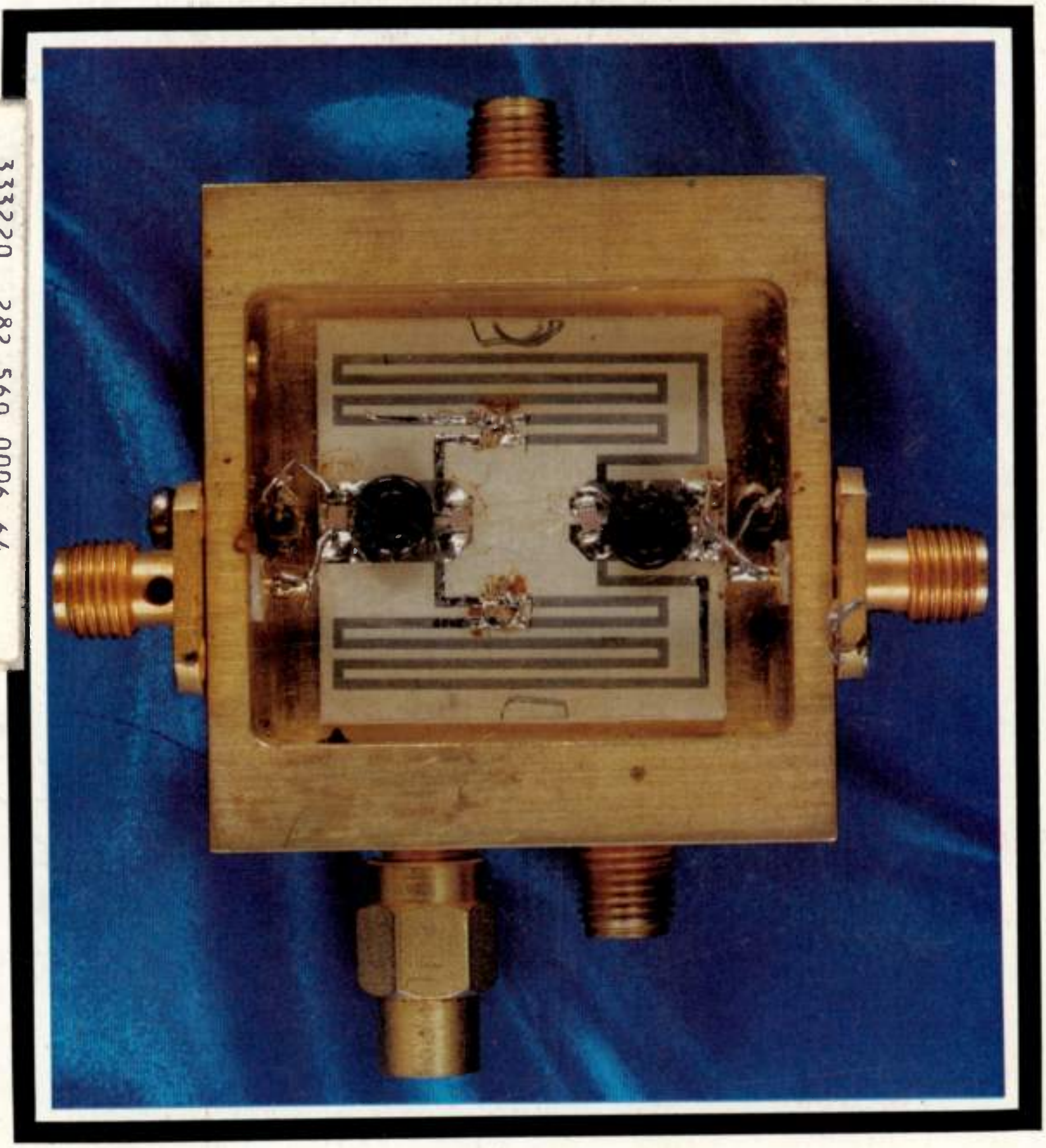
September/October 1979

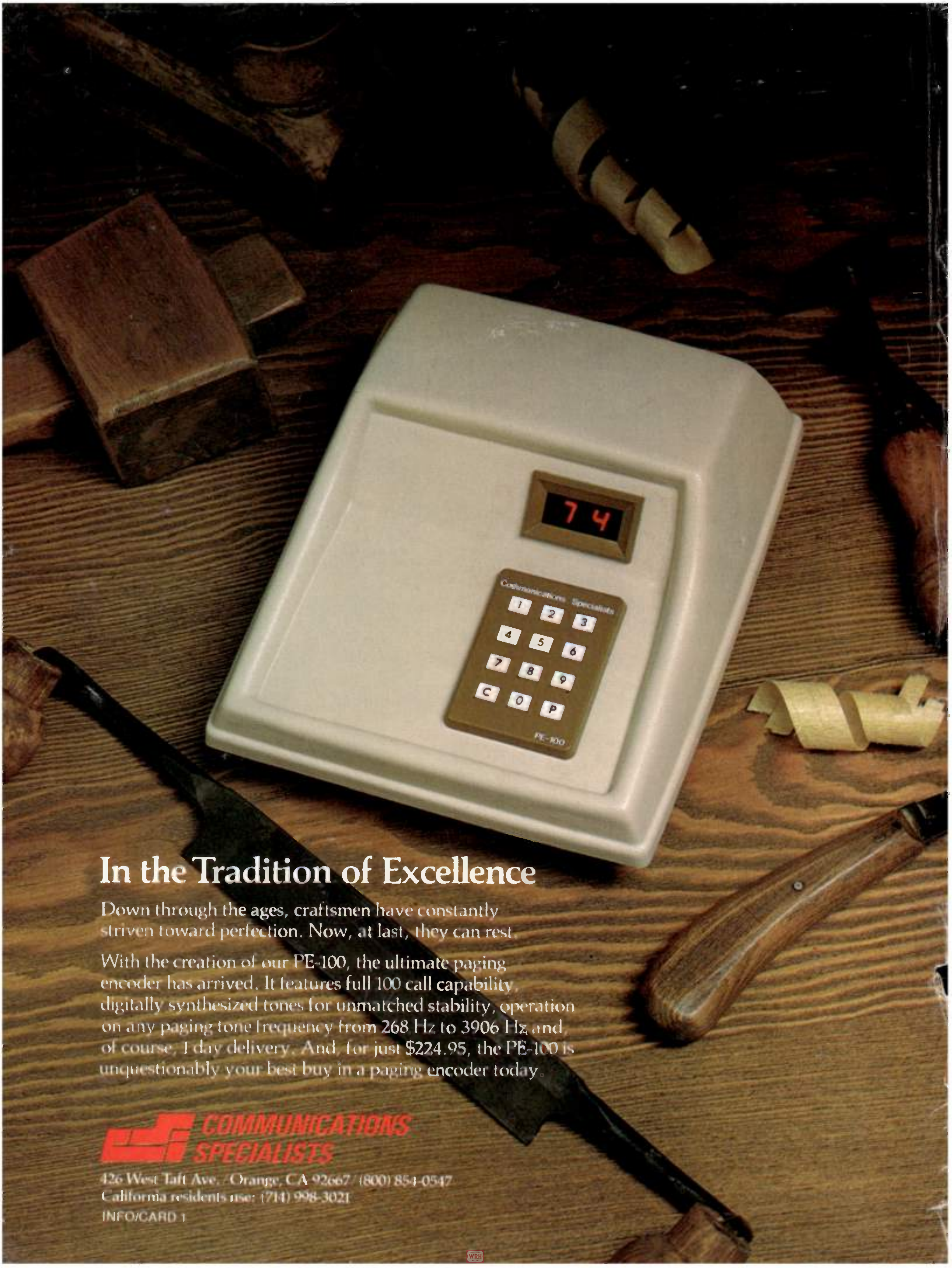
A Cardiff Publication

rf design



Filters ● PLL's
Quads ● Couplers

GET YOUR FREE SUBSCRIPTION . . . SEE PAGE 17



7 4
Communications Specialists
1 2 3
4 5 6
7 8 9
C 0 P
PE-100
In the Tradition of Excellence
Down through the ages, craftsmen have constantly striven toward perfection. Now, at last, they can rest.
With the creation of our PE-100, the ultimate paging encoder has arrived. It features full 100 call capability, digitally synthesized tones for unmatched stability, operation on any paging tone frequency from 268 Hz to 3906 Hz and, of course, 1 day delivery. And, for just $224.95, the PE-100 is unquestionably your best buy in a paging encoder today.
COMMUNICATIONS SPECIALISTS
426 West Taft Ave. / Orange, CA 92667 / (800) 854-0547
California residents use: (714) 998-3021
INFO/CARD 1

Solid State Microwave can solve your pulsed power transistor problems

■ GOLD METALLIZATION ■ RUGGED BALLASTED DESIGNS ■ BROADBAND, INTERNALLY MATCHED STRUCTURES
■ HIGH VOLUME PRODUCTION CAPABILITY
■ BROAD SELECTION OF POWER/GAIN/PACKAGE AND SUPPLY VOLTAGE COMBINATIONS
■ LOW COST PACKAGING AVAILABLE

For over a decade Solid State Microwave* has been a leading supplier of RF power transistors to the land mobile, aircraft and marine communications equipment industries. Consistent performance in delivering high volume, high quality, cost effective devices has earned us an enviable reputation unsurpassed in the industry.

We are now equipped to meet your most critical microwave pulsed power transistor requirements with a full line of devices designed for **DME; TACAN; IFF; Weather Radar** and **Phased Array Radar** applications.

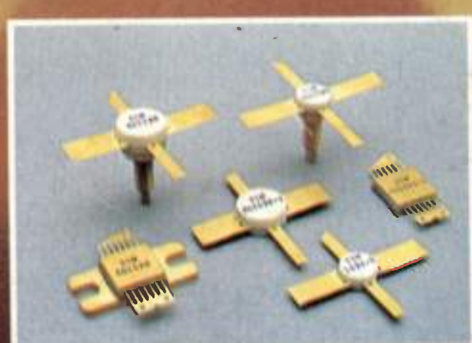
For fast action on your next microwave pulsed power transistor problem, call John Walsh at (215) 362-8500. After all . . . our name *is* Solid State Microwave.

**Formerly the RF Division of Solid State Scientific Inc.*

Weather Radar

DME; TACAN

IFF



SSM

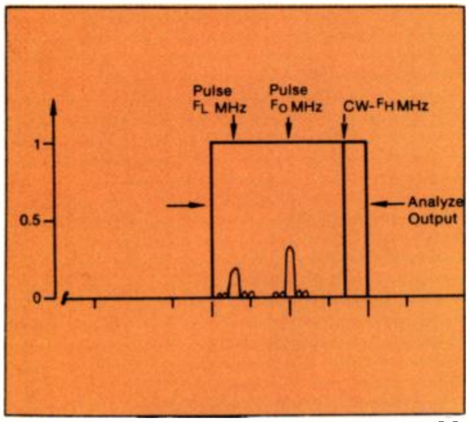
SOLID STATE MICROWAVE

a division of Thomson-CSF Components Corporation

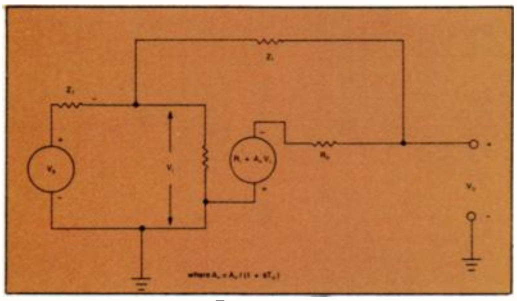
Montgomeryville Industrial Center, Montgomeryville, PA 18936 • (215) 362-8500 • TWX: 510-661-6548

rf design

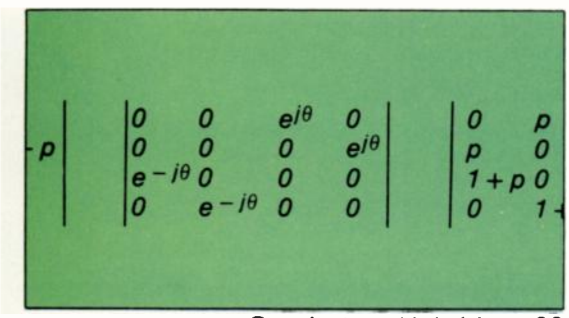
September/October 1979



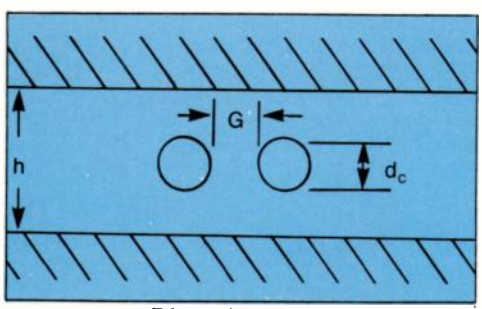
25,000 Filters In One p. 20



Phase Lock Loops p. 24



Quadrature Hybrids p. 32



Directional Couplers p. 40

Cover Two narrow band quadrature hybrids cascaded in microstrips result in a broadband hybrid. **1**

25,000 Filters In One The spectrum of pulsed signals can be analyzed using a SAW dispersive delay line. **20**

Phase Lock Loops Including the effects of finite gain finite bandwidth op-amp results in a 5th order open loop transfer function. **24**

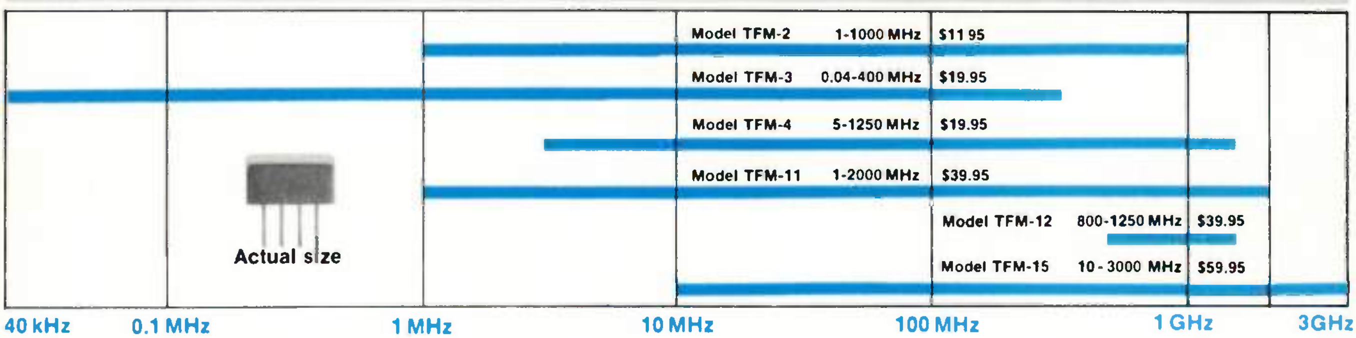
Design of VHF Quadrature Hybrids Part II The scattering parameter matrix of the cover hybrid is derived. **32**

Directional Couplers Coupling between adjacent transmission lines can be determined empirically. **40**

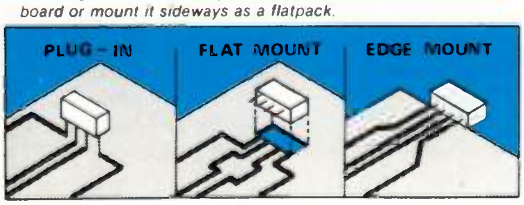
Editorial	9	Subscription Card	17
Letters	10	INFO/CARD	43
News	12	Products & Literature	50

September/October 1979, Volume 2, No. 5. **r.f. design** (USPS 453-490) is published every two months by Cardiff Publishing Company, a subsidiary of Cardiff Industries, Inc., 3900 S. Wadsworth Blvd., Denver, Colo. 80235, (303) 988-4670. Copyright © Cardiff Publishing Company. Controlled circulation postage paid at Denver, Colorado. Contents may not be reproduced in any form without written permission. Please address subscription correspondence and Postmaster, please send PS form 3579 to Box 17361, Denver, Colo. 80217. For telephone subscription inquiries, please call Thelma Drinkwine at 800-525-1297. **r.f. design** is circulated without charge throughout the United States to qualified recipients. Completed qualification form is required. To all others there is a charge: Domestic, $15 per year, Canada/Mexico, $15 year; Other foreign, $20 year. Single copies available $3 each. Postmaster: Please send PS form 3579 to P.O. Box 17361, Denver, Colo. 80217.

