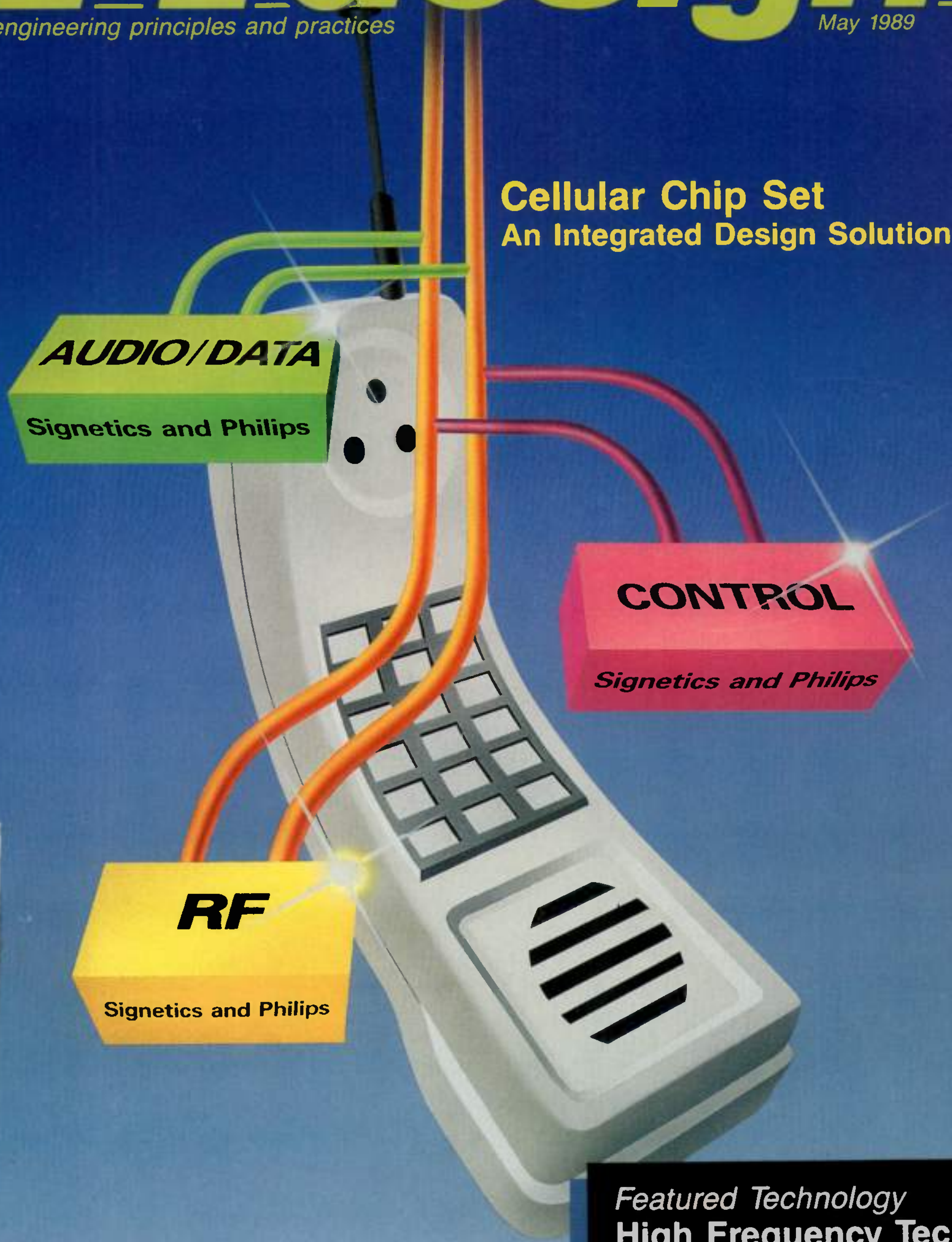
rf design

engineering principles and practices

May 1989

Cellular Chip Set
An Integrated Design Solution

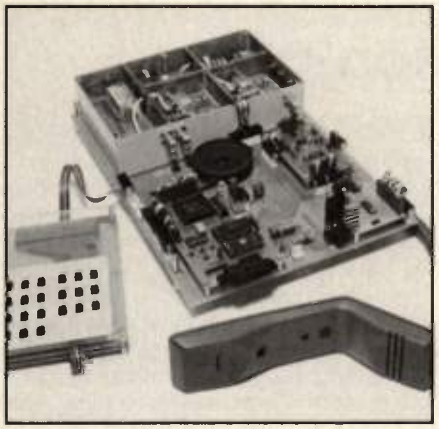


Featured Technology
High Frequency Techniques

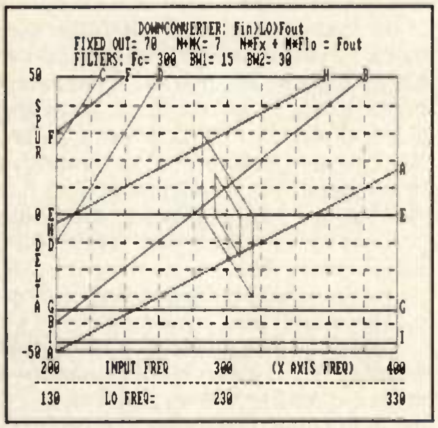
Industry Insight
Frequency Synthesis

rf design

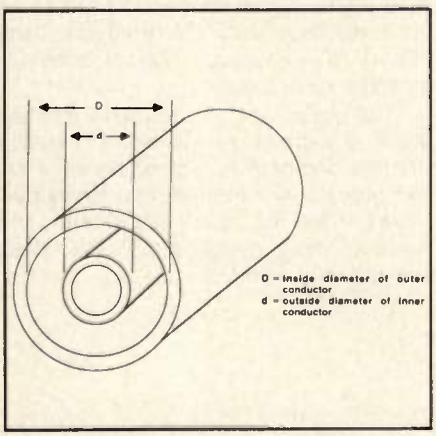
May 1989



Page 26 — Cellular Chip Set



Page 32 — Mixer Spurious Analysis

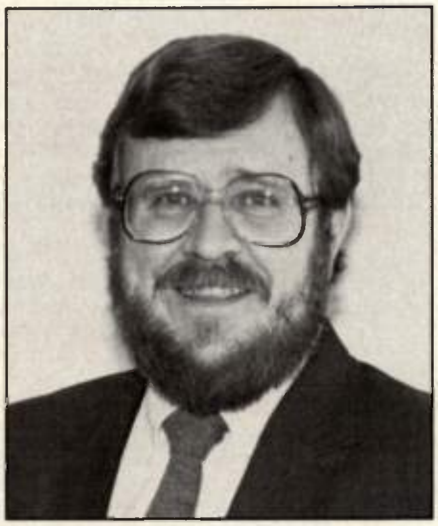


Page 58 — Coaxial Line Attenuation

R.F. DESIGN (ISSN: 0163-321X USPS: 453-490) is published monthly plus one extra issue in September. May 1989, Vol. 12, No. 5. Copyright 1989 by Cardiff Publishing Company, a subsidiary of Argus Press Holdings, Inc., 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111 (303) 220-0600. Contents may not be reproduced in any form without written permission. Second-Class Postage paid at Englewood, CO and at additional mailing offices. Subscription office: 1 East First Street, Duluth, MN 55802, (218-723-9355). Domestic subscriptions are sent free to qualified individuals responsible for the design and development of communications equipment. Other subscriptions are: $33 per year in the United States; $43 per year in Canada and Mexico; $47 (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 $4.00 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 N. Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700.
POSTMASTER & SUBSCRIBERS: Please send address changes to: R.F. Design, P.O. Box 6317, Duluth, MN 55806.

rf editorial

Where's the Action?



By Gary A. Breed
Editor

At a recent meeting of the New Jersey RF and Microwave Industries Association, I was asked to spend a few minutes talking about "what's hot" in RF. Since the tides and currents of business and technology sometimes move rapidly, considerable research and reflection was required to come up with a ten-minute summary. Here's what I came up with (not necessarily in order of importance):

Cellular radio is a very active area for both business and design engineering. Europe has a generally cohesive development plan, and the United States is finally getting to the point where mobile phones are no longer considered a luxury item. Digital radio technology is being rapidly developed for implementation as soon as possible. Component manufacturers are gearing up for the growth that is foreseen, and test instrument makers are already noting increased demand from their customers for cellular-related capabilities.

Medical electronics is in an extremely rapid growth stage, with magnetic resonance imaging and hyperthermia getting most of the attention. Although it is not a large segment of the RF industry, power amplifier makers have a considerable stake in these active technologies. It is definitely one area to watch.

Short-range communications is getting ready to really take off. Wireless convenience is the driving force, just like cordless phones, TV/VCR remote controls, and the good old garage door opener. With spread-spectrum systems on the way, we should see rapid growth in data collection systems, industrial process control, security monitoring, in-plant voice communications, remote-reading ID and inventory tags, and a whole lot more. The technical demands for these systems are substantial, with special difficulties in signal propagation, modulation techniques, data integrity, and usable range.

No matter what the Federal budget, military systems will continue to be the single biggest RF market. Frequency-hopping communications is providing plenty of work for RF engineers, as are the countermeasures being developed to combat it. SDI development work has slowed, but as the more promising portions of it reach the deployment stage, there will be demand for RF power sources, plus supporting communications and radar equipment.

These are the application areas that are truly RF, but one more growth area might be dubbed "RF as a part of____" (fill in the blank). Data acquisition, fiber optics, supercomputers, video displays, and digital signal processing are some of these multi-disciplinary efforts, combining RF with digital, optical, acoustic, or other technologies.

The outlook for the future is exciting from a technology viewpoint. From a market perspective, not all areas of the RF industry will benefit from these new ideas. Like the spark transmitter and vacuum tube computers, some ideas will get left behind.

Gary A. Breed

rf design

a Cardiff publication — Established 1978
Main Office:
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111 • (303) 220-0600
Fax: (303) 773-9716

Publisher
Kathryn Walsh

Editor
Gary A. Breed

Technical Editor
Mark Gomez

Assistant Editor
Katie McCormick

Consulting Editors
Andy Przedpelski
Robert J. Zavrel, Jr.

Advertising:
National Accounts Manager
Mary Bandfield
1341 Ocean Ave., Ste. 58
Santa Monica, CA 90401
(213) 458-6683
Fax: (213) 458-0335

Account Executive
Bill Pettit
Main Office

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

Advertising Services
Mary Brussell

Secretary
Carol Richards

Assistant Circulation Manager
Cindy Zimmer

Convention Manager
April DeBaker

Trade Show Assistant
Barb Binge

Convention Assistant
Paula Newman

Associate Production Manager
Matt Park

Assistant Production Manager
Mary Barr Felker

Artists
Maurice Lydick
Mary Modeer
Brigitte Nadon
Paul Rivera
Bill Schmitt

Composition
Ruth Schmidt
Marcie Tichenor

Published by

CARDIFF
PUBLISHING COMPANY, INC

BPA

President
Robert A. Searle

Vice President — Production
Cherryl Greenman

Vice President — Convention Management
Kathy Kriner

Circulation Director
Patricia Shapiro

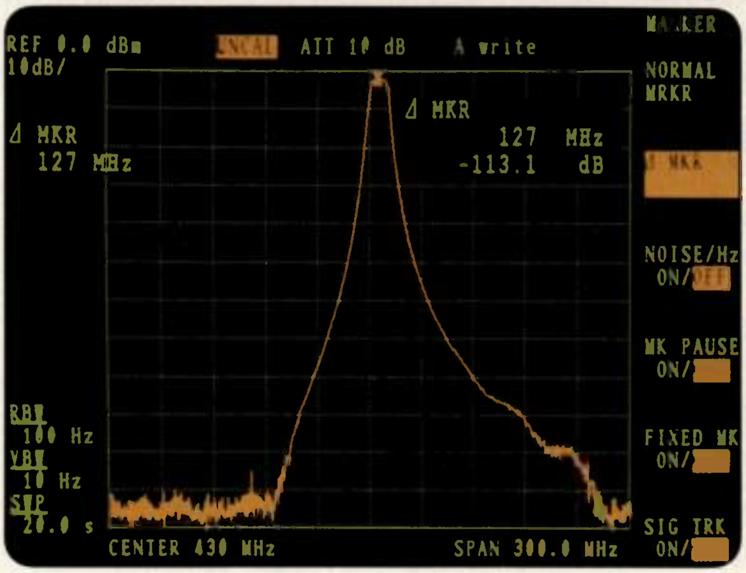
Administrative Services Manager
Susan See

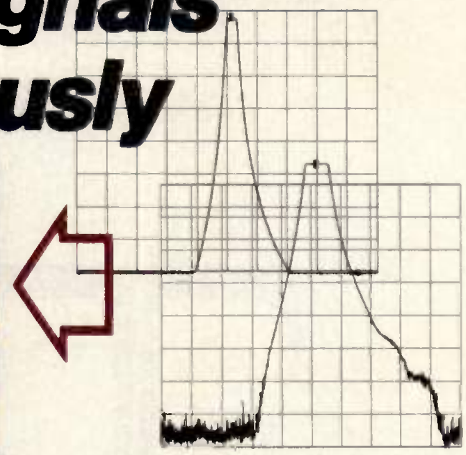
Controller
Jennifer Burger

Credit Manager
Patti McManness

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.

A Dynamic Range of 120dB puts High and Low Level Signals on Screen Simultaneously





The R3261/3361 series synthesized spectrum analyzers are compact, lightweight, synthesized analyzers covering the frequency ranges of 9kHz to 2.4GHz (R3261A/3361A) and 9kHz to 3.6GHz (R3261B/3361B). They represent the combination of ADVANTEST's many years of experience in RF circuit technology with the latest in software calibration technology. The bottom line for the user is a guaranteed overall level accuracy of 1dB. In addition, these analyzers feature: stop, start, and center frequency resolution to 1Hz, together with a built-in frequency counter, also with 1Hz resolution. The result is a truly powerful analyzer in an amazingly compact package.

New R3261/3361 Series Spectrum Analyzer

- Frequency range···9kHz to 3.6GHz (R3261B/3361B)
  9kHz to 2.4GHz (R3261A/3361A)
- Built-in tracking generator (R3361A/3361B)
- Overall level accuracy of 1dB
- 120dB displayable dynamic range
- Synthesis technique used for 1Hz-resolution setting and measurements
- High performance and portability
- Quasi-peak measurements 70dB dynamic range
- Memory card and GP-IB provided as standard
- Built-in control function (option)
- User definable soft keys

ADVANTEST®

Advantest America, Inc. 300 Knightsbridge Parkway, Lincolnshire, IL 60069, U.S.A. Phone:(312)634-2552 Facsimile:(312)634-2872

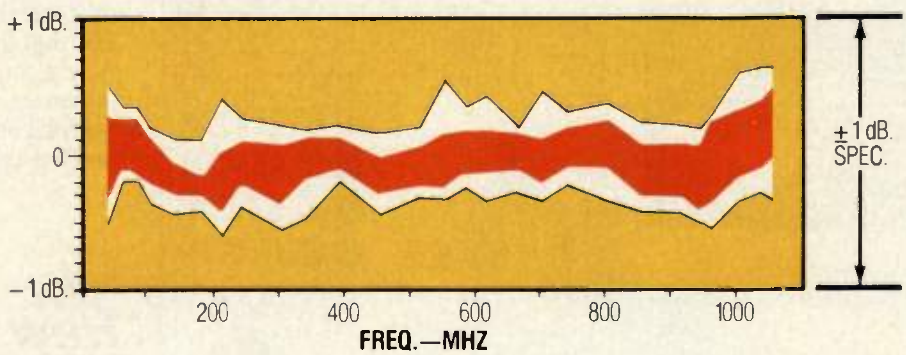
Advantest UK Limited CI Tower, St. Georges Square, High Street, New Malden, Surrey, KT3 4HH. U.K. Phone:(01)336-1606 Facsimile:(01)336-1657

For R4136 Demo, Circle INFO/CARD 46
For R4136 Literature, Circle INFO/CARD 47
For R4131 Demo, Circle INFO/CARD 48
For R4131 Literature, Circle INFO/CARD 49

WRH

FLUKE

Truth.



6060B typical level accuracy vs. frequency at −127 dBm.

Sample: 38 units. Solid line: worst case. Shaded: Typical (75%).

Getting the performance you expect from your instruments can sometimes be a pain. But not when it comes to the Fluke 6060B RF signal generator. It delivers more performance than you thought you paid for, even at the extremes.

On paper, most general purpose RF signal generators look pretty much the same.

But how they perform in your real-world test environment is another matter.

Take the Fluke 6060B. Its specified amplitude level accuracy in a typical working environment is ±1 dB. Nothing surprising there. Except that this performance is available over the entire dynamic range of −127 dBm to +13 dBm. What's more, as the chart above shows, typical performance is much better: 2:1 or more. Even at −127 dBm. And in the over range areas to +16 dBm and −140 dBm, the 6060B typically stays within its ±1 dB specification.

That means the devices you test can be specified and measured more precisely with increased confidence. Your test yields go up. And you can process more workload with a single signal generator.

What is the key to this extra margin of performance? Attention to the details. Software compensation techniques. And outstanding linearity and repeatability over the 6060B's amplitude and frequency range.

Which means you can be sure of your measurements. From instrument to instrument. Test to test.

ALLIANCE IN TEST & MEASUREMENT

PHILIPS

Hertz.

The 1.05 GHz Fluke 6060B.

The 6060B also offers a number of amenities that make it easy to use. Uncluttered front panel layout. Bright digit editing. Stored front panel set-ups. Increment stepping. And relative amplitude and frequency. To name a few.

The 6060B is just one member of a family of general purpose RF signal generators from Fluke, each designed to deliver more performance than you thought you paid for.

Test the true performance of the 6060B for yourself. Because what you don't know might hurt you. Call Fluke toll-free at **1-800-44-FLUKE** and arrange for a demonstration.

Fluke 6060B
10 kHz — 1.05 GHz
+13 dBm maximum output level
±1 dB level accuracy
-60 dBc spurious

John Fluke Mfg. Co., Inc., P.O. Box C9090, M/S 250C, Everett, WA 98206. U.S. (206) 356-5400. Canada (416) 890-7600. Other countries: (206) 356-5500. Specifications subject to change without notice. Ad no. 0881-F6060.

FLUKE

INFO/CARD 11

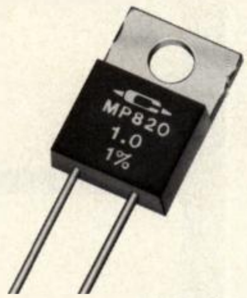
CADDOCK
ELECTRONICS, INCORPORATED

Low Resistance Power Resistors

Non-Inductive with Values Down to 0.1Ω

Type MP Kool-Tab™ Power Film Resistors

20 Watts in the TO-220 Package

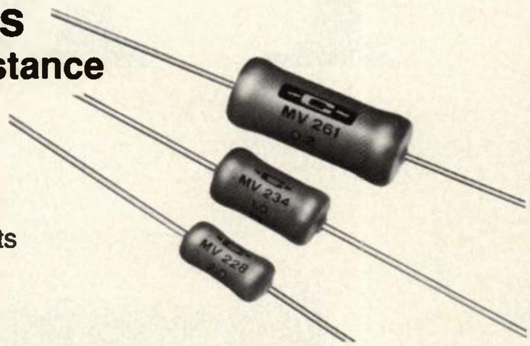


NEW

- ***Now available as low as 1 Ω***
- ***Non-Inductive***
- Made with Micronox® resistance film
- 20 Watts at 25°C case temperature
- Standard resistance tolerance of ±1%.

Type MV Power Film Resistors

Axial Lead Design with Very Low Resistance

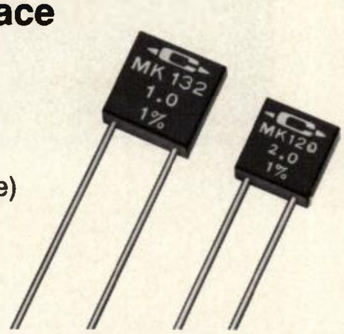


NEW

- ***Now available as low as 0.1 Ω***
- ***Non-Inductive***
- Made with Micronox® resistance film
- Wattage ratings from 1.5 watts to 10 watts
- Standard resistance tolerance of ±1%

Type MK Precision Power Film Resistors

Radial Lead Design Takes Less Board Space



NEW

- ***Now available as low as 1 Ω***
- ***Non-Inductive***
- Made with Micronox® resistance film
- 3/4 watt (CK06 size) and 1/2 watt (CK05 size)
- Full power rating at 125°C
- Standard resistance tolerance of ±1%

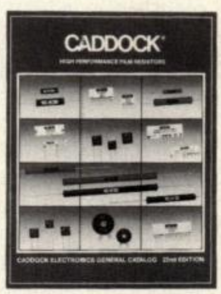
More high performance resistor products from

CADDOCK
ELECTRONICS, INCORPORATED

Call or write for your copies of product data sheets.

Applications Engineering
Caddock Electronics, Inc.
1717 Chicago Avenue
Riverside, Calif. 92507
(714) 788-1700

Also ask for the Caddock General Catalog which includes specifications on over 200 models of high performance resistor products.



rf letters

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

Antenna Reference

Editor:

In the February 1989 review of *The ARRL Antenna Book*, the reviewer stated that there was an error in the log periodic antenna data because the early work by Carrell, which later proved to be inaccurate, was used. Can your reviewer provide the reference for the later work which corrected Carrell's error? This reference was not given in the review.

William Orr
Menlo Park, California

The work referred to is:

P.C. Butson and G.T. Thompson, "A Note on the Calculation of the Gain of Log-Periodic Dipole Antennas," IEEE Trans. on Antennas and Propagation, *Jan. 1976, pp. 105-106.—Editor*

An Attentive Reader

Editor:

I have found Peter Martin's article 'Design of Line Matching Networks" (Feb. 1989, *RF Design*) very useful. I have, however, found a few bugs in the published article. Equation 8 should read as follows:

$$g_a = [b_b^2 + g_b^2 + y^2) \pm \sqrt{(b_b^2 + g_b^2 + y^2)^2 - 4y^2g_b^2}]/2g_b$$

Also, the last reference to Equation 7 (p. 101) should reference Equation 8.

Larry Leighton
Santa Cruz, California

Correction

In "CAD Optimizes the Gain of Dual Gate MOSFET VHF Amplifiers" (Feb. 1989, *RF Design*), Equations 1 and 2 should read:

$$Y_i' = K_0 + K_1F_i + K_2F_i^2 + ... + K_mF_i^m \quad (1)$$

$$S = \sum_{i=1}^{N} (Y_i' - y_i)^2 = \sum_{i=1}^{N} (K_0 + K_1F_i + ... + K_mF_i^m - y_i)^2 \quad (2)$$

NIST Scientists Investigate Diamond Films

Materials scientists at the National Institute of Standards and Technology (NIST) are developing the measurement information needed to produce diamond films with many of the properties of natural diamond. The physical and chemical properties of diamond make it a highly desirable material for aerospace products, electronics and industrial equipment. Diamond, the hardest known natural material, also has the highest thermal conductivity, and has very high electrical insulation characteristics. In addition, it is optically transparent and chemically stable or inert under most conditions.

Many applications for diamond film in advanced technologies are being considered, including high-temperature diamond transistors for use in unmanned spacecraft, diamond coatings for industrial applications, and microwave power generation. Diamond film substrates in electronic chips can improve efficiency by permitting a higher density of components, because diamond dissipates heat faster than other materials.

With modern technology, hydrocarbon vapors mixed with hydrogen can be made to deposit a film of diamond on hot objects. Scientists at NIST are focusing research on characterizing production processes, structures and other properties of diamond films to gain information that will aid in producing high-quality, high-performance advanced materials. Researchers are evaluating the production of diamond films by a hot filament chemical vapor deposition (CVD) method.

A variety of analytical techniques are being used to evaluate the synthesized diamond crystals on various materials. Diamond purity, surface quality of diamond films, the physical shape or morphology of diamond crystals, and diamond crystal structure are among the properties being studied. NIST researchers are measuring the thermal conductivity of diamond, particularly for optical applications like window material for anti-missile systems and for optoelectronics uses such as ultraviolet detectors. The scientists will also work to develop a better understanding of how defects such as nitrogen impurities and crystal lattice vacancies or voids can affect the performance of diamond films.

The scientists are concerned about the differences in the thermal expansion of various substrates and diamond as they cool during processing. This can lead to stress, fracture and the delamination of films. The substrate materials under investigation are silicon, silicon carbide and mullite — a silicate of aluminum with thermal expansion properties similar to those of diamond. Plans at NIST call for studies on how the crystal structure of each substrate material affects the growth and orientation of diamond crystals.

Denver to Host EMC Symposium and Frequency Control Symposium—The 1989 National IEEE Symposium on Electromagnetic Compatibility will convene May 23-25, 1989, at the Radisson Hotel in Denver, Colo. Enhancing Measurement Capability is the theme of this year's symposium, and a wide range of related topics will be covered in the technical program. Approximately 100 papers are scheduled to be presented in four concurrent sessions. Highlights include sessions on shielding, EMI test facilities, open area test sites, conducted EMI, electromagnetic pulse, EMC measurements, and automotive EMC. There will also be a workshop on New Measurement Procedures for Computing Devices, and one on RF Absorber Evaluation Techniques. More than 100 exhibits will be offering a look at the latest EMC equipment available. In addition, tours of the National Institute of Standards and Technology (NIST) and of Martin Marietta will be offered. For more information on the EMC Symposium, contact Jon Tary, Tri-State, 12076 Grant Street, Denver, CO 80233. Tel: (303) 452-6111

The 43rd Annual Frequency Control Symposium will be held May 31-June 2, 1989, at the Marriott Hotel, City Center in Denver, Colo. The symposium, cosponsored by the Institute of Electrical and Electronics Engineers (IEEE) and the Ultrasonics, Ferroelectrics and Frequency Control Society (UFFC), will present over 90 papers addressing frequency control and precision timekeeping topics. Highlights of the 20 technical sessions include a special session on environmental effects and their measurements, a session on surface preparation of quartz, including a tutorial on abrasive processes, and a session on two-way time transfer. Additional sessions will focus on microwave resonators and oscillators, resonator effects and phase noise, time and frequency measurement, crystal oscillators, piezoelectric resonators and filters, SAW devices and phase noise, and testing and measurement. Also scheduled is a tour of NIST, located in Boulder, Colo. For further information on the symposium, contact Michael Mirachi, Synergistic Management Inc., 3100 Route 138, Wall Township, NJ 07719. Tel: (201) 280-2022

Scientists Voice Opinions on Research Spending—The results of a recent survey indicate that most of the nation's top research scientists feel the U.S. government should spend less on defense-related research such as "Star Wars" and more on civilian programs like AIDS research. The survey, conducted by *Research & Development Magazine,* found that 56 percent of the scientists responding said the federal government spends too much on defense research. While not all the scientists agreed that defense-related R&D should be cut, fully 86 percent of those surveyed favored an average 10 percent increase in the amount of civilian-related research the government does.

Asked which research programs should be given top priority by the Bush administration, 65 percent of the scientists said work on high-temperature superconductivity should get top priority. Next, cited by 63 percent, was AIDS research. The Manned Space Station was ranked third in importance. To pay for the increase in medical and other civilian-related research, the majority of respondents favored cuts in defense spending, combined with increases in the federal taxes on cigarettes and liquor. A strong majority (60 percent) also favored boosting research and development tax credits for the private sector as a way of stimulating privately funded research.

