of .690, .750, and 1.375 in. Pricing for Series 5933 (.750 in.) is $0.185 each in 1,000 quantities. **Aavid Engineering, Inc., Laconia, N.H. INFO/CARD #144.**

5-1000 MHz Amplifier Has 1.75 dB Noise Figure

The MLA-1001 low noise amplifier from Step Microwave has a guaranteed maximum noise figure of 1.75 dB (1.5 dB typical) over the frequency range of 5-1000 MHz. Minimum gain is 23 dB with

gain variation of less than ±1.75 dB, and the unit draws less than 70 mA from a 15V supply. In the 2.5 x 1.0 x 0.8 inch package with SMA connectors the MLA-1001 is available from stock for $350.00 (1-9). **Step Microwave, Los Gatos, Calif. INFO/CARD #143.**

TO-8 Noise Modules Designed for B.I.T.E.

Noise Com has developed a family of inexpensive noise modules ideal for self-testing receivers. These modules contain a complete energizing circuit and DC blocked output, and are packaged in the TO-8 metal can. Model NC501 supplies 31 dB ENR with ±dB flatness of White Gaussian Noise over 0.2 MHz to 500 MHz in a 50 ohm circuit. It operates from 28V supply with a typical 5mA current consumption. Units operating on 15 volts with 1mA current are also available. Other models are NC502 (0.2 MHz to 1000 MHz), and NC503 (10 MHz to 2000 MHz). The model NC501. $39.00 each (1-9), in stock. **Noise Com Inc., Hackensack, N.J. INFO/CARD #142.**

TVRO Spectrum Analyzer

AVCOM's PSA-35 Portable Spectrum Analyzer is designed for the TVRO industry, and offers frequency coverages of 10 and 1500 MHz and 3.7 to 4.2 GHz for checking signal strength, inband attenuations, terrestrial interference, filter alignment, faulty connectors, LNAs, feedhorn

isolation, and cable loss at all commonly used frequencies in the TVRO industry, including 12 GHz downconverters. The PSA-35 features a built-in DC block with +18 VDC for powering LNAs and BDCs, calibrated signal amplitude display and rechargeable internal battery with recharger. The price is $1965.00. **AVCOM of Virginia, Inc., Richmond, Va., please circle INFO/CARD #138.**

GaP Bragg Cell

A 1000 Time-Bandwidth gallium phosphide Bragg Call has been produced in the acousto-optic division of Brimrose Corporation. Diffraction efficiency of the

device is over 40 percent at 1 GHz center frequency and bandwidth of 500 MHz. Optical aperture is 2 μs. This modulator is made out of the high purity GaP tested by X-ray diffraction techniques. **Brimrose Corporation of America, Baltimore, Md., INFO/CARD #137.**

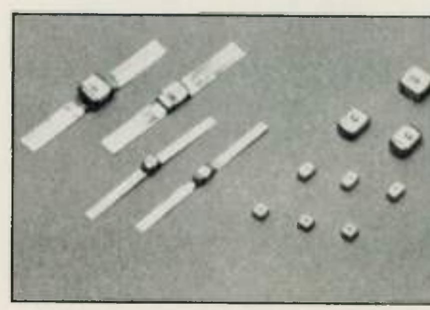
EMC Test System Meets IEC Recommendations

American HV Test Systems, Inc. has prepared a complete test set in accordance with the IEC TC 65/WG4 recommendations, soon to be published as an IEC 801 standard. The system consists of an electrostatic discharge simulator, type PSD15A, a fast transient generator (burst), Type PB, with HF-coupling clamp and coupling filter for inductive load switching

simulation, and a hybrid generator, Type PC6-288 with open circuit output voltage wave 1.2/50 micro seconds (up to 6 kV) and short circuit current wave 8/20 micro seconds (up to 3 kA). This equipment serves to test the susceptibility of electronic appliances and systems with regard to electromagnetic compatibility. **American HV Test Systems, Inc., Accident, Md. INFO/CARD #141.**