ACT NOW TO IMPROVE YOUR SYSTEM DESIGNS,
increase your packaging density, and lower your costs . . . specify Mini-Circuits new microminiature TFM series. These tiny units, 0.5" x 0.21" x 0.25" the smallest off-the-shelf Double Balanced Mixers available today, cover the 40 kHz - 3 GHz range and offer isolation greater than 45 dB and conversion loss of 6 dB. Each unit carries with it a 1-year guarantee by MCL. Upgrade your new system designs with the TFM, rapidly becoming the new industry standard for high performance at low cost.



Simple mounting options offer optimum circuit layout.
Use the TFM series to solve your tight space problems. Take advantage of the mounting versatility—plug it upright on a PC board or mount it sideways as a flatpack.



Model	Frequency, MHz			Conv. loss, dB				Isolation, dB												Cost	
				One Octave From Band Edge		Total Range		Lower Band Edge To one Decade Higher				Mid Range				Upper Band Edge To Octave Lower					
								LO-RF		LO-IF		LO-RF		LO-IF		LO-RF		LO-IF			
Model No	LO	RF	IF	Typ	Max	Typ	Max	Typ	Min	Typ	Min	Typ	Min	Typ	Min	Typ	Min	Typ	Min	Quantity	Price
TFM-2	1-1000	1-1000	DC-1000	6.0	7.5	7.0	8.5	50	45	45	40	40	25	35	25	30	25	25	20	6-49	$11.95
TFM-3	.04-400	.04-400	DC-400	5.3	7.0	6.0	8.0	60	50	55	40	50	35	45	30	35	25	35	25	5-49	$19.95
TFM-4	5-1250	5-1250	DC-1250	6.0	7.5	7.5	8.5	50	45	45	40	40	30	35	25	30	25	25	20	5-49	$19.95
TFM-11	1-2000	1-2000	5-600	7.0	8.5	7.5	9.0	50	45	45	40	35	25	27	20	25	20	25	20	1-24	$39.95
TFM-12	800-1250	800-1250	50-90	—	—	6.0	7.5	35	25	30	20	35	25	30	20	35	25	30	20	1-24	$39.95
*TFM-15	10-3000	10-3000	10-800	6.3	7.5	6.5	9.0	30	20	30	20	30	20	30	20	30	20	30	20	1-9	$59.95

Signal 1 dB compression level +1 dBm. Impedance, all ports 50 ohms. Total input power 50 mW. Total input, current peak 40 mA. Operating and storage temperature -55°C to +100°C. Pin temperature 510°F (10 sec).
*LO power +10 dBm. 1 dB compression +5 dBm.

World's largest manufacturer of Double Balanced Mixers

Mini-Circuits

A Division of Scientific Components Corp

2625 East 14th Street Brooklyn, New York 11235 (212) 769-0200
Domestic and International Telex 125460 International Telex 620156

International Representatives: ☐ **AFRICA:** Afitra (PTY) Ltd., P.O. Box 9813, Johannesburg 2000, South Africa ☐ **AUSTRALIA:** General Electronic Service, 99 Alexander St., New South Wales, Australia 2065 ☐ **EASTERN CANADA:** B.D. Hummel, 2224 Maynard Ave., Utica, NY 13502 ☐ **ENGLAND:** Dale Electronics Ltd., Dale House, Wharf Road, Frimley Green, Camberley Surrey, United Kingdom ☐ **FRANCE:** S.C.I.E.-D.I.M.E.S., 31 Rue George-Sand, 91120 Palaiseau, France ☐ **GERMANY, AUSTRIA, SWITZERLAND, DENMARK:** Industrial Electronics GMBH, 6000 Frankfurt Main, Kluberstrasse 14, West Germany ☐ **INDIA:** Gaekwar Enterprises, Kamal Mahal, 17 M.L. Dahanukar Marg, Bombay 400 026, India ☐ **ISRAEL:** Vectronics Ltd., 69 Gordon St., Tel-Aviv, Israel ☐ **JAPAN:** Densho Kaisha, Ltd., Eguchi Building 8-1 1-Chome, Hamamatsucho Minato-Ku, Tokyo, Japan ☐ **NETHERLANDS, LUXEMBOURG, BELGIUM:** B.V. Technische Handelsonderneming, COIMEX, P.O. Box 19, 8050 AA Hattem, Holland ☐ **NORWAY:** Datamatick As, Postboks 111, BRYN, Oslo 6, Ostensjoveien 62, Norway ☐ **SINGAPORE & MALAYSIA:** Electronics Trading Co. (PTE) Ltd. Suites C13, C22 & C23 (1st Floor), President Hotel Shopping Complex, 181 Kitchener Road, Singapore-8, Republic of Singapore ☐ **SWEDEN:** Integrerad Elektronik AB, Box 43 S-182 51, Djursholm, Sweden

U.S. Distributors: ☐ **NORTHERN CALIFORNIA:** Pen Stock, 105 Fremont Ave., Los Altos, CA 94022. Tel. (415) 948-6533 ☐ **SOUTHERN CALIFORNIA, ARIZONA:** Crown Electronics, 11440 Collins St., N. Hollywood, CA 91601. Tel. (213) 877-3550 ☐ **METROPOLITAN NEW YORK, NORTHERN NEW JERSEY, WESTCHESTER COUNTY:** Microwave Distributors, 61 Mall Drive, Commack, NY 11725. Tel. (516) 543-4771

INFO/CARD 3

B32/REV D

7L5
Baseband Measurements
20 Hz to 5 MHz

7L13
Communications applications
1 KHz to 1.8 GHz

7L18
Microwave applications
1.5 GHz to 60 GHz

Our transportable spectrum analyzers are part of the growing family of Tektronix 7000-Series Mainframes and Plug-Ins designed to meet all your test and measurement applications with high performance, flexibility and expandability.

TEKTRONIX SPECTRUM ANALYZER FAMILY

Laboratory performance plus transportability.

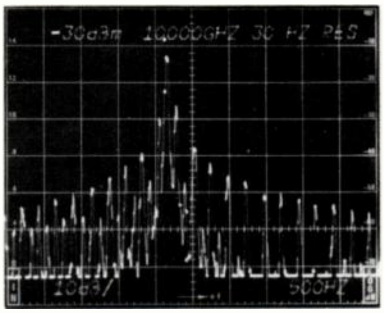
Tektronix Spectrum Analyzers deliver superior performance on the bench and in the field from 20 Hz to 60 GHz.

Top performance at the top of the spectrum: 7L18 (1.5 GHz to 60 GHz)

Engineers who design or measure state-of-the-art microwave systems obtain supreme accuracy from the 7L18.

Imagine resolving frequencies as close as 180 Hz, 60 dB down, with 30 Hz resolution to 12 GHz and 10 Hz residual fm peak-to-peak... with full calibration to 60 GHz—the highest available.

Displays are clear and bright...

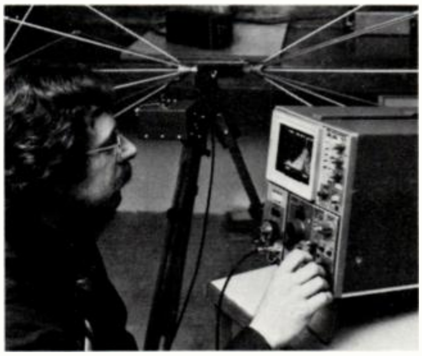


like this sample of 240 Hz sidebands at 10 GHz.

And other features like digital storage and digital signal processing are easy to use with the 7L18's microprocessor-aided controls... plus a built-in tracking preselector, automatic and fully calibrated. In application after application, you get flicker-free traces, even at slow sweep speeds. And you can compare waveforms or make a long series of measurements with repeatable accuracy.

The 7L18 is ideal for testing and evaluating new microwave systems, including ECM, satellite communication systems, and microwave links. All this performance costs under $17 thousand.

Communications measurements without the jitters: 7L13 (1 KHz to 1.8 GHz)



Now you can make every important communications measurement accurately and conveniently for EMI, FM, TV, navigation, avionics, two-way and many other applications.

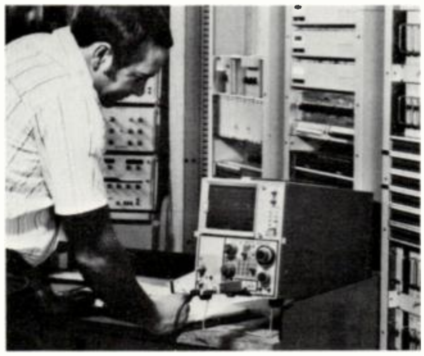
The 7L13 features jitter-free displays even at 30 Hz resolution with designed-in 10 Hz fm stability. This provides the ultra-critical accuracy necessary for design and proof-of-performance measurements.

The 7L13's top performance costs under $13 thousand.

Put a Tektronix Tracking Generator in tandem with the 7L13, and you can make precise swept frequency measurements, too. All parameters, including center frequency, are read out on the crt itself for easy referencing.

Application notes for communications engineers are available. Just write or call.

Precision and convenience for baseband measurements up to 960 channels: 7L5 (20 Hz to 5 MHz)



Sweep your baseband for spurious response, leakage, noise, shifts, distortion and transient bursts with the certainty of 10 Hz resolution.

Comparing baseband channel performance is easy because the 7L5 switches from a single channel to a 60-channel supergroup without retuning. You see all channel amplitudes at a glance, side-by-side. And, you get frequency accuracy that resolves an individual channel frequency down to 10 Hz, including signals at –140 dBv.

A 7L5 Spectrum Analyzer costs under $9 thousand.

With every member of our spectrum analyzer family, you receive Tektronix' reliability, quality and service.

Contact the Tektronix Field Office nearest you for applications assistance, a demonstration or pricing information.

For literature only, call our toll-free number: 1-800-547-1512.
Oregon residents call collect: 644-9051.

In Europe: Tektronix, Ltd., Box 36, St. Peter Port, Guernsey, Channel Islands

Tektronix®
COMMITTED TO EXCELLENCE

NEW
AL—51-A
With High Level Audio!

Stop With Phase Lock Stability and Manual Tuned Sweep Control

Look With Long Persistance CRT and Variable Dispersion from 500 Hz to 1000 MHz

Listen With Output Provided to Monitor AM & FM Audio Modulation

Measure
- Signal Level • Frequency
- RFI • EMI • Intermod
- Spurious • Harmonics
- Leakage

.4 TO 1000 MHz SPECTRUM ANALYZER

Texscan's new Model AL—51-A combines the operating convenience of small battery-operated portable instruments with the high performance features usually available only in higher priced laboratory instruments. The AL—51-A will display 60 db amplitude variations in signal level. Frequency dispersion is continuously variable, 2 kHz/div. to 100 MHz/div. In order to achieve the highly stable 500 Hz narrow band measurement capability, a phase lock mode of operation is included. Crystal controlled frequency identification markers at 1, 10 and 50 MHz are included. Housed in a rugged carrying case, the instrument is completely portable, weighing only 27 lbs. including battery. The AL—51-A will operate continuously for 3 hours on internal battery. Provision for external 12V DC and 115/60 Hz or 230/50 Hz is included.

write for our catalog

Texscan CORPORATION

TEXSCAN CORPORATION, 2446 N. Shadeland, Indianapolis, Indiana 46219, Phone: (317) 357-8781 • 2960 Grand, Phoenix, Arizona 85017, P.O. Box 27548, 85061, Phone: (602) 252-5021 • 1 Northbridge Road, Berkhansted, Hertfordshire, England, UK, Phone: 04427-71138 • Munchen 90, Schlierseestrasse 31A, West Germany, Phone: 0811/69 5421

INFO/CARD 4

r.f. design

Editor and Publisher
E. Patrick Wiesner

Managing Editor
Bart Gates

Production Mgr.
Cherryl Greenman

Art Director
Claire Moulton

Artists
Marjorie Asher
Deb Patterson
Anthony Tyre

Composition
Tami Frazier
Dottie Johnson

Published by

Cardiff Publishing Company
Subsidiary of Cardiff Industries, Inc.
3900 So. Wadsworth Blvd.
Denver, Colo. 80235
(303) 988-4670

President
E. Patrick Wiesner

Treasurer
Patrick T. Pogue

Vice President
Robert A. Searle

Advertising Services
Mercy Clark

Production Director
Mark Day

Circulation Manager
Chris Risom

Circulation Fulfillment Mgr.
Barbara Pike

West Coast Representatives
Buckley Boris Associates
22136 Clarendon Street
Woodland Hills, Calif. 91367
(213) 999-5721
(714) 957-2552

Midwest Representative
Berry Conner
88 W. Shiller
Suite 2208
Chicago, Ill. 60610
(312) 266-0008

East Coast Representative
Manfred Meisels
Scientific Advertising Sales, Inc.
40 Caterson Terrace
Hartsdale, N.Y. 10530
(914) 948-2108

ISSN 0163-321X

Want To Write?