William W. Eitel, 1908-1989— William W. Eitel, co-founder of what is now Varian's EIMAC Division, died February 26, 1989 in Palm Springs, Calif., where he was undergoing treatment for cancer. In 1934, Mr. Eitel joined with a fellow amateur radio enthusiast, Jack A. McCullough, to found Eitel-McCullough Inc. Their vacuum tubes, originally designed for amateur radio use, were quickly adopted for commercial and military transmitters and led to important advances in radio communications. "Eimac," as the new company was known, went on to become a leading U.S. producer of electron tubes and related devices. Under Mr. Eitel's leadership, the company continued to provide technical data and equipment to radio amateurs world-wide for many years. In August 1965, Eimac was merged into another Silicon Valley electron tube manufacturer, Varian Associates, and its locations in San Carlos, Calif., and Salt Lake City became Varian divisions, designations they retain to this day. Mr. Eitel served on Varian's Board of Directors from 1965 until his retirement in 1974, and remained a director emeritus of the company.

Company Offers Japanese Technology Reports—To assist U.S. and European companies in gaining immediate access to information about developments taking place in advanced materials research in Japan, a Japanese research and consulting institute, KRI International Inc., has initiated a major technology translation and analysis project. KRI's program is aimed at improving the traditionally limited access U.S. and European companies have had to information about Japanese technological advances. For example, last year, less than 20 percent of Japanese technical information —patent filings, research briefs and documentation — was translated and made available in English.

KRI's multi-phase program will include 12 in-depth reports on Japanese R&D activities in areas such as new magnetic materials, gallium arsenide and other semiconductors, liquid crystals, structural ceramics, ceramic composites, and ceramic sensors. The reports will include English translations of technical research currently underway in Japan, as well as market information, statistics and analysis. Thus far, KRI has produced three reports, focusing on photoresist materials, elctroconductive polymers, and polymer alloys and blends. For further information about these reports, contact: Takako Kawakami, Director, KRI-USA, 160 W. Santa Clara Street, Suite 810, San Jose, CA 95113. Tel: (408) 280-0733.

Varian Awarded Superconductivity Contract—Varian Associates Inc. has received a $1.5 million, two-year contract to fabricate and characterize high-temperature superconducting materials for potential use in linear accelerators. Awarded by the U.S. Army Strategic Defense Command in Huntsville, Ala., the contract calls for Varian to measure various properties of superconducting materials produced by Varian and other companies. Among the properties to be measured are secondary electron yield and RF breakdown, both of which are expected to be critical to the materials' suitability for use in compact high-efficiency linear accelerators. Linear accelerators are sophisticated microwave devices which speed up or accelerate electrons and direct them at a target material which converts the electrons into X-rays. The project will be conducted by Varian's Coupled-Cavity Tube Division in Palo Alto, Calif.

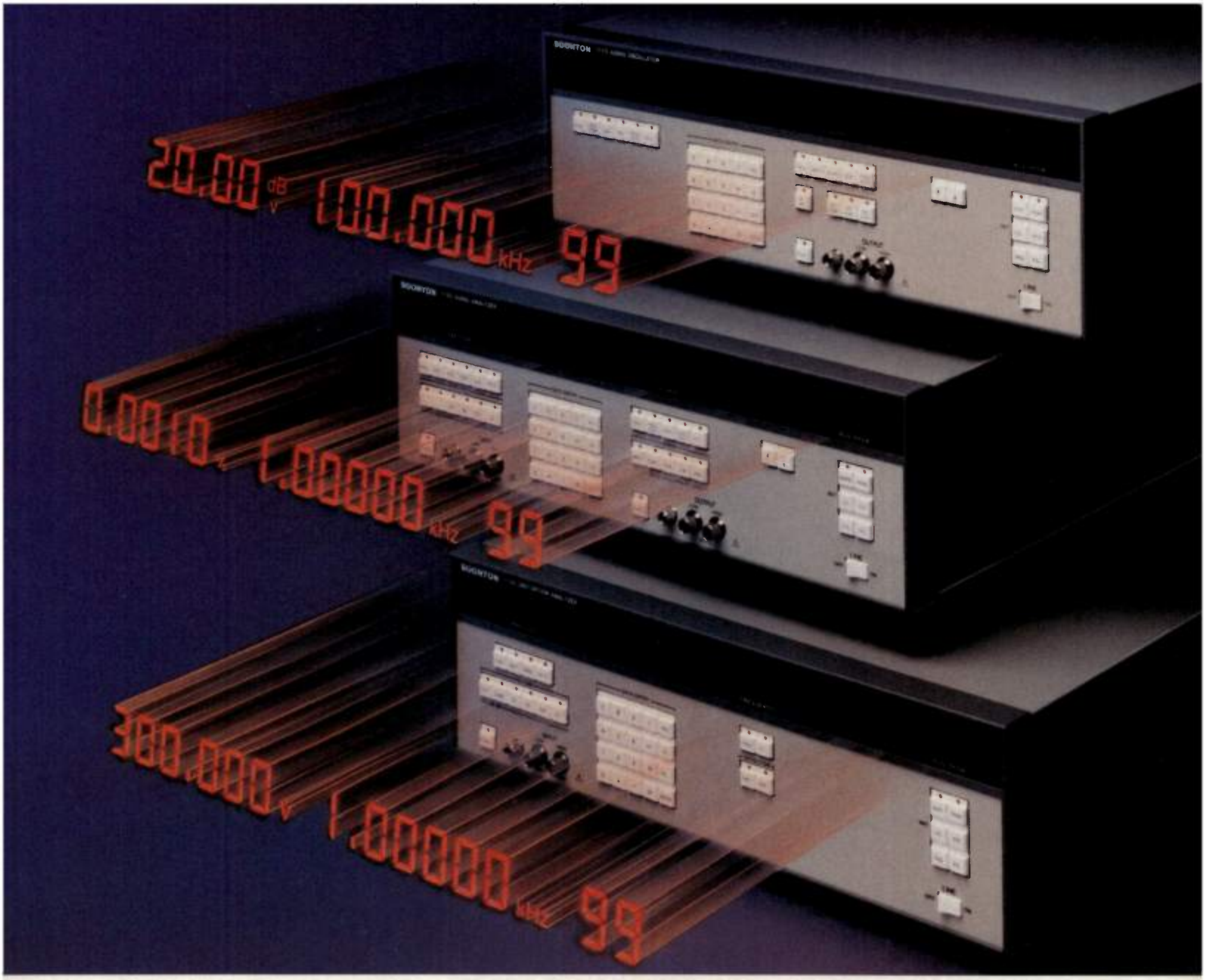
New RF Enterprise Announced—Richard A. Wainwright, founder of I-Tel Inc. and Cir-Q-Tel Inc., and two fellow engineers have founded a new company, Nano-Tech, P.O. Box 116, Kensington, MD 20895. The new company will deal with microminiature to very high power filters and PIN diode switches in the 5 kHz to 26 GHz frequency range, with heavy emphasis on surface mount. Nano-Tech has indicated it will soon be introducing superconductivity into many of its devices.

COMSAT Earth Station Contract Awarded—TIW Systems Inc., of Sunnyvale, Calif., has been awarded a $19 million contract by COMSAT World Systems Division to build and install Tracking, Telemetry and Control (TT&C) earth stations at Paumalu, Hawaii and Clarksburg, Md. The stations will be part of INTELSAT's Post 1989 TT&C Network. As COMSAT's turnkey supplier on these two earth station projects, TIW Systems will provide full and limited motion antennas for 9 and 19 meter C-Band, 15 meter TRMS, and 14.2 meter Ku-Band, as well as civil works, control buildings, feed systems, steptrack and monopulse tracking systems, full RF transmit and receive equipment, up and down conversion equipment, and monitor and control facilities.

AEL/Sanders Venture Chosen for TACJAM-A Work—The joint venture team of American Electronic Laboratories Inc. (AEL), an AEL Industries company, and Sanders Associates, a Lockheed company, has been selected to perform Phase II engineering and development on the Army's ground-based TACJAM-A mobile tactical jamming system. Initial funding of $3.9 million was received for the design, development and fabrication of a prototype and four engineering development models of the TACJAM-A system.

TUV/EMACO Merger Announced—TUV America Inc., of Danvers, Mass., and EMACO Inc., of San Diego, Calif., have announced the merger of their two companies. The new organization will offer expanded services for both Product Safety Service (PSS) and Radio Frequency Interference (RFI) compliance in U.S. and global markets.

Andersen Labs in Management Buyout—Andersen Laboratories Inc., of Bloomfield, Conn. has been purchased by a partnership led by the company's president, Ernest P. Hodur. Hodur purchased the company's assets with a partner, Creative Electric Inc., of Auburn, N.Y. Andersen Laboratories will continue to occupy its Bloomfield facilities, but has a new mailing address and phone number: Andersen Laboratories Inc., 45 Old Iron Ore Road, Bloomfield, CT 06002; (203) 286-9090.


20.00
dB
V
100.000
kHz
99
0.0010
1.00000
kHz
99
300.000
V
1.00000
kHz
99

In Ferrites for EMI suppression…

WE'RE INNOVATORS — NOT IMITATORS

WE'RE FAIR-RITE

While other ferrite manufacturers exploited existing markets, our R&D looked to the future—and keeps looking—to find better ways to put ferrite to work in the control of Electromagnetic Interference.

In addition to the beads and sleeves which are industry standards, we developed most of the ferrite EMI suppressors widely imitated today, and were the first to offer what has become a series of Engineering Evaluation Kits.

No other source offers faster service and more tooling know-how for unique shapes than Fair-Rite Products.

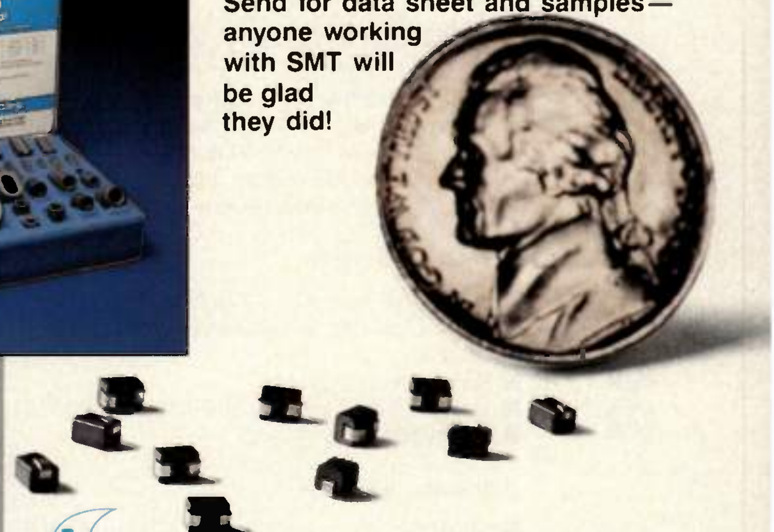
When it comes to EMI ferrites, the leaders come to Source One for quality, service and price from a U.S. manufacturer that supplies the world—FAIR-RITE

SURFACE MOUNT BEADS UPDATE

Z where you need it—
in a still smaller package.

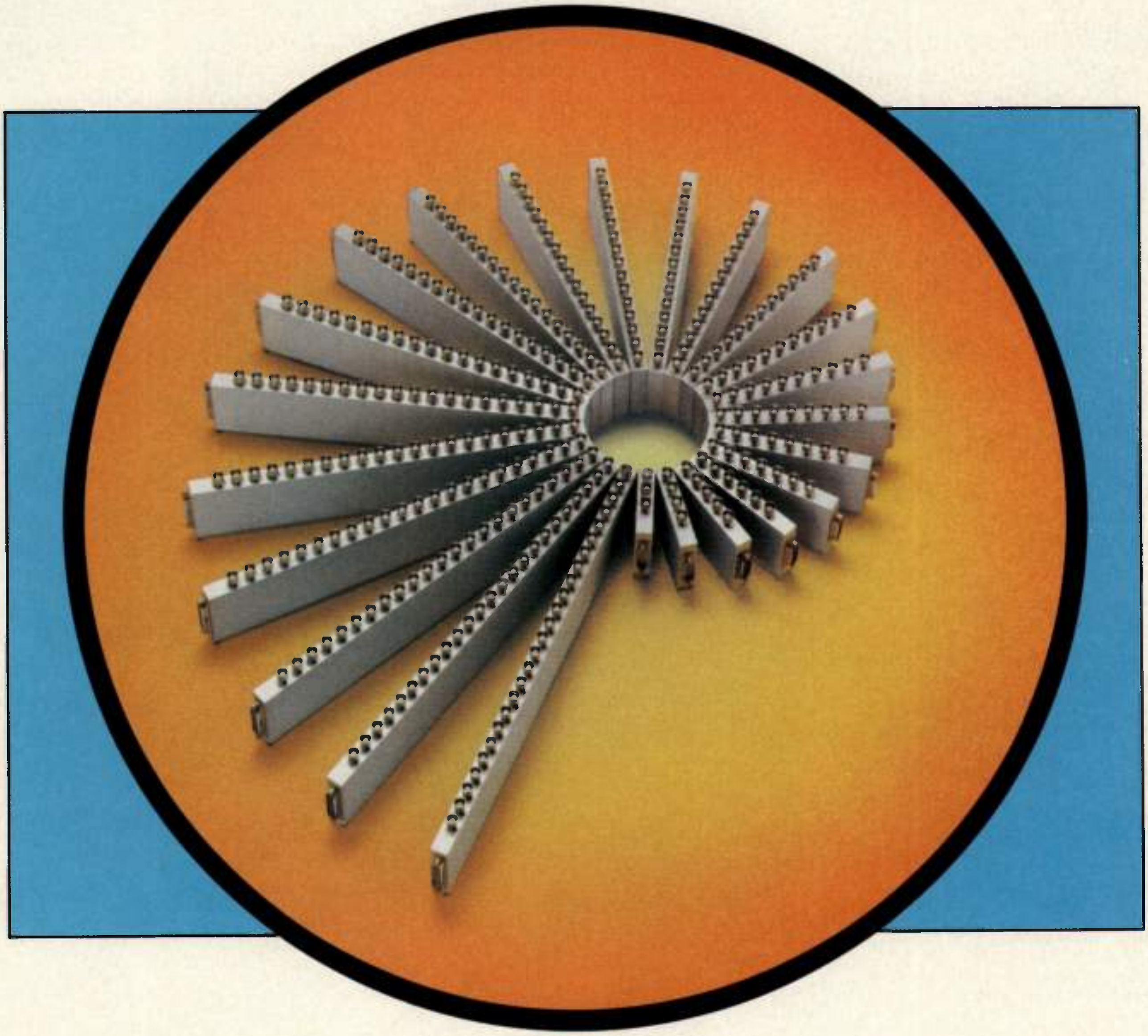
Part number 2743027447 offers a minimum impedance of 20 ohms from 100 MHz thru 1 GHz, and a maximum of .7 milliohm DC; all in a rugged package 1.75mm wide × 1.5mm high × 2.0mm long. The terminal electrodes measure 0.2mm thick × 0.6mm square. Manufactured from application proven 43 material ferrite, stability and reliability far exceed what other manufacturers achieve using multiple turn, high resistivity thru hole plating.

Send for data sheet and samples—anyone working with SMT will be glad they did!



Fair-Rite Products Corp.
PO Box J, One Commercial Row, Wallkill, NY 12589
Phone (914) 895-2055 • TWX 510-249-4819 • FAX (914) 895-2629

NEED BROAD-BAND COAXIAL RELAYS? FROM 2 TO 24 THROW, MATRIX HAS THE ANSWER



Our versatile 7000 series of coaxial relays have band-widths from DC up to 800 MHz. They're available from 2 to 24 throw. And by using our 9000 series cross-straps, switching matrices of any size can be configured.

Why have Matrix broad-band relays become the industry standard? Because we construct them of precision machined anodized aluminum alloy, all signal shield paths are silver plated, and basic switch elements are hermetically sealed in nitrogen filled gas envelopes with rhodium plated contacts to insure non-stick operation.

The end result is extremely low crosstalk, EMI and VSWR. Another plus, all switchpoints are individually field replaceable.

The units are plug compatible with Matrix 6100A and 1600 Series Logic Modules for compatibility with RS-232, RS-422 and IEEE-488 Interface busses as well as 16 bit parallel.

Non-blocking Matrix configuration may be easily assembled using our self-terminating relays and 5100A series power dividers. Built-in Video/RF amplifiers allow zero insertion loss designs.

So if you're looking for broad-band relays, it pays to deal with Matrix. After all, we've been designing state-of-the-art reed relay and semiconductor switching systems for over 18 years.

Our customers include government agencies, defense contractors, the TV industry, ATE and telecommunications companies—and more.

MATRIX
SYSTEMS CORPORATION

5177 NORTH DOUGLAS FIR ROAD
CALABASAS, CALIFORNIA 91302

Phone: 818-992-6776
TWX: 910-494-4975
FAX: 818-992-8521

INFO/CARD 19

Coilcraft Designer's Kits

First they save you time. Then they save you money.

These kits make it easier than ever to pick the right coils, chokes and other magnetics for your project.

Why waste hours calling around for samples or trying to wind them yourself. Coilcraft's low-cost kits put dozens of values right at your fingertips!

You not only save time on engineering. You also save money when you go into production because we stock just about all the parts in our kits at low off-the-shelf prices.

Call in today, and you can have your kit tomorrow!

To order, phone **800/322-COIL** (in Illinois 312/639-6400).

"Unicoil" 7/10 mm Tuneable Inductors
.0435 μH - 1.5 μH
49 shielded, 49 unshielded (2 of each)
Kit M102 $60

"Slot Ten" 10 mm Tuneable Inductors
0.7 μH - 1143 μH
18 shielded, 18 unshielded (3 of each)
Kit M100 $60

Surface Mount Inductors
4 nH - 33 μH
48 values (10 of each)
Kit C100 $125

Axial Lead Chokes
0.1 μH - 1000 μH
25 values (5 of each)
Kit F101 $50

Horizontal Mount Inductors
Tuneable and fixed
Inductance: 31.5 - 720nH
33 Values (6 of each)
Kit M104 $60

Common Mode Data Line Filters
Attenuation bandwidth: 15 dBm,1.5-30 mHz
DC current capacity: 100 mA
2, 3, 4 and 8 line styles (4 of each)
Kit D101 $65

Common Mode Line Chokes
Current: .25 - 9 amps RMS
Inductance: 508 μH - 10.5 mH
8 styles (2 of each)
Kit P202 $100

Current Sensors
Sensing range: 0.5-35 amps
Freq. resp.: 1 - 100 kHz, 50 - 400 Hz
Transformer and sensor-only versions
8 styles (15 total pieces)
Kit P203 $50

Base/Gate Driver Transformers
Inductance: 1.5 mH Min.
Frequency: 10 - 250 kHz
2 single, 2 double section (2 of each)
Kit P204 $50

Mag Amp Toroids
Current: 1, 5 amps
Volt-time product: 42 - 372 V-μsec
6 styles (2 of each)
Kit P206 $100

Power Filter Chokes
Current: 3, 5, 10 amps
Inductance: 5 - 300 μH
18 styles (48 total pieces)
Kit P205 $75

Axial Lead Power Chokes
Current: .03-4.3 amps
Inductance: 3.9 μH - 100 mH
60 styles (2 of each)
Kit P209 $150

Coilcraft

eem/electronic engineers master See our catalog in Vol. A, Section 1800

1102 Silver Lake Road, Cary IL 60013 800/322-COIL Fax 312/639-1469

Current Activity in Frequency Synthesis

By Mark Gomez
Technical Editor

Direct-digital synthesis (DDS) has been receiving a great deal of attention recently. This is because it has a relatively high speed of acquisition and is easier to FM modulate than phase-locked loops (PLLs) over a broad bandwidth. There have also been breakthroughs in spurious noise levels to the point where they are useful for various new applications. "Small frequency steps usually translate into slow acquisition. However, this acquisition is practically instantaneous when a direct-digital synthesizer is used," says Andy Przedpelski, vice-president—development at A.R.F. Products. According to Earl McCune, vice-president of engineering and technology at Digital RF Solutions, the growth in DDS is primarily because spurious levels are down to where they are useful in radio applications. In terms of numbers, this is in the 60 to 70 dBc range. "Achieving parameters such as low phase noise, agility, and resolution in the low hertz type range is especially good for marketplaces like frequency hopping radios," comments McCune. "DDS approaches theoretical perfection as a signal source when its two limiting characteristics improve," says Henry Eisenson, president of Sciteq. "Its limitations," he points out, "are bandwidth and spectral purity."

One of the main reasons for the limitations in DDS clocking frequency is the digital-to-analog converter (DAC). "It is the DAC technology that is holding up the advancement of DDS. We are waiting for high-speed 12-bit DACs to become available," says Gwyn Edwards, custom products manager at Stanford Telecommunications. Steve Morley, VLSI product manager at Qualcomm, feels that from a performance point of view, the improvements in DAC technology will actually assist in the DDS market development much more than perhaps new evolutionary DDS products themselves.

As improvements occur in bandwidth and spurious performance, the applications for DDS increase. This translates into market growth. "I feel the marketplace growing very rapidly and we are in the middle of it," says McCune. "We are starting to move into all sorts of new markets from instrumentation to control systems," states Edwards. When applications increase, quantities increase and this in turn results in more competitive pricing. As companies move down the learning curve, they are able to offer these products at lower prices. Also, after an evaluation period, vendors start seeing quantity orders and this helps in cost reduction. Morley sees about a one-year evaluation cycle before high volume orders are placed. "Pricing is headed down. This is because as usage increases, the demand pushes prices down," comments Eisenson.

To promote new technologies, education is needed. DDS is no exception. RF engineers who know about phase-locked loops, voltage-controlled oscillators (VCOs) and other synthesis products are having to rethink their design approach to use the special characteristics that make DDS an efficient and powerful means of synthesizing frequencies. McCune says, "The big thing is demonstrating that DDS really does solve problems." Eisenson comments that he quite often runs into system architects that do not understand the DDS function. He adds, "We are currently embarked on a very serious education program for those folks." In general, it is wise to look beyond trying to retrofit a phase-locked loop circuit with a DDS and examine the functions that can be performed with DDS that could not be done by conventional methods. "Our challenge has been to educate the market on how to rethink frequency synthesis with digital techniques. Most engineers know the basics, but we usually have to highlight the special advantages and features," remarks Morley.

Other Forms of Synthesis

Frequency synthesis includes three fundamental disciplines: direct-analog, direct-digital, and phase-locked loops. Combination of a DDS with a PLL produces lower division ratios for a given step size. This translates to lower phase noise. Similarly, direct-analog in conjunction with a DDS reduces the number of echelons of direct-analog stages required for a given step size.

Conventional circuits like phase-locked loops have attributes that make them more desirable for various circuit functions. "For high frequencies, above the DDS basic frequency range, it is useful to stay with phase-locked loops. This is because the designer has to multiply the frequency as needed and still use a PLL," says Przedpelski. He adds that for a single frequency synthesis, it is generally simpler to use a PLL than a DDS.

As DDS advances, technologies surrounding other forms of frequency synthesis are also advancing. In the area of PLLs, advancements in products such as prescalars and voltage-controlled oscillators are evident. "There are substantial technological advances occurring in phase-locked loop design," says Eisenson. According to Bob Dixon, chief scientist at Spread Spectrum Sciences, there is a great deal of emphasis going into lower current prescalars. "One of the toughest things to build," he says, "is a low current frequency synthesizer that is supposed to shift frequencies quickly." Dan Gavin, president of RF Prototype Systems, stresses that there are not enough intermediate-performance, reasonably priced products like VCOs available on the market. "Many designers do not need the high performance but end up paying for it," he remarks. "Over the next nine months, we will be introducing a line of phase-locked VCOs that are priced fairly low while maybe sacrificing some performance," notes Gavin.

Frequency synthesizers range from simple, digitally tuned oscillators to complex instruments. Products like "pure" synthesizers are also seeing new advances. "We have recently completed the design of a GPIB for our synthesizers that covers phase rotation," says George Lohrer, president of Programmed Test Sources. A 20 percent over-range option is also being used on his instruments. This feature will overcome problems encountered while working at the edge of a band.

In general, frequency synthesis will see continued change over the next year. More competitive pricing, better specifications and new options are just some of the things that RF engineers can expect from this rapidly advancing field. rf

rf calendar

May 22-24, 1989
39th Electronic Components Conference
The Westin Hotels, Houston, TX
Information: EIA, 1722 Eye Street, N.W., Washington, DC 20006. Tel: (202) 457-4930

May 23-25, 1989
IEEE 1989 National EMC Symposium
Radisson Hotel, Denver, CO
Information: Jon Tary, Tri-State, 12076 Grant Street, Denver, CO 80233. Tel: (303) 452-6111

May 23-25, 1989
SEMICON/West 89
San Mateo County Fairgrounds, San Mateo, CA
Information: Semiconductor Equipment and Materials International, 805 E. Middlefield Road, Mountain View, CA 94043. Tel: (415) 946-5111

May 31-June 2, 1989
43rd Annual Frequency Control Symposium
Denver Marriott Hotel — City Center, Denver, CO
Information: Michael Mirachi, Synergistic Management Inc., 3100 Route 138, Wall Township, NJ 07719. Tel: (201) 280-2022

June 5-7, 1989
NBS/Boulder Time and Frequency Seminar
Boulder, CO
Information: David Allan, NIST, 325 Broadway, M/S 576, Boulder, CO 80303. Tel: (303) 497-5637

June 12-13, 1989
1989 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium
Long Beach Convention Center, Long Beach, CA
Information: LRW Associates, 1218 Balfour Drive, Arnold, MD 21012. Tel: (301) 647-1591

June 13-15, 1989
1989 IEEE/MTT-S Exhibition
Long Beach Convention Center, Long Beach, CA
Information: Chuck Swift, Symposium Steering Committee Chairman, C.W. Swift and Associates, 15216 Burbank Boulevard, Suite 300, Van Nuys, CA 91411. Tel: (818) 989-1133

June 14, 1989
EEsof User's Group Meeting
Ramada Renaissance Hotel, Long Beach, CA
Information: M. Surks, EEsof Inc., 5795 Lindero Canyon Road, Westlake Village, CA 91362. Tel: (818) 991-7530, ext. 135.

June 15-16, 1989
33rd Annual ARFTG Conference
Long Beach Convention Center, Long Beach, CA
Information: Automatic RF Techniques Group (ARFTG), P.O. Box 2182, Longmont, CO 80502-2182.

rf courses

The George Washington University

Mobile Cellular Telecommunications Systems
June 5-9, 1989, Washington, DC
Spread-Spectrum Communications Systems
June 5-9, 1989, Washington, DC
ELINT: Analyzing Radar Signals
June 6-8, 1989, Washington, DC
Electronic Countermeasures
June 19-23, 1989, San Diego, CA

Information: Misael Rodriguez, Continuing Engineering Education, George Washington University, Washington, DC 20052. Tel: (800) 424-9773; (202) 994-6106

Compliance Engineering

EMI
June 20, 1989, Chicago, IL
Safety
June 21, 1989, Chicago, IL
ESD
June 22, 1989, Chicago, IL
Telecom
June 23, 1989, Chicago, IL

Information: Compliance Engineering, 629 Massachusetts Avenue, Boxboro, MA 01719. Tel: (508) 264-4208.

EEsof Inc.