Ceramic Chip Capacitors Are Usable to 18 GHz

A new line of ceramic chip capacitors is announced by F-TEC. The multilayer (monolithic) capacitors are usable to 18 GHz with low loss and low equivalent series resistance (ESR). Their capacitance range is from 0.1 to 1000 pF, with



custom available in addition to standard values. The standard voltage range is from 50 to 500 WVDC, and the temperature range is from –55 C to +125 C. The new line is designed to meet MIL-C-55681 and MIL-C-11272 and exceed the requirements of MIL-STD-202. **F-TEC, Piscataway, N.J. INFO/CARD #140.**

AM Stereo Signal Generator Aids Production and Repairs

Leader Instruments Corporation announces a new AM Stereo Synthesized

Signal Generator, Model LSG-245. Designed for Motorola's C-QUAM® system, the LSG-245 can be used over the entire AM band, as well as at IF, in addition to providing a variety of modulation and output conditions. All parameters are entered by front panel pushbuttons and verified by LED displays. In addition, up to 100 sets of user defined test conditions (frequency, output and modulation) can be stored and recalled. List price is $3,850. **Leader Instruments Corporation, Hauppauge, N.Y. INFO/CARD #139.**

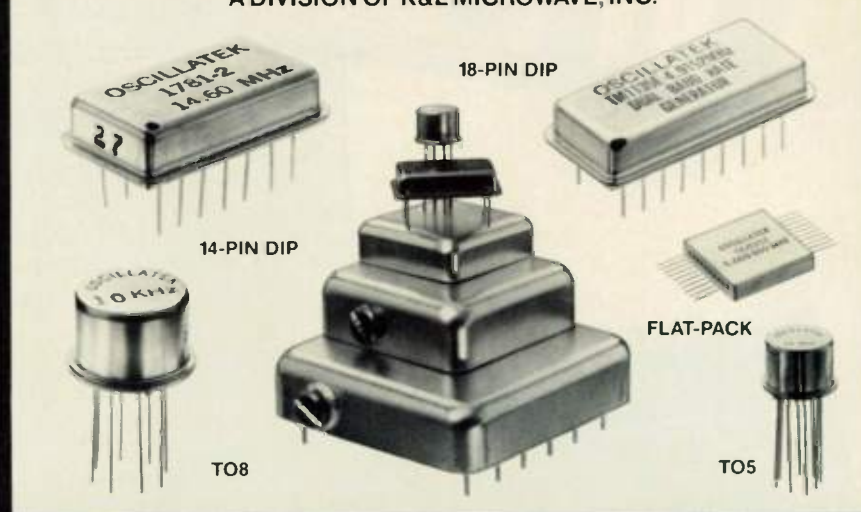
Vector Modulator Controls Gain and Phase

Mirage Systems introduces the VMA-002 Vector Modulator, a precision RF gain and phase control element for use in applications requiring fast and precise control of RF signals over a broad range of frequencies. Accuracy is achieved without

calibration or use of look-up tables. Amplitude resolution is 0.07 dB and phase resolution is 0.45 deg, amplitude accuracy of 0.15 dB RMS and phase accuracy of 1.5 deg RMS. Full accuracy is maintained between 135 MHz and 235 MHz. **Mirage Systems, Sunnyvale, Calif. Please circle INFO/CARD #138.**