Too many years ago to want to remember exactly how many, I went to work as the Midwest Editor for one of the big design magazines. We officed in Chicago. I had been a design engineer for ITT-Kelloge during work on 465L, the Atlas Missile project. I was very apprehensive about my ability to write or edit articles for a magazine.

But what I found was that it was really pretty easy . . . and very exciting to get people's work and ideas into print. I discovered that, almost without exception, every engineer has a worthwhile story to tell. Often the problem is that the potential author is so close to his designs that he sometimes is unaware of the contribution his work makes. Others would say, "Yes, but I'm no writer." Still others say, "Yes, but I'm busy."

E. Patrick Wiesner, Publisher

I think you'd be surprised at the amount of help that is available from the editors of all the trade magazines. What they are looking for is good material, good ideas. They gladly provide their readers with interesting and helpful information. In the process, they can get you and your company good publicity.

It's good for your career to place articles in trade magazines. In many cases you can get paid as well, but the real benefit to you is the prestige and recognition inside, and outside, of your company.

During 1980, *r.f. design* will be going monthly and we're particularly interested in articles in these and other areas:

Network Analyzers	Filters
R.F. Amps	R.F. Components
RFI-EMI	R.F. Instruments
Spectrum Analyzers	R.F. Design Ideas
Antennas	

All it takes to get started with us (or most other magazines) is a phone conversation or letter with a brief outline of what you have in mind. Decide now to take advantage of the opportunity to enjoy the benefits of being an author. Call or write an editor today!

E. Patrick Wiesner
Editor and Publisher

PS: If you think you might like to be an editor for *r.f. design* . . . give me a call at (303) 988-4670.

Dear Bart:

I think you failed to mention in your response to the letter from Mr. Durkin, concerning my Smith Chart Article, that the technique I used was a *short-cut* approximation method, and while not true for the whole Smith Chart, extremely useful in quickly performing matching between low impedance values typical of those encountered in RF Power Transistors input and output impedances.

For higher impedance paths, a constant VSWR must be followed for correct solutions and I apologize for not covering that point in my article.

Sincerely,
Thomas P. Litty
President
Digicast Systems, Inc.

Dear Tom,

I did fail to mention that your short-cut was well suited for low impedance paths. Thank you for clearing that point up.

It is pleasing, furthermore, that this kind of dialogue is beginning to take place in *r.f. design.*

Bart Gates
Managing Editor

As a non-EE trained engineer faced with the management of RF related programs, I would personally welcome a series, or a regular feature, written at the non-specialist level. Purpose: Point out management issues; Filter, condense and translate technical issues and trade-offs; Emphasize applications and advanced technology trends.

Jim Wilson
Manager
Tracor, Inc. □

HP introduces a new concept in RF measurement

Now measure frequency, power, AM, FM, ΦM from 150 kHz to 1300 MHz

HP's New 8901A Modulation Analyzer

For the first time all the capability you need to measure RF frequency, power and modulation is in one instrument.

The new HP 8901A Modulation Analyzer—essentially a precision calibrated heterodyne receiver—quickly characterizes transmitters and accurately calibrates signal generators.

The 8901A design minimizes measurement error, eg. residual FM on the internal local oscillator is <1Hz at 100 MHz (50Hz-3kHz BW).

AM & FM accuracy is ± 1% (ΦM ± 3%). Well isolated detectors let you separate small values of incidental AM or FM from large values of primary modulation.

Easy to use too, the HP 8901A automatically selects the strongest signal, makes the measurement and displays the result. All in all, it's not only a new concept in RF measurements, but an extremely powerful tool for the analysis of modulated signals.

Take a look at the features above, then if you want more information call your nearby HP field sales office or write.

Price $7500;* Calibrator, $500.*

*Domestic U.S. price only

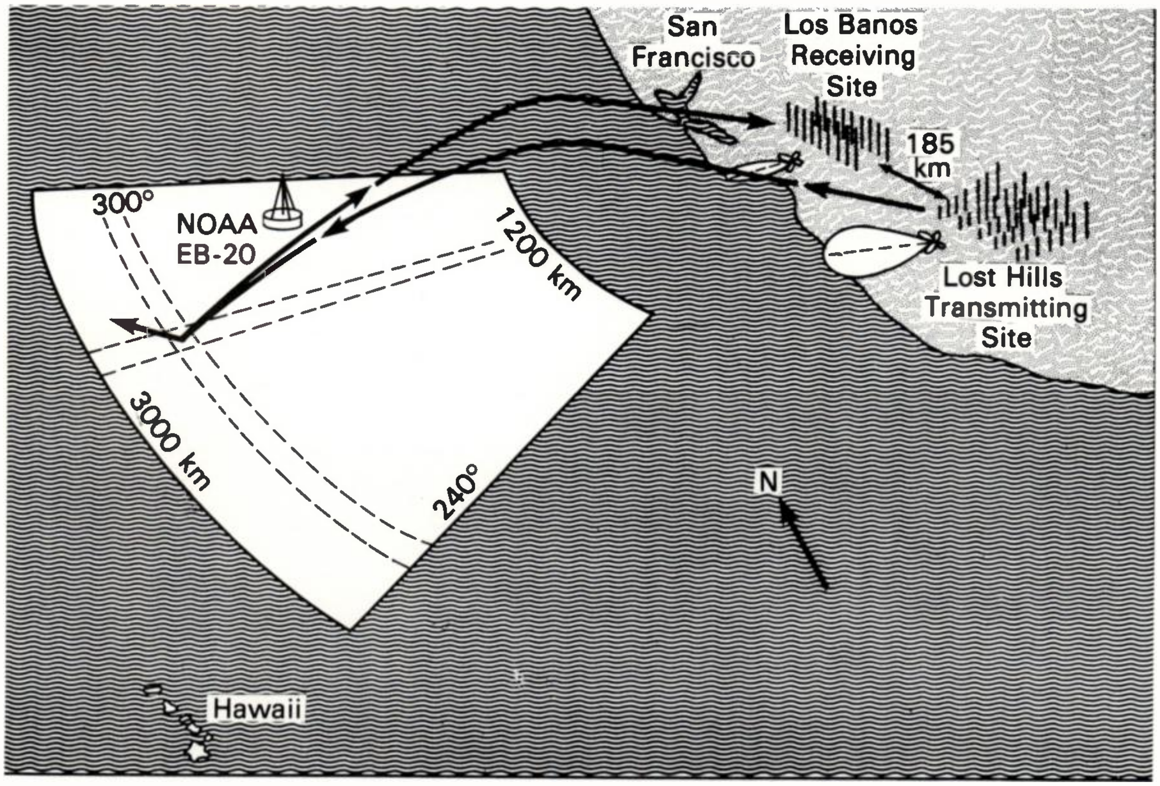
HEWLETT hp PACKARD

1507 Page Mill Road, Palo Alto, California 94304

INFO/CARD 7

For assistance call: Washington (301) 258-2000, Chicago (312) 255-9800, Atlanta (404) 955-1500, Los Angeles (213) 877-1282

04902



"Skywave" Ocean-Monitoring Radar

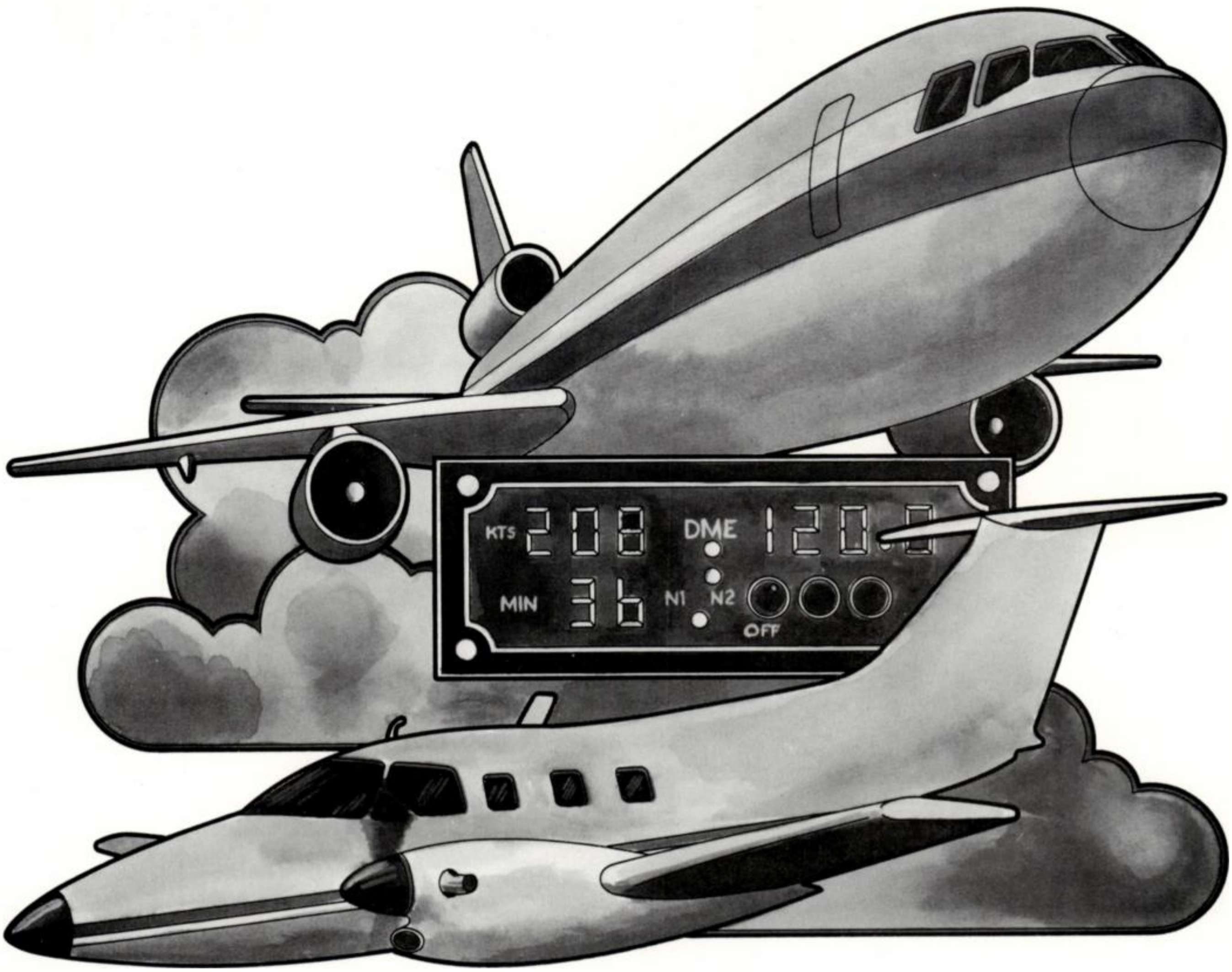
The National Oceanic and Atmospheric Administration (NOAA) and SRI International (formerly Stanford Research Institute) have demonstrated that it is feasible to monitor an arc of ocean surface out to 3000 km from shore using an over-the-horizon radar. By illuminating the sea with HF (10-20 MHz) radio waves bounced off the ionosphere, an experimental "skywave" radar in central California obtains information about the height of distant ocean waves, their frequency spectrum and the direction of surface winds. The information is contained in the frequency spectrum of weak sea echoes that return to the radar over the same ionospheric path. With such information, the progress of storms at sea can be more effectively monitored, not only for the benefit of fishing and shipping interests but also to permit more accurate forecasts of coastal storm damage.

For several years, scientists have been aware of the potential of over-the-horizon radars for monitoring vast ocean areas, but early experiments showed that ionospheric motions so contaminated the sea echoes that most of their spectral information was lost. Within the last two years, the NOAA/SRI team have shown that only a radar capable of searching with a very narrow azimuthal beam (less than a degree wide) and using adaptive searching and signal-processing methods could avoid much of the ionospheric contamination, which is caused by multipath propagation. Furthermore, ionospheric conditions must be continuously monitored and translated into optimum radar operating parameters.

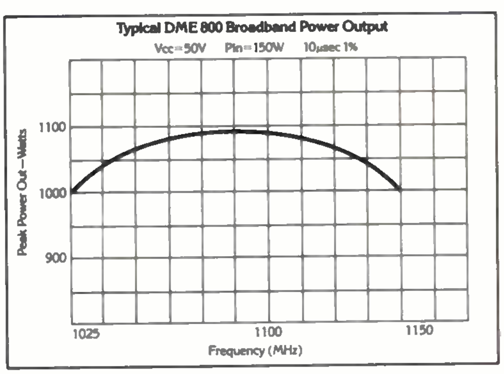
The heart of the experimental radar system is the Wide Aperture Research Facility (WARF), a very high resolution HF skywave (ionospheric) radar operated by SRI for a variety of surveillance and propagation-research purposes.

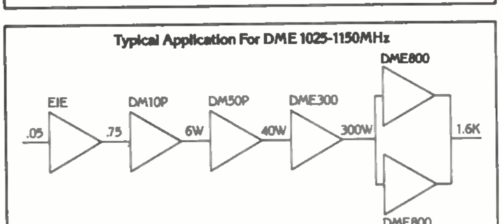
WARF consists of a transmitting site at Lost Hills, California and a receiving site at Los Banos, California, 185 km to the north. The radar can look either eastward or westward in 64-deg arcs. The eastward beam can look into the Gulf of Mexico and has successfully tracked tropical storms there by mapping their surface-wind-direction fields. The westward looking beam can see almost to Hawaii via one-hop ionospheric propagation.

The radar operates in a SFCW (sweep-frequency, continuous-wave) mode that requires the two sites to be separated. The transmitted radar waveform is a linear frequency ramp typically 50 kHz wide for sea-scatter applications. SFCW modulation offers several advantages over conventional pulse radars: higher signal-to-noise ratio for a given peak power (because of its 100-percent duty cycle), less vulnerability to interfacing signals, and increased flexibility



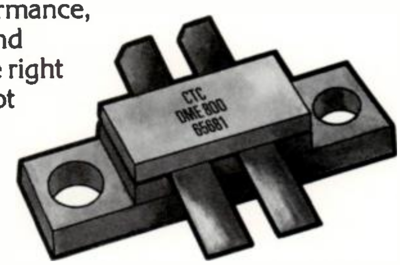
800 Watts P$_{OUT}$ DME





No one else even comes close. More power. Higher gain. Higher efficiency. With our exclusive BALANCED TRANSISTORS. More power per square mil of silicon than you've ever seen before. Easier to work with. Remarkably consistent. Outstanding performance at unprecedented power levels.