Computer-Aided Engineering for Nonlinear Microwave Circuits (mwSpice)
May 18-19, 1989, Westlake Village, CA
Computer-Aided Engineering/Drafting for Microwave Circuits (Academy)
June 5-7, 1989, Westlake Village, CA
Computer-Aided Engineering for Linear Microwave Circuits (Touchstone)
June 19-21, 1989, Westlake Village, CA

Information: Sande Scoredos, Training Coordinator, EEsof Inc., 5795 Lindero Canyon Road, Westlake Village, CA 91362. Tel: (818) 991-7530, ext. 197

Integrated Computer Systems

C Programming Hands-On Workshop
May 23-26, 1989, Los Angeles, CA
June 20-23, 1989, San Francisco, CA
Introduction to Telecommunications
May 23-26, 1989, Boston, MA
June 20-23, 1989, Washington, DC
Digital Signal Processing: Techniques and Applications
May 23-26, 1989, Washington, DC
June 27-30, 1989, San Diego, CA

Information: John Valenti, Integrated Computer Systems, 6053 W. Century Boulevard, P.O. Box 45974, Los Angeles, CA 90045-0974. Tel: (800) 421-8166; (213) 417-8888

rf courses Continued

Interference Control Technologies, Inc.

Practical EMI Fixes
May 22-26, 1989, Palo Alto, CA
Intro to EMI/RFI/EMC
May 23-25, 1989, Washington, DC
EMC Design and Measurement
June 5-9, 1989, Washington, DC
TEMPEST Design and Measurement
June 20-23, 1989, Washington, DC

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

Liberty Labs, Inc.

EMC Laboratory Quality Assurance and Assessment Seminar
June 13-15, 1989, Main Amana, IA

Information: Liberty Labs, Inc., 4920 Johnson Avenue N.W., P.O. Box 8268, Cedar Rapids, IA 52408. Tel: (319) 390-3646

R & B Enterprises

Introduction to MIL-STD-461C
May 24, 1989, San Francisco, CA
Printed Circuit Board and Wiring Design for EMI and ESD Control
May 31-June 1, 1989, Philadelphia, PA
TEMPEST: Facility Design
June 6-8, 1989, Philadelphia, PA
TEMPEST: Documentation and Reports
June 12-14, 1989, Philadelphia, PA

Information: Registrar, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428. Tel: (215) 825-1966

Research Associates of Syracuse Inc.

Electronic Intelligence Interception
May 15-17, 1989, Syracuse, NY
Electronic Intelligence Analysis
July 19-21, 1989, Syracuse, NY

Information: Research Associates of Syracuse Inc., Hancock Army Complex, 510 Stewart Drive, N. Syracuse, NY 13212. Tel: (315) 455-7157.

UCLA Extension

Microwave Circuit Design I: Linear Circuits
June 19-23, 1989, Los Angeles, CA
Microwave Circuit Design II: Nonlinear Circuits
June 26-30, 1989, Los Angeles, CA

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

PERFORMANCE THAT RIVALS NATURE'S POWER

Versatile, super-power tetrodes are designed for tough, on-the-job results under difficult circumstances. For CW or long pulse service in plasma heating and accelerator applications, rugged Varian Eimac power tubes fill your needs.

The table below shows examples of 8973 performance.

Ion Cyclotron Heating		
Frequency (MHz)	Power Output	Pulse Length
25-50	1.5 MW	20 Seconds
110-130	750 KW	10 Seconds
10-40	1.5 MW	300 Milliseconds
29-50	1.5 MW	3 Seconds

It takes a sturdy, reliable power tube to have results like these and the 8973 is doing it, day after day.

Another example, the X-2242 has demonstrated 2.5 megawatts at 80 MHz and 1.5 megawatts at 110 MHz. All of this, plus 1.4 megawatts anode dissipation rating make Eimac tubes the best choice.

varian
eimac san carlos division

301 Industrial Way, San Carlos, CA 94070, 415 592-1221

Varian Eimac cavity RF amplifiers and oscillators have proven to be rugged and reliable, especially when pulse power is required. Typical cavity products are listed below and have demonstrated performance in TACAN, IFF, Electronic Warfare, Radar, Communications, Hyperthermia and Linear Accelerators.

	CV-8020	CV-8025	CV-8055	CV-8024
Frequency (MHz)	960-1215 (Single knob tuned)	900-970 (Instantaneous bandwidth)	400-900 (Any 100 MHz segment)	400-500 (Single knob tuned)
Power (Watts)	5,000 peak	15,000 peak	40,000 peak	60,000 peak
Pulse Length	3.5μ Sec Gaussian	10μ Sec	10μ Sec	60μ Sec
Duty Cycle	0.04	0.03	0.02	0.02
Gain	>13 dB	>13 dB	>13 dB	>13 dB

A complete line of high frequency RF products is available.

For over two decades a tradition of manufacturing quality products has shown Varian Eimac to be the recognized leader in cost effective cavity amplifiers and oscillators.

varian
eimac salt lake division

1678 S. Pioneer Road, Salt Lake City, UT 84104, 801 972-5000

Cellular Chip Set Speeds Design-to-Production Process

Cellular radio telephones have gained a popularity that has exceeded most industry predictions, but the most rapid growth has only begun. Two factors are contributing to the developing boom: Consumer acceptance, now that the technology has been proven; and the falling cost of equipment. Both of these factors have been aided substantially by the worldwide implementation of cellular systems.

A highly integrated chip set for cellular telephones has been developed by Philips Components, Surrey, England and Signetics Company, Sunnyvale, California. In an effort coordinated by Philips headquarters in The Netherlands, these divisions will offer a six-device set targeted at battery-powered portable handsets, in addition to supporting traditional mobile telephones. The set is intended for single-board designs, where its high level of integration can reduce component count and circuit complexity. It is compatible with both the AMPS (Advanced Mobile Phone Service) protocol used in the U.S. and TACS (Total Access Communication System), used in the U.K. Other systems

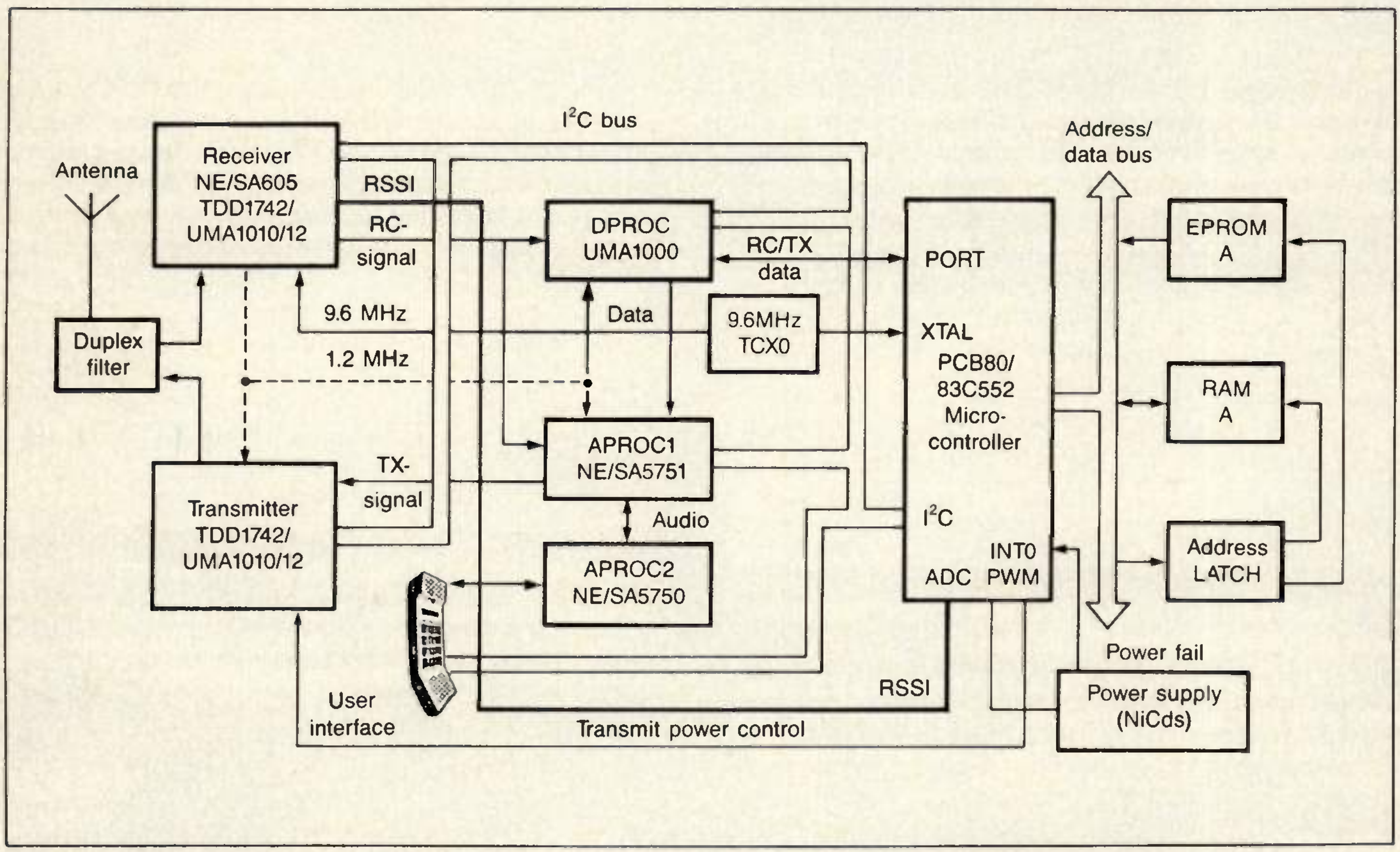
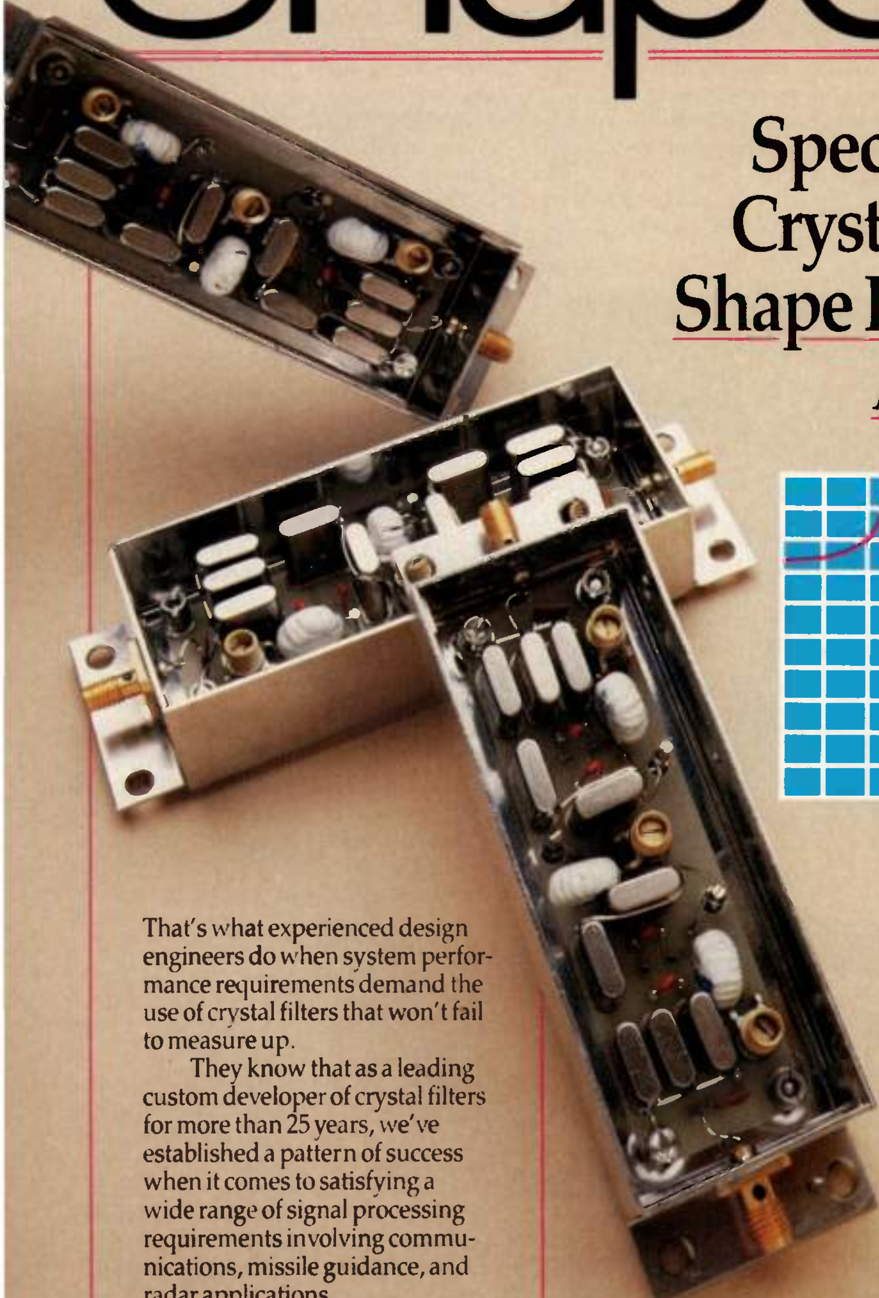
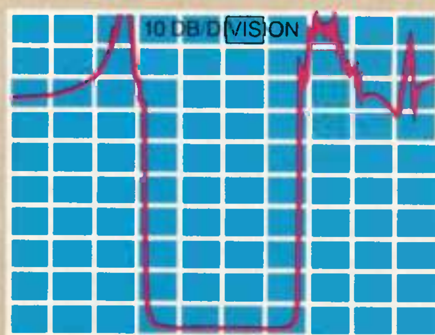


Figure 1. AMPS or TACS cellular radio telephone system using the Philips/Signetics chip set.

Shape Up!



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



That's what experienced design engineers do when system performance requirements demand the use of crystal filters that won't fail to measure up.

They know that as a leading custom developer of crystal filters for more than 25 years, we've established a pattern of success when it comes to satisfying a wide range of signal processing requirements involving communications, missile guidance, and radar applications.

And that in the process, we've earned a reputation for meeting some rather imposing specifications in the 10KHz–150MHz range with a set of equally imposing accomplishments that include: Shape factors as steep as 1.05:1 with 80dB attenuation levels... Phase and amplitude matching within the tightest tolerances... And passbands that remain constant over a wide temperature range.

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

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

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

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

Damon also manufactures a full line of V.C.X.O.'s, T.C.X.O.'s and S.A.W. Delay Lines.

DAMON/ELECTRONICS DIVISION

80 WILSON WAY, WESTWOOD, MASS. 02090, TEL: (617) 329-2460
FAX (617) 329-0551, TWX 710-348-6722

are supported by all or part of the set.

The Chip Set Devices

Refer to the block diagram shown in Figure 1. Note that only a portion of the 900 MHz receiver and transmitter stages are part of the chip set, although Philips has components for the remaining circuits available from their Amperex division. The following six devices make up the set:

UMA1000 Data Processor for Cellular Radio (DPROC). This is a fully integrated data processing chip, handling all data transceiving, data processing and SAT (Supervisory Audio Tone) functions associated with cellular communications. This CMOS device draws only 2 mA from a 5-volt supply, meeting its part of the chip set's goal of minimum power consumption. Also, the functions included in the UMA1000 allow the system's microcontroller to be in a power-down mode as much as 90 percent of the time.

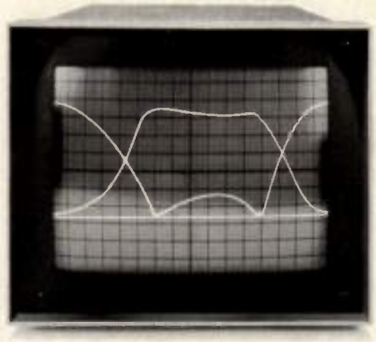
80C552/83C552 Single-Chip 8-bit Microcontroller. Derived from the more familiar 80C51 family, this chip comes in two versions: the 83C552 has 8 K bytes of mask-programmable ROM, while the 80C552 does not include the ROM. Both share all other features described here, including 256 bytes of RAM, six 8-bit input/output (I/O) ports, an 8-input analog-to-digital converter (ADC), and two pulse width modulated (PWM) outputs with 8-bit resolution. The microcontroller can be expanded using external TTL-compatible memories and logic.

Additional features include two 16-bit timer/event counters, another 16-bit counter coupled to capture and compare latches, five 8-bit I/O ports, full-duplex UART, on-chip watchdog timer, and an interface for the Philips I^{2}C serial bus. This communications bus allows a simple two-wire connection to tie together the various members of the chip set.

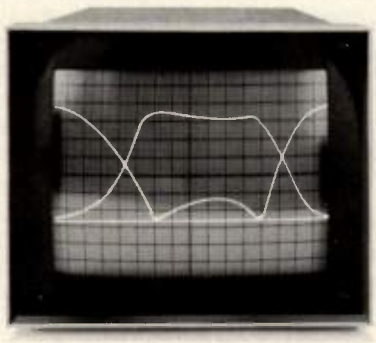
NE5750 and NE5751 Audio Processor System. Two more members of the IC family provide audio processing functions. The NE5750 contains functions more easily obtained with its bipolar process. On this chip are a low-noise microphone preamplifier with adjustable gain, a noise-cancellation switching amplifier with adjustable threshold, voice-operated transmit (VOX) switch and controls, audio compressor, audio expander, speaker amplifier, earphone amplifier with sidetone capabilities, and an internal voltage regulator with power-down capability drawing only 2.4 mA at 5.0 V in the standby mode.

The CMOS NE5751 contains the I^{2}C interface circuitry for the audio processing pair, plus these additional functions: complementary 300-3000 Hz transmit and receive switched-capacitor bandpass filters, including pre- and de-emphasis, a transmit lowpass filter, deviation limiter, digitally controlled volume control with 30 dB range, audio mute switches, programmable DTMF generator, power-down and power-up reset circuitry. Simple interconnection and minimum external circuitry were designed into this audio processing system.

NE605 Mixer/Oscillator and FM IF System. The second mixer, intermediate frequency (IF), and detector functions



Their $14,000 sweep.



Wavetek's $7,000 sweep.

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

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

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

Exactly what you want.

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

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

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

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

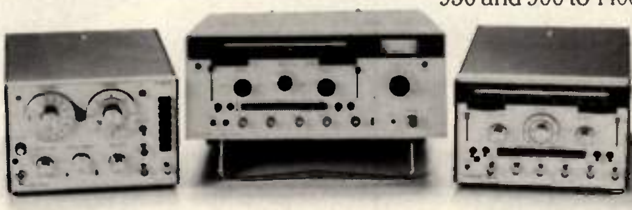
And our 1801C, with its 75 Ω output and 1 to 1000 MHz range, is ideal for CATV and broadband LAN applications. Its one wide band VCO eliminates the transients found in band switching instruments.

You buy only what you need.

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

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

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



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

WAVETEK®

INFO/CARD 45

are performed by this IC. The mixer can operate up to 500 MHz, and the internal oscillator can be used up to 150 MHz, or an external local oscillator (LO) as high as 1 GHz can be employed. A two-section limiting IF can operate as high as 21 MHz, and provides 102 dB gain, with interstage impedances compatible with inexpensive ceramic IF filters. An internal quadrature detector provides demodulation, and both unmuted and muted audio outputs are included. The received signal strength indicator (RSSI) has 90 dB dynamic range.

TDD1742 Low Power Frequency Synthesizer. A low-power CMOS circuit, the TDD1742 has a high gain phase comparator, on-chip sample-and-hold capacitor, and phase modulator. An auxiliary digital phase detector allows fast locking. The chip can be used for either transmitter or receiver frequency control with an external prescaler. A bus-structured interface connects the synthesizer to the microcontroller.

Use of these devices is not limited to one or two cellular systems. Support of systems other than AMPS or TACS is outlined in Table 1.

More on the I²C Bus

One of the key elements of the system is the I²C serial cata bus, a true multi-master control bus that preserves simple master/slave relationships between ICs. A simple two-wire system, the bus is software-enab ed, allowing additional chips without additional wires. It was designed to reduce circuit board area, assembly time, and production testing. Software control of power-down and "wake-up" when an incoming call is received greatly extends battery life in handheld portable units. It is expected that battery life (in a standby mode, waiting for a call) would be increased from an hour or two to as long as eight hours, with battery packs presently used.

The I²C bus is used in other Philips IC families, as well, for space-saving interface of microccntrollers, I/O devices, displays, memories, and analog signal circuits. Applications include telephones, instruments, audio/video/radio systems, data acquis tion, and automotive systems, as well as cellular radio. Other I²C bus devices which might be used in mobile telephone systems are

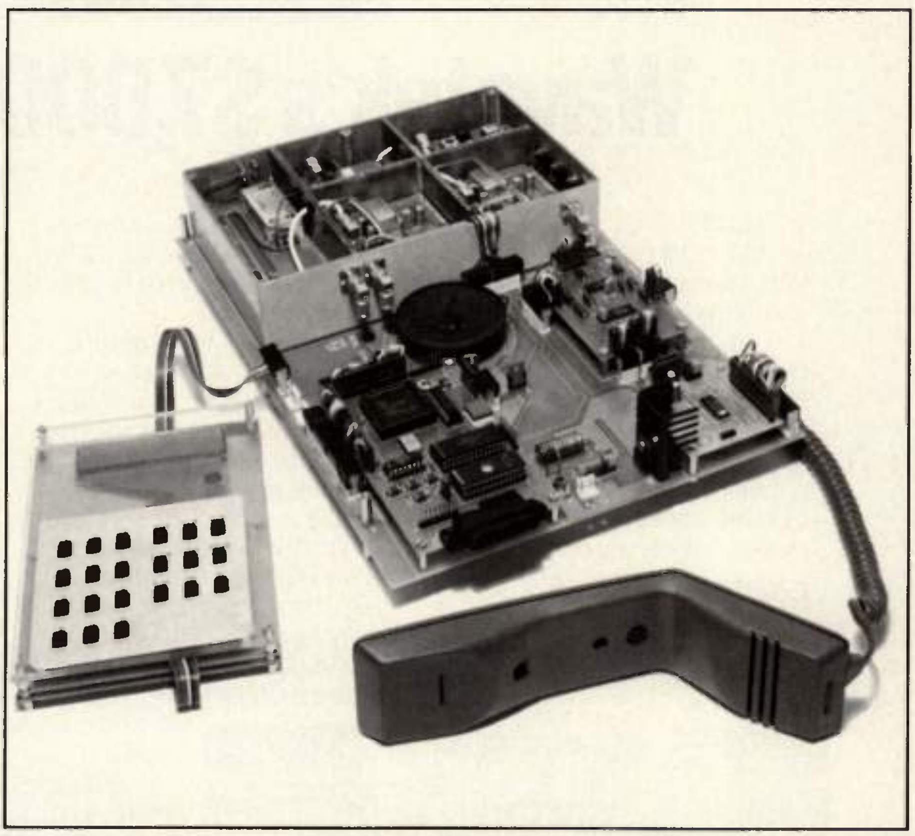


Figure 2. An evaluation system is available to demonstrate the use of the chip set.

	F. Synth.	UMA1000	NE5750	NE5751	NE605	Micro
AMPS	TDD1742T UMA1010T	✓	✓	✓	✓	80C552
TACS	TDD1742T UMA1010T	✓	✓	✓	✓	80C552
NMT450	TDD1742T UMA1010T/12T	N/A	Compandor not used	Addition.4kHz not required	✓	80C552
NMT900	TDD1742T UMA1010T	N/A	✓	Addition.4kHz not required	✓	80C552
RC2000	TDD1742T UMA1010T/12T	N/A	Possible	Extra filtering required	✓	80C552/652
NETZC	TDD1742T UMA1012T	N/A	N/A	N/A	✓	80C552/652
cordless CEPT-900	TDD1742T UMA1010T	N/A	✓	✓	Possible	33xx 84Cxx 80C652/751
cordless 46/49 MHz	TDD1742T possible	N/A	Possible	Possible	Possible	33xx
Band 3 trunked	TDD1742T UMA1012T	N/A	Possible	Possible	✓	80C652
P.M.R.	TDD1742T UMA1012T	N/A	Possible	Possible	✓	80C652/751

Table 1. Chip set applications in different systems.

shown in Table 2.

This integrated solution to the design of cellular radio telephones will allow small companies to bring products to market quickly, at competitive prices. For all cellular manufacturers, of all sizes, the chip set will lead the way to inexpensive units, but with sufficient expansion capability for additional operating convenience and performance features.

In production quantities, the chip set will cost approximately $60. Extensive applications support is available, including an evaluation system which includes this chip set, plus additional circuitry to make a complete and functioning cellular telephone (Figure 2). For more information on this chip set and Signetics/Philips efforts to support the cellular industry, contact Matt Robison at Signetics Company, MS-79, P.O. Box 3409, Sunnyvale, CA 94088-3409. The telephone number is (408) 991-4535. Information may also be obtained by circling INFO/CARD #181.

PCD3311/12	– DTMF tone generator
PCF8566	– Universal LCD driver max 96 segments
PCF8570	– 256 × 8-Bit static RAM
PCF8571	– 128 × 8-Bit static RAM
PCF8573	– Clock calendar chip
PCF8574	– Remote 8-Bit I/O expander
PCF8576	– Universal LCD driver max 160 segments
PCF8577	– Direct LCD driver 64 segments
PCF8582	– 256 × 8-Bit EEPROM
PCF8583	– 256 byte static RAM with clock/calendar
PCF8584	– 8-Bit parallel Bus to I²C protocol converter
PCF8591	– 8-Bit A/D D/A converter

Table 2. Additional I²C bus devices which may be used in mobile radio telephone systems.

rf featured technology

A Mixer Spurious Plotting Program

By Richard Bain
E-Systems, ECI Division

Mixers are essential building blocks in most communications systems and many pieces of test equipment. Unfortunately, the nonlinear characteristics that enable them to translate signals up and down in frequency result in many undesired products. The frequencies and orders of these products must be identified to determine whether or not they interfere with desired signals in the equipment being designed. It is possible to analyze these signals with pencil, paper and a calculator, or using a normalized spur chart, but this can be tedious and lengthy when considering many orders of spurious. The program described in this article, named SPURPLOT, will quickly calculate and plot these spurious products.

The mixer-generated spurious that the designer is concerned with can be expressed as either:

$$N^*F_x + M^*F_{lo} = F_{out} \quad (1), \text{ or}$$
$$F_x = N^*F_{in} + M^*F_{lo} \quad (2)$$

Where, N and M are integer multipliers, N + M is the order of the spurious, F_x is the frequency of the undesired signal, F_{in} is the mixer input frequency, F_{out} is the mixer output frequency, and F_{lo} is the LO (local oscillator) frequency.

There are two equations shown for spurious because there are two different situations where spurious are of concern. The first situation is what I call the receiver (RX) case and equation 1 is appropriate. I call the second the transmitter (TX) case, and equation 2 is appropriate. In the receiver case, a low level desired signal is generally being mixed down to some lower frequency, the IF (intermediate frequency). The concern in the RX case is that a high level undesired or adjacent channel signal at some frequency within the mixer input bandwidth causes an interfering signal at the same frequency as the desired output. This undesired output is caused by harmonics of the undesired signal mixing with harmonics of the LO.

In the second (TX) case, the spurious signal falls somewhere in the bandwidth of the mixer output filter. The spurious signal is generated by harmonics of the desired signal mixing with harmonics of the LO. Therefore, equation 2 is useful in predicting this type of spurious at the output of transmitters, upconverters and synthesizers that use mixers. In the receiver case, high level signals from an antenna can be present at the mixer input, but in the transmitter case, the only high level signals that would normally be present are the intended inputs and their harmonics.