Amplifier Isolates Load VSWRs

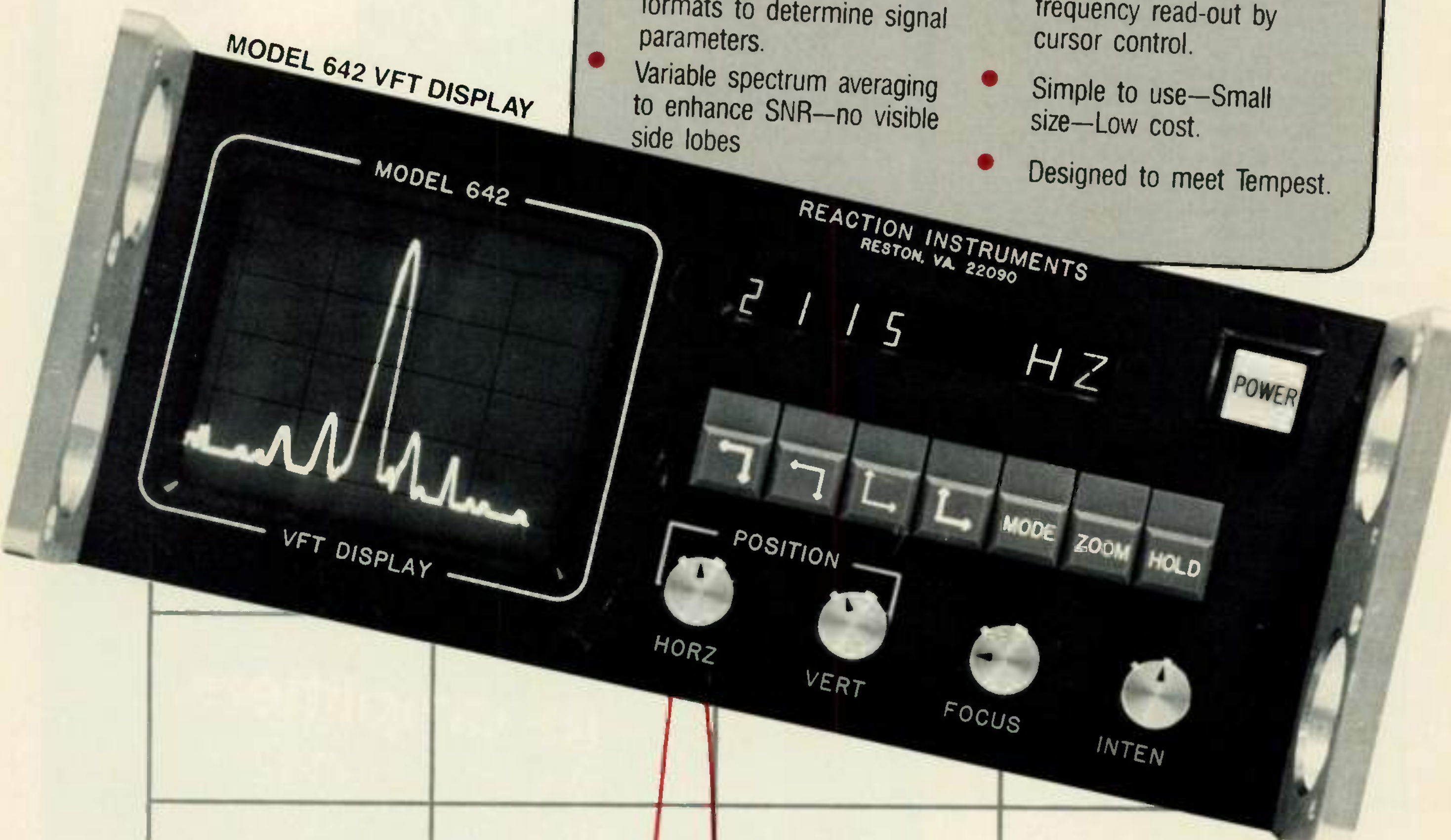
Interad Ltd. announces the introduction of a low noise, high dynamic range amplifier. The Model 2713 has 0 dB gain used for isolating load VSWRs over the frequency range of 5-28 MHz. The unit's specifications include a noise figure of 7 dB max., two tone intermodulation intercept points of +45 dBm min. (3rd order) and +95 dBm min. (2nd order). Impedance (input/output) is 50 ohms, and the size is 4"x 3"x 1". Price of the amplifier is $650. **Interad Ltd., Gaithersburg, Md. INFO/CARD #137.**



VFT DISPLAY

- High resolution FFT audio band spectrum analyzer for surveillance system applications.
- Optimized for processing and analyzing unknown VFT formats to determine signal parameters.
- Variable spectrum averaging to enhance SNR—no visible side lobes
- Displays 4 kHz channel and can digitally zoom to expand any 500 Hz segment of the band.
- Absolute or differential frequency read-out by cursor control.
- Simple to use—Small size—Low cost.
- Designed to meet Tempest.