Get the complete story on C.T.C.'s full line for DME/IFF applications. Including a whole new line-up of low power, 28 volt, single-ended or balanced transistors as well as resistors and terminations. You're building systems with tough requirements for performance, reliability, design simplicity and dependable supply—all at the right price. Come to C.T.C. We've got what it takes. Contact Communications Transistor Corporation, 301 Industrial Way, San Carlos, California 94070. (415) 592-9390.



CTC has the power. Go for it.

varian

INFO/CARD 8

for adjusting range and Doppler resolution during off-line processing.

Whereas HF radars that illuminate the sea with surface waves can measure the ocean's surface currents (*r.f. design,* July, August issue), the ionosphere imposes unknown and variable frequency shifts on skywave radar echoes that prevent current measurements, unless an echo from a nearby stationary target is available for reference. Surface currents can thus be measured only near shorelines, islands or oil platforms that provide a zero-Doppler reference echo.

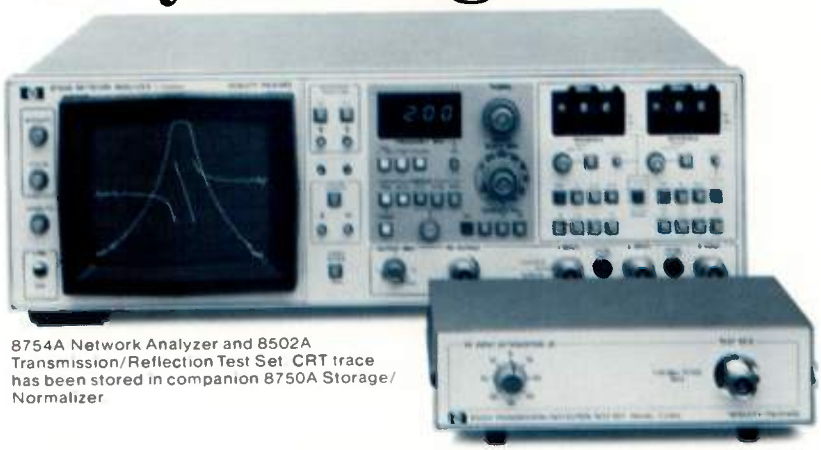
Tropical storms are tracked by mapping the characteristic cyclonic surface-wind-direction field over the storm area using the ratio of energy back-scattered by ocean waves traveling toward and away from the radar. Such wind-direction maps can now be routinely produced, their quality being less sensitive to ionospheric contamination than are wave-height measurements.

To measure wave height, the radar uses a special searching and signal-processing strategy that sorts the received echoes according to a spectral-quality index. Prior to incoherent spectral averaging over adjacent space-time cells, variable frequency shifts introduced by the ionosphere are removed. In a recent test, the experimental radar system was able to track changes in ocean wave height and the scalar ocean-wave spectrum during the passage of a North Pacific storm front 1600 km from the radar. Simultaneous in-situ measurements by a NOAA data buoy showed good agreement with the radar measurements.

Only a few such radars, located perhaps 1000 km inland, would be needed to monitor sea conditions from near shore to 2000 km offshore in the North Pacific, the North Atlantic and the Gulf of Mexico. For example, a single radar located in Tennessee with two antenna systems for looking southward and eastward, could monitor and track most of the hurricanes that threaten the U.S. eastern seaboard.

T.M. Georges □

When your RF network measurement needs are large, but your budget isn't.



8754A Network Analyzer and 8502A Transmission/Reflection Test Set. CRT trace has been stored in companion 8750A Storage/Normalizer.

HP's New 1300 MHz Network Analyzer. It brings speed and convenience to RF measurements for only $11,500.

The HP 8754A consists of:

- 4-1300 MHz swept source with +10 dBm leveled output, calibrated sweeps and crystal markers.
- Three channel receiver to measure any two transmission/reflection parameters simultaneously with >80 dB dynamic range.
- CRT display for rectilinear and polar plots with resolution 0.25 dB and 2.5°/major division.

Just add the appropriate test set and you can make thorough and accurate measurements quickly and easily. Such as:

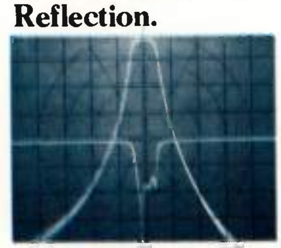
Transmission Magnitude and Phase.

Measure loss, gain and phase shift using the 11850 Power Splitter ($600). Completely identify filter passbands and skirt characteristics without misleading harmonic or spurious responses.

Impedance.

Measure and display impedance in polar form, with crystal markers to give precise frequency data. Test sets are available for both 50 and 75 Ω systems.

Simultaneous Transmission and Reflection.



Use the 8502 Test Set ($2000) and see the trade offs between transmission gain/loss and input match in a single setup. For two-port characteristics of networks, including transistors, an S-parameter test set is available.

Storage/Normalizer increases the 8754A's capabilities.

Add the 8750A and you can automatically remove system frequency response variations, also make comparison measurements easily. Digital storage permits flicker-free displays even for measurements requiring slow sweep rates.

A call to your nearby HP field sales office is all you have to do to get more information, or write.

Domestic US prices only.

HEWLETT hp PACKARD

1507 Page Mill Road, Palo Alto, California 94304

INFO/CARD 10

45907

For assistance call: Washington (301) 258-2000, Chicago (312) 255-9800, Atlanta (404) 955-1500, Los Angeles (213) 877-1282

The seventh digit we've added to our newest signal generators has improved their resolution to 100 Hz. Lucky for you. Because now you can have the 100-Hz resolution that you've been asking for, in addition to all the other popular Wavetek features.

Features like modulation capabilities that allow complex or simultaneous modulation (AM-FM, FM-FM, AM-AM). Features like four FM and two AM modulation scales and four internal modulation frequencies (two that are adjustable between 100 Hz and 10 kHz). Features like 0.001% frequency accuracy over the entire range and calibrated output power range of +13 to -137 dBm.

Of course our newest models still have standard frequency programmability—and optional output level programming and reverse power protection.

The new models continue to provide the Wavetek value that you've come to expect. Model 3005 covers the entire frequency range from 1 MHz to 520 MHz and is just $3675.* Model 3006 covers the entire 1 kHz to 520 MHz range and is priced at $3990.*

Our reader service number can be lucky, too. Circle it and we'll send all kinds of free information.

Wavetek Indiana, Inc., 66 North First Avenue, P.O. Box 190, Beech Grove, IN 46107. Phone (317) 783-3221, TWX (810) 341-3226.

WAVETEK®

*U.S. Prices only

Now...a line of SAW Bandpass Filters with production proven designs.

You probably know something about the advantages of SAW Bandpass Filters...their compact size, low shape factor, high rejection, linear phase and adjustment-free life.

But did you know that Andersen has taken SAW filters out of the lab and onto the production line?

Only Andersen offers as many established designs with proven production history. Today, our SAW Bandpass Filters are being used by leading manufacturers of satellite, radio, television and digital data systems all over the world.

With our engineering and production facilities, we can design and manufacture SAW filters for almost any IF filtering problem. And we can computer-test the filters under simulated systems conditions for your actual performance requirements.

The chart at right is only a representative listing of SAW Bandpass Filters available from Andersen. For complete information, contact us today.

This Andersen Family of SAW filters is available for delivery from stock to 30 days. Large production quantities can be scheduled quickly.

PARTIAL LISTING OF ANDERSEN SAW BANDPASS FILTERS IN CURRENT PRODUCTION

MODEL	CENTER FREQUENCY f_o MHz	1 dB BANDWIDTH MIN KHz	REJECTION BANDWIDTH MHz @ dB MAX
BP 22-400-40	21.9	400	1 @ 30
BP 44-6000-127	43.9	6,000 @ 1.5dB	7.5 @ 45
BP 53-400-95A	53.3	400	1.4 @ 40
BP 60-5000-114	60	5,000	8.0 @ 40
BP 66-350-40	65.75	350	1.4 @ 40
BP 70-60-118	70	60	.28 @ 25
BP 70-100-128	70	100	.25 @ 15
BP 70-150-130	70	150	.36 @ 15
BP 70-300-134	70	300	.7 @ 25
BP 70-200-124	70	200	.7 @ 25
BP 70-400-107Q	70	400	1.0 @ 25
BP 70-670-102A	70	670	2.5 @ 40
BP 70-900-103Q	70	900	3.2 @ 40
BP 70-1300-133Q	70	1,300	4 @ 40
BP 70-1900-132	70	1,900	4.5 @ 40
BP 70-2500-137	70	2,500 @ 1.5dB	6.0 @ 40
BP 70-3800-120	70	3,800	7.5 @ 40
BP 70-6400-91	70	6,400	11 @ 40
BP 70-9700-146	70	9,700	27.5 @ 40
BP 70-10000-176	70	10,000	15 @ 40
BP 70-36000-99	70	36,000 @ 1.5dB	48 @ 30
BP148-330-57	148.5	330	1.5 @ 40
BP150-700-67Q	150	700	4 @ 40
BP150-2000-69A	150.4	2,000	4.5 @ 30
BP160-450-95A	159.75	450	1.5 @ 30
VSBM-1-79	43.9	5,250	7.5 @ 40
BP272-2500-84	271.75	2,500	13.5 @ 13

Andersen SAW filters have been qualified for a wide range of environments for military, space and commercial applications.

ANDERSEN

INFO/CARD 12

Andersen Laboratories, Inc.
1280 Blue Hills Avenue
Bloomfield, CT 06002
Telephone (203) 242-0761
TWX 710-425-2390

– 25,000 Filters in One

Compressive IF receivers using dispersive delay lines provide real time frequency domain signal analysis.

By Walter A. Crofut
Anderson Laboratories, Inc.

Compressive IF Receivers are finding increasing application in surveillance and ELINT/ESM systems. This type of receiver uses SAW or IMCON® Dispersive Delay lines to provide real time analysis over large IF bandwidths for systems operating in the HF, VHF, UHF, or microwave bands. A 100 percent probability of signal interception is realized with adequate resolution for threat identification. The output of the compressive IF receiver is an instantaneous time display of the amplitude of the Fourier transform of the analysis band. As a result, key parameters such as pulse width and repetition rate can be instantaneously determined. In addition, multiple signals can be identified and separated over a wide dynamic range including the combination of CW and single pulse which can not be easily analyzed with other types of receivers.

Range of Performance

The shaded area of Figure 1 represents the range of performance achievable with today's compressive receiver technology in terms of analysis bandwidth versus process time. In addition, the achievable spectral resolution limits for various bandwidths is indicated. Three representative performance extremes are tabulated below:

Analysis Bandwidth MHz	Resolution kHz	Process Time µS	RF Band of Interest
250	1500	1	Microwave
20	30	50	VHF, UHF
2.5	.150	10,000	HF

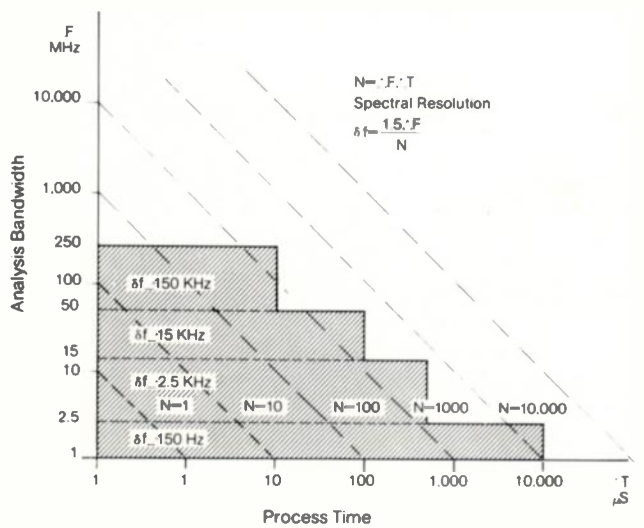
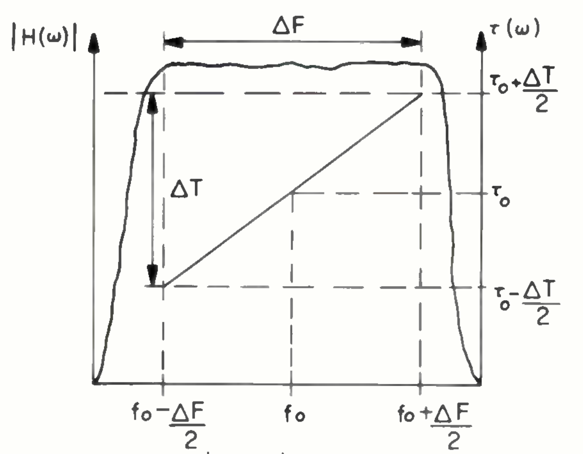


Figure 1. Range of Performance.



$$H(\omega) = |H(\omega)| \exp(j\phi(\omega))$$

$\tau(\omega)$ ~group delay

$$\tau(\omega) = -\frac{d\phi(\omega)}{d\omega}$$

Figure 2. Transfer Function.

Dispersive Delay Lines Key

The Dispersive Delay Line (DDL), is the heart of a Compressive IF Receiver. It has the unique property of providing a linear time delay versus operating frequency characteristic and is fabricated from SAW or IMCON® technology. Figure 2 defines the amplitude and group delay characteristics of a typical DDL. A key parameter for a DDL is its time bandwidth N = ΔF ΔT which is a measure of its signal processing capability. When a linear FM signal of bandwidth ΔF and length ΔT is applied to a DDL followed by a weighting filter as shown in Figure 3, a compressed pulse is obtained. This pulse is characterized by a width of 1.5/ΔF and sidelobes suppression in the 30-50 dB range. The pulse is compressed in time by 1.5/N and a processing gain of approximately N is realized in the process. It is this compression principle of a DDL which makes compressive receivers possible.