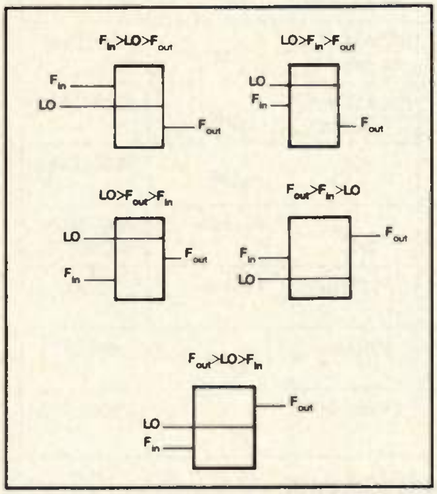


Figure 1. Frequency relationships for the five menu selections.

The idea for this program came from an article in *Electronic Design* by David Westwood (1). He described the five possible mixer modes and derived the equations needed to analyze the spurious products for several cases. The basic equations he started with are as follows:

$$N1^*F_{in} + M1^*LO = F_{out} \quad (3)$$
$$N^*F_x + M^*LO = F_{out} \quad (4)$$
$$deltaf_x = F_x - F_{in} \quad (5)$$

Where, N1 and M1 are +1 or −1 to designate whether the signals are added or subtracted, and $deltaf_x$ is the difference between the frequency of the desired input signal and that of the undesired signal. Equation 4 is the same as equation 1. Note that for the transmitter case, equation 4 should be replaced with equation 2.

Equations 3, 4, and 5 are used to derive equations which are then used to plot the difference between the X axis frequency and the spurious frequency. Four different sets of equations must be derived to cover the combination of the three fixed frequency options and the RX and TX conditions. The equations used by the program are listed in Appendix 1, and a sample derivation for two of the equations is shown in Appendix 2. These equations are solved by the program to obtain the coordinates of the points where the spurious lines intercept the edges of the plotting area. These points are then used to plot the spurious lines.

The Westwood article had a graphical representation that is helpful in understanding the relationship of the frequencies involved in the five different mixer modes. A similar representation, with the symbols used in this article, is shown in Figure 1.

SPURPLOT Features

The SPURPLOT program will analyze any of the five mixer modes shown in Figure 1. The input menu is reproduced in Figure 2. The relationship of the input, output and LO frequencies is shown to the right of each of the menu selections. There is also a program information section that explains some of the program features. Once the mixer mode has been selected, the user is asked to specify which of the mixer ports has a fixed frequency input and what the fixed frequency is. The program then uses the mixer mode and the fixed frequency port information to decide whether the analysis will be a receiver (RX) type, or a transmitter (TX) type, as discussed in the previous section. Either equation 1 or 2, as appropriate, is printed at the top of each plot. Figure 3 shows the type of analysis done for each combination of mixer mode and fixed frequency port. The selections were set up to match the type of analysis with the most likely use of that particular mixer mode and fixed frequency port. Figure 4 shows an RX case where spurious is plotted on the input frequency axis, and Figure 5 shows a TX case where spurious is plotted on the output frequency axis.

When the user chooses to plot the spurious responses, the program provides the option to plot one or two filter bandpasses on the same axis as the american technical ceramics CORP.

News From ATC

Published by ATC May 1989

SPECIAL REPORT

48 Hour Shipment for 250 Capacitors or Less.

ATC is the industry leader for quality, rugged, reliable **UHF/Microwave Capacitors.** Our new **QUIK-PICK™** System launches our commitment to be the leader in service and customer satisfaction. At American Technical Ceramics, we know the importance of your deadline.

At ATC, Deadlines Are No Joke.

☐ Call me. I have immediate requirements.
☐ I want more information. Please send me ATC's 3-Ring Binder Product Catalog.
☐ Put me on your mailing list.

NAME/TITLE ____________

COMPANY ____________

ADDRESS ____________

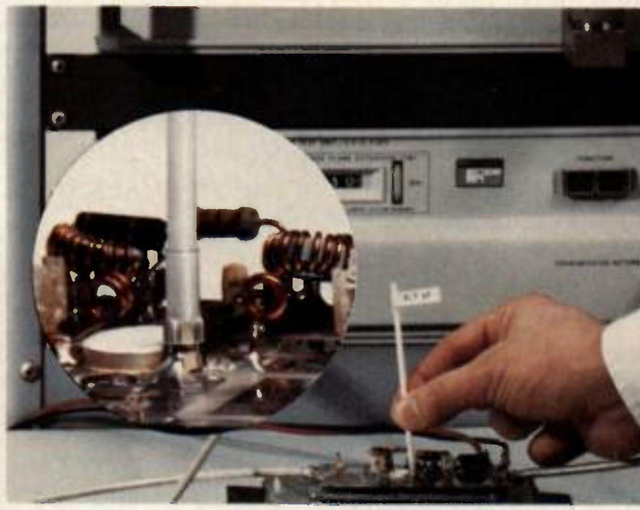
CITY/STATE ____________ ZIP ________

PHONE ____________

Mail to:
American Technical Ceramics, Advertising Dept.
One Norden La., Huntington Station, NY 11746-2102

RFD 5-89

INFO/CARD 79



Expand Your Present Tuning Stick™ Kit

Select the capacity value your circuit needs with ease.

Now it is possible to extend the range of your Tuning Stick™ Kit to include all in-between values from 0.1 pF to 1000 pF. Like the original Tuning Stick™ Kits (ATC TS1001), the new kits contain ATC 100 Series Superchip® Radial Wire Leaded Capacitors labeled with their specific values. Each capacitor is permanently attached to a non-conductive holder.

Request **ATC TS1002** (26 values) for **$79.95**, or **ATC TS1001** (20 values) for **$49.95.** Order both Kits for **$124.99.** ATC offers 48 Hour **QUIK-PICK℠** Shipment.

The ATC TS1002 Tuning Stick™ Kit contains 26 values:

CAPACITY VALUE (pF)	TOLERANCE
0.2, 0.3, 0.4	B
0.6, 0.7, 0.8, 0.9	C
12, 15, 18, 22, 27, 33	J

CAPACITY VALUE (pF)	TOLERANCE
39, 56, 82, 120	J
150, 180, 220, 270, 330, 390, 560, 680, 820	K

TOLERANCE CODE: B = ±0.1 pf; C = ±0.25 pf; J = ±5%; K = ±10%

INFO/CARD 80

american technical ceramics CORP.

one norden lane, huntington station, new york 11746-2102 • (516) 547-5700 • fax 516-547-5748 • telex 825707

```
****************  CONVERSION TYPE MENU  ******************

  1 = LOW SIDE INJECTION, DOWN CONVERTER:    Fin>LO>Fout
  2 = HIGH SIDE INJECTION, DOWN CONVERTER:   LO>Fin>Fout
  3 = LOW SIDEBAND, UP CONVERTER:            LO>Fout>Fin
  4 = LOW SIDE INJECTION, UP CONVERTER:      Fout>Fin>LO
  5 = HIGH SIDE INJECTION, UP CONVERTER:     Fout>LO>Fin
  6 = EXIT PROGRAM
  7 = PROGRAM INFORMATION

NOTE: USE THE SAME UNITS FOR ALL FREQUENCIES ENTERED, KHZ, MHZ, ETC.
```

Figure 2. SPURPLOT conversion type menu.

	Fixed Input or Output		
Mixer Type	F_{out}	LO	F_{in}
F_{in}>LO>F_{out}	RX	RX	TX
LO>F_{in}>F_{out}	RX	RX	TX
F_{out}>F_{in}>LO	RX	TX	TX
F_{out}>F_{in}>LO	RX	TX	TX
F_{out}>LO>F_{in}	RX	TX	TX

Figure 3. Type of analysis for each mixer type and fixed in/out combination.

spurious. A plot with two filter responses plotted on it is shown in Figure 4. This option allows the user to determine whether the spurious responses fall in the passband, on the filter skirts, or in the reject band of an input or output filter. The passband plots as a parallelogram because at the low end of the filter, the passband lies all above the input/output frequency, whereas at the upper end of the passband, the passband lies below the input/output frequency.

SPURPLOT also provides an option to analyze and print spurious responses at a single frequency. The output can be directed to either the screen or a printer. The printout of a single frequency analysis is shown in Figure 6. The column titled "INPUT FREQ DELTAFx0" is the calculated intercept point of the spurious product with the input (or output) frequency axis. The single frequency analysis is useful when the exact frequency of a spurious product is needed.

The letters at each end of the spurious lines in Figures 4 and 5 correspond to the same letters to the left of N and M columns' entries. These letters enable the user to identify the order of each spurious product plotted. If the N and M columns reach the bottom of the defined page, a second column of letters, N, and M values will be printed. This makes it possible to identify up to 46 lines, after which a warning message will be printed. Anything more than 20 or 25 lines gets to be rather messy and probably indicates that you ought to look for a better frequency plan! There can be a problem identifying some lines when a line meets another at both its ends or when two or more lines lie nearly on top of each other. This difficulty can be resolved either by using the single frequency

THE CHOICE IS YOURS

Avantek Offers Both GaAs & Silicon Wideband MMIC Amplifiers

Now, both GaAs and silicon MMIC amplifiers covering the frequency range from DC to 18.0 GHz, are available from one reliable source... Avantek. Avantek's GaAs and silicon MMICs offer outstanding broadband amplifier performance, providing increased circuit density, and reduced system complexity. They are ideal solutions to your system performance and cost goals.

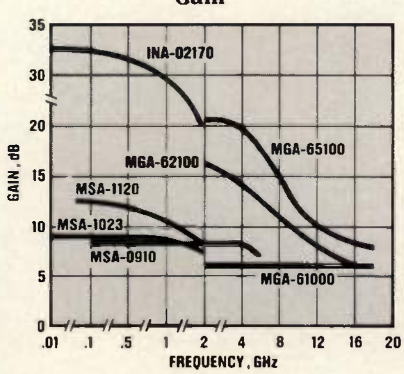
Performance Options to Meet Your Design Needs

Avantek's MMIC amplifiers are available with a wide spectrum of performance options to satisfy nearly every design need. These easy to use MMIC amplifiers provide premium performance and reliability. They are available with a range of chip to hermetic package options for use in the most demanding industrial and military applications.

Typical MMIC Performance

Model	Test Frequency (GHz)	Gain (dB)	Noise Figure (dB)	P_{1dB} (dBm)
INA-02170	0.5	31.0	1.9	11.0
MSA-1120	0.5	12.0	3.5	18.0
MSA-1023	1.0	9.0	—	27.0
MSA-0910	2.0	8.0	6.0	11.0
MGA-62100	4.0	14.0	2.5	12.0
MGA-65100	14.0	10.0	—	24.0
MGA-61000	18.0	6.0	6.5	14.0

Gain



GaAs and Silicon MMICs... Distributor Direct

Each year Avantek produces more than ten million high performance, high frequency MMICs. So you can be assured the MMICs you need, in packaged and chip form, will be available to support your volume production needs. And, these MMICs are in stock at your local Avantek distributor for immediate delivery. For additional information, or the name and address of your local distributor, contact the regional sales office nearest you.

Regional Sales Offices

North American

Eastern:	(301) 381-2600
Central:	(312) 358-8963
Western:	(805) 373-3870
European	(44) 276-685753

MMIC Technology Leadership

AVANTEK

INFO/CARD 37

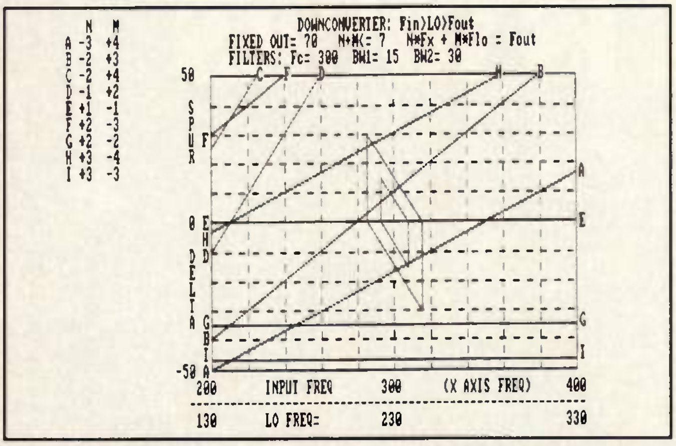


Figure 4. Downconverter plot with filter responses. Menu selection 1 with fixed output frequency (RX).

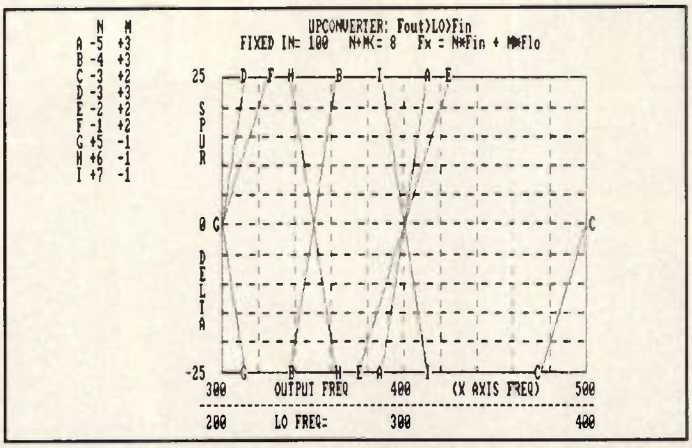


Figure 5. Upconverter plot. Menu selection 5 with fixed input frequency (TX).

analysis to identify the lines, or by changing the X axis or Y axis limits.

There are two sets of frequencies printed at the bottom of the plot. The one just below the plot is the X (center) axis frequency that the spurious is plotted against. The other set is the remaining variable frequency, given for reference. This second set corresponds frequency for frequency with the X axis frequency, so it may run from low to high or from high to low, depending on the mixer mode.

Interpretation and Use of the Spurious Plots

Figure 4, Downconverter Plot. Each of the lines plotted in Figure 4 (A-I) represents the frequency difference between the desired input frequency (the center axis) and an undesired signal at the mixer input that causes a spurious response to appear at the mixer output on the desired mixer output frequency. For instance, consider line H. At an input frequency of 270 MHz, the spurious lies 10 MHz above the desired input, or at

240+10=250 MHz. To check this, plug the numbers into the formula at the top of the plot: $N*F_x+M*F_{lo}=F_{out}$. For line H, N= 3, M = -4. From the lower scale below the plot, F_{lo} = 170 MHz. Therefore:

$$(3)*(250)+(-4)*(170)=750-680=70 \text{ MHz}$$

This shows that the spurious output is at 70 MHz.

Which of the spurious responses plotted would cause a serious interference problem? To determine this, we must consider two factors: First, what is the order of the spurious? (Order M+N) Second, do the signals causing the spurious responses fall in the passband of the input filter? If the two parallelograms plotted in Figure 4 represent the 3 dB and the 60 dB passbands of a receiver front-end filter, for example, it can be seen that lines H, B and A fall in the 60 dB bandwidth, and A and B fall in the 3 dB bandwidth. A and H are 7th order spurious and may receive enough suppression in the mixer to be discounted as problems. The B line, however, passes through the 3 dB bandwidth window and is a 5th order spurious response. This could be a problem.

If the proposed receiver in the previous paragraph is tuneable, the filter bandwidth windows move left or right on the input frequency axis as the receiver is tuned. As the windows move they encounter spurious crossovers, such as the point where line B crosses the input frequency axis at 280 MHz. This crossover is a point at which the input frequency itself would cause a spurious response falling on the desired output frequency. This could be serious in the case of a low-order spurious such as that caused by the signal represented by line D. The spurious created at or near the crossover receives no attenuation from filters at either the mixer input or output. In such a case, the designer could change from low side to high side injection and/or to a different mixer output frequency to eliminate the problem spurious responses.

Figure 5, Upconverter Plot. The plot shown represents the TX case. Consider line E at a frequency of 420 MHz. Plugging the frequencies into the formula $F_x = N{*}F_{in} + M{*}F_{lo}$, we get:

$$F_x = (-2){*}(100) + (2){*}(320) = 440 \text{ MHz}$$

If this mixer were in a transmitter, a spurious signal would be transmitted 20 MHz above the desired signal. Notice that at 400 MHz on Figure 5 three crossovers occur. As is true for the RX case described for Figure 4, the created spurious cannot be filtered out and could be a serious problem.

Once the spurious signals have been identified in frequency, their amplitude needs to be determined with respect to the desired input or output signal before it can be determined whether or not the spurious signal is a problem. This can be done using the mixer charts several manufacturers provide in their catalogs, and applying the rule that the spurious level in dB drops M + N dB for each dB drop of the input signal (2). When equipped with knowledge of both the frequencies and amplitudes of the spurious products, the designer or system analyst can choose the optimum frequency plan for the system being designed.

SPURPLOT was written using Microsoft's Quick Basic 4.0, so the source code is not fully compatible with BASICA or GWBASIC. A compiled version that will run from DOS is available from the RF Design Software Service (see page 65). Please note that the program is written to run on computers with CGA-compatible color or monochrome monitors. For Hercules, or other non-CGA display formats, third-party software will

```
SPURIOUS DATA AT AN OUTPUT FREQ OF 150.00
 FIXED FREQUENCY LO=  400
 LOW SIDEBAND (HSI), UP-CONVERTER:    FLO>FOUT>FIN
 SPUR: MIN=  2 MAX=  7
 TYPE OF CALCULATION: Fx = N*Fin + M*Flo

  N       M         DELTAFx     OUTPUT FREQ
                    @Fout       @DELTAFx-0

 -4       3         +50.000      +133.333
 -1       1          +0.000        +0.000
  2      -1         -50.000      +133.333
  4      -2         +50.000      +160.000

If DELTAFx in 3rd column is 0, spurious is at Fin or Fout freq.
If Fin or Fout=0 @ DELTATFX-0, spurious is at a fixed delta Fx
```

Figure 6. Single frequency analysis. Menu selection 3 with fixed LO frequency (TX).

be required to allow CGA graphics to be displayed on those systems. Readers wishing to have only a program listing may send a self-addressed business-sized envelope with 25 cents postage to *RF Design* at the address on page 8.

Important notice: At the request of the author's company, this program will not be distributed outside the U.S.A.

References

1. David Westwood, "Rid Mixers of Spurious Signals," *Electronic Design*, August 1966.
2. B.C. Henderson, "Mixers, Part I," *Tech Notes*, Vol. 8, No. 2, Watkins-Johnson Company, March/April 1981.

About the Author

Richard Bain is a senior engineer in the Space Systems Department of the ECI Division of E-Systems, P.O. Box 12248, St. Petersburg, FL 33710. He is engaged in receiver systems design and analysis work.

Fixed output frequency option:

$$Delf_{x1} = [F_{min}(N1M - M1N) - F_{out}(M - M1)]/M1N$$

$$Delf_{x2} = [F_{max}(N1M - M1N) - F_{out}(M - M1)]/M1N$$

$$F_{rf1} = \frac{N(Df_{xmax}) + F_{lo}(M - M1)}{N1 - N} \quad F_{rf2} = \frac{N(-Df_{xmax}) + F_{lo}(M-M1)}{N1 - N}$$

Fixed LO frequency, menu selections 1 and 2:

$$Delf_{x1} = [F_{min}(N1-N)-F_{lo}(M-M1)]/N \quad Delf_{x2} = [F_{max}(N1-N)-F_{lo}(M-M1)]/N$$

$$F_{rf1} = \frac{N(Df_{xmax}) + F_{lo}(M - M1)}{N1 - N} \quad F_{rf2} = \frac{N(-Df_{xmax}) + F_{lo}(M - M1)}{N1 - N}$$

Fixed LO frequency, menu selections 3, 4 and 5:

$$Delf_{x1} = \frac{F_{lo}(N1M-M1N) - F_{min}(N1-N)}{N1 - N}$$

$$Delf_{x2} = \frac{F_{lo}(N1M-M1N) - F_{max}(N1-N)}{N1 - N}$$

$$F_{rf1} = \frac{F_{lo}(N1M-NM1) - N1(Df_{xmax})}{N1 - N}$$

$$F_{rf2} = \frac{F_{lo}(N1M-NM1) + N1(Df_{xmax})}{N1 - N}$$

Fixed input frequency option:

$$Delf_{x1} = \frac{F_{min}(M1-M) - F_{in}(M1N-N1M)}{M1}$$

$$Delf_{x2} = \frac{F_{max}(M1-M) - F_{in}(M1N-N1M)}{M1}$$

$$F_{rf1} = \frac{F_{in}(M1N-N1M) - M1(Df_{xmax})}{M1 - M}$$

$$F_{rf2} = \frac{F_{in}(M1N-N1M) + M1(Df_{xmax})}{M1 - M}$$

Meaning of variables:

$Delf_{x1}$: Intercept of spurious line with plot right side
$Delf_{x2}$: Intercept of spurious line with plot left side
F_{rf1}: Intercept of spurious line with top of plot area
F_{rf2}: Intercept of spurious line with bottom of plot
F_{min}: Minimum frequency of plot center axis
F_{max}: Maximum frequency of plot center axis
Df_{xmax}: Maximum offset of plotted spurious (top of plot)
$-Df_{xmax}$: Minimum offset of plotted spurious (bottom)
F_{rf}: Input frequency
N, M, N1, M1: Defined in article

Appendix 1. Formulas used in SPURPLOT. *(Continued on page 43.)*

Your Ship Has Come In!

1989 IEEE/MTT-S International Microwave Symposium/Exhibition

Long Beach, California, June 13-15, 1989

■ **An Outstanding Technical Program of Full Length and Short Papers, and Open Forum.**

Featuring Sessions on:
Phased and Active Array Technique • Ferrite Applications • Medical Applications • Optical/Microwave Interaction • Passive Components • Microwave Acoustics • Modeling and Application of Active Devices to Circuit Design • Gallium Arsenide Capabilities • Microwave Properties of Superconductors • Filters • Microwave CAD - European Activity Overview • Microwave Superconductor Applications • Millimeter Wave Sources • Guiding Structure Analysis • Lightwave Links • Millimeter Wave Amplifiers • Microwave Manufacturing • Microwave Integrated Circuit Measurements • FET Amplifiers • Losses in Guided Wave Structures • Microwave Measurements • High Power • Time Domain Applications • Solid State Devices • Microwave Integrated Circuits • Millimeter Wave Applications • Monolithic Integrated Circuits

■ **Special Workshops and Panel Sessions**

Optical/Microwave Circuit Interactions • High Power Passive Equipment for Satellite Application • High Power Generation and Microwave Applications • Microwave & Millimeter Wave Synthesizers • High Frequency Interconnections • Microwave Characterization of Superconductors • MMIC Package Standards and Problems in Packaging • Recent Advances in Microwave & Millimeter Wave Superconductor Applications • Microwave Education: Present Status & Future Trends • Hetrojunction Devices, Circuits and Reliability • Microwave Hardware Descriptive Language • Entrepreneurship and the Engineer • MMIC Design Approaches for Low Cost, High Volume Applications • Improving Time to Market

■ **The World's Largest Microwave Exhibition**

Visit the displays of more than 300 microwave component, device, instrumentation, material, and subsystems suppliers.

■ **Full Social Program**

Spouses' tours, an exhibitor reception and the MTT-S Awards Banquet provide a memorable complement to the industry's premier event.

■ **Register Now**

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

- -

☐ **Yes,** I would like additional information on attending MTT-S '89. Please send it to: F

Name ____________________ **Title** ____________________

Organization ____

Address ____

City ____________________ **State** ________ **Zip** ________

Country ____________________ **Telephone** ____________________

Are you an MTT-S member? ☐ Yes ☐ No

Have you ever attended MTT-S before? ☐ Yes ☐ No **How many times?** ________

Microwave Journal 685 Canton Street, Norwood, Massachusettes 02062

A. Formulas for single frequency analysis

Fixed output frequency:

$$\text{Deltaf}_x = \frac{F_{calc}(N1M-M1N) - F_{if}(M-M1)}{M1N} \qquad F_{xicpt} = \frac{F_{if}(M-M1)}{N1M-M1N}$$

Fixed LO frequency, menu selections 1 and 2:

$$\text{Deltaf}_x = \frac{F_{calc}(N1-N) - F_{lo}(M-M1)}{N} \qquad F_{xicpt} = \frac{F_{lo}(M-M1)}{N-N1}$$

Fixed LO frequency, menu selections 3, 4 and 5:

$$\text{Deltaf}_x = \frac{F_{calc}(N1M-NM1) - F_{calc}(N1-N)}{N1} \qquad F_{xicpt} = \frac{F_{lo}(N1M-NM1)}{N1-N}$$

Fixed input frequency:

$$\text{Deltaf}_x = \frac{F_{calc}(M1-M) - F_{rf}(M1N-MN1)}{M1} \qquad F_{xicpt} = \frac{F_{rf}(M1N-MN1)}{M1-M}$$

Variables:

Deltaf_x: Frequency difference between desired and undesired signals
F_{xicpt}: Frequency at which desired and undesired signal frequencies are equal
F_{calc}: Frequency at which Deltaf_x and F_{xicpt} are calculated
F_{if}: Desired output frequency

B. Filter plotting formulas

$$F_2 = \frac{BW1 + (BW1 \wedge 2 + 4F_c) \wedge .5}{2}$$

$$F_1 = F_2 - BW1$$

Variables:

F_2 is the upper 3 dB point of the filter
F_1 is the lower 3 dB point of the filter
BW1 is the 3 dB bandwidth of the filter
F_c is the center frequency of the filter

Appendix 1. (Continued)

I. Deriving Delf_{x1}

Basic equations:

$$N1F_{in} + M1F_{lo} = F_{out}$$
$$NF_x + MF_{lo} = F_{out}$$
$$\text{Deltaf}_{x1} = F_x - F_{in}$$

Given: $F_{in} = F_{min}$, $\text{Deltaf}_x = \text{Delf}_{x1}$
Constants: F_{out}, N, M, N1 and M1

A.
$$N1MF_{min} + M1MF_{lo} = MF_{out}$$
$$NM1F_x + M1MF_{lo} = M1F_{out}$$
$$\overline{N1MF_{min} - NM1F_x = F_{out}(M-M1)}$$

B. $F_x = \text{Delf}_{x1} + F_{min}$

$$NM1(\text{Delf}_{x1} + F_{min}) = N1MF_{min} - F_{out}(M-M1)$$

$$\text{Delf}_{x1} = \frac{F_{min}(N1M-NM1) - F_{out}(M-M1)}{NM1}$$

II. Deriving F_{rf1}

Given: $F_{in} = F_{rf1}$, $\text{Deltaf}_x = Df_{xmax}$
Constants: F_{out}, N, M, N1 and M1

A.
$$N1F_{rf1} + M1F_{lo} = F_{out}$$
$$NF_x + MF_{lo} = F_{out}$$
$$\overline{N1F_{rf1} - NF_x + F_{lo}(M1-M) = 0}$$

B. $F_x = \text{Deltaf}_x + F_{in} = Df_{xmax} + F_{rf1}$

$$N1F_{rf1} - N(Df_{xmax} + F_{rf1}) + F_{lo}(M1-M) = 0$$

$$F_{rf1} = \frac{NDf_{xmax} + F_{lo}(M-M1)}{N1-N}$$

Appendix 2. Sample derivations for menu selection 1.

Increased Dynamic Range Measurements Using a Network Analyzer

By Chris Day
Hewlett Packard Company
Network Measurements Division

Transmission measurements on two-port devices using a network analyzer often require a high dynamic range. This article describes how an amplifier and the external leveling capability of the system source can be used to increase the measurement dynamic range. The technique relies on a leveling loop to increase the source power as the device under test (DUT) transmission decreases. A particular application of the technique using the HP 8753 network analyzer is discussed.