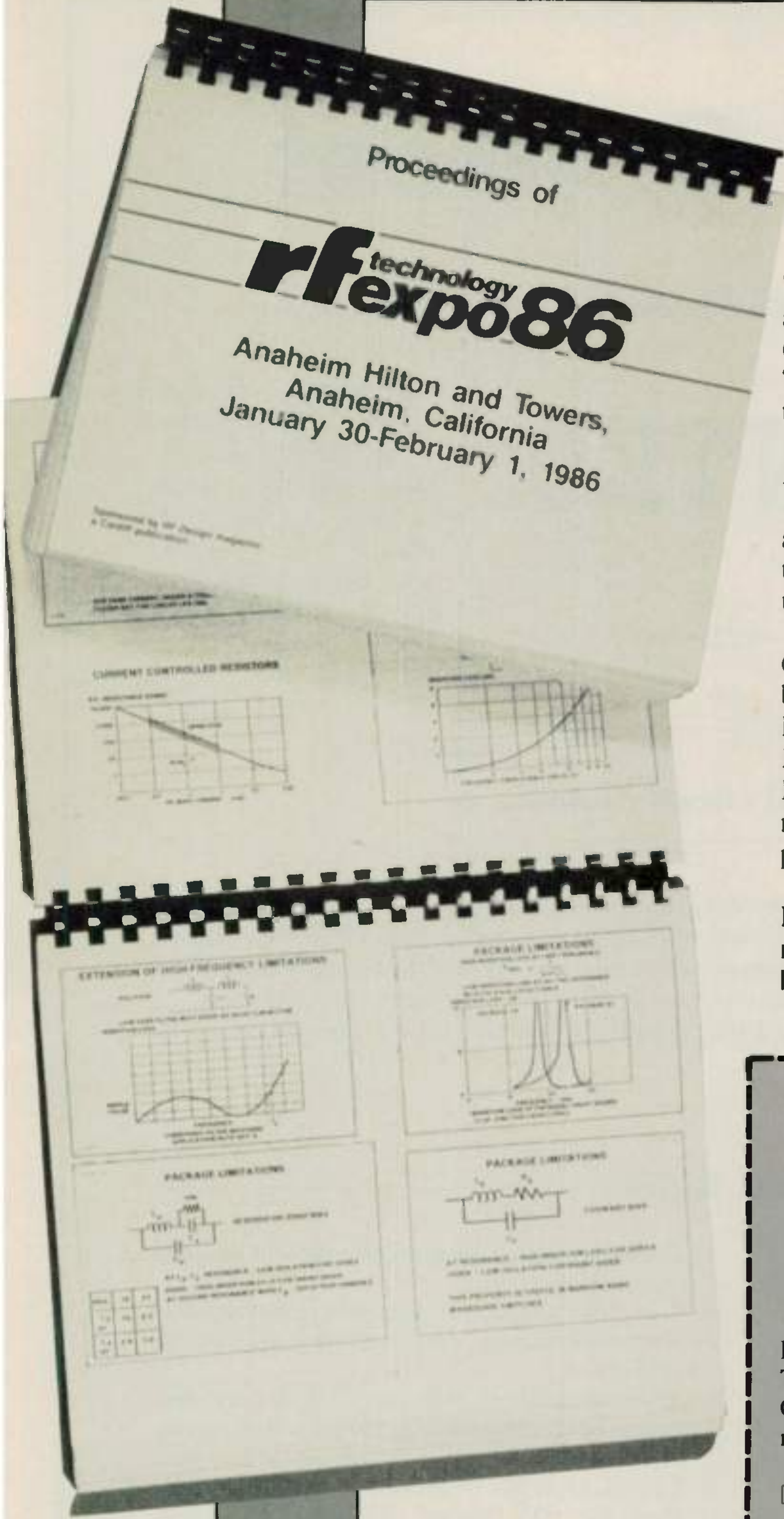
MODEL 642 VFT DISPLAY



Bandwidth	10 Hz-4 kHz
Resolution	10 Hz
Dynamic Range	>70 dB
FFT Size	2048 points
Cycle Time	100 ms
Chassis Size	20" × 8½" × 3½"