Operating Principles

In normal operation, the incoming signal is mixed with a sweeping local oscillator of the same slope as the DDL frequency — time delay response but with twice the duration and bandwidth as shown in Figure 4. The lower sideband is chosen for the IF and a CW signal present in the analysis band such as shown at F_H is converted to a negative slope linear FM signal in the IF band. When each such linear FM signal passes through the DDL, a compressed pulse is created. The location of the pulse in time is directly proportional to the incoming frequency component and the magnitude of the compressed pulse is proportional to the magnitude of that frequency component. A weighting filter is employed to suppress the sidelobe structure into the −30 dB to −50 dB range. The corresponding compressed pulse has a width of 1.5/ΔF. The time scale is converted to frequency by multiplying by ΔF/ΔT and the spectral resolution of the receiver is 1.5/ΔT.

If the signal is a pulse such as shown at F_0 and F_L similar results occur except that the compressed pulse widens and closely approximates the expected sinx/x Fourier spectrum. Thus, the output signal of a compressive IF receiver is essentially equivalent to the magnitude of the Fourier transform of the signals present in the analysis band. Its performance is somewhat analogous to a channelized receiver with N contiguous channels and all channels being processed in immediate sequence. N can be as high as 25,000.

Comparison with Conventional Scanning Spectrum Analyzer

The conventional scanning spectrum analyzer is similar in appearance to the compressive IF receiver, except that the DDL and weighting filter are replaced with a narrow band filter of bandwidth δf, the system resolution.

1. Spectral resolution versus process time: The optimum resolution of a scanning spectrum analysis is:

$$\delta f = \frac{\Delta F}{\Delta T}$$

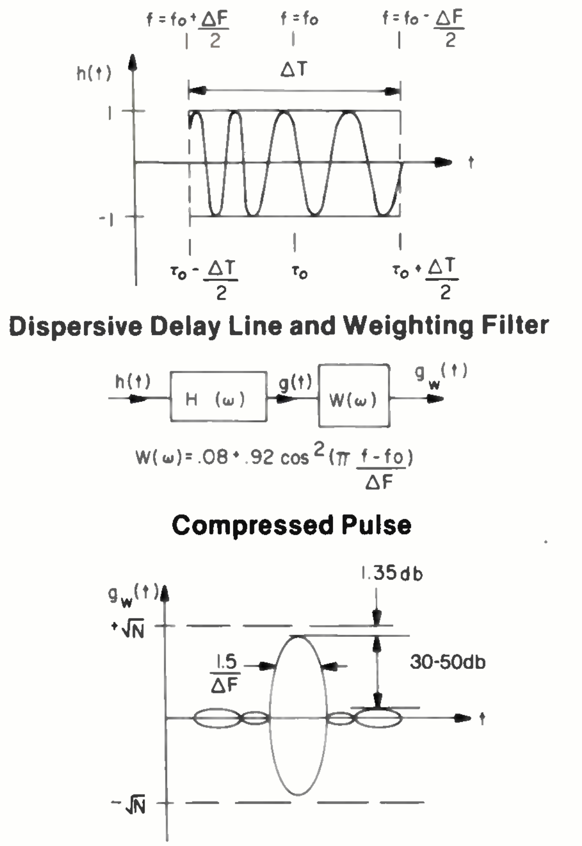


Figure 3.

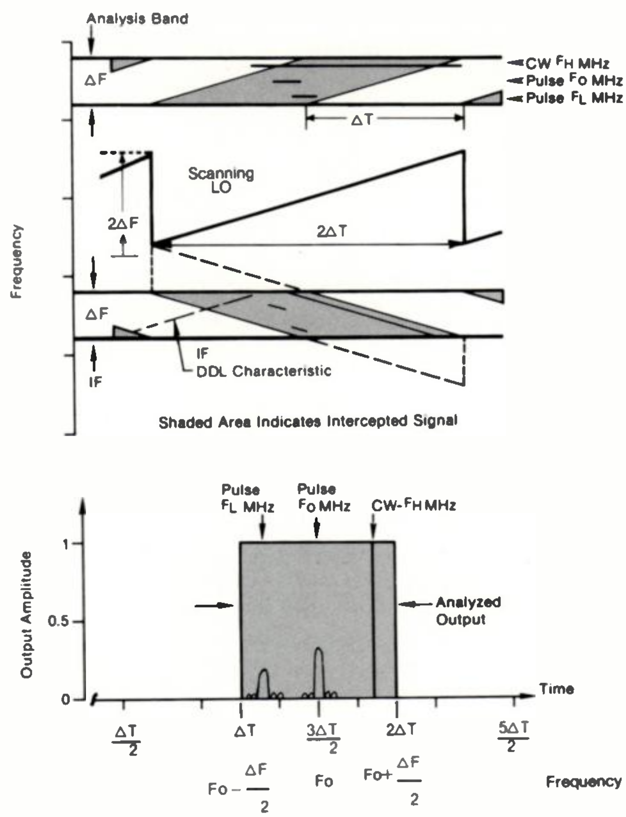


Figure 4. Time Frequency Diagram.

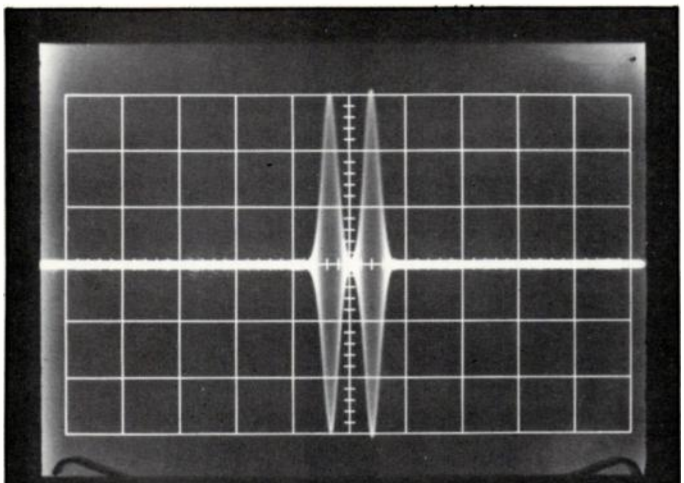


Figure 5.

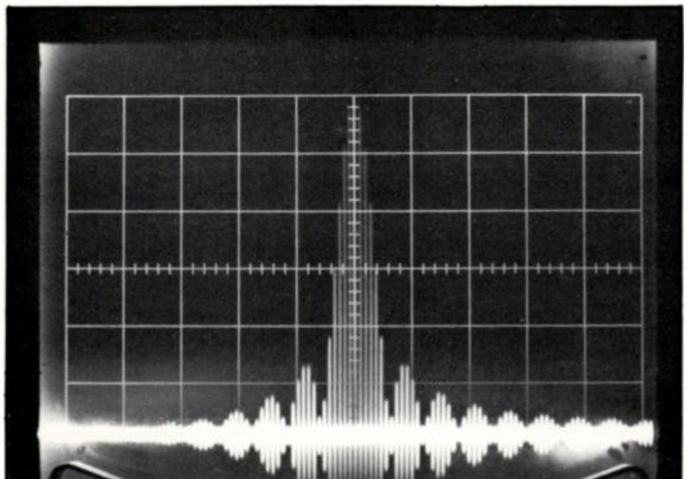


Figure 6.

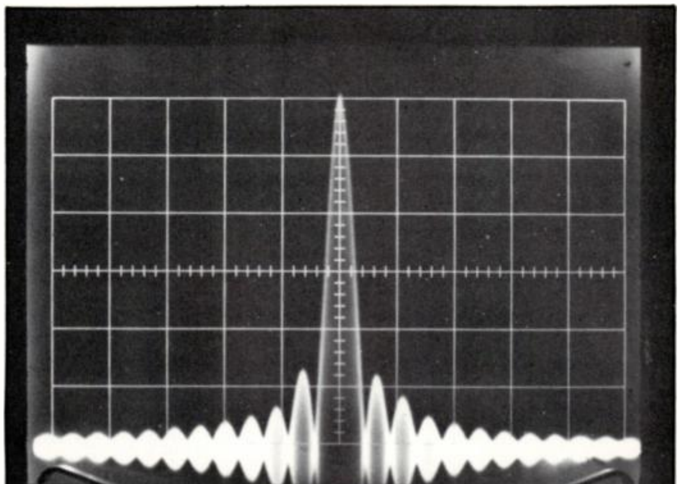


Figure 7.

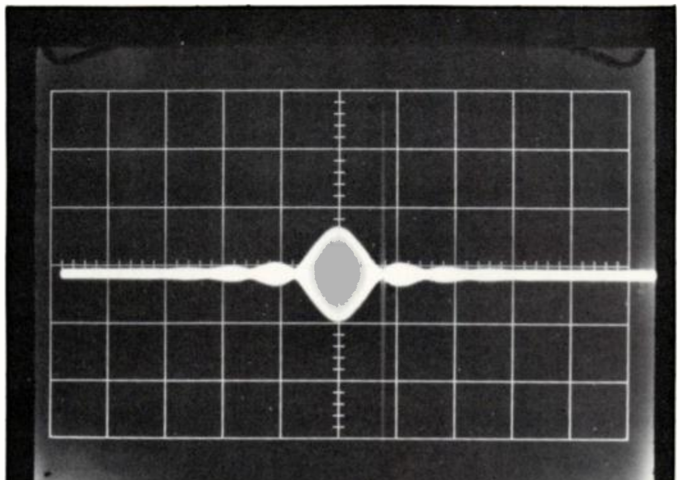


Figure 8.

The resolution for a compressive IF receiver is:

$$\delta f = \frac{1.5}{\Delta T}$$

A comparison can be made based on these constraints. If both systems are designed for the same resolution, δf, then the compressive IF receiver offers an improvement in processing speed of $N/(1.5)^2$. If both type systems are designed for the same processing speed then the compressive receiver offers an increase in resolution of $\sqrt{N}/1.5$.

2. Probability of Intercept: The probability of intercept for a conventional scanning spectrum analyzer with pulsed signals is $\delta f/\Delta F$ which is typically a small fraction of 1 percent. For the compressive IF receiver it is 50 percent. Two such systems working in tandem, provide 100 percent probability of intercept.

3. Dynamic Range: Dynamic range is primarily determined by thermal noise and compressed pulse sidelobe considerations. Due to the pulse compression process in the compressive receiver, its effective noise bandwidth is $\Delta F/N \approx \delta f$ which is the same as would be expected for a scanning spectrum analyzer of resolution δf. Therefore, for CW signals the dynamic range limitations related to thermal noise are equivalent for the two types of systems. For pulses shorter than ΔT in length, the compressive receiver experiences a processing loss of:

$L = (\tau/\Delta T)$ where τ is the pulse length

$$L = 0 \text{ for } \tau = \Delta T$$

$$L = -10 \log N \text{ for } \tau = \frac{\Delta T}{\Delta F}$$

$$L = -20 \log N \text{ for } \tau = \frac{1}{\Delta F}$$

For pulse performance in the scanning spectrum analyzer, pulses greater than $\sqrt{\Delta T/\Delta F}$ can be detected without any processing gain loss if intercepted. However, the probability of interception is extremely low. When the pulse is shorter than $\sqrt{\Delta T/\Delta F}$, there is not any meaningful output.

Sidelobes limit the compressive receiver dynamic range from 30 to 50 dB depending on specification in the output frequency interval of $\pm\sqrt{\Delta F/\Delta T}$ about the compressed pulse. Outside this interval the dynamic range is essentially limited by the thermal noise floor.

Performance Examples

As stated earlier, the output of a compressive IF receiver closely approximates the magnitude of the Fourier transform of the analysis band. Several examples, of actual data are given below for Andersen's CR-15-1.25-3 compressive IF receiver. This system has the following specifications:

Center frequency	15 MHz
Instantaneous Bandwidth ΔF	1.25 MHz
Resolution δf -3 dB	3 kHz max
Process Time ΔT	550 μS
Dynamic Range	
Peak Close-In Sidelobes within $\pm$ 70 kHz	40 dB typical; 35 dB min
Outside $\pm$ 70 kHz	50 dB typical
Output Signal to Noise	60 dB min
Intermodulation products (Two -26 dBm tones)	-50 dBm
Probability of Intercept	100%
Duty Cycle	50%

1. CW Signals: Figure 5 clearly shows the ability of the system to separate two closely spaced CW signals.

2. Repetitive Pulses: Figure 6 displays the output for an RF pulse train with a repetition rate $>1/\Delta T$. The display closely approximates the classical Fourier transform and one can easily determine pulse width and PRF.

3. Single Pulse: Figure 7 displays the receiver response to a single RF pulse with repetition rate $<1/\Delta T$. Again the output closely represents the expected Fourier transform and pulse width is easily determined.

4. Single Pulse and CW Signal: Figure 8 shows the receiver output when both a single RF pulse and a CW tone are present simultaneously in the analysis band. The two signals are easily distinguishable. Since the pulse bandwidth is starting to approach the system bandwidth, there is some distortion of the normal sinx/x spectrum. This type of distortion is reasonably insignificant if the pulse width is greater than $4/\Delta F$ in length.

Conclusion:

Compressive IF Receivers provide real time spectrum analysis of the IF band of interest allowing the separation and identification of a variety of signals in a multiple signal environment. Performance is somewhat analogous to a channelized receiver with N continuous channels where N can be as large as 25,000. In comparison to the conventional scanning spectrum analyzer, dynamic range is reduced by compressed pulse sidelobes. However, this is offset by a 100 percent probability of intercept for a single pulse and a processing speed which is many orders of magnitude faster. □

Phase Lock Loops

Andrzej B. Przedpelski
R&D Laboratory
A.R.F. Products, Inc.
Boulder, Colorado

The advantages of a third order type 2 loop for frequency generation has been well established. In the literature, the third order loop is usually restricted to circuit constants which permit the use of well established second order calculations. A better approach is the exact calculation of an ideal third order loop presented elsewhere.(1) Even this approach can lead to problems when the ideal loop is reduced to real hardware. The solution of a third order loop using available components, presented herein, takes into account the finite DC gain of the integrator, the main low frequency pole of the integrator operational amplifier and the finite modulation high frequency limit of the VTO. Thus, if no additional poles are introduced below the VTO modulation input pole, the calculated performance reflects very accurately the actual data. The stray poles can be usually moved outside the range of interest by careful physical layout of the circuit, using good RF techniques. On the other hand, if a fixed known pole exists below the VTO pole frequency, it can be used in the calculations in its place.