Filter rejection and switch isolation are two examples of device specifications that cannot be verified unless the test system has at least as much dynamic range as the device has performance. Ideally, specifications should be based on device performance, not on test equipment capability. As the performance of these devices improves, test systems must also improve.

Techniques commonly used for improving dynamic range include reducing the receiver bandwidth and averaging. Both increase the measurement time and are hence undesirable for production line tuning and testing. Preferably, test systems should be fast enough to allow for near-real-time tuning while also having adequate dynamic range.

Dynamic Range

An important distinction to make is that between receiver dynamic range and test system dynamic range. Receiver dynamic range can be thought of as the ratio of maximum specified input power to minimum detectable power. The maximum level is usually limited by compression or burnout, while the minimum is typically governed by the noise floor. For example, a receiver which compresses at +20 dBm and has a -60 dBm noise floor has an 80 dB dynamic range.

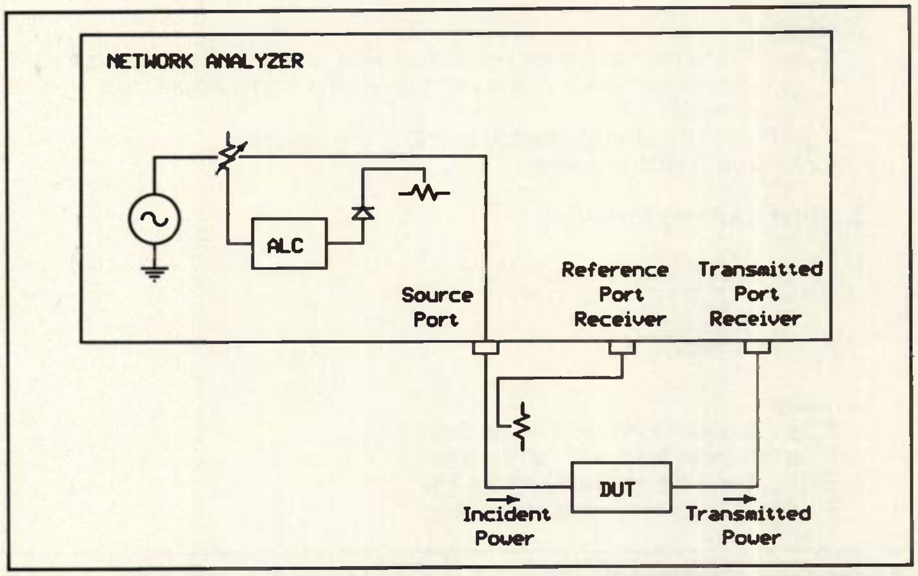


Figure 1(a). Simplified transmission measurement system with source power leveled at device-under-test input.

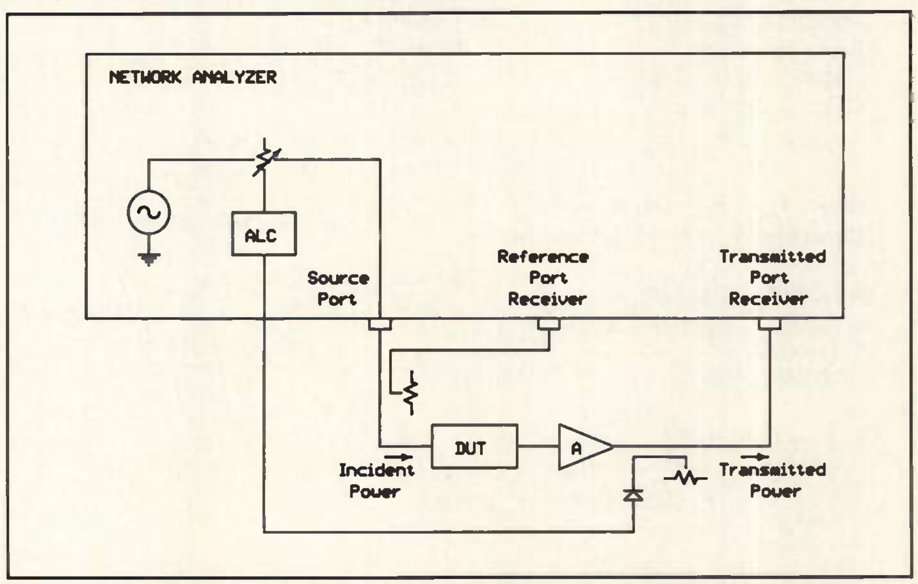


Figure 1(b). Simplified transmission measurement system with source power leveled at the transmitted port.

Test system dynamic range is more complicated and is often smaller than receiver range since it depends on both receiver and source capability. For instance, if the test system shown in Figure 1(a) has the above described receiver and a source able to supply only +10 dBm, test system dynamic range is 70 dB — 10 dB less than the receiver dynamic range. A special case arises if the DUT is an amplifier; the effective source power becomes the amplifier output power.

Dynamic range of a test system can be thought of in terms of a ratio of maximum to minimum transmission through the DUT. The transmission of the DUT is itself a ratio of transmitted to incident power. Using a coupling device, incident power can be measured in the reference port. Test system dynamic range is then a ratio of ratios, as shown in Figure 2.

Most network analyzers are configured to level DUT incident power at a predetermined value (Figure 1(a)). In that case, the incident power terms of the equation cancel and system dynamic range becomes transmitted power (DUT equals "through") divided by the noise floor.

Incident Power Variation

Test system dynamic range may be increased by varying the incident power as DUT transmission changes. This can be accomplished by changing the system to *externally* level the transmitted power rather than *internally* leveling the incident power (Figure 1(b)). In this case, the incident power will no longer be constant since the source power will vary with DUT transmission.

As an example, assume the source in Figure 1(b) can supply up to +20 dBm, amplifier gain is 10 dB, and the receiver is able to handle a 0 dBm maximum. The source power can be adjusted by the leveling loop to keep the transmitted power near its 0 dBm maximum. If the DUT has 0 dB of loss, the source power will be adjusted to -10 dBm. If the loss increases, the source power will increase an equal amount. Eventually, the leveling loop runs out of range when the DUT has 30 dB of loss; the source power is then at its +20 dBm maximum. Although the incident power is varying, the ratio of transmitted to incident power remains the DUT transmission. The amplifier serves to increase the incident power variation, with total variation limited to the leveling range of the source. The incident power level now varies with the DUT response and, from the earlier definition, the extension in system dynamic range is roughly the variation in incident power. (By using a low-noise amplifier, the effective noise floor may be reduced, resulting in a further increase in dynamic range.)

HP 8753 Configuration

Such a system can be configured using the HP 8753 network analyzer, as shown in Figure 3. An S-parameter test set can be the required coupling device. Test set parameters are generalized for coupling (C) from the HP 8753 source to reference port and loss (L) from the source to DUT. The reference port is labeled "R" on the HP 8753 and "B" port is the receiver for the transmitted path. An amplifier, the HP 8347A, provides the circuitry to level the B port power at nearly 0 dBm. Both R and B ports handle 0 dBm maximum power.

To understand how the system operates, consider a transmission measurement made on a bandpass filter using the HP 85046 S-parameter test set. For source frequencies where the filter is in its passband, the loop levels the B power at 0 dBm by adjusting the HP 8753 source power. Because the amplifier provides gain, the source power is adjusted toward the minimum of its range. The reference power level tracks the source power and is a function of the amplifier gain, test set loss (L) and coupling (C). For instance, with the B port power leveled at 0 dBm, the source power is 0 dBm minus the net amplifier gain plus the loss (L) in the test set. The R power is the source power less the coupling (C). The HP 85046 test set has 13 dB loss and 19 dB coupling; the source power is then +3 dBm and the R power is -16 dBm. Remember, this calculation was for the case of the filter in its passband, having nearly 0 dB loss.

As filter attenuation increases over frequency, the loop attempts to stay leveled by increasing the source power as needed up to a point where the R port is close to its 0 dBm maximum, while limiting the increase so that the R port is not overdriven. As attenuation increases to near infinite, the noise floor dominates in the B port.

The resulting transmitted and reference power levels are shown in Figure 4. The variation in reference power is roughly the extension in dynamic range. Figure 5 shows a comparison of a non-extended measurement with an extended measurement. The amount of extension depends on the loss (L) and coupling (C) of the test set, as well as amplifier gain. Typically, 15 dB extension in dynamic range can be obtained when using the HP 85046 test set. (For frequencies below passband, device rejection is not low enough to show extended test system noise floor.)

Amplifier gain increases reference power variation while test set loss reduces it. The HP 8347A has 30 dB of typical gain and +20 dBm output power. Variations from the above setup are possible using different amplifiers or leveling loops. The configuration serves as an example of the technique, since the HP 8347A includes the leveling circuitry needed to control the HP 8753 source.

It is important to note that for some DUTs the technique has limitations. Devices having little attenuation over the network analyzer's frequency range, such as notch filters, can pass source

$$\text{Test System Dynamic Range} = \frac{\text{Maximum Transmission}}{\text{Minimum Transmission}} = \frac{\left.\dfrac{\text{Transmitted Power}}{\text{Incident Power}}\right\} \text{evaluated when DUT = "through"}}{\left.\dfrac{\text{Noise Floor}}{\text{Incident Power}}\right\} \text{evaluated when DUT has infinite attenuation}}$$

Figure 2. Test system dynamic range expressed as a ratio.

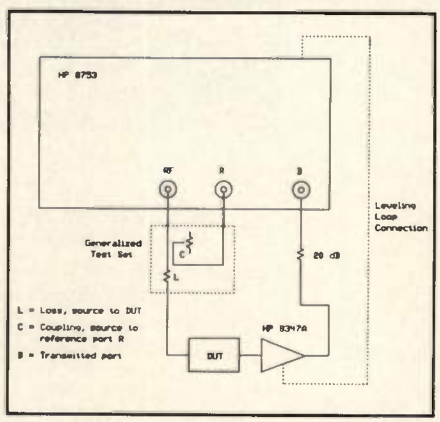
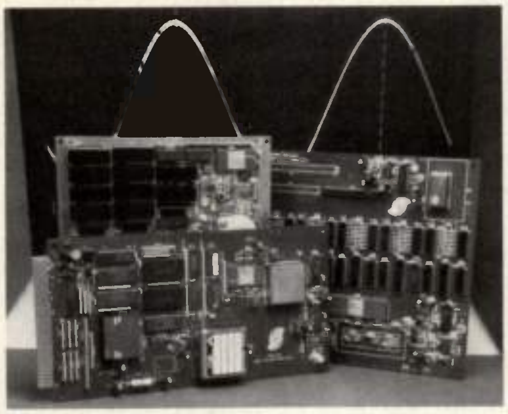


Figure 3. Extended dynamic range system.

FREQUENCY SYNTHESIZERS

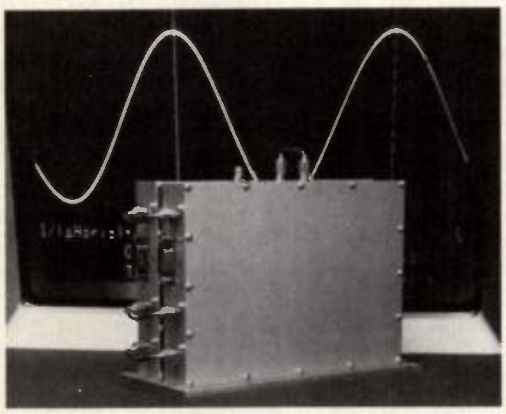


DDS

SCITEQ DDS products provide submicrosecond switching and fine steps - all at less cost than alternative approaches. As modulators, some have phase control in steps as fine as 0.09°, and all switch frequencies without glitch.

- **ADS-2 & 3:** all GaAs DDS up to 300MHz BW
- **VDS-3, 8 & 15:** patented BCD boards and instuments
- **VDS-3000:** HF band w/phase control

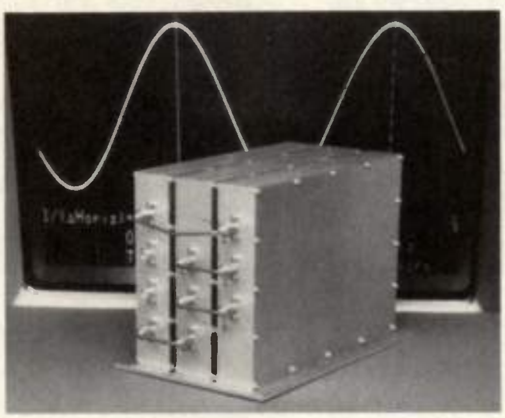
VME, STD, IBM-PC, Cambion, and custom formats



PLL

SCITEQ PLL synthesizers are new designs that use GaAs components and SAW references, achieving excellent performance at low cost.

- **VDS-G:** 10% coverage up to 6GHz, excellent spectral purity
- **VDS-1500:** octave coverage below 250MHz, 1 MHz steps
- **VDS-1800:** cost-effective SATCOM synthesizer



DDS+PLL

SCITEQ DDS+PLL designs achieve fine steps with excellent spectral purity, because division ratios are kept low. The result is multi-loop performance at single-loop prices.

- **VDS-1700:** ≤20% coverage below 3GHz, low phase noise
- **VDS-1400:** any octave up to 250MHz, in 0.1 steps

... other designs

Sciteq offers the broadest menu of DDS and combination designs in the industry, including DDS+mix/filter products that cover up to 1GHz in 1/16Hz steps with submicrosecond switching. Call us and we will show you how to improve the cost-effectiveness of your system.

SCITEQ ELECTRONICS, INC.

8401 AERO DRIVE
SAN DIEGO, CA 92123
619-292-0500
FAX 619-292-9120
TLX882008

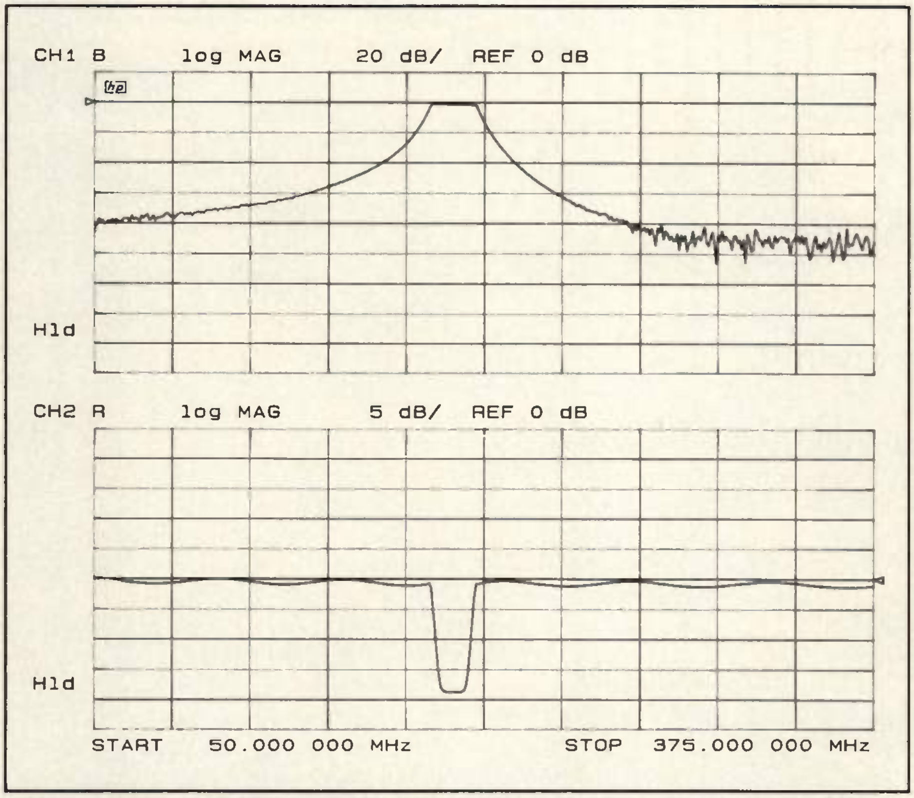


Figure 4. Transmitted (B) power and reference (R) power for measurement made with extended setup.

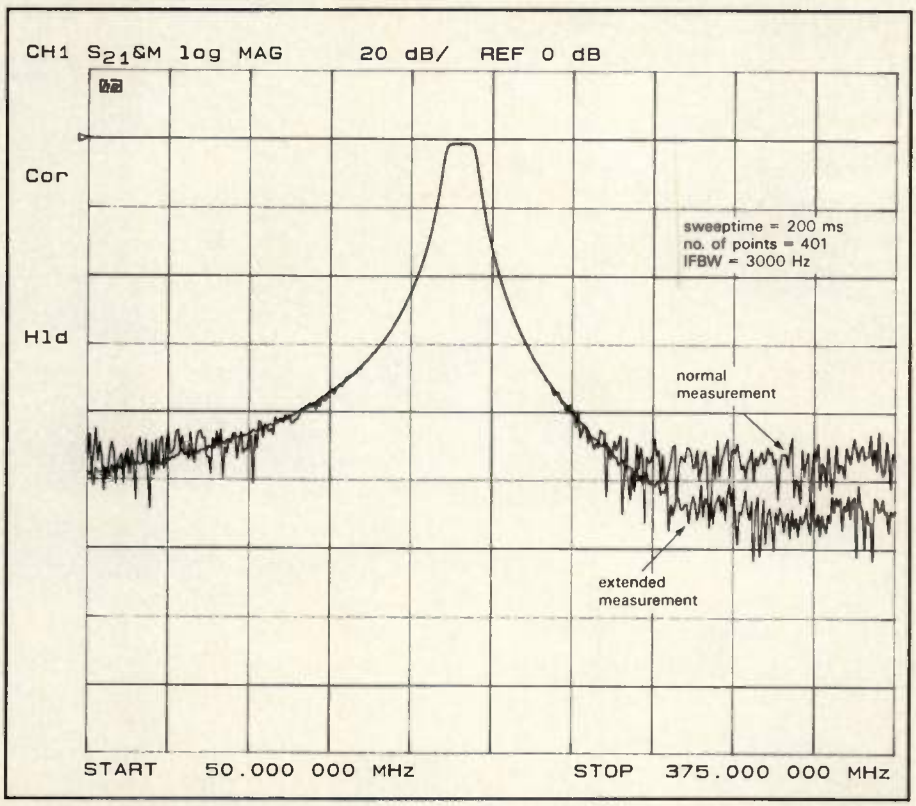


Figure 5. Transmission measurements made on filter showing the increase in dynamic range.

noise on to the receiver. If the source noise is large enough, the receiver noise floor can effectively be raised. In the case of a sampling receiver, as in the HP 8753, source noise over the entire frequency range can be sampled down into the receiver IF. Adding a bandpass filter in the measurement path can limit the noise bandwidth to the frequencies of measurement, thereby reducing broadband source noise. Another difficulty arises for DUTs with large group delay. Devices with more than 2 microseconds delay in the passband can cause instability in the ALC circuitry leveling the B port power to 0 dBm. The ALC circuitry has been optimized to work with passive DUTs; as such, devices with gain may also cause instability.

While an increase in system dynamic range is always welcome, it is often more desirable to maintain the same dynamic range but with a faster measurement time. For example, if 100 dB of dynamic range is needed to measure a filter, the HP 8753 and a test set alone can make the measurement, but the receiver bandwidth must be narrowed to 10 Hz. For the measurement in Figure 5, this would translate to a sweep time of nearly 42 seconds. By using the extended system, the same 100 dB measurement could be made with a receiver bandwidth of 3000 Hz and a sweep time of 0.2 seconds. The amount of speed improvement depends on start and stop frequencies and on which calibration is used.

Summary

The dynamic range of a transmission measurement is a key factor in a measurement system. It may be increased by varying the incident power based on the DUT transmission. This technique was illustrated by a configuration to increase the dynamic range of the HP 8753 by 15 dB when used with the HP 85046 test set and HP 8347A amplifier. Configurations using other test sets are also possible. Also shown was how this technique could be used to decrease the sweep time of a measurement while maintaining high dynamic range. rf

About the Author

Chris Day is a development engineer for RF network analyzers with Hewlett Packard Company's Network Measurements Division, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403. He can be reached at (707) 577-4599.

EMI Reduction Techniques for Analog and Digital Circuits

Circuit and System Level Solutions to EMI Are Discussed

By Michael J. Chernus
Chernus Designs

Today's high-speed digital and analog components with nanosecond rise and fall times pose various problems for the design engineer. This article provides information on how to deal with electromagnetic interference (EMI) on a circuit and system level in order to pass EMI specifications such as FCC Part 15 and MIL STD-461.

Nothing is worse than a call for help because a new product being rushed to the marketplace does not meet Part 15 specifications and cannot be sold. High-speed circuit elements create this kind of difficult job for the EMI engineer, because fast circuits have a wealth of harmonic energy and access to a low-impedance power supply. Clock frequencies of 20 MHz, 30 MHz or even 100 MHz are common. These combine to produce RF energy which is radiated to the outside world.

The best way to eliminate EMI is to avoid generating it in the first place. The designer should look over his system design to see which areas will generate high levels of RF energy. These areas should be isolated from each other and the outside world, and common circuit elements between such areas should be avoided. The only way to keep EMI from becoming an issue later on is to plan for it at the start of the design process. Note that either the portions of the design which contain RF energy have to be shielded or the RF energy absorbed.

Most digital and some analog circuits are laid out on a printed circuit (p.c.)

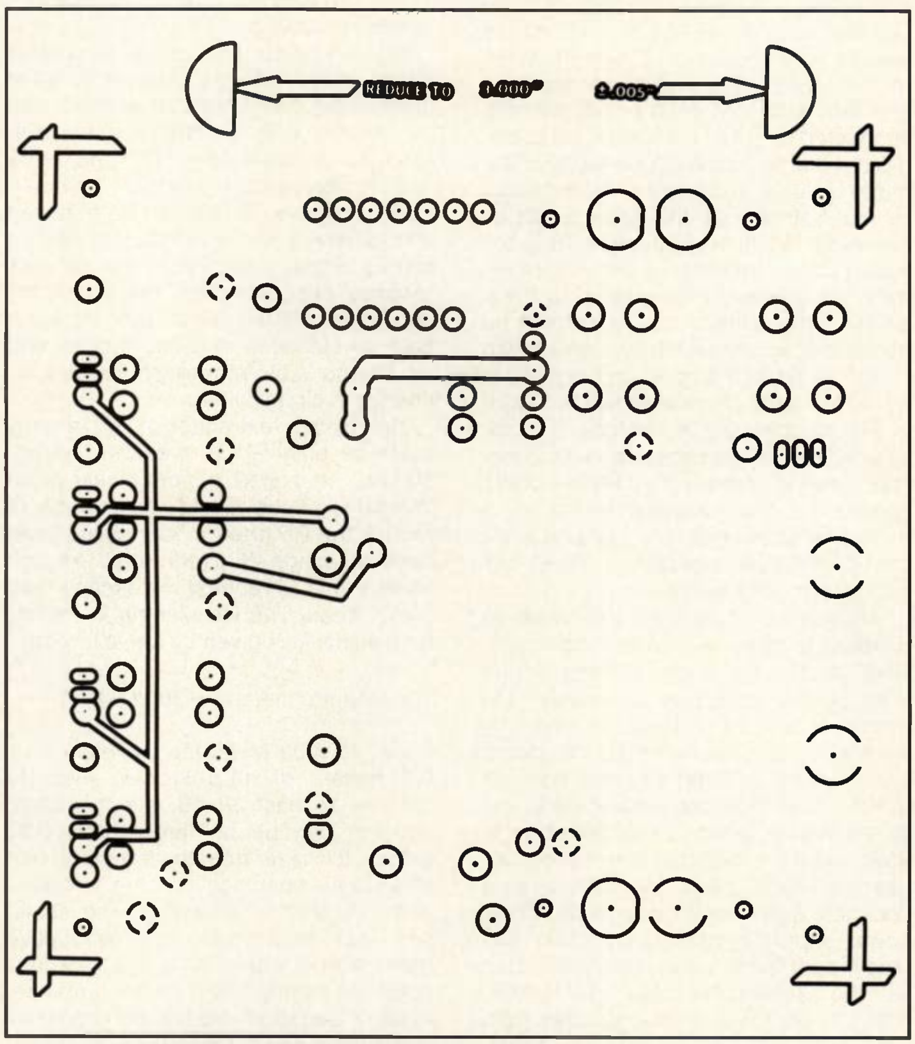


Figure 1. Example of a photo ground plane.

board using CAD techniques. This yields the smallest board for a given circuit. The CAD layout can connect circuit elements in the same package, thus causing built-in interference. The placement of one area of the circuit next to another may be difficult with CAD circuit layout. Certain elements of the circuit design should be spaced at a distance on the board so they do not couple energy to each other. A HEX inverter with six signals present in one package can combine them to provide signals into the RF spectrum to at least 1000 MHz.

Design Techniques

A photo ground plane should be added to all digital and analog board designs when the board is laid out. This provides on-board circuit isolation at low cost. The photo ground plane is generated when the p.c. layout is made by instructing the photo reduction shop to provide a 0.015 to 0.025 inch space around all traces on one or both sides of the board. There are no separate ground traces and each circuit element connected to ground is connected to this ground plane. There will be areas of the photo ground which are not connected to the balance of the ground plane. Normally, this is not a problem. In cases where these islands of ground plane must be connected to ground, a trace on the other side of the board will be necessary to connect these areas with "vias" or feed-throughs. An example of a photo ground plane is shown in Figure 1. For complex digital designs, a multilayer board may be necessary with a one-layer ground plane. An additional photo ground on the component side of a multilayer board may add just that extra circuit isolation needed to meet the radiation requirements.

Another way to control the radiation problem is to avoid having long traces. Also, by placing all components of one part of the circuit in one area, the problem can be further reduced. A parallel transmission line on the board can be used to bring different portions of the circuit from one area of the board to another. A good rule of thumb is to keep different signals from having access to each other by not using a common buffer and to provide direct power supply bypassing by using surface mount "chip" filter capacitors such as the Johanson 500R15W103KP, 0.01 uF, 50 VDC. Similar devices from other manufacturers are also applicable.

The author recommends using these "chip caps" at the V_{CC} of each IC, transistor and any other active element, spacing them along the power supply traces on all boards with a maximum spacing of 3 inches. A trick is to use chip capacitors on the back-plane from all power supply voltage rails to ground every 3 inches. The author's experience with surface mount components has shown a 10:1 improvement in the radiated signal levels by using the components discussed.

There will be some signals that cannot be filtered with a "chip cap" and the solution may be to use a "chip bead" or ferrite filter bead on these lines, available from Fair-Rite Products and other ferrite manufacturers. These beads are available as slip-on components for existing leaded components. They can be obtained with built-in wire leads for automatic insertion. Surface mount chip beads are also available. These are ideal for filtering signals with minimum radiation.

Some signals cannot be eliminated at the source. Those present in wires connecting one board to another can be filtered with a filtered connector. Circular, subminiature "D" and other special filtered connectors are commercially available. These can be obtained with different levels of filtering, from a simple bypass capacitor to a pi network lowpass filter built into the connector pin. These filtered connectors are available as bulkhead or cable mount, and as filtered adapters which require no change in circuit wiring.