REACTION INSTRUMENTS

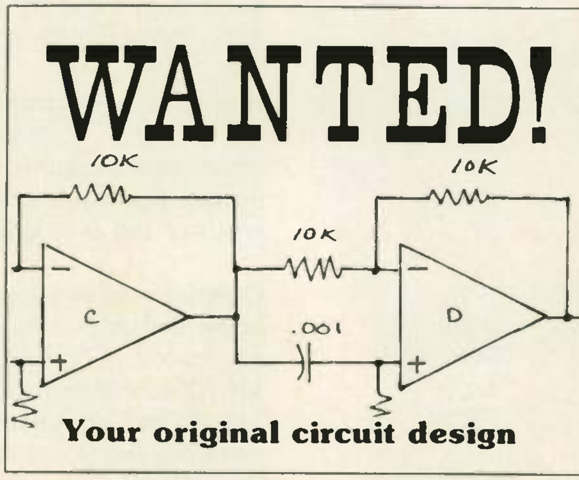
For further information, please call, or write to, our Marketing Department, Reaction Instruments, Inc., 1930 Isaac Newton Square, Reston, VA 22090.
Phone (703) 471-6060, TWX 710 833 9031.
INFO/CARD 48


Proceedings of
rf technology expo 86
Anaheim Hilton and Towers,
Anaheim, California
January 30-February 1, 1986

Design Contest

Sponsored by *RF Design* magazine

Enter your original circuit design in the first Design Contest sponsored by *RF Design*. The winning design will be featured in the July 1986 issue of *RF Design*, and will receive an HP 41CX calculator, courtesy of Hewlett-Packard, plus a recognition plaque. Other top designs will receive recognition plaques and several will be published in the "Designer's Notebook."



Judging criteria include originality of concept, imaginative application of design, significant cost or labor savings, elegance, exceptional performance, usefulness, clear description of function and reproducibility. All circuit components must be available for purchase. The designer must be able to document that the circuit operates and performs as decribed.

DEADLINE FOR ENTRIES is April 15, 1986. Send your entries to: *RF Design*, 6530 S. Yosemite St., Englewood, CO 80111.

Contest Rules

1. Design must be an active RF circuit, from VLF to UHF. Active circuit is defined as one that introduces gain or has a directional function, i.e., an amplifier, oscillator, mixer, modulator or demodulator.
2. Design must be original work, not previously published.
3. If the design develops from the entrant's employment, the employer must give permission to enter it.
4. The design must contain a complete description and parts list.
5. Complete schematic diagram and any other necessary photos or drawings must be included.
6. All components must be available for purchase.
7. Patent or copyright infringement will disqualify the design.
8. Entries must be received by April 15, 1986. Mail to: *RF Design*, 6530 S. Yosemite, Englewood, CO 80111.

Contest will be conducted in accordance with all applicable laws and regulations.

Non-Magnetic Trimmer Capacitors

Voltronics has issued a catalog covering its non-magnetic precision trimmer capacitors for users of NMR spectrometers and MR imaging equipment. Capacitance ranges are from 3.5 to 120 pF, and dielectrics include quartz, glass and sapphire. Data is given on typical RF breakdown voltages at 50 and 200 MHz with DC breakdown ratings of up to 6,000 V. **Voltronics Corporation, East Hanover, N.J. INFO/CARD #176.**