The open loop response (see Figure 1):

$$T(s) = G(s)\,H(s) \tag{1}$$

determines the loop performance. The loop stability can be determined directly from the Bode diagram phase margin, since the damping factor concept, as commonly used in the second order loop, is not applicable for the higher order loops.

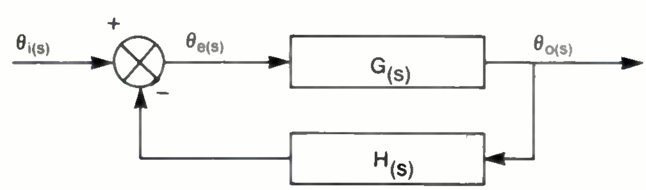


Figure 1. Feedback System

From Figure 1,

$$\theta_e(s) = \theta_i(s) - H(s)\,\theta_0(s) \tag{2}$$

and

$$\theta_e(s)\,G(s) = \theta_0(s) \tag{3}$$

by eliminating either θ_e(s) or θ_0(s) we can obtain the loop reduction of the VTO noise (see Figure 2),

$$\frac{e}{e_n} = \frac{\theta_e(s)}{\theta_i(s)} = \frac{1}{1 + G(s)\,H(s)} \tag{4}$$

and the closed loop characteristics,

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{G(s)}{1 + G(s)\,H(s)} \tag{5}$$

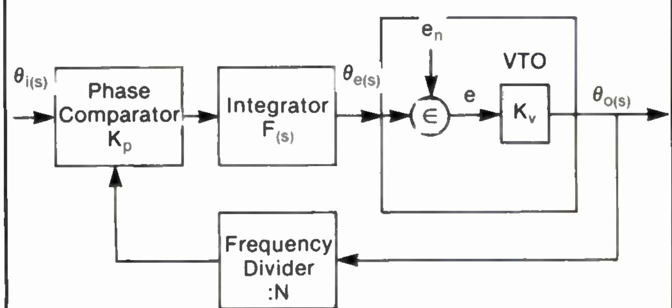


Figure 2. Typical Third Order Type 2 PLL

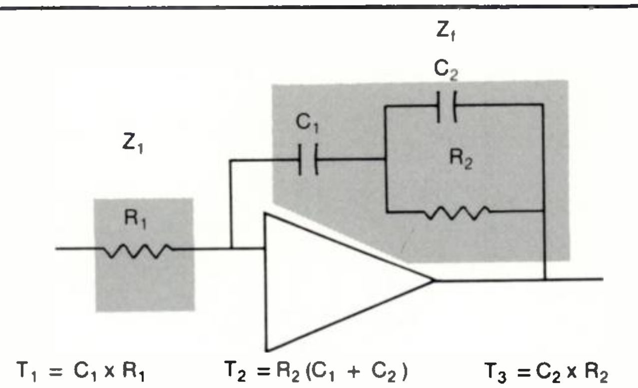


Figure 3. Third Order Loop Integrator

Using the typical loop of Figure 2, the feed forward function is:

$$G(s) = \frac{Kp\ F(s)\ Kv}{s} \tag{6}$$

And the feedback transfer function is:

$$H(s) = \frac{1}{N} \tag{7}$$

Thus the open loop response becomes:

$$G(s)\ H(s) = \frac{Kp\ F(s)\ Kv}{sN} \tag{8}$$

The integrator transfer function, F(s), determines the basic order of the PLL. Referring to Figure 3, when the operational amplifier has infinite gain, F(s) = $A_{CL} = -Z_f/Z_1$.

$$F(s) = \frac{sT_2 + 1}{sT_1(sT_3 + 1)} \tag{9}$$

with time constants T_1, T_2 and T_3 defined in Figure 3.

However, the operational amplifier has neither infinite gain nor infinite bandwidth. An inverting operational amplifier with finite gain and bandwidth can be modeled in the following manner.

For the purpose of this discussion we assume

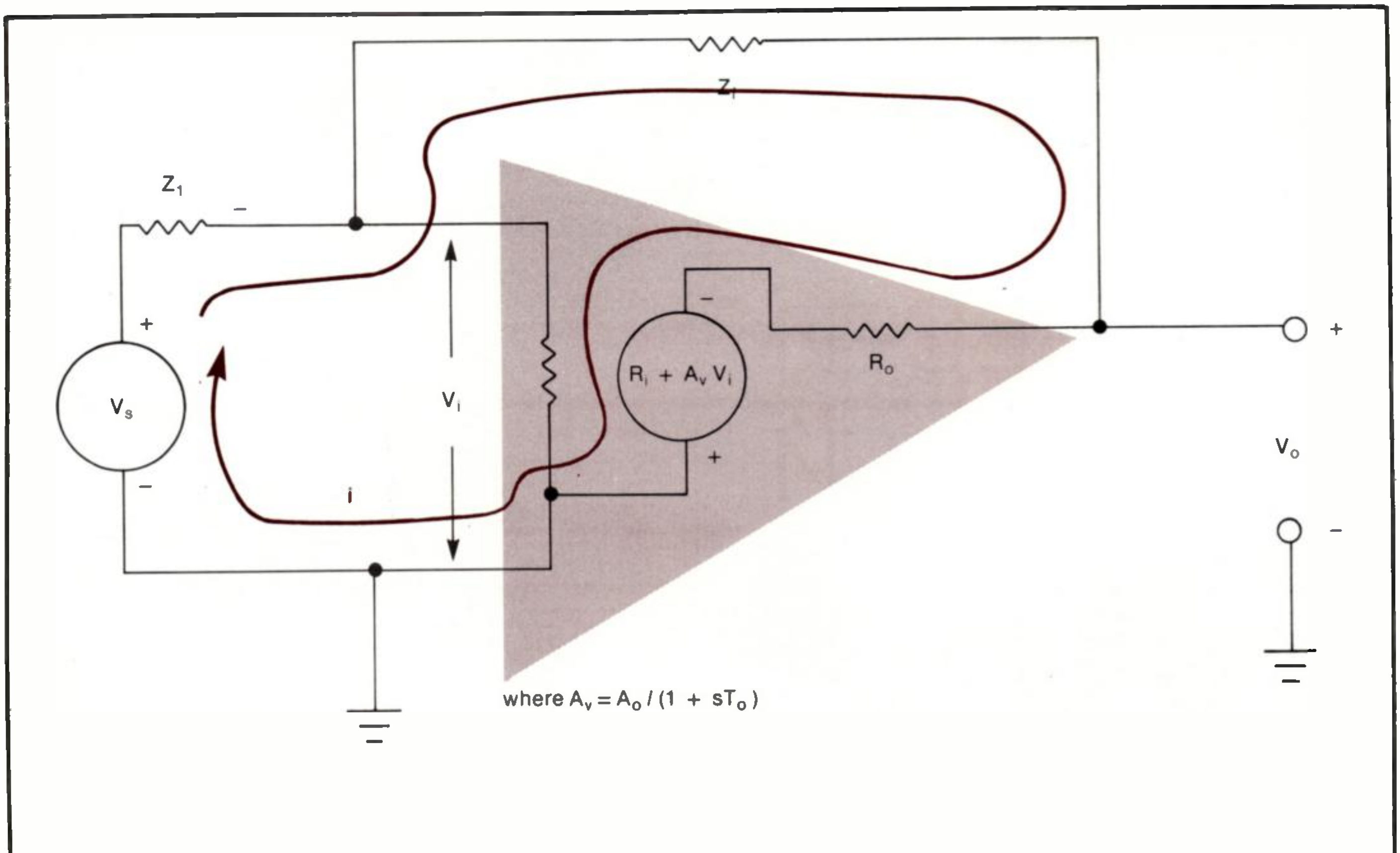


Figure 4. Circuit Model of Finite Gain Finite Bandwidth Diverting OP-AMP.

Ri →∞ and Ro →0. Hence only one mesh equation needs to be written to obtain the transfer function $F(s) = V_0/V_s$.

$$V_s = (Z_1 + Z_f)i - A_v V_i \tag{10}$$

where

$$V_i = V_s - Z_1 i \tag{11}$$

and

$$-V_0 = A_v V_i \tag{12}$$

hence

$$F(s) = A_{CL} = \frac{-Z_f/Z_1}{1 + 1/A_v + Z_f/A_v Z_1} \tag{13}$$

where A_v is a function of frequency:

$A_v = A_0/(1 + sT_0)$ with A_v being the DC operational amplifier gain and T_o the time constant of its first predominate pole as shown in Figure 5. Note that as $A_v \to \infty$ equation (13) becomes $F(s) = Z_f/Z_1$, the third order loop case.

Substituting for A_v, Z_f and Z_1 and solving:

$$F(s) = \frac{sA_0T_2 + A_0}{S^3(T_oT_1T_3) + S^2(A_0T_1T_3 + T_1T_3 + T_0T_1 + T_0T_2) + s(A_0T_1 + T_1 + T_2 + T_0) + 1} \tag{14}$$

The ideal VTO transfer function, K_v/s, also has to be modified to include the effect of the modulation frequency response, shown in Figure 6. The complete VTO transfer function becomes then:

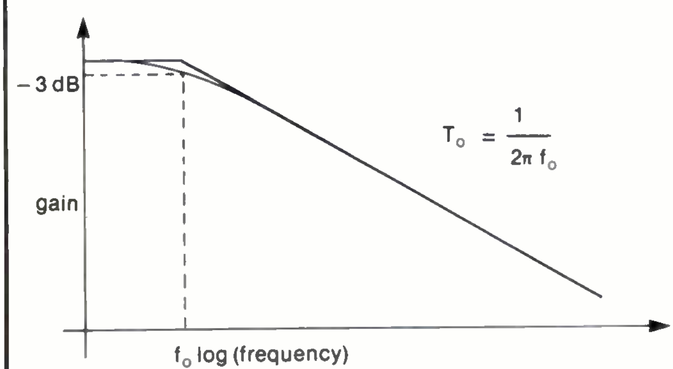


Figure 5. Typical Operational Amplifier Response

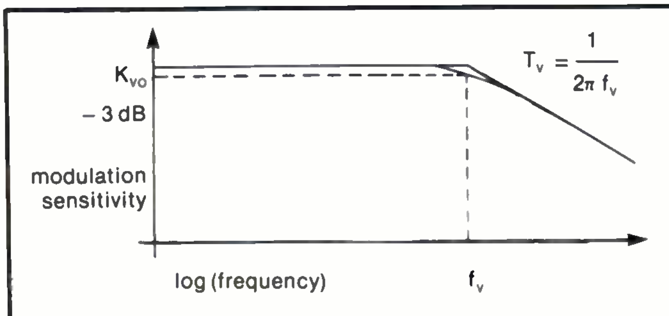


Figure 6. Typical VTO Modulation Response

$$\frac{Kv}{s} = \frac{Kv_o}{s(1 + sT_v)} \tag{15}$$

where K_{vo} = DC VTC sensitivity

Using the modified transfer functions of the integrator (14) and the VTO (15) in equation (8) we obtain:

$$G(s)\,H(s) = \frac{sBC + B}{s^5 D + s^4 E + s^3 F + s^2 L + s} \qquad (16)$$

$$\text{where } B = \frac{A_0 K_p K_{v0}}{N}$$

$$C = T_2$$

$$D = T_0 T_v T_1 T_3$$

$$E = T_v\,[T_0(T_1 + T_2) + T_1 T_3 (A_0 + 1)] + T_0 T_1 T_3$$

$$F = T_v(A_0 T_1 + T_0 + T_1 + T_2) + T_0 (T_1 + T_2) + T_1 T_3 (A_0 + 1)$$

$$L = A_0 T_1 + T_0 + T_v + T_1 + T_2$$

showing that the basic third order loop is actually a fifth order when the limited gain and frequency response of the integrator operational amplifier and the VTO modulation pole are considered. For final solution equation (16) can be rewritten:

$$G(s)\,H(s) = \frac{sBC + B}{s(s^4 D + s^2 F + 1) + (s^4 E + s^2 L)} \qquad (17)$$

In addition, if

$A_0 >> 1$
and
$T_0, T_v, T_1, T_2, T_3 < 1$

some of the coefficients can be simplified:

$$E = A_0 T_v T_1 T_3$$

$$F = A_0 T_1 (T_3 + T_v)$$

$$L = A_0 T_1$$

equation (17) becoming then, in terms of frequency:

$$G(s)\,H(s) = \frac{j\omega \left(\frac{K_{vo} K_p}{N}\right) \left(T_2\right) + \left(\frac{K_{vo} K_p}{N}\right)}{j\omega \left[\omega^2 T_1 \left(\omega^2 \frac{T_o}{A_o} T_v T_3 - T_3 - T_v\right) + \frac{1}{A_o}\right] + \omega^2 (\omega^2 T_v T_1 T_3 - T_1)} \qquad (18)$$

which can be further rearranged for a calculator program:

$$G(s)\,H(s) = \frac{K_p K_{v0}}{N\omega\, T_1} \left[\frac{j\omega T_2 + 1}{j\left(\omega^2 \left[\omega^2 \frac{T_0}{A_0} T_v T_3 - T_3 - T_v\right] + \frac{1}{A_0 T_1}\right)\Big] + \left(\omega \left[\omega^2 T_v T_3 - 1\right]\right)} \right] \qquad (19)$$

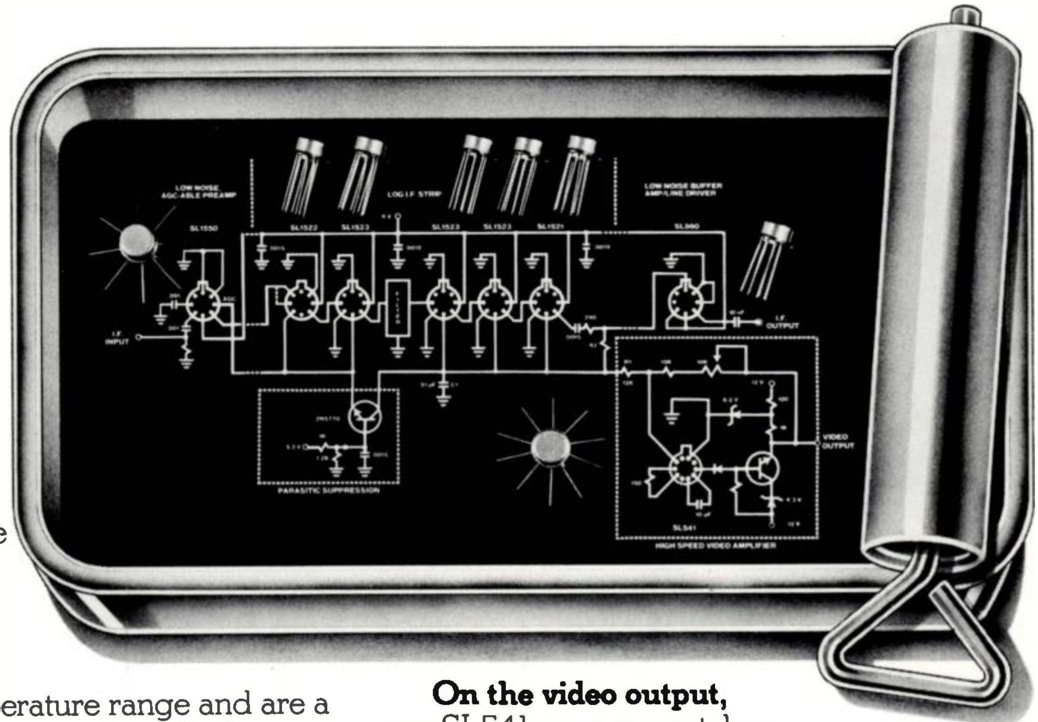
A calculator program to solve for the absolute value of G(s) H(s) and its phase margin is shown in Table I. To obtain the actual phase angle of G(s) H(s) 180° should be subtracted from the answer in step 49. The VTO noise reduction is also calculated using equation (4). This program was written for a 98 step RPN calculator such as the HP-19C/29C.