Remaining extraneous RF energy must be shielded if it cannot be absorbed. An overall system shield or an individual circuit shield will contain or reduce the RF energy. Any shield must have openings or joints small enough so very little RF energy will escape from these areas. The wavelength in meters for a signal in is given by the following:

Wavelength (meters) = 300/f (MHz)

Thus, at 1000 MHz, the wavelength is 0.3 meters or 11.8 inches. Also, to achieve at least 30 dB, the maximum opening can be no larger than 0.37 inches. It is clear from the foregoing that very small openings can be tolerated and still provide shielding. The shield can be made from any conductive material and, within limits, the thickness does not greatly affect its performance. Thus, a plated shield will be almost as effective as one 0.1 inch thick.

Cables used to provide communication between one board and another or from one equipment enclosure to another must also be shielded to keep RF energy from radiating from them. Shielded wire can be purchased with braid or foil shields. Braid is more flexible and tolerant of hard use. Foil shields provide a higher shielding capability. Note that care must be given to the selection of a foil shield to make sure the shield is effective at high RF frequencies, since the foil joint in certain designs reduces shielding effectiveness at high frequencies. A wire that is 1/4 wavelength long or a loose joint (or slot) in a shield both pass RF energy.

An Example

Radiated emissions can cause a product to fail certain regulations. A recent example was a modem that radiated excessive RF energy and failed FCC Part 15. The solution required to make this product pass FCC Part 15, Part B was this:

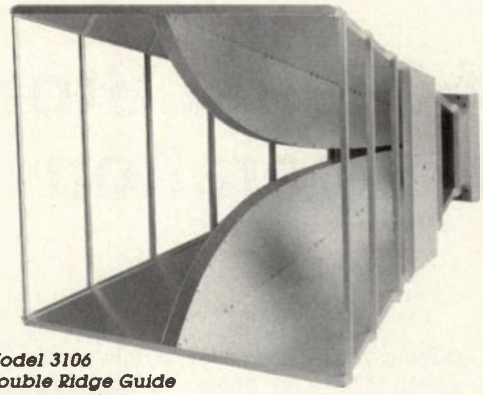
1. A photo ground plane was provided on the circuit side of the p.c. board.
2. A re-layout of the circuit was done to eliminate use of the same buffers for certain circuits, and to shorten long circuit traces.
3. Chip capacitors were included on all V_{CC} lines for the ICs.
4. Ferrite beads were installed on output lines and in between circuit elements. Shielding was not possible on this product.

The best way to eliminate EMI is to avoid generating it in the first place. Careful system and circuit design will go a long way toward keeping the level of extraneous RF signals generated by a product low. Proper bypassing of all power supply voltages with chip capacitors, careful p.c. board layout, and inclusion of a photo ground all help hold EMI levels down. Filter ferrite beads and filtered connectors are other tools for fighting EMI. Finally, the shielding of components, boards, cables and enclosures completes the engineer's arsenal of design tools.

About the Author

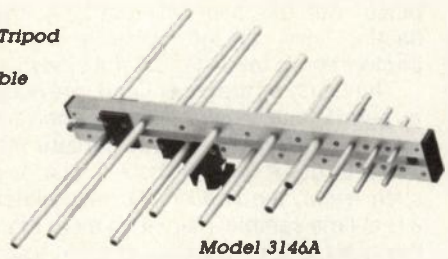
Michael J. Chernus is a design and development engineer with Chernus Designs, 12568 Camarero Court, San Diego, CA 92130. His work spans from DC to 40 GHz and covers from EMI to antennas. He can be reached at (619) 259-1480.

Model 3115 Double Ridge Guide
1–18 GHz
Model 3116 Double Ridge Guide
18–40 GHz



Model 3106
Double Ridge Guide
200 MHz–2 GHz

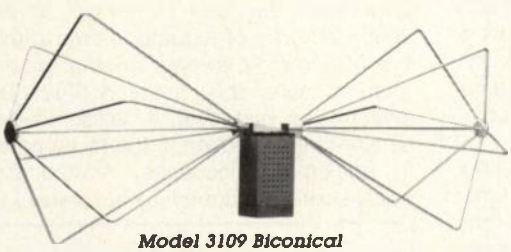
Model TR3 Non-Metallic Tripod
22.68 kg capacity
two other models available



Model 3146A
Log Periodic
300 MHz–1 GHz
four other models available

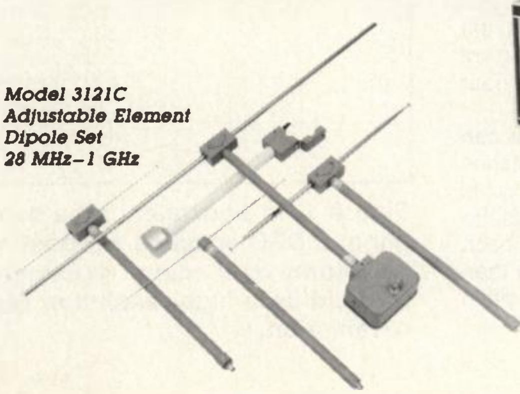
Model 1060 Turntable
with controller and IEEE-488 bus option
1-7.6 meter diameter available
three other models available

Model 6502
Active Loop
10 kHz–30 MHz
four other models available



Model 3109 Biconical
20–300 MHz
three other models available

Model 3925 PLISN
5 kHz–1 GHz
five other models available



Model 3121C
Adjustable Element
Dipole Set
28 MHz–1 GHz

TEST WITH CONFIDENCE.

ENGINEERED TO PERFORM

If compliance testing is your primary responsibility, you need top-of-the-line products you can count on. Like EMCO antennas, designed for repeatable FCC/VDE testing. Manufactured for the stringent requirements of MIL-STD testing. With high sensitivity for TEMPEST testing. Most have VSWR ratios of less than 2:1. And all exhibit exceptional dynamic range and linearity.

CALIBRATED INDIVIDUALLY

Every EMCO antenna is individually calibrated using both C63.4 and ARP 958 standards, then shipped to you with a signed Certificate of Compliance—a claim no other manufacturer of test antennas can make.

MANUFACTURED WITH CARE

We choose only the best and most durable materials for EMCO products. Then we pay close attention to details—machined tolerances are often less than one one-thousandth of an inch. And while we've automated for efficiency, we still take the time to hand-assemble and inspect each one of our products.

TWO-YEAR WARRANTY, SERVICE WORLD-WIDE

Because we know how well every EMCO product is engineered and built, we can back each one with a two-year warranty—twice the industry standard. And EMCO has more than 30 representatives worldwide to help you—wherever you are. Call our 800 number for more information and the name of your EMCO representative. Ask for your free catalog of EMCO products, too!

1-800-253-3761

EMCO™
The Electro-Mechanics Company

Call toll-free between 7:30 AM and 4:30 PM Central Time
800-253-3761 in USA or 512-835-4684 in Texas
Telex 797627 Fax 512-835-4729
P.O. Box 1546 Austin, Texas 78767

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

Principles of Digital Storage Oscilloscope Operation

By Gene Andrews
Tektronix Lab Instruments Division

Digital storage oscilloscopes (DSOs) provide viewing and measurement capabilities that can simplify both analog and digital design work. However, there is some confusion about how these instruments work, which may prevent an engineer from taking advantage of their benefits. This article discusses fundamental concepts of DSO operation, in order to increase understanding of their operation.

DSOs differ from analog scopes in that they digitize signals and use the digitized data to provide a continuously refreshed display of the most recently acquired signal. A significant benefit for the designer is the ability of the DSO to look back in time before a trigger event, much more than the little time an analog oscilloscope can provide. Because the digital storage oscilloscope has been continuously taking samples ahead of the time when the qualified trigger occurs, it can hold those pre-trigger samples to achieve this capability.

As with all instruments, DSOs must be used correctly to ensure accuracy. A difficult task for all oscilloscopes is the capture of single, or occasional, narrow glitches or spikes. These glitches can challenge the risetime/bandwidth performance of the oscilloscope by its ability to respond to the glitch and then present this glitch to the user. Assume, for example, that a user needs to see a glitch of 2 ns duration that repeats at about 10 second intervals. First, he has to look at this glitch with the oscilloscope to see the exact shape and time location of this aberrant event. With an analog oscilloscope he will probably have to trigger on the glitch itself, unless there is a more reliable trigger source that occurs ahead of the glitch or within 5 ns following. The advantage of the DSO is that it can trigger on any subsequent, telltale signal that occurs within the sweep time.

But what about the DSO's ability to display the glitch? A standard analog oscilloscope may not have a high enough CRT writing rate to provide a reliable, viewable display of this occasional glitch. An analog oscilloscope outfitted with a micro-channel plate CRT can do a good job of displaying each pulse, but the user will get only the fleeting view of the pulse unless a photograph is taken for careful study.

The DSO, on the other hand, provides a permanent view of each aberrant event, if the DSO can only capture the event to begin with. If there is just one such event, the DSO must have either a real-time sample interval no more than the glitch's 2 ns duration (i.e., at least 500 Msamples/s, as with the Tektronix 2440) or must have a glitch-capture feature (such as that in the 100 Msamples/s Tektronix 2432) that stretches glitches to the actual real-time sample interval. Even with these DSO alternatives, the glitch time location and width are limited to the time interval of the digitizing.

If a glitch repeats, even with a repetition period of 10 seconds or much longer, the DSO's equivalent time operation can take over. Equivalent time sampling constructs an accurate replica of the glitch by recording the signal's exact value at different points at each occurrence (Figure 1). The sampling rate or the DSO's speed need not be so high as to find the glitch on every pass, although a higher rate will enable acquiring the waveform more quickly.

Another approach to the triggering problem is to trigger at a specific time location and then look repeatedly at that time location for an aberrant occurrence. (Here again the micro-channel plate analog oscilloscope permits users to see very occasional glitches in the presence of the usual non-aberrant signal, providing the glitches occur near or after the trigger.)

For the DSO, a couple of features can be employed to find occasional glitches at suspected time locations. The first is envelope mode, which accumulates the lowest and highest signal value at each time location. Envelope mode can then accurately display the aberrant glitch accumulated over time.

Infinite-persistence or point-accumulate modes are more sophisticated variations of this idea that display all the values which occurred within the history time of the waveform being displayed. If the glitch is a meta-stable event, this method will show the details of the many intermediate values the glitch has traversed over this history.

Unless a DSO has an analog glitch capture feature, its ability to capture single-shot (transient) signals depends mainly on the Nyquist rate — the frequency at which a signal must be sampled to provide a true representation. This frequency must be at least twice as high as the highest frequency in the transient signal.

DSO Confusion

One of the greatest sources of confusion about DSOs comes from the terminology used to describe various features. The terms are unfamiliar because they are unique to DSOs, referring to digital functions instead of analog operations. Also, different manufacturers use different terms to describe the same functions. For example, one manufacturer uses the term "window" to describe an area of expanded time within the DSO's main sweep; another manufacturer calls this function "delayed sweep" to hint that it is somewhat similar to the function of the same name in analog oscilloscopes. Additionally, equivalent time sampling is referred to

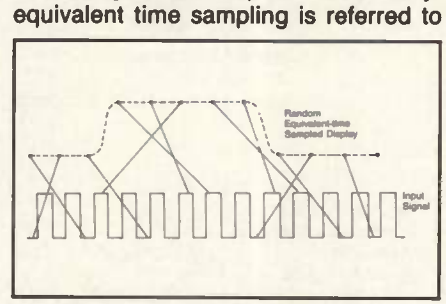


Figure 1. In equivalent time sampling, a DSO samples a repeating waveform over many repetitions to build up a high-resolution representation.

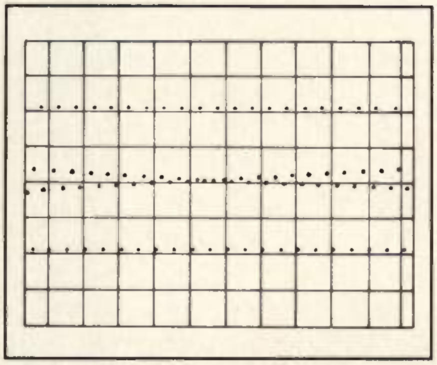


Figure 2(a). Aliasing causes a high-frequency waveform to appear as four low frequency signals.

as random equivalent time sampling, random repetitive sampling, or random interleaved sampling.

Another example involves describing a DSO's ability to capture a large number of samples over time and display them all on the screen. The longer the DSO does this, the more dots appear on the screen, giving a good feel for the way a waveform varies over time. Tektronix refers to this function as "point accumulate mode," while another manufacturer calls it "infinite persistence."

In addition to DSO terminology, there are three other factors that cause confusion: interpolation between measured points, aliasing, and equivalent time sampling. The main confusion about equivalent time sampling relates to its ability to actually increase a DSO's effective bandwidth. Users tend to link bandwidth with sample rate. Random equivalent time sampling is used in most DSOs and the repetitive signal bandwidth and sampling rate are not coupled in these instruments. The user's knowledge of the Nyquist limit does remain valid for the single-event signals in these instruments.

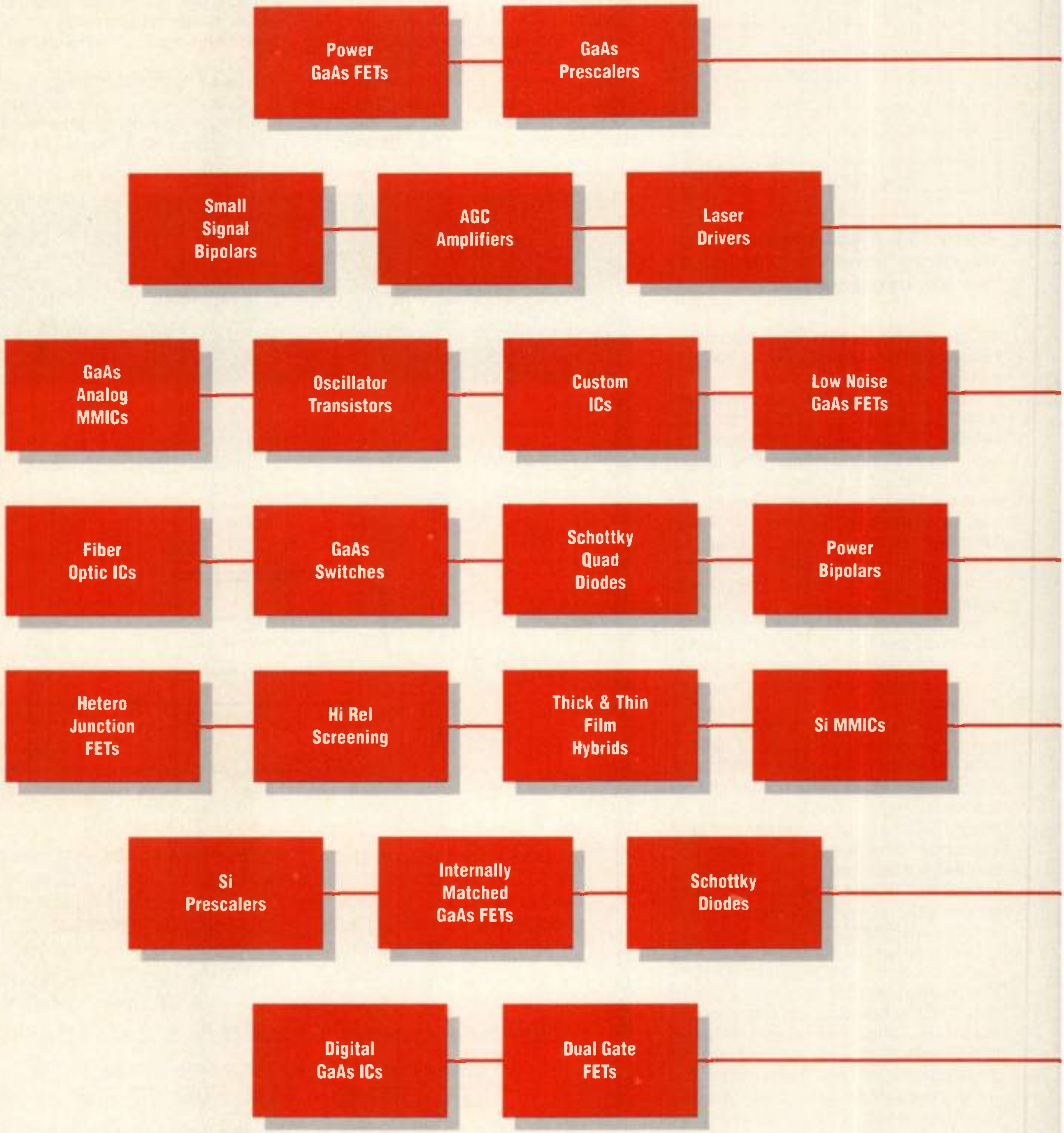
Interpolation in DSOs also causes confusion. Some DSOs cannot perform interpolation, and some allow users to turn it off, so that dots are displayed on the screen without connections between them. This approach allows users to make up their own minds about what the waveform might be doing between dots. However, when a signal's frequency content approaches the Nyquist rate, a dots-only waveform can prove hard to interpret because of a problem called visual aliasing (Figure 2(a)). To avoid such problems and make waveforms easier to see, some DSOs connect dots with straight-line vectors, as shown in Figure 2(b).

Sinx/x interpolation provides a more accurate display by acting as a time filter whose amplitude function is sinx/x (Figure 3). This algorithm reconstructs the implied curves between dots and enables a correct waveform display when there is no signal (or noise) energy at frequencies above half the effective sampling frequency. One drawback is that ringing (preshoot and overshoot) is generated at abrupt voltage steps. Some DSOs use a modified sinx/x algorithm to eliminate ringing, with the tradeoff of introducing some nonlinearities.

How to Avoid Aliasing

One of the most confusing DSO factors is aliasing. Engineers are generally aware that a too-low sampling rate

INFO/CARD 39


Power GaAs FETs
GaAs Prescalers
Small Signal Bipolars
AGC Amplifiers
Laser Drivers
GaAs Analog MMICs
Oscillator Transistors
Custom ICs
Low Noise GaAs FETs
Fiber Optic ICs
GaAs Switches
Schottky Quad Diodes
Power Bipolars
Hetero Junction FETs
Hi Rel Screening
Thick & Thin Film Hybrids
Si MMICs
Si Prescalers
Internally Matched GaAs FETs
Schottky Diodes
Digital GaAs ICs
Dual Gate FETs

Visit us at MTT-S, Booth #515

When it's time to let your fingers do the walking, CEL can make it a short trip.

You could spend hours on the phone hunting products. Or you could call CEL.

For over 25 years we've been your exclusive source for NEC's family of microwave semiconductors. With offices throughout North America, those products are virtually a local call away.

NEC means quality, reliability and a wide selection of Space, Military and commercial devices.

CEL means local service and experienced applications engineering support. We can provide special selections, High Rel and Military screening, and the characterization data you need to accurately evaluate your circuit's performance using NEC products.

So if you're looking for selection, custom capability, and the engineering support it takes to get your designs off to a fast start, save yourself a search. Call CEL first.

NEC®

California Eastern Laboratories

CEL, 3260 Jay Street, Santa Clara, CA 95054; (408) 988-3500 □ Los Angeles, CA (213) 645-0985 □ Bellevue, WA (206) 455-1101 □ Scottsdale, AZ (602) 945-1381 or 941-3927 Richardson, TX (214) 437-5487 □ Burr Ridge, IL (312) 655-0089 □ Cockeysville, MD (301) 667-1310 □ Peabody, MA (617) 535-2885 □ Hackensack, NJ (201) 487-1155 or 487-1160 Palm Bay, FL (305) 727-8045 □ Norcross, GA (404) 446-7300 □ Nepean, Ontario, Canada (613) 726-0626

WRH

can cause aliasing, which results in a misrepresented waveform. However, because the true nature of aliasing is not well understood, all DSO displays are distrusted. This is like distrusting an analog scope because it can reduce a very high frequency square-wave to a sine wave. With either instrument, it is important to know the limits.

To understand aliasing, consider Figure 4, which illustrates a pulse waveform that is undersampled in a DSO operating with 100 Msamples/s real-time sampling. The display is a double-exposure photo of two occurrences of this signal, which appears to be a square-wave pulse with a period of 100 ns. It is actually a square-wave with a period of 11.1 ns.

Probably the most important point to understand about aliasing is that a DSO does not always sample at its highest rate. As a user decreases a DSO's sweep speed, the sample rate also decreases. Thus, even though the DSO's sample rate seems high enough to handle a certain frequency, at low sweep speeds the lower rate might cause aliasing.

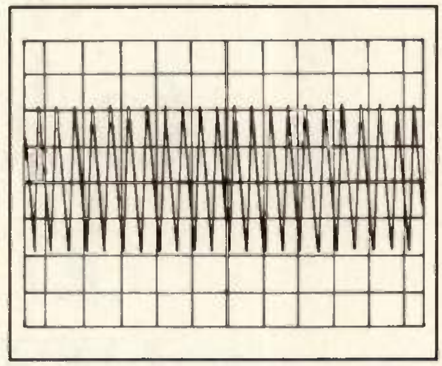


Figure 2(b). Straight-line vector connections between data points reveal that the signal period is about four sample intervals.

Several methods are used in more sophisticated DSOs to keep a higher effective sample rate with lower sweep speeds. Analog glitch capture and digital min-max are methods that provide the minimum and maximum values within each of the sample intervals on the DSO screen. These methods assure, within certain limits, that the high-frequency peak content is not lost at slower sweep speeds.

Min-max methods do not provide detailed information because they only keep peak values. Long record lengths, on the other hand, do retain the detailed information, which can be expanded out for higher resolution display.

Another solution to aliasing is to use envelope mode. Envelope mode essentially allows users to zoom in and out on a waveform without changing the sampling rate, and is similar to min-max but applies to repetitive signals. At each memory address, envelope mode accumulates the minimum and maximum values from repetitive occurrences of the waveform sampling process. The random location of sampling points with respect to the signal results in an eventual accumulation of the peak values of the higher frequency content. This requires the non-synchronous sampling of random equivalent time sampling, a technique that in itself offers a good way to reveal hidden high-frequency signal components.

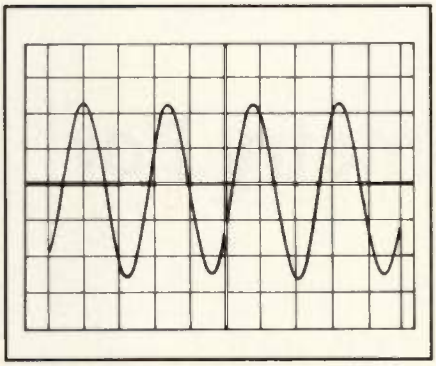


Figure 3. A 40 MHz sine wave has been sampled at 100 Msamples/s, or 2.5 samples per cycle and reconstructed using the sinx/x interpolation alorithm.

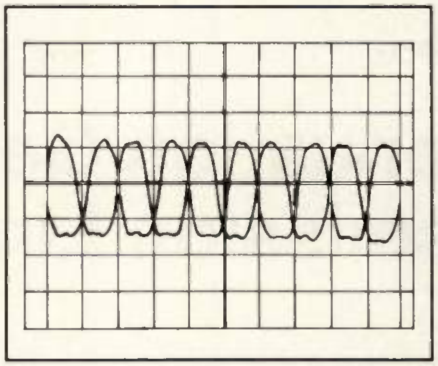


Figure 4. An aliased pulse waveform appears to have a 100 ns period, but it actually has an 11.1 ns period.

Some DSOs include an aliasing warning light that indicates the presence of frequencies above the Nyquist rate. Users should be aware, however, that aliasing can occur without lighting the indicator if the DSO is not set to trigger on the signal's highest frequency.

A universal method used to check for aliasing is to switch to higher sweep speeds while watching whether the displayed waveform changes proportionally with the increased speed. An aliased signal will not change naturally with these changes in sampling frequency.

Specifications

Specifications are potential sources of confusion in just about any system and DSOs are no exception. One of the biggest problems here is the relationship between sample rate, bandwidth, and maximum trigger rate. Confusion arises when users attempt to infer a DSO's bandwidth from either the sample rate or the maximum trigger rate. But for repetitive signals, a DSO's bandwidth is determined by the bandwidth of its front-end amplifier and track-and-hold sampler — not by its sampling frequency.

There is also a somewhat subjective judgment about how many samples are needed to adequately describe the highest frequency sine wave the DSO can capture. Some users want 10 samples, while others say 2.5 is enough. Because the final answer depends on the capabilities of a specific instrument, it is best simply to take a DSO's specified bandwidth as the bottom line of its performance capability.

Another confusing factor with specifications involves additional bits of resolution. Going from eight to 10 bits, for example, provides four times as many amplitude resolution intervals.

The final source of DSO confusion is measurement accuracy. Few engineers realize that DSOs can furnish inherently greater accuracy than analog scopes. This is because measurements on analog scopes are typically made visually from the screen. At best, users can expect approximately 3 percent accuracy. A DSO, on the other hand, measures signals immediately after the digitizing stage. DSOs can also make measurements automatically, eliminating visual error.

Confusion about accuracy also comes into play when engineers consider signal averaging — an algorithmic technique that actually increases a DSO's resolution. The confusion can be cleared up by understanding that signal averaging improves resolution only in the presence of at least 1 LSB of noise. This much noise is almost always present. Without averaging, the noise will cause individual measurements to differ slightly. Averaging gives a truer picture of what the underlying signal is like over time.

There are many other aspects of DSOs that potential users do not fully grasp, but the factors presented here are the ones that are most commonly misunderstood. rf

About the Author

Gene Andrews is chief engineer and manager of technology development in the Laboratory Instruments Division of Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077. His phone number is (503) 627-3062.

Minimum Attenuation Geometry For Coaxial Transmission Line

Optimization Principles for Best Outer-to-Inner Conductor Diameter Ratios

By Ernie Franke
E-Systems, ECI Division

For a given maximum coaxial cable diameter and a given dielectric material, there is an optimum impedance for achieving minimum transmission cable loss. To achieve the highest Q for coaxial cavity structures, the geometry must be optimized in this manner for the best outer-to-inner conductor diameter ratio.

The first design consideration for a coaxial transmission line is the maximum allowable outer conductor diameter. The cost of the cable is largely determined by this diameter because it affects most of the metallic and dielectric costs (cost increases approximately by the square of the diameter). As the allowable diameter is increased the loss decreases, but the cost rises. Hence, there is a tradeoff between transmission loss and cost.

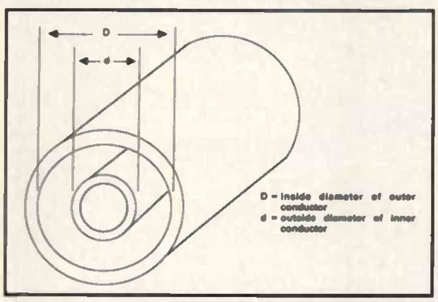


Figure 1. The characteristic impedance of a coaxial transmission line is a function of the conductor diameters.

Next, the dielectric material must be chosen for dielectric loss and physical properties, with the lowest-loss dielectric being air. While the optimum choice is air, foam dielectric materials that approach the dielectric constant of air are available. Typically, however, low-loss dielectrics are expensive, lack ruggedness or allow moisture penetration. The use of higher operating temperature low-loss dielectrics such as solid PTFE, an example of which is DuPont's Teflon®, increases the price several-fold over that of polyethylene.

Once the outer conductor diameter and dielectric material have been chosen, the center conductor diameter is then adjusted to achieve the desired characteristic impedance. An optimum geometry exists for achieving minimum attenuation in a coaxial transmission line. The characteristic impedance of the cable is directly related to the geometry of the conductor diameters. The minimum attenuation geometry is also important for achieving the highest possible Q for such applications as synthesizer VCOs, where the phase noise is a function of unloaded resonator Q, or in cavity duplexer filters, where excess loss increases the effective receiver noise figure and reduces the available transmitter output power. The optimum geometry for coaxial cable is not a new relationship (1,2). Often it is suggested that 75 ohm coaxial cable should yield a lower attenuation than that of the more common 50 ohm cable. The widespread use of 75 ohm cable for CATV applications is not proof of minimal attenuation for transmission lines with available solid dielectrics. For commonly available dielectric materials, the 50 ohm cable has the same or less attenuation than that of 75 ohm cable with the same dielectric and outer conductor diameter.