RFI/EMI Filters

An updated RFI/EMI filter catalog is offered by LectroMagnetics, Inc. The catalog contains new UL-listed EMI power line filters, filter panels, signal, control and data communication filters. Also included are listings for custom filters, common mode filters, power factor correction networks and Tempest filtering. LMI's all-welded and clamp-together RF shielded rooms, anechoic chambers, and chambers for Nuclear Magnetic Resonance are also described. **LectroMagnetics, Inc., Los Angeles, Calif. INFO/CARD #166.**

Test Equipment for Broadcasting

The "Sound and TV Broadcasting 1985/86" catalog from Rohde & Schwarz provides an overview of in-service and measuring equipment for TV and sound broadcasting. Supplementary equipment from the measuring instruments and systems division is presented in an Appendix, which also describes CCIR and FCC standards. **Rohde & Schwarz GmbH & Co. KG, Munich, W. Germany. INFO/CARD #174.**

Materials for Electronics

A new catalog dexcribes Electro-Science Laboratories' line of electronic material systems for SMT, packages, hybrids, multilayer and flexible circuits, optoelectronics, sensors, high frequency circuits, photovoltaic cells, thermal printheads, and displays. Solder pastes for surface mounting and polymer thick film materials for printed circuit applications are also described. **Electro-Science Laboratories, Inc., King of Prussia, Pa. INFO/CARD #173.**

P.C. Board Educational Bulletin

An educational bulletin (EB 5007) on printed circuit board inspection procedures and practices has been released by Bishop Graphics, Inc. The bulletin describes a new book, *Quality Assessment of Printed Circuit Boards,* by Preben Lund, outlining the contents of the 29 chapters, citing many of the specific goals of the book (which sells for $59.95). **Bishop Graphics, Inc., Westlake Village, Calif. INFO/CARD #172.**

Tantalum Chips 'n Dips

A color booklet presents Stantel's TP range of solid tantalum capacitors and TQ Series of Tantalum chip capacitors. The TP Series is offered in 0.1-680 μF over 3-50 V range in 20%, 10% and 5% tolerances. They feature radial leads and conformal coated bodies. The TQ Series of tantalum capacitors are designed for thick-film circuits and direct mounting onto PCBs. They are fully encapsulated and resistant to damage and moisture. **Stantel Components, Inc., Schaumburg, Ill. INFO/CARD #170.**

RFI Filter Data Sheets

Voltage, insertion loss and dimensional data for the GF-4000 series of tubular RF filters are provided on data sheets from Genisco Electronics Division. The data sheets provide feed-through circuit diagrams and mounting schematics for these filters, which satisfy MIL-F-15733 specifications. **Genisco Electronics Division, Rancho Dominguez, Calif. INFO/CARD #171.**

Analog-Digital Conversion Handbook

Analog Devices, Inc., and Prentice-Hall have published a comprehensive guide to conversion for engineers and scientists. The third edition of the well-known handbook has grown to 700 hard-bound pages, with seven new chapters, bibliography and index. A new section, "Converters for Special Applications," covers conversion for video speeds, synchros and resolvers, high resolution, and wide dynamic ranges, as well as V/F and F/V. The book is available for $32.95 from Analog Devices or the publisher. **Analog Devices, Inc., Norwood, Mass. INFO/CARD #175.**

Electronic Hardware Catalog

Accurate Screw Machine Co. has announced its new catalog of stock screw machine parts. The 235-page catalog displays their line of products, which includes standoffs, washers, screws, spacers and handles. These products are available in a variety of materials that meet ASTM and MIL specs. New products include positive locking knurled swage standoffs and high torque locking fasteners. **Accurate Screw Machine Co., Nutley, N.J. INFO/CARD #165.**

Advertiser's Index

Yes. Silicon Frequency-Linear Tuning Varactors.

Eliminate costly linearizer circuits with FSI field proven Frequency Linear Tuning Varactors. The GC-15000 series FLTVAR is produced by state-of-the-art computer controlled epitaxial technology, which provides the resistivity gradient and resulting CV curve necessary for linear tuning.

The FLTVAR is well suited for use in bipolar and FET VCO's, Gunn VCO's and tunable filters for wideband tuning through KU band.