Table I

Step	Instructions	Input Data Units	Keys		Output Data Units
1	Enter program				
2	Store	T_o	STO	0	
		T_1	STO	1	
		T_2	STO	2	
		T_3	STO	3	
		T_v	STO	4	
		K_p	STO	5	
		K_{vo}	STO	6	
		N	STO	7	
		A_o	STO	8	
3	Key in f, start program	f_1 (Hz)	GSB	0	Phase Margin /degrees Open loop Gain/dB Noise Aπ /dB
4	Repeat step 3 for other frequencies	f_n (Hz)	GSB	0	Phase Margin /degrees Open loop Gain/dB Noise Aπ dB

Step	Key Entry	Key Code	Step	Key Entry	Key Code
001	(g) LBL 0	25 14 00		X	51
	PRX	65		1	01
	(g) π	25 63		(g)→P	25 34
	X	51		R↓	12
	2	02		+	41
	X	51		PRX	65
	STO .0	45.0	050	1	01
	(g) X²	25 53		8	08
	RCL 0	55 00		0	00
010	X	51		—	31
	RCL 8	55 08		STO .1	45.1
	÷	61		R↓	12
	RCL 4	55 04		÷	61
	X	51		RCL 5	55 05
	RCL 3	55 03		X	51
	X	51		RCL 6	55 06
	RCL 3	55 03	060	X	51
	—	31		RCL 7	55 07
020	RCL 4	55 04		÷	61
	—	31		RCL 1	55 01
	RCL .0	55 .0		÷	61
	(g) X²	25 53		RCL .0	55.0
	X	51		÷	61
	RCL 8	55 08		STO .2	45 .2
	RCL 1	55 01		(f) log	16 33
	X	51		2	02
	(g) 1/x	25 64	070	0	00
	+	41		X	51
030	RCL .0	55.0		PRX	65
	(g) X²	25 53		RCL .1	55 .1
	RCL 3	55 03		RCL .2	55 .2
	X	51		(f)→R	16 34
	RCL 4	55 04		1	01
	X	51		+	41
	1	00		(g)→P	25 34
	—	31		(g) 1/x	25 64
	RCL .0	55 .0	080	(f) log	16 33
	X	51		2	02
040	CHS	22		0	00
	(g)→P	25 34		X	51
	X⇌y	11		PRX	65
	RCL 2	55 02		(g) SPC	25 65
	RCL .0	55.0		(g) RTN	25 13

I.F. cram course



In a nutshell, Plessey IC's will cut the costs, reduce the size, and increase the reliability of your IF strips.

Into each IC can, we've packed more functional capability than you would believe possible, especially once you've seen the prices.

Our IC's operate over the full MIL-temperature range and are a simpler, less expensive, more flexible alternative to whatever you're using now for any IF strip up to 240 MHz. Whether you're working with radar and ECM, communications, weapons control or navigation and guidance systems.

Let's go through the diagram function by function and we'll show you exactly what we mean.

The log IF strip is based on the Plessey SL1521, the simplest, easiest-to-use and least expensive wideband amplifier you can buy. It has a gain of 12 dB and an upper cut-off frequency of 300 MHz (our less expensive SL521 is available if you're working under 100 MHz). The SL1522 is two 1521's in parallel with a resistive divider for increasing the IF strip's dynamic range, while the SL1523 is two 1521's in series. With these devices, it takes just five cans and a single interstage filter to build a log IF strip at 160±15 MHz with a logging range of 90 dB, ±1 dB accuracy, −90 dBm tangential sensitivity and a video rise time of 20 nsec or less. It's reliable, inexpensive and field repairable, which is more than can be said about the hybrids or discretes you're buying now.

On the video output, our SL541 op amp matches the IF strip to your system, and lets you vary video sensitivity. It has the high slew rate (175 V/μsec), fast settling time (1% in 50 nsec) and high gain stability you need, with on-chip compensation so it's not tricky to use.

For the front end, just slip in the Plessey SL1550 to improve your noise figure, dynamic range and sensitivity. The SL1550 is a low noise, AGC-able preamp with a bandwidth of 320 MHz, 2 dB noise figure and 38 dB gain.

And for the IF output, the Plessey SL560 buffer amp/line driver operates up to 320 MHz with a noise figure less than 2 dB, gain of up to 40 dB, and drives 50 ohm lines with a minimum of external compensation (none in this application).

If all this looks almost too easy, send for complete details today.

When it comes to communications IC's, nobody delivers like Plessey can.

PLESSEY SEMICONDUCTORS

1641 Kaiser Avenue, Irvine, CA 92714.
Telephone (714) 540-9979

All things to some people.

INFO/CARD 14

Table II. Comparison of Exact and Third Order Approximation Calculated Data.

$T_0 = 7.96 \times 10^{-4}$ $T_3 = 5.64 \times 10^{-7}$ $K_p = 0.16$
$T_1 = 3.53 \times 10^{-5}$ $T_v = 1.59 \times 10^{-7}$ $K_{v0} = 3.14 \times 10^8$
$T_2 = 5.72 \times 10^{-6}$ $N = 16$ $A_0 = 320{,}000$

	Exact Calculation			Third Order Approximation		
Frequency Hz	G(s) H(s) dB	>°	e/e_n dB	G(s) H(s) dB	>°	e/e_n dB
1.0	187.06	– 179.19	– 187.06	187.06	– 179.99	– 187.06
10	147.06	– 179.90	– 147.06	147.06	– 179.98	– 147.06
100	107.06	– 179.81	– 107.06	107.06	– 179.81	– 107.06
1000	67.06	– 178.20	– 67.06	67.06	– 178.15	– 67.07
10,000	27.58	– 162.83	– 27.22	27.58	– 162.26	– 27.92
81,800	0	– 129.62	1.395	0	– 124.95	– 4.99
100,000	– 2.07	– 130.764	2.28	– 2.02	– 125.06	– 4.05
496,800	– 22.80	– 180.00	0.653	—	—	—
1,000,000	– 36.08	– 211.11	0.12	– 33.15	– 165.84	– 0.18
Phase Margin		50.38°			55.05°	

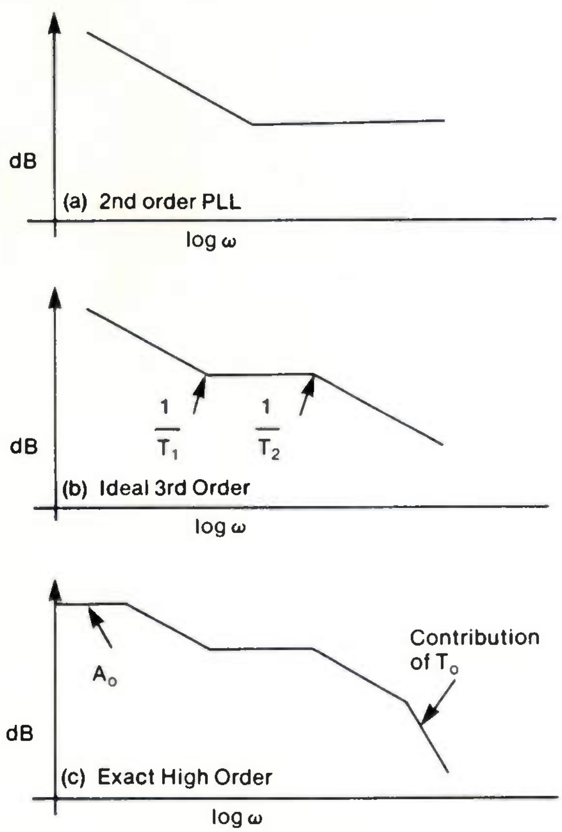


Figure 7. Idealized (Bode Approximation) Integrator Response

The program is written for the 19C version. To use it in the 29C calculator, delete step 2 and 85; replace PRx in steps 49.

The refinement of incorporating the additional poles and finite gain into the ideal third order solution shows up mainly at high values of frequency. However, in critical applications, it may be worthwhile. A numerical example of this difference is shown in Table II. A high frequency (960 MHz) loop with large bandwidth (approximately 100 kHz) and adequate phase magin (60°) was calculated using the optimizing program of reference(2). Closest standard capacitor and resistor values were used for the integrator time constants. The use of standard values reduced the calculated phase margin by 4.95°. The exact calculation indicates that the phase margin is actually about another 5° lower. The exact calculation also shows a gain margin of 22.8 dB, while the third order calculation indicates an infinite gain margin which, of course, is not possible in a real circuit.

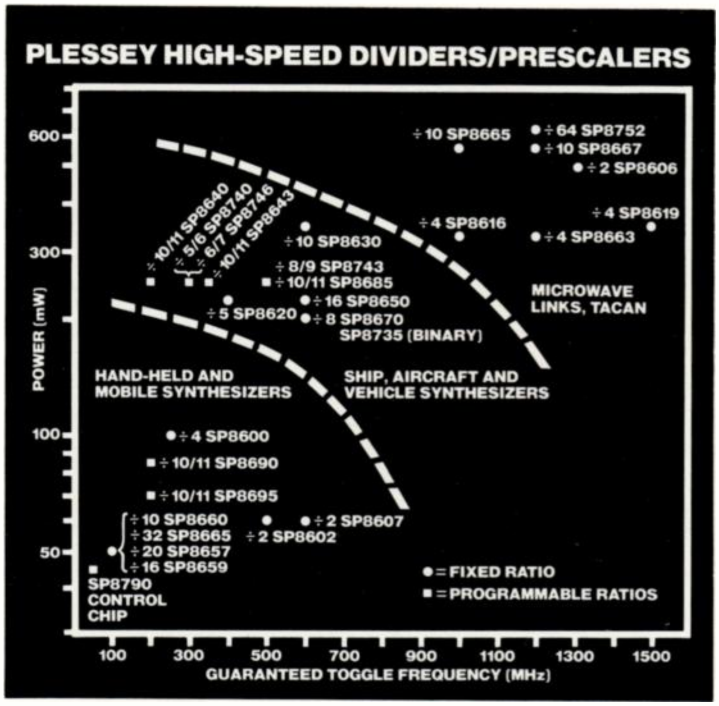
It becomes apparent, from the above discussion, that, while the VTO modulation frequency response has some effect on the PLL performance, the integrator design is the main determining factor. Figure 7 shows the basic difference in the frequency response of the second order PLL, ideal third order and exact high order.

In general, the exact high order PLL solution should be considered when $1/T_v$ is less than about twice the loop bandwidth and/or when the $1/T_2$ point approaches the open loop operational amplifier response.

Bibliography

1. Andrzej B. Przedpelski, "Analyze, don't estimate, phase-lock-loop performance," Electronic Design, May 10, 1978, pp. 120-122.
2. Andrzej B. Przedpelski, "Optimize phase-lock-loops to meet your needs," Electronic Design, September 13, 1978, pp. 134-137.
3. Andrzej B. Przedpelski, "Reduce Reference Frequency Sidebands."
4. Vadim Manassevitsch, "Frequency Synthesizer, Theory and Design," John Wiley and Sons, N.Y., 1976.
5. "Phase-Locked Loop Data Book," Motorola Semiconductor Products, inc., Second Edition, August, 1973.
6. David F. Stout, Milton Kaufman, "Handbook of Operational Amplifier Circuit Design," McGraw-Hill Book Company, N.Y., 1976.
7. Jerzy Gorski-Popiel, "Frequency Synthesis: Techniques and Applications," IEEE Press, N.Y., 1975. □

Divide and conquer



Pick a Plessey prescaler and you've conquered the major problems in your high-speed counters, timers and frequency synthesizers.

Because we can give you everything from ultra-fast dividers that tame the terrors of TACAN to inexpensive IC's that cut the costs of your CB's.

They're all guaranteed to operate from dc to at least the frequencies shown. They all provide low power consumption, low propagation delays and easy system interfaces, with most of them available in commercial and MIL-temp versions.

And they're all available now, so contact us for details or a demonstration. We'll show you a winner.

Show me, Plessey:

Your dividers and prescalers sound like they can save me some money and a lot of grief.

☐ Have a salesman call ☐ Send more details

Name______________________________

Telephone______________________________

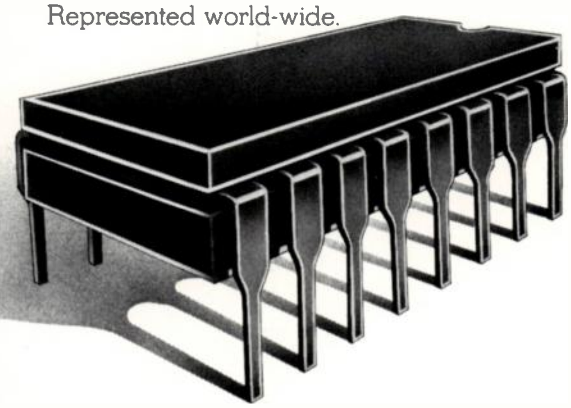
Company______________________________

Address______________________________

City/State/Zip______________________________

PLESSEY SEMICONDUCTORS

1641 Kaiser Avenue, Irvine, CA 92714
Tel: (714) 540-9979. TWX: 910-595-1930
Represented world-wide.



INFO/CARD 15

Design of VHF Quadrature Hybrids — Part II

By Chen Y. Ho and Bob Furlow
Motorola, Inc. — Government Electronics Division

The first part of this two part series, discussed the design of a narrow band quadrature hybrid. The scattering parameter matrix was derived. The desired characteristics of the hybrid then place constraints on this matrix. From these constraints design equations were derived.