Optimum Conductor Diameter Ratio

For coaxial lines used at high frequencies (>1 MHz), the total distributed resistance of both the inner and outer conductor of the coaxial line is given as:

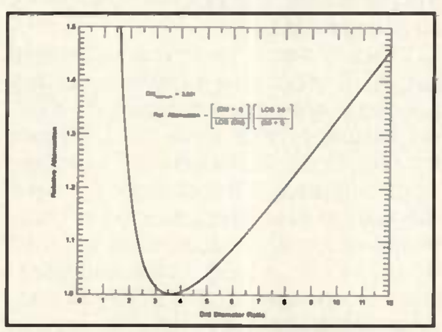


Figure 2. Relative attenuation for various conductor diameter ratios.

Dielectric Material	Relative Dielectric Constant (ε_r)	Optimum Impedance Z_{opt} (ohms)	Relative Attenuation of 50 Ohm Cable to Z_{opt}
Air	1.00	76.6	1.102
Polyfoam, PE or PTFE	1.52	62.2	1.020
Teflon[R], PTFE	2.07	53.2	1.002
Polyethylene, PE	2.30	50.5	1.000

Table 1. Comparison chart of optimum impedance for commonly available dielectric materials.

$$R_{HF} = (R_s/\pi D)(1 + D/d) \quad (1)$$

where d is the outside diameter of the inner conductor, D is the inside diameter of the outer conductor and R_S is the surface resistivity of the conductor material, as shown in Figure 1. Assuming that the dielectric material is not magnetic, the characteristic impedance, Z_O, is given by:

$$Z_O\ (\text{ohms}) = (138/\sqrt{\varepsilon_r})\log_{10}(D/d)\text{ohms}$$
$$= (60/\sqrt{\varepsilon_r})\ln(D/d) \quad (2)$$

where ε_r is the relative dielectric constant and ln is the naperian logarithm, loge.

The attenuation factor for a high frequency transmission line is given (3) as:

$$\alpha_{HF} = (R_{HF}/2Z_O) + (GZ_O/2) \quad (3)$$

The leakage conductance term, G, is negligible for typical low-loss dielectric materials and is thus dropped from the equation. Substituting the coaxial cable expressions from above yields the following loss expressions for inner and outer conductors that are constructed from the same material:

$$\alpha_{HF}(\text{coax}) = \frac{(R_S\sqrt{\varepsilon_r}/\pi D)(1 + D/d)}{(276\log_{10}D/d)} \quad (4)$$

$$\alpha_{HF}(\text{coax}) = \frac{(R_S\sqrt{\varepsilon_r}/\pi D)(1 + D/d)}{(120\ \ln D/d)} \quad (5)$$

In Figure 2, the relative attenuation is plotted as a function of the outer-to-inner conductor diameter ratio. It has been normalized to the minimum attenuation value. Differentiating with respect to D/d and equating to zero to determine this minimum attenuation inflection point leads to the relationship:

$$\ln(D/d) = 1 + (d/D) \quad (6)$$

This minimum attenuation point results in a conductor diameter ratio of 3.591, with a resultant characteristic impedance of 76.62 ohms for a transmission line with air dielectric. The minimum in the relative attenuation factor as a function of the diameter ratio is broad, with less than a 0.5 percent increase from conductor diameter ratios over the range of D/d = 3.22 to D/d = 4.05. Thus, a moderate departure from the optimum geometry does not greatly increase the line losses. The relative loss increases by only 1 percent at D/d ratios over the range of 3.08 and 4.24.

For a given outer conductor diameter and a given dielectric, there is an optimum impedance for minimum attenuation. The exact point for highest Q is:

$$Z_{opt}(\text{ohms}) = \frac{138\log 3.591}{\sqrt{\varepsilon_r}} \quad (7)$$

Dielectric Material	Relative Dielectric Constant (ε_r)	Relative Velocity of Propagation (V_P)	Approx. Power Factor Loss Tangent	Normal Operating Temperature Range (°C)
Air	1.00	1.00068	0.00000	−250 to +250
Foam Teflon[R], PTFE	1.40	0.85	0.00015	−250 to +250
Foam FEP	1.50	0.82	0.00030	−70 to +200
Foam Polyethylene, PE	1.52	0.81	0.00031	−65 to +80
Teflon[R], PTFE	2.07	0.69	0.00015	−250 to +250
FEP	2.10	0.69	0.00030	−70 to +200
Ethylene Propylene	2.24	0.67	0.00046	−40 to +105
Solid Polyethylene, PE	2.30	0.66	0.00031	−65 to +80

Table 2. Comparison chart of commonly available dielectric materials.

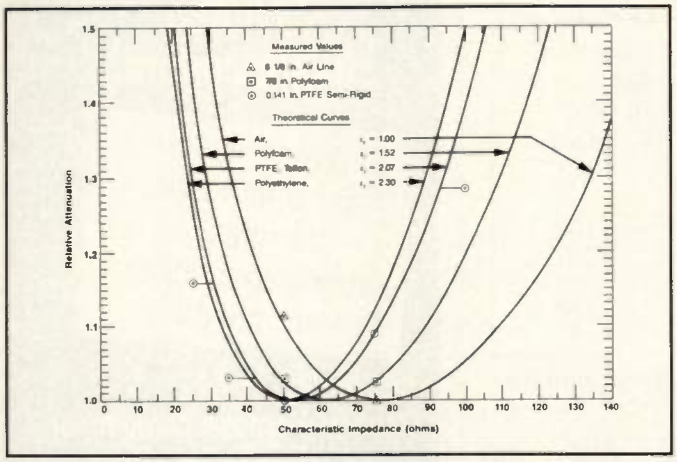


Figure 3. Optimum characteristic impedance for several common dielectrics.

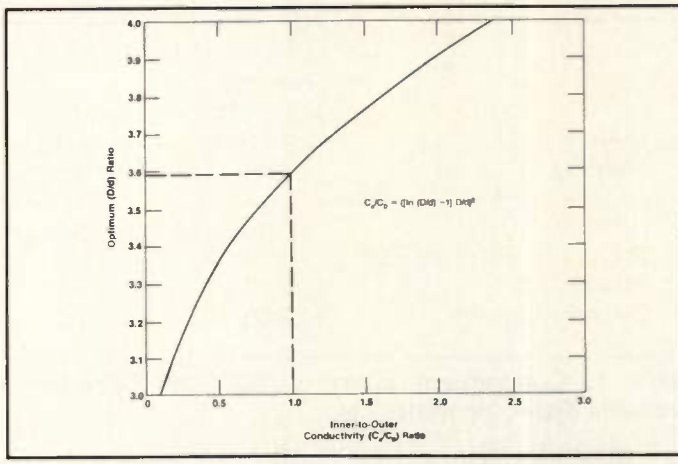


Figure 5. Optimum geometry for various ratios of inner to outer conductor conductivity.

$$Z_{opt}(\text{ohms}) = \frac{76.62}{\sqrt{\varepsilon_r}} \quad (8)$$

Since the relative velocity of propagation in a transmission line, V_P, is given as:

$$V_P = \frac{1}{\sqrt{\varepsilon_r}} \quad (9)$$

The optimum impedance for coaxial cable is:

$$Z_{opt}(\text{ohms}) = 76.62\ V_P \quad (10)$$

If the dielectric constant is included, the variation in relative attenuation as a function of characteristic impedance is shown in Figure 3 for several common dielectrics. Experimental evidence for coaxial cables with various dielectrics fits these theoretical curves. Measured values of relative attenuation in Figure 3 are shown with circles for 0.141 in. semi-rigid coaxial cable with solid PTFE dielectric for impedance values from 25 ohms to 100 ohms. Because the data was taken at 1 GHz, part of the measured attenuation is due to dielectric loss. Therefore the agreement with theory is quite close, but not exact. The 7/8 in. diameter foam polyethylene cable data, shown as squares, was measured between 30 MHz and 1 GHz. The measured values for the 6 1/8 in. diameter rigid air-line was taken at television channels 2 to 69 (50 to 800 MHz).

Because the relative attenuation function is broad, the penalty for using the commonly available, non-optimum value of 50 ohms for coaxial cable with solid PTFE or polyethylene dielectrics is quite small, as shown in Table 1. Considering coaxial cable using PTFE dielectric, the effect is a 0.2 percent increase in attenuation above a theoretical optimum loss for a cable with an impedance of 53.2 ohms. The best method for reducing losses is to reduce the dielectric relative constant, because this term is seen both in the conductor losses and in the dielectric losses. By reducing the dielectric constant, through changing material or aerating it, the size of the center conductor may be increased for the same impedance, thus reducing the copper losses. Formed by means of a foaming agent intimately dispersed in the dielectric granules before melting and extrusion, cellular material approaches the dielectric constant of air.

The total attenuation in a coaxial line is the sum of the attenuations due to conductor losses and dielectric losses:

$$\alpha_T = \alpha_C + \alpha_D \quad (11)$$

where α_T is the total attenuation, α_C is the attenuation resulting from conductor losses, and α_D is the attenuation resulting from dielectric losses. The attenuation due to copper losses alone is:

$$\alpha_C(\text{dB/100 ft}) = \left(\frac{0.435}{Z_O}\right)\left(\frac{1}{d} + \frac{1}{D}\right)\sqrt{f} \quad (12)$$

where f is in megahertz and the conductor diameters are in inches. The attenuation in a coaxial transmission line resulting from dielectric losses alone is given as:

$$\alpha_D(\text{dB/100 ft}) = 2.78f\sqrt{\varepsilon_r}\tan\delta \quad (13)$$

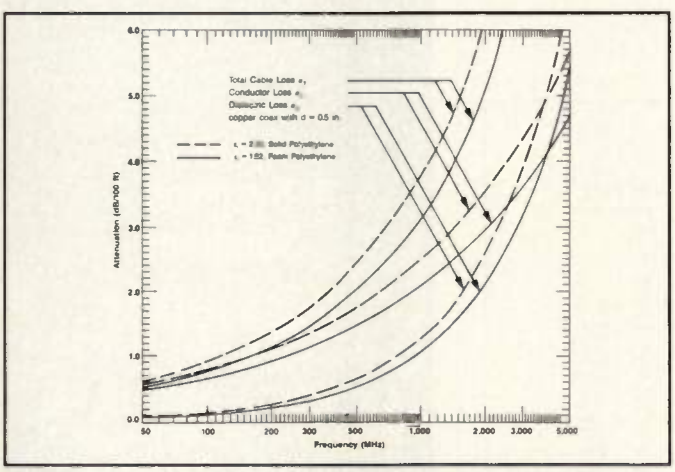


Figure 4. The total cable loss is divided between conductor losses and dielectric losses.

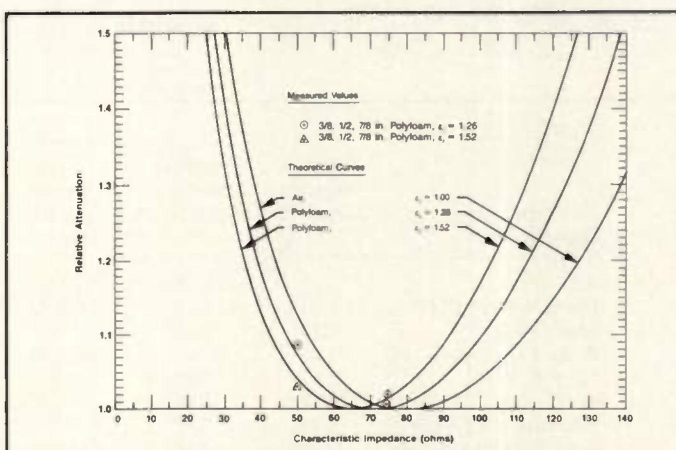


Figure 6. Optimum impedance for aluminum sheath coaxial cable.

where tanδ is the loss tangent or power factor of the dielectric. Thus, the conductor losses are proportional to the square root of frequency and the dielectric losses are linearly proportional to frequency. Rigid-line, using air as the dielectric, does not have any measurable dielectric loss. The entire transmission loss is due to conductor losses. This frequency effect may be seen more clearly in Figure 4, which shows results for both solid (ε_r=2.30) and for foam (ε_r=1.52) polyethylene, 0.5 in. diameter, copper coaxial cable. The total cable loss is the sum of the conductor and dielectric losses. In the region of 2 to 3 GHz the dielectric losses dominate over the conductor losses.

The dielectric material must be examined for the relative dielectric constant, loss tangent and physical characteristics as summarized for several dielectric materials in Table 2. Polyethylene dielectric is limited to continuous operation at an inner conductor temperature of 100 degrees C, whereas the use of PTFE extends this maximum temperature to 250 degrees C. PTFE also shows a lower loss tangent to yield lower cable loss beyond the region of 1 GHz.

Several cable manufacturers have substituted aluminum for copper in the outer conductor to reduce the cost of coaxial cable. The optimum conductor diameter ratio for various mixtures of conductor metals is shown in Figure 5. This optimum conductor ratio, D/d, is solved from the following equation:

$$\sqrt{n} = [\ln(D/d) - 1](D/d) \qquad (14)$$

where n is the ratio of the inner-to-outer conductor conductivity. The relative conductivities for several common metals are compared with copper in Table 3. Thus the effect of using a silver-plated center conductor where the ratio of inner conductor to copper outer conductor conductivity is 1.064 can be evaluated. The optimum D/d geometry is 3.616, only a slight variation from the case where both inner and outer conductors were constructed using the same metal.

Because of the ready availability of less expensive coaxial cable with an aluminum outer conductor or sheath, the optimum impedance is plotted in Figure 6 for several dielectric materials, where the ratio of the copper inner conductor conductivity to the aluminum outer conductor conductivity is 1.52. Several experimental points are included to verify these relative attenuation curves. The minimum attenuation impedance is greater than that of a cable

Metal	Relative Conductivity with Respect to Copper
Silver	1.064
Copper	1.000
Gold	0.707
Aluminum	0.658
Brass	0.442
Zinc	0.287
Nickel	0.250
Tin	0.151

Table 3. Conductor conductivity comparison table.

using similar materials both for the inner and outer conductor. This is summarized in Table 4 for several common dielectric materials.

The attenuation of coaxial cable using aluminum is always greater than that of a similar outer diameter cable constructed using copper. The optimum impedance of low-density, polyethylene polyfoam with an aluminum outer conductor approaches the 75 ohm CATV cable which is commonly available.

Cut-Off Frequency

Energy transmission in a coaxial cable takes place in the normal transverse electromagnetic (TEM) mode. Both the electric and magnetic fields are entirely normal (perpendicular) to the direction of propagation. The cut-off frequency of a coaxial cable is that frequency at which modes of energy transmission other than the TEM mode can be generated. The frequency is a function of the mean diameter of the conductors and the velocity of propagation of the cable. These higher modes are generated at impedance discontinuities. Above the cut-off frequency, other modes can exist and the transmission properties are no longer defined. For these higher modes the coaxial line acts as a highpass filter. An approximate formula for the cut-off frequency, f_{co}, is:

$$f_{co}(\text{GHz}) = \frac{7.52}{[(\sqrt{\varepsilon_r})(D + d)]} \qquad (15)$$

where the diameters D and d are given in inches.

Conclusion

For copper rigid coaxial transmission line, where the center conductor is minimally supported with beads or disks to achieve a relative dielectric constant very close to that of air, a characteristic impedance of 75 ohms is chosen for minimum attenuation. This value is very close to the theoretical lowest-loss value of 76.6 ohms. As solid dielectrics are added to achieve flexibility and inner conductor support, the impedance for maximum Q is reduced by the relative velocity factor. For flexible coaxial cable with a foam polyethylene or foam PTFE dielectric, the attenuation is almost exactly the same for 50 or 75 ohm cable. For solid polyethylene or PTFE, the attenuation of 50 ohm cable is, however, about 8 percent lower than that of a similar 75 ohm cable. If the metal used for the center conductor differs from that of the outer conductor, the geometry of the cable must be adjusted to achieve minimum attenuation. The absolute lowest loss is achieved using the highest conductivity metal (copper or silver) and the lowest relative dielectric constant (air or foam), high quality (low loss tangent) material. As the operating frequency is increased and dielectric losses tend to predominate, the effects of an optimum impedance based on conductor losses become less important. Once a tolerable cable diameter has been set and a dielectric material chosen, the optimum impedance can then be determined to yield the lowest relative loss.

Dielectric Material	Relative Dielectric Constant (ε_r)	Optimum Impedance Z_{opt}(ohms)	Relative Attenuation of 50 Ohm Cable to Z_{opt}
Air	1.00	79.5	1.125
Polyfoam, PE	1.26	70.7	1.070
Polyfoam, PE	1.52	64.4	1.039

Table 4. Optimum impedance of aluminum sheath coaxial cables.

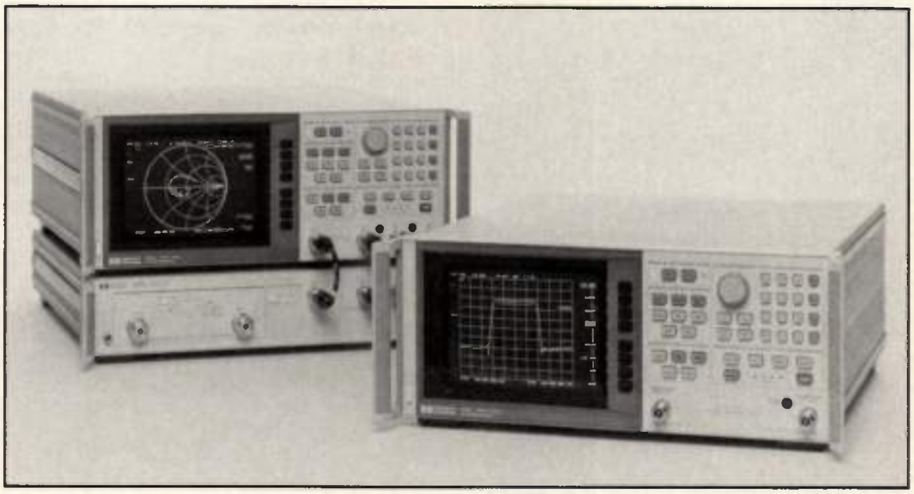
References

1. E.J. Sterba and C.B. Feldman, "Transmission Lines for Short-Wave Radio Systems," *Proc. IRE*, vol. 20, July 1932, pp. 1163-1202.
2. E.I. Green, F.A. Leibe, and H.E. Curtis, "The Proportioning of Shielding Circuits for Minimum High-Frequency Attenuation," *Bell System Technical Journal*, vol. 15, April 1936, pp. 248-283.
3. R. A. Chipman, *Theory and Problems of Transmission Lines*, McGraw-Hill, Inc., New York, 1968, p. 49.

About the Author

Ernie Franke is a member of the technical staff at E-Systems, ECI Division, P.O. Box 12248, St. Petersburg, FL 33733-2248. Tel: (813) 381-2000

HP Introduces Two Network Analyzers

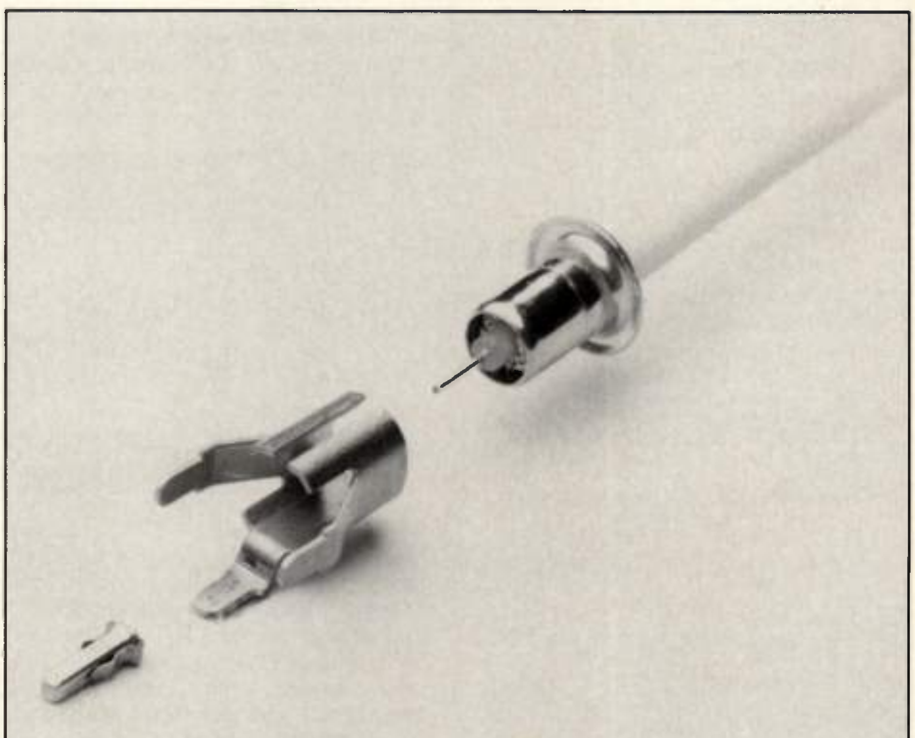


The HP 8752A network analyzer features a 300 kHz to 1.3 GHz frequency range with an option to extend it to 3 GHz. The instrument includes a synthesized source, a receiver, and a transmission-and-reflection test set. Capabilities include a swept-synthesized source with 1 Hz resolution, a tuned receiver with 100 dB dynamic range, a direct group-delay measurement of better than 1 ps resolution, and an optional time-domain-analysis feature.

Also from HP is the 8753C network analyzer, which replaces the HP 8753B and includes a color display. Its measurement capabilities include a 300 kHz to 3 GHz range, with optional 6 GHz coverage; swept-harmonic measurement of amplifiers using the same configuration used to test gain and reflections; measurement of frequency-translation devices; absolute power measurements with any of the three receiver inputs; forward and reverse measurement of device transmission and reflection characteristics using a single connection; optional time-domain-analysis capability; 50 and 75 ohm options; and a line of calibration and accessory kits.

The HP 8752A network analyzer is priced at $22,000, with the 3 GHz option priced at $6,000. The time-domain analysis feature is $4,800 and Option 802, which consists of a 3.5 in. dual disk drive and HP-IB cable, is $1,495. The cost of the HP 8753C is $25,500. Its optional harmonic measurement capability is $3,000, 6 GHz operation is $3,000 and the time-domain analysis option is priced at $4,800. Option 802 is also available for this network analyzer. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #230.**

RF Interconnect System From Tektronix



The Peltola™ RF interconnect system, previously used only on Tektronix instrumentation, is available commercially in either 50 or 75 ohm options. The system consists of close tolerance coaxial cable and special connectors designed to provide circuit board connections for RF signals up to 2 GHz.

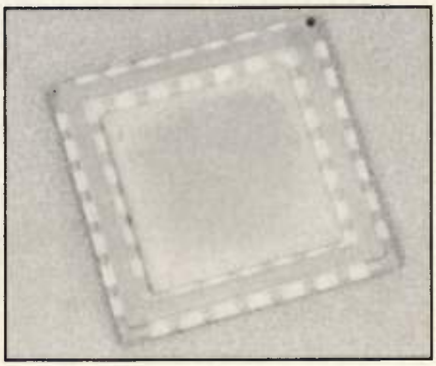
The system offers a solderless connector assembly that can be used to provide a connection between circuit boards or from circuit boards to the back side of a panel. The assembly is made possible by having both the cable shield and center conductor run completely through the connector body with the center conductor becoming the male pin. It offers a cost-effective alternative solution to the typical SMB type connectors.

The price of the assembly varies according to cable length and annual volume. For example, a Peltola assembly with Peltola connectors on each end, 12 inches of cable in 1,000 piece quantity, is typically priced less than $3.00. **Tektronix, Inc., Vancouver, WA. INFO/CARD #229.**

rf products Continued

Ceramic Packages

Oxley introduces a line of microwave packages, the XJ Series, that offers semiconductor designers a hermetically sealed ceramic enclosure for GaAs MMICs and silicon devices operating up to 10 GHz. Various package options are available including 8-, 16- or 24-port



configurations, low and high power, and either lead framed or non-leaded. I/O ports are 50 ohm microstrip compatible. High purity CERAMOX alumina, cofired with tungsten, is used to achieve optimum RF and microwave performance. The tungsten is electroplated with nickel and gold to give a surface suitable for wire or ribbon bonding. Integral vias provide grounding and Kovar package lids with gold/tin eutectic solder are used. **Oxley, Inc., Branford, CT. Please circle INFO/CARD #228.**

4-Channel Network Analyzer

The Boonton 2300 scalar network analyzer features four inputs: A, B, R and DVM. The A input features an 80

dB dynamic range from +20 to -60 dBm with a 100 kHz to 60 GHz frequency range. Any user-selected monochrome or color display, composite video or IBM-compatible RGB TTL may be used. GPIB and RS-232 interfaces are standard. The instrument is priced at $4,000. **Boonton Electronics Corp., Randolph, NJ. INFO/CARD #227.**

High-Intercept Amplifier

Model AR30050066-1 high-intercept amplifier covers 10 to 500 MHz with 27 dB gain and a 3.3 dB noise factor. The

IP3 is +43 dBm while the IP2 is +78 dBm. For a 1 dB compression point of +28 dBm, the device requires 300 mA at 28 V. **Advanced Milliwave Laboratories, Inc., Camarillo, CA. Please circle INFO/CARD #226.**

Power Sensor Calibrator

Bird Electronics introduces the Model 4029 power sensor calibrator for use with the 4420 Series RF power meters.

The calibrator, when used in conjunction with a CRT terminal or PC with a serial port, provides in-field calibration of power meters to within 3 percent of a known RF standard. The 4029 features a menu-driven protocol to the terminal that guides the user through the calibration process. It can add or delete individual calibration points, clear all calibration points, and list calibration points for review. **Bird Electronic Corp., Cleveland, OH. INFO/CARD #225.**

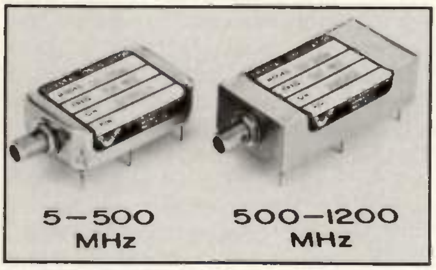
Synthesized Signal Generator

The HP 8657B is a synthesized signal generator that features AM, FM and

optional pulse modulation with under 35 ns rise/fall times and 70 to 95 dB on/off ratios. Phase noise at 2 GHz is under -118 dBc/Hz at 20 kHz offset, spurious is less than -60 dBc, and dynamic range is +13 dB to -143 dBm with ± 1 dB accuracy. The instrument is priced at $12,500. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #224.**

5-1200 MHz Crystal Oscillators

Models CO-285W (5-500 MHz) and CO-286W (500-1200 MHz) feature stability better than ± 25 ppm over the 0 to +70 degrees C temperature range.