Engineering services are available to provide assistance in the event our standard catalog types do not meet your requirements.

and GaAs Varactors too.

Where ultra high Q is desired, these GC-51000 series abrupt junction GaAs Tuning Varactors are available. These devices are ideal for tunable VCO's, frequency synthesizers, voltage tunable filters, phase shifters, as well as linear frequency and phase modulators for communications equipment.

Quality workmanship and reliability of FSI's GaAs Tuning Varactors are assured by our strict process control standards.

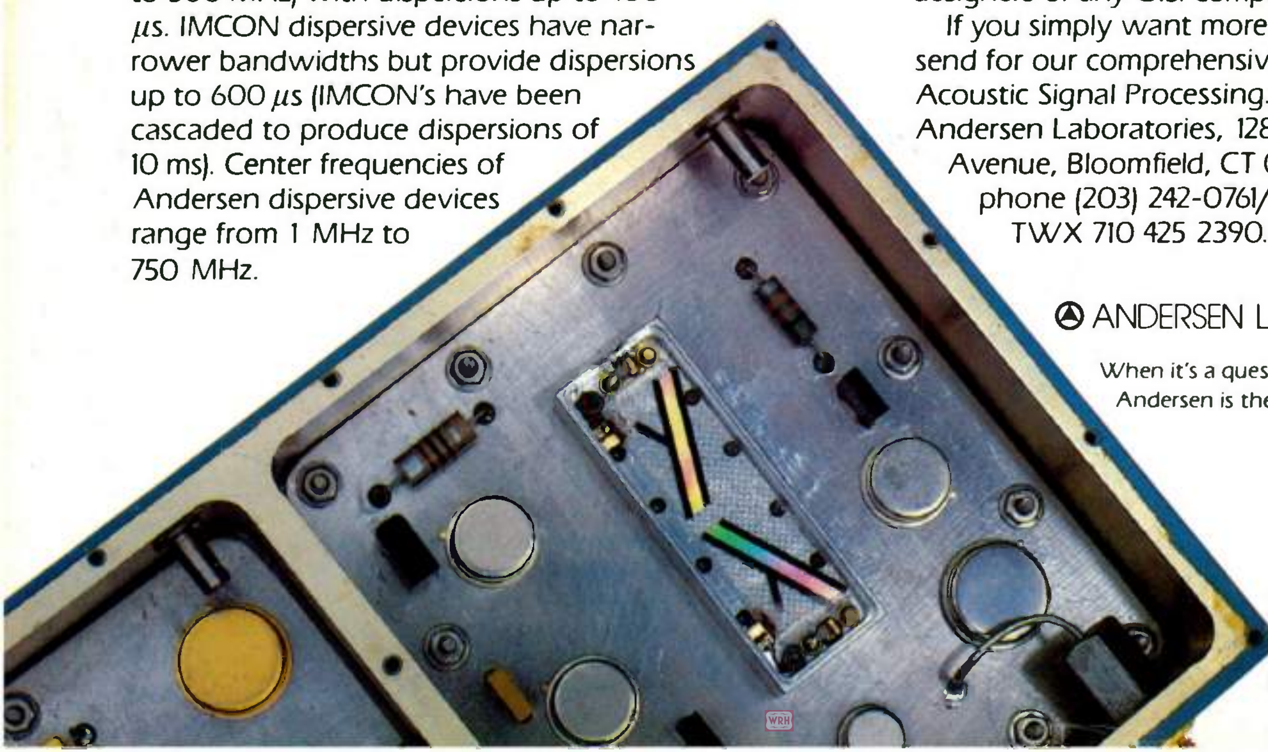
Write for complete details.

FREQUENCY SOURCES
SEMICONDUCTOR DIVISION

A SUBSIDIARY OF LORAL CORPORATION

16 Maple Road
Chelmsford, MA 01824
(617) 256-8101
TWX (710) 343-0404

INFO/CARD 52



Compressive Receiver (actual size)