Stability options include ± 3 ppm from 0 to +50 degrees C and ± 50 ppm over the -55 to +85 degrees C temperature range. The oscillators are set to within ± 10 ppm of specified frequency and a frequency adjustment for setting to within 1 ppm is optionally available in the 285W. The output level exceeds +7 dBm with +13 dBm optional. Noise floor at 100 MHz is -155 dBc/Hz. Surface-mount packaging is available. **Vectron Laboratories, Inc., Norwalk, CT. Please circle INFO/CARD #223.**

MMIC Pulse Modulator

The 612M001 pulse modulator is a MMIC housed in an SMA-connectorized package covering from 0.010 to 6.0 GHz. This TTL unit offers less than 20 ns total switching time with 2 ns rise and fall times. The video transients are less than -60 dBm in-band. The MMIC is priced at $704. **New England Micronetics, Inc., Hudson, NH. Please circle INFO/CARD #222.**

Scalar Network Analyzer

Wiltron introduces the Model 562 scalar network analyzer which features

RF Design Software Service

Computer programs published in *RF Design* are available on disk, as a service to readers. For a minimal cost, you can avoid the problems of typing listings into your computer.

The following is a complete listing of available programs. All are in MS-DOS format:

Disk RFD-0589 (May 1989 RF Design)

SPURPLOT, from "A Mixer Spurious Plotting Program," by Richard Bain (QuickBasic™, compiled; CGA graphics only, or use conversion software). *This program will not be distributed outside the U.S.A.*

Disk RFD-0489 (April 1989 RF Design)

1. "Design of Constant Phase Difference Networks," (Lotus Spreadsheets).
2. "A BASIC Program for 90-Degree Allpass Networks," (GWBASIC and compiled versions).
3. "Bridged-Tee Delay Equalizers — A Computer-Aided Realization," (HPBASIC, not compatible with BASICA or GWBASIC).
4. "Design of Line Matching Networks," (MATCH program, GWBASIC).

Disk RFD-0389 (March 1989 RF Design)

1. "A Design Program for Butterworth Lowpass Filters" (QuickBasic™, compiled).
2. "A Parallel-Coupled Resonator Filter Program" (QuickBasic™, compiled).

Disk RFD-029 (February 1989 RF Design)

1. "CAD for Lumped-Element Matching Circuits" (GWBASIC).
2. "Modeling PLL Tracking of Noisy Signals" (QuickBasic™, compiled; requires EGA or VGA graphics).

Disks are $9.00 each (5 1/4 in.), or $10.00 (3 1/2 in.). Outside of the U.S. and Canada, add $8.00 (disks will be sent airmail).

Specify disks wanted. Payment must accompany order. Send check or money order to:

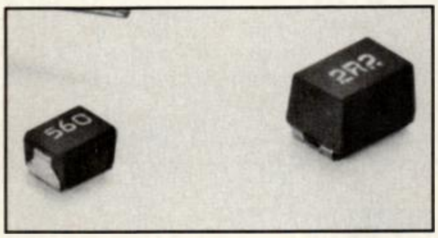
RF Design Software Service
P. O. Box 3702
Littleton, CO 80161-3702

Questions and comments should be directed to *RF Design* magazine.

a 10 MHz to 40 GHz range. Dynamic range is 76 dB, and sensitivity is -60 dBm. The instrument features the ability to display reflections directly in SWR or as return loss in dB. It is priced at $7,400. **Wiltron, Morgan Hill, CA. INFO/CARD #221.**

SMT Chip Inductors

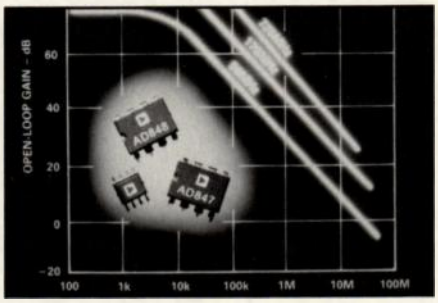
These inductors are available for inductances from 0.047 uH to 1000 uH and are available in a shielded version.



These Surfcoil chip inductors are standard in carrier and reel packaging. Prices start at $0.28 each in 5000-piece quantity. **Sprague-Goodman Electronics, Inc., Garden City Park, NY. Please circle INFO/CARD #220.**

Operational Amplifiers

Analog Devices unveils two operational amplifiers designated Models AD849 and AD848. Model 849 features a gain-bandwidth product of 725 MHz for gains greater than or equal to 25. The 848 has a gain-bandwidth product of 175 MHz for gains greater than or equal to 5. Slew rate is measured at 300 V/us, and



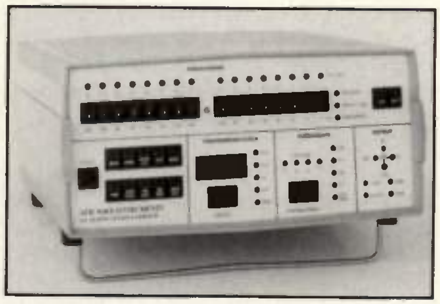
settling time is 100 ns to 0.1 percent for the 848 and 80 ns for the 849 for a 10 volt step. Available packaging includes 8-pin miniDIP, CERDIP and small outline. In 100-piece quantity, price starts at $2.95. **Analog Devices, Inc., Norwood, MA. INFO/CARD #219.**

Oven-Controlled Crystal Oscillator

This device features a nominal frequency of 10 MHz in a 3rd overtone SC-cut crystal. Stability is ± 3 X 10^{-5} and aging is under 8 X 10^{-7} from 3 days to 10 years. From 1 kHz to 100 kHz, spurs are measured at -120 dBc and ripple is 100 mV p-p from 100 kHz to 1 MHz. **Piezo Technology, Inc., Orlando, FL. INFO/CARD #218.**

Spread Spectrum Generator

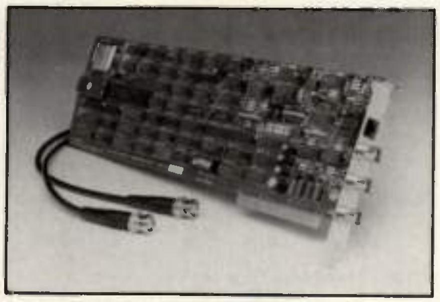
The LRS-100 is a pseudorandom sequence generator that is useful for developing and testing spread spectrum and conventional data communication systems. The desired linear recursive sequence (LRS) is selected by setting the feedback pattern and initial contents of a 16-bit shift register. The length of the LRS sequence can be varied from 1 to 2^{16}-1 and the internal clock can be varied from 1 Hz to 25 MHz in steps of 1-2-5. Modes of operation include BPSK, QPSK, GOLD/JPL, staggered, and burst. For spread spectrum applications, a second pseudorandom se-



quence is available for use as a second source. **New Wave Instruments, Provo, UT. INFO/CARD #217.**

PC-Based Universal Counter

This universal counter is a single PC/XT card with a DOS-based software package that provides its front panel on a PC monitor. Standard functions include time interval, frequency, period, period average, totalize, ratio, time interval delay, and pulse width. Phase, rise/fall time and read peak amplitude are also available. Frequency range is DC to 75 MHz and sensitivity is 75 mV RMS from DC to 30 MHz for a sine wave. This instrument is priced at $1,495. **Guide Technology, Inc., Los Altos, CA. Please circle INFO/CARD #216.**

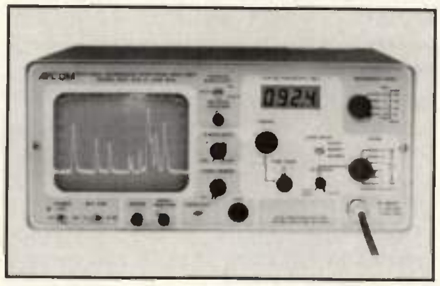


100 W Class AB Power Amplifier

Model BHE 5819-1000 delivers 1000 watts CW output power from 500 to 1000 MHz with instantaneous bandwidth of 500 MHz. RF input is 0 dBm min and output load VSWR is 1.3:1. Even harmonics are -20 dBc max and spurious signals are -60 dBc max. **Power Systems Technology, Inc., Hauppague, NY. INFO/CARD #215.**

Portable Spectrum Analyzer

Model PSA-65A covers through 1000 MHz with sensitivity greater than -90 dBm. This line- or battery-operated unit is available with an optional frequency extender. **Avcom of VA, Inc., Richmond, VA. INFO/CARD #214.**



rf products *Continued*

SC-Cut Oscillator

Piezo Crystal Company introduces the Model 2880068 SC-cut oscillator which features SSB phase noise characteristics of -90 dBc/Hz at 10 Hz, -120 dBc/Hz at 100 Hz, -150 dBc/Hz at 1 kHz, and -158 dBc/Hz at 10 kHz. Frequency stability is ± 1 ppm from -40 to +85 degrees C and typical vibrational sensitivity is 5 X 10^{-10}/g. Price for the device ranges from $500 to $700 in small quantities. **Piezo Crystal Company, Carlisle, PA. INFO/CARD #213.**

Video A/D Converter

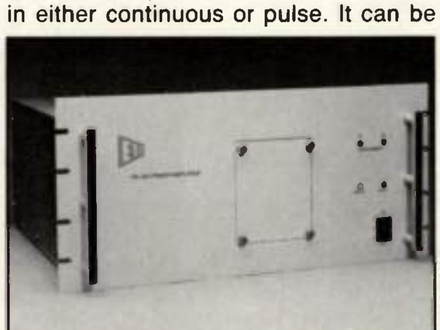
Model TDC1058 is an 8-bit A/D converter that operates on a +5 volt supply. It is capable of Nyquist sampling at 30 MSPS and has a signal-to-noise ratio of 46 dB with a 5 MHz input. Packaging options include CERDIP, plastic DIP and PLCC. Price ranges from $4.50 to $6.75 each. **TRW LSI Products, Inc., La Jolla, CA. INFO/CARD #212.**

TEMPEST Shielding Windows

Optical Coating Laboratory introduces a line of TEMPEST shielding windows which are coated with a transparent conductive layer. It eliminates moire patterns while blocking RFI/EMI radiation. **Optical Coating Laboratory, Inc., Santa Rosa, CA. INFO/CARD #210.**

RF Power Amplifier

The PA-1D5 provides 1500 watts output in either continuous or pulse. It can be configured for any frequency from 2 to 50 MHz. In single unit quantities, the price is $3690. **Ehrhorn Technological Operations, Inc., Colorado Springs, CO. INFO/CARD #209.**

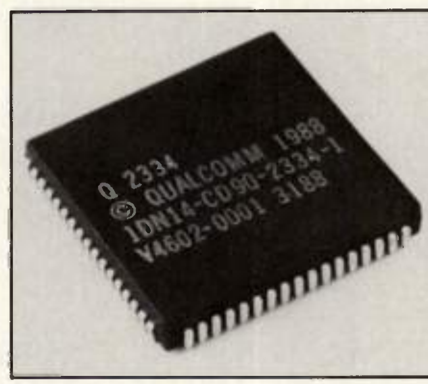


Voltage-Controlled Attenuator

Daico introduces the P/N DA0645 voltage-controlled attenuator that features a 5 to 2000 MHz range with +17 dBm power handling. The attenuation range is greater than 31 dB from 5 to 500 MHz, greater than 25 dB from 500 to 1000 MHz, and greater than 18 dB from 1000 to 2000 MHz. VSWR is 1.3:1 and insertion loss is 1.7 dB typ from 5 to 1000 MHz. The attenuation response time is 60 microseconds typical from 10 percent to 90 percent RF envelope. **Daico Industries, Inc., Compton, CA. INFO/CARD #208.**

Dual Direct Digital Synthesizer

The Q2334I-20 is a dual direct digital synthesizer which generates digitized sinewave signals using phase accumulation techniques combined with on-chip sine lookup. It operates at a maximum sampling rate of 20 MHz, allowing synthesis of waveforms from DC to 10 MHz with frequency resolution better than 0.005 Hz. Spur rejection is better than -70 dBc. In small quantities (2-99), the device costs $85. **Qualcomm, Inc., San Diego, CA. INFO/CARD #207.**

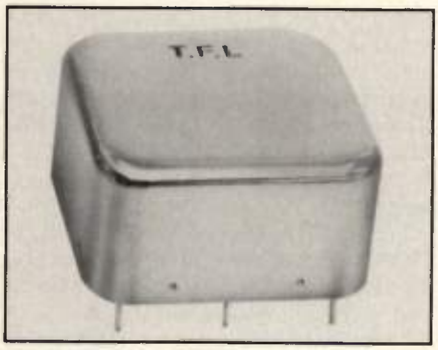


GaAs Downconverter

Pacific Monolithics unveils the PM-CV0701-A/D/S GaAs downconverter that converts from 2-7 GHz to 0.1-1 GHz. It contains an LO buffer, RF amplifier, a double-balanced mixer and an IF amplifier. **Pacific Monolithics, Inc., Sunnyvale, CA. INFO/CARD #206.**

Oven-Controlled Crystal Oscillator

Time & Frequency Ltd. announces an oven-controlled oscillator that is avail-



able for frequencies from 8 to 20 MHz. Model TF-65018A features a frequency stability of ± 1 X 10^{-7} from -20 degrees C to +50 degrees C. **Time and Frequency Ltd., Mitchel Field, NY. INFO/CARD #205.**

PIN Diode Switches

These PIN diode RF switches are designed for CW and pulse application up to 2 kW peak. These 50 ohm devices are available in SP2T, SP3T and SP4T configurations and operate in multiple octave frequencies from 20 MHz to 1000 MHz. Switching times are 1 to 20 microseconds. **Lorch Electronics Div., Vernitron Corp., Englewood, NJ. INFO/CARD #204.**

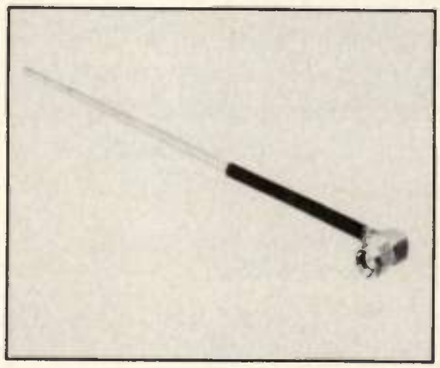
50 Watt Termination

Model 50LH50 is a 50 watt termination that features a DC to 2 GHz range and VSWR of 1.25:1. Peak power rating is

1000 watts. When purchased in quantities of 1 to 24 with N connectors, price is $115. BNC and TNC connectors are available at additional cost. **Alan Industries, Inc., Columbus, IN. Please circle INFO/CARD #203.**

Microstrip Test Probe

A test probe for microstrip RF and microwave circuitry is available from Micro-Coax. It works both independently and in conjunction with spectrum ana-



lyzers on microstrip components, subsystems and systems. It acts as an antenna to look at signal levels at microwave frequencies. **Micro-Coax Components, Inc., Collegeville, PA. INFO/CARD #202.**

Analog DMOS Switches

Calogic Corp. introduces a family of DMOS FETS designed for analog switches, analog multipliers, sample and hold circuits, and A/D and D/A converters. Input-to-output isolation is

120 dB and on-resistance is 30 ohms. The SD211 is a ± 30 volt analog switch driver, the SD213 is a ± 5 volt analog switch, and the SD215 is a ± 10 volt analog switch. The devices are available in TO-72 packaging and die form for hybrid applications. Price in 100,000-piece quantity ranges from $0.67 to $0.82. **Calogic Corp., Fremont, CA. INFO/CARD #201.**

Volute Telemetry Antennas

The RHC and LHC polarized telemetry antennas from Scientific Research Laboratories feature a frequency range of 100 MHz to 800 MHz. A range of antenna patterns are available for satellite and multi-point telemetry applications. Special designs are available for light weight (balloon) applications or multi-band use. **Scientific Research Laboratories, Inc., Santa Maria, CA. INFO/CARD #183.**

Amplifier Driver Stage

The MC-5879 from NEC is a module designed as the driver stage for a high power amplifier from 12.75 to 13.25 GHz. It consists of three stages of GaAs FET chips and impedance matching circuits to achieve 50 ohms. Noise figure is 20 dB at +31 dBm and input and output return loss is measured at 6 dB. The device is priced at $407 each when purchased in quantities of 10. **California Eastern Laboratories, Inc., Santa Clara, CA. INFO/CARD #182.**

Shielding Catalog

The Frontier of Performance in Beryllium Copper — A Guide to Interference Control provides technical information on the selection of shielding to protect electronic equipment from electromagnetic and RF interference. It incorporates a metals compatibility chart to minimize the potential for galvanic corrosion in shielding applications. Also covered are interference testing services, engineering kits, plating finishes, and ordering information. **Instrument Specialties Co., Inc., Delaware Water Gap, PA. INFO/CARD #200.**

VCO/Synthesizer Selector Guide

This guide from Z-Communications features specifications on voltage-controlled oscillators and frequency synthesizers. Information on available package styles is included. **Z-Communications, Inc., Ft. Lauderdale, FL. Please circle INFO/CARD #199.**

Brochure Describes Frequency and Time-Interval Measurement Instruments

HP introduces a brochure that covers its entire line of electronic counters and includes the HP 5371A frequency and time-interval analyzer. It lists information on frequency range and resolution, sensitivity, time-interval resolution, additional features, and accessories. A description of applications in which an electronic counter or frequency and time-interval analyzer should be considered is included. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #198.**

Coils and Inductive Components Catalog

Delevan introduces a catalog that describes its line of coils and inductive components. It highlights electrical and physical parameters for shielded and unshielded axial leaded inductors, variable RF coils, toroidal inductors and power chokes. Also featured are operational and physical parameters for the LCR series of molded unshielded RF coils. **Delevan Div., American Precision Industries, East Aurora, NY. Please circle INFO/CARD #197.**

Custom Cable Assembly Brochure

This brochure from Kaman features custom, high-precision, high-reliability EW transmission and delay line assemblies. It includes specifications on semi-rigid SiO_2 insulated cable assemblies in six standard cable diameters with various connector configurations. Also detailed are mechanical and electrical characteristics. **Kaman Instrumentation Corp., Colorado Springs, CO. INFO/CARD #196.**

Catalog Describes High-Voltage RF Capacitors

Ceramic high-voltage capacitors for RF applications are described in this catalog. Typical specifications for the products featured include a 10 kHz to 500 MHz frequency range, voltage ratings up to 60 kVDC and current ratings up to 50 A RMS. A tutorial section describes ratings, dielectric materials, processing and applications for these devices. **High Voltage Components, Inc., Cedarburg, WI. INFO/CARD #195.**

Transistor Short Form Catalog

This publication from Acrian features various bipolar and FET devices. Frequency, power output, power gain, voltage, packages, common base/emitter and application specifications are detailed. Package outlines on the standard packages are provided. **Acrian, Inc., San Jose, CA. INFO/CARD #194.**

RF Data Manual

Motorola introduces its RF Products Data Manual that includes information about products made in their Lawndale and Bordeaux facilities, and contains an additional 280 devices and 23 application notes. DL110/D is comprised of two volumes. Volume 1 features discrete transistors while Volume 2 features amplifiers, diodes and application notes. A total of 63 application notes and engineering bulletins are included. The publication costs $11.60. **Motorola, Inc., Phoenix, AZ. INFO/CARD #192.**

Technical Summary on Test Software

This technical summary describes ANACAT™, a test software program for the calibration, measurement, management, de-embedding, and embedding of vector network analyzer data. It covers data management, data representation, transportability, and other capabilities of the program. **EEsof, Inc., Westlake Village, CA. Please circle INFO/CARD #191.**

EMI/RFI Shielding Products Brochure

EMI/RFI shielding and suppression products for architectural, commercial, financial, industrial and military applications are the subject of this brochure. The products described include windows, door gaskets and air filters for shielded structures, conductive adhesives, coatings, elastomers, and wire-in-silicone and knitted wire mesh. Specifications, properties, performance data and ordering information are provided as well. **Electro-Kinetic Systems, Inc., Trainer, PA. INFO/CARD #193.**

Capability Brochure

MDM, a manufacturer of microwave antennas and components for radar and communications systems, introduces a capability brochure. It describes the company's capability to design, fabricate, assemble and test a range of microwave devices from L-band to millimeter-wave. **MDM, Inc., Chatsworth, CA. INFO/CARD #190.**

Switch Data Sheet

This catalog describes Lorch Electronics' series of CW and pulse RF switches that cover from 20 MHz to 1 GHz in multiple octaves. They are available in SP2T, SP3T and SP4T configurations at power levels from 10 watts to 2000 watts peak. **Lorch Electronics Div., Vernitron Corp., Englewood, NJ. INFO/CARD #189.**

EMI/RFI Brochure

Electrical Insulation Suppliers introduces a brochure that features various products to control electromagnetic and radio frequency interference. It includes foil tapes, conductive gaskets, conductive coatings, conductive caulks, cable shielding, and EMI absorbers. A section on EMI test services is featured. **Electrical Insulation Suppliers, Inc., Hillside, IL. INFO/CARD #188.**

Amplifier Catalog

This catalog summarizes the guaranteed amplifier specifications and presents typical performance data on Miteq's AU, AM and AMMIC series of power amplifiers. The AU and AM series feature bipolar amplifier designs for the 1 MHz to 2 GHz range. The AMMIC series offers monolithic GaAs FET amplifiers from 50 MHz to 2 GHz. **Miteq, Hauppauge, NY. INFO/CARD #187.**

Power MOSFET Catalog

Featured in the publication are specifications for M/A-COM PHI's line of HF, VHF and UHF power MOSFETs. A selector guide together with a section on DMOS FET technology is included. Various application notes and a list of domestic and international sales offices complete this catalog. **M/A-COM PHI, Torrance, CA. INFO/CARD #186.**

Time Domain Software Application Note

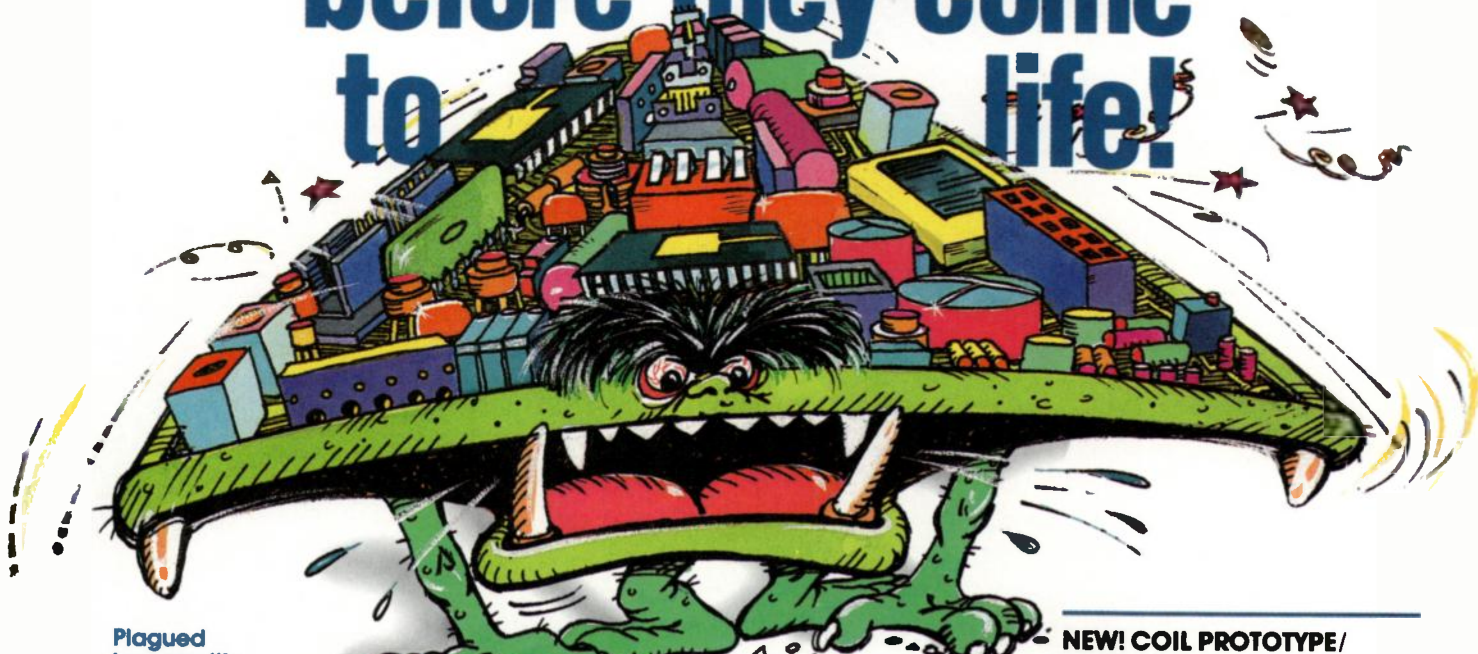
Covered in this application note are the capabilities of the Option 02 time domain software for the Wiltron 360 vector network analyzer. The features of time domain are described along with four different measurement modes — lowpass processing, bandpass processing, phasor impulse processing and frequency with time gate. Graphs and text guide the user on how to make precise time domain measurements. **Wiltron, Inc., Morgan Hill, CA. Please circle INFO/CARD #185.**

Directional Couplers Brochure

Werlatone introduces a brochure that covers a line of dual directional couplers in the 10 kHz to 1000 MHz frequency range. Featured are specifications, coupling and directivity graphs, and general descriptions. A short section that describes the selection factors used in specifying directional couplers is included. **Werlatone, Inc., Brewster, NY. INFO/CARD #184.**

ADVERTISER INDEX

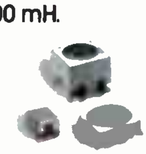
Toko coils and filters attack RF design problems before they come to life!



Plagued by parasitic oscillations, spurs, harmonics and feedback? The problem may not be your design, but the coils and filters you selected. Toko is the world's largest manufacturer of quality small coils and filters, with a selection so large, you're sure to find the right components to neutralize your rf design problems.

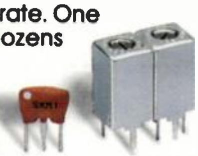
SUBMINIATURE ADJUSTABLE AND FIXED
Toko has what you need, so you won't need to compromise... subminiature adjustable coils and transformers, molded coils, radial fixed coils and fixed coils with axial leads. Toko high-Q coils are engineered in sizes from 5mm to 15mm, and inductance ranges from .02 μH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

CHIP AND ADJUSTABLE SMD



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

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



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

ACTIVE FILTERS
If you're advancing the state-of-the-art in digital audio or PCM products you'll appreciate Toko active filters. Especially designed for small size and low distortion, they're also very cost-effective.

Custom Modules, INFO/CARD 74
RF & I-F Filters, INFO/CARD 75

NEW! COIL PROTOTYPE/ SAMPLE KITS

Toko sample kits give you more choices and cost less!

- Molded Sample Kit: 82 values (123 parts) 30MHz-150MHz; 0.0393-1.173 μH
- 7mm Sample Kit: 54 values (108 parts), 70kHz-50MHz; 0.1-22.0 mH
- 10mm Sample Kit: 68 values (136 parts), 79kHz-75MHz; 0.08 μH-56 mH

INTRODUCTORY PRICED AT $49 EACH. ORDER YOURS TODAY!

Isn't it time to tame the design monsters before they bite back...call or write Toko today for a free coil and filter catalog or a quote on your needs.

Your strategic partner... for all the right reasons.

TOKO
TOKO AMERICA, INC.

(CORPORATE HEADQUARTERS)
1250 Feehanville Drive
Mt. Prospect, IL 60056
(312) 297-0070, FAX (GIII): (312) 699-7864
(Western Branch) (408) 432-8281
(Eastern Branch) (914) 694-5618
(Southeastern Branch) (205) 830-0952

Active Filters, INFO/CARD 76
Sample Kit, INFO/CARD 77