The second part of this article deals with the design of a broadband quadrature hybrid by cascading two narrow band hybrids with transmission lines of appropriate length. Paralleling the discussion in Part I, a composite scattering parameter matrix is derived. Design equations are then generated from constraints placed on this matrix.

Analysis and Design of A Broadband Quadrature Hybrid

The configuration of the broadband quadrature hybrid is shown in Figure 1, which consists of two identical narrow band quadrature hybrids of Figure 1 and two pieces of transmission line with characteristic impedance Z_0 and electrical length θ_0.

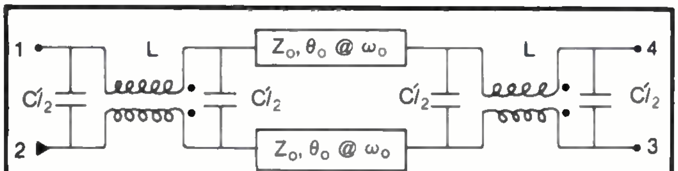


Figure 1. Configuration for Broadband Quadrature Hybrid

The hybrid of Figure 1 can be described in terms of S-parameters. Let the incidental waves to the hybrid be a_1, a_2, a_3 and a_4 and the reflected waves of the hybrid be b_1, b_2, b_3 and b_4 as is shown in Figure 2. The S-parameters of the hybrid are described by:

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{vmatrix} 0 & c & 0 & t \\ c & 0 & t & 0 \\ 0 & t & 0 & c \\ t & 0 & c & 0 \end{vmatrix} \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{vmatrix}$$

Where $c = j\omega L/(Z_0 + j\omega L)$ and $t = Z_0/(Z_0 + j\omega L)$. Let us see how matrix (2) is formed. Assume that a_1 is the only incidental wave to the hybrid, signal ca_1 will appear at port 2 and signal ta_1 at port

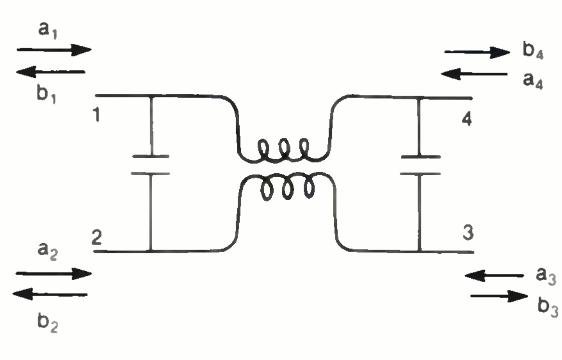


Figure 2. 4 Port Designation for NarrowBand Hybrid.

4. Since the hybrid is matched for all frequencies, no signal will appear at port 1, therefore $S_{11} = 0$. Also no signal will appear at port 3 for the reason of perfect isolation for all frequencies, so $S_{31} = 0$. And $S_{21} = c$ and $S_{41} = t$. The first column of the S-parameter matrix is thus formed. Similar arguments will be used for the forming of the remaining columns of the matrix.

The matrix (2) can not be directly used since multiplication of two such matrices does not represent the cascading of two circuit components, as in the case of an ABCD transmission matrix. However, a simple manipulation of variables in (2) will lead to a new matrix which has properties similar to that of an ABCD matrix. To do this, we need to express variables b_1, b_2, a_1, a_2 in terms of b_4, b_3, a_4 and a_3 so that variables on the right side of the hybrid (or the side to be connected with other circuit) may be associated with the variables of next circuit to be cascaded. Matrix (2) can be written in following form:

$$b_1 = ca_2 + ta_4 \tag{3a}$$
$$b_2 = ca_1 + ta_3 \tag{3b}$$
$$b_3 = ca_4 + ta_2 \tag{3c}$$
$$b_4 = ca_3 + ta_1 \tag{3d}$$

From (3c), we have

$$a_2 = (1/t)b_3 - (c/t)a_4 \tag{4a}$$

and from (3d), we have

$$a_1 = (1/t)b_4 - (c/t)a_3 \tag{4b}$$

Substituting (4a) into (3a) and (4b) into (3b), we have

$$b_1 = (c/t)b_3 - ([c^2 - t^2]/t)a_4 \tag{4c}$$
$$b_2 = (c/t)b_4 - ([c^2 - t^2]/t)a_3 \tag{4d}$$

Combining (4a), (4b), (4c) and (4d) into matrix form, we obtain

$$\begin{vmatrix} b_1 \\ b_2 \\ a_1 \\ a_2 \end{vmatrix} = \begin{vmatrix} 0 & c/t & -(c^2 - t^2)/t & 0 \\ c/t & 0 & 0 & -(c^2 - t^2)/t \\ 1/t & 0 & 0 & -c/t \\ 0 & 1/t & -c/t & 0 \end{vmatrix} \begin{vmatrix} b_4 \\ b_3 \\ a_4 \\ a_3 \end{vmatrix} \tag{4}$$

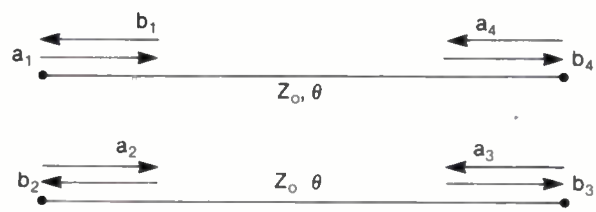
We can also show that

$$-(c^2 - t^2)/t = 1 - p$$
$$c/t = p \tag{5}$$
$$1/t = 1 + p$$

where $p = j\omega L/Z_0$. Then (4) can be expressed in terms of p as:

$$\begin{vmatrix} b_1 \\ b_2 \\ a_1 \\ a_2 \end{vmatrix} = \begin{vmatrix} 0 & p & 1-p & 0 \\ p & 0 & 0 & 1-p \\ 1+p & 0 & 0 & -p \\ 0 & 1+p & -p & 0 \end{vmatrix} \begin{vmatrix} b_4 \\ b_3 \\ a_4 \\ a_3 \end{vmatrix} \tag{6}$$

To obtain the S-parameters of two pieces of transmission line with a characteristic impedance Z_0 and an electrical length θ_0 at ω_0, we use the same principle as for the narrow band hybrid.



Port Designation for Transmission Lines.

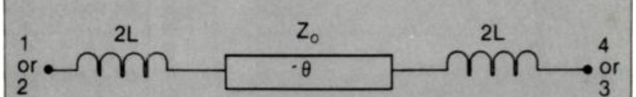
Even-Mode, Odd-Mode Analysis

An alternate approach to rearranging the scattering parameter matrices, is to carry out the even-mode, odd-mode analysis in the same way it was done in Part I of this series.

The scattering parameter matrix for the broadband hybrid can now be found by using the same equations and process that was used in Part I to generate the scattering parameter matrix for the narrow band hybrid. Recall that the narrow band hybrids used to make the broadband hybrid are constrained to have perfect match and infinite isolation, i.e.

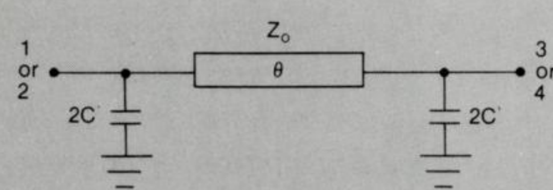
$$Z_0^2 = L/C$$

The reader may therefore prove the scattering parameter matrix generated in this manor is the same as that found in equation (10).



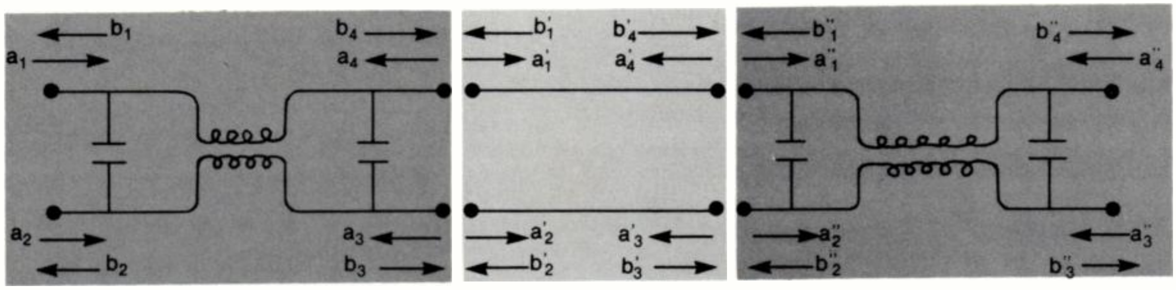
$$M+ = \begin{bmatrix} 1 & j\omega 2L \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta) & jZ_0 \sin(\theta) \\ j\sin(\theta)/Z_0 & \cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & j2\omega L \\ 0 & 1 \end{bmatrix}$$

even-mode excitation



$$M- = \begin{bmatrix} 1 & 0 \\ j2\omega C & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta) & jZ_0 \sin(\theta) \\ j\sin(\theta)/Z_0 & \cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j2\omega C & 1 \end{bmatrix}$$

odd-mode excitation



$b_4 = a'_1,\ b_3 = a'_2$
$a_4 = b'_1,\ a_3 = b'_2$

$b'_4 = a''_1,\ b'_3 = a''_2$
$a'_4 = b''_1,\ a'_3 = b''_2$

Figure 3. Port Designation.

The port designations for the section consisting of two pieces of transmission line. It is apparent that following relations

$$b_4 = e^{-j\theta} a_1 \quad (7a)$$
$$b_1 = e^{-j\theta} a_4 \quad (7b)$$
$$b_3 = e^{-j\theta} a_2 \quad (7c)$$
$$b_2 = e^{-j\theta} a_3 \quad (7d)$$

hold. The S-parameters, when the variables a_1, a_2, b_1, b_2 are expressed in terms of a_4, a_3, b_4, b_3, are given by

$$\begin{vmatrix} a_1 \\ a_2 \\ b_1 \\ b_2 \end{vmatrix} = \begin{vmatrix} 0 & 0 & e^{j\theta} & 0 \\ 0 & 0 & 0 & e^{j\theta} \\ e^{-j\theta} & 0 & 0 & 0 \\ 0 & e^{-j\theta} & 0 & 0 \end{vmatrix} \begin{vmatrix} a_4 \\ a_3 \\ b_4 \\ b_3 \end{vmatrix} \quad (7)$$

Now we have the S-parameter matrix for all three circuit components of the broadband quadrature hybrid, two narrow band quadrature hybrids and transmission lines (6) and (7), which will be multiplied to give a S-parameter matrix for the hybrid as follows.

$$\begin{vmatrix} 0 & p & 1-p & 0 \\ p & 0 & 0 & 1-p \\ 1+p & 0 & 0 & -p \\ 0 & 1+p & -p & 0 \end{vmatrix} \begin{vmatrix} 0 & 0 & e^{j\theta} & 0 \\ 0 & 0 & 0 & e^{j\theta} \\ e^{-j\theta} & 0 & 0 & 0 \\ 0 & e^{-j\theta} & 0 & 0 \end{vmatrix} \begin{vmatrix} 0 & p & 1-p & 0 \\ p & 0 & 0 & 1-0 \\ 1+p & 0 & 0 & -p \\ 0 & 1+p & -p & 0 \end{vmatrix} \tag{8}$$

The multiplication is possible if the following relations are recognized, (refer to Figure 3).

$$\begin{vmatrix} b_1 \\ b_2 \\ a_1 \\ a_2 \end{vmatrix} = \begin{vmatrix} 0 & A & B & 0 \\ A & 0 & 0 & B \\ D & 0 & 0 & -A \\ 0 & D & -A & 0 \end{vmatrix} \begin{vmatrix} b_4'' \\ b_3'' \\ a_4'' \\ a_3'' \end{vmatrix} \tag{9}$$

where

$$A = p(1+p)e^{j\theta} + p(1-p)e^{-j\theta}$$
$$B = -p^2 e^{j\theta} + (1-p)^2 e^{-j\theta}$$
$$D = (1+p)^2 e^{j\theta} - p^2 e^{-j\theta}$$

All we have to do now is to express b_1, b_2, b_3'', b_4'' in terms of a_1, a_2, a_3'', a_4'' using (9). This can be done in the same way we convert (2) into (4) which is

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3'' \\ b_4'' \end{vmatrix} = \begin{vmatrix} 0 & A/D & 0 & (A^2+BD)/D \\ A/D & 0 & (A^2+BD)/D & 0 \\ 0 & 1/D & 0 & A/D \\ 1/D & 0 & A/D & 0 \end{vmatrix} \begin{vmatrix} a_1 \\ a_2 \\ a_3'' \\ a_4'' \end{vmatrix} \tag{10}$$

A good check for the correct manipulation at this moment is to make sure that $A^2 + BD = 1$, which is required for hybrid symmetry.

$$\begin{aligned} A^2 + BD &= (p[1-p]e^{-j\theta} + p[1+p]e^{j\theta})^2 + \\ &\quad ([1-p]^2 e^{-j\theta} - p^2 e^{j\theta})([1+p]^2 e^{j\theta} - p^2 e^{-j\theta}) \\ &= p^2(1-p)^2 e^{-j2\theta} + p^2(1+p)^2 e^{j2\theta} + \\ &\quad 2p^2(1-p^2) + (1-p)^2(1+p)^2 - \\ &\quad p^2(1+p)^2 e^{j2\theta} - p^2(1-p)^2 e^{-j2\theta} + p^4 \\ &= 2p^2(1-p^2) + (1-p^2)^2 + p^4 \\ &= (1-p^2+p^2)^2 = 1. \qquad \text{Check} \end{aligned}$$

It is apparent that the broadband hybrid of Figure 1 has the properties of a perfect match and infinite isolation, i.e. $S_{ii} = 0$, $i = 1, 2, 3, 4$ and $S_{i,i+2} = S_{i+2,i} = 0$, $i = 1, 2$. And transmission from port 1 to port 2 is

$$T_{21} = \begin{vmatrix} 2p\cos(\theta) & j2p^2\sin(\theta) \\ (1+p)^2 e^{j\theta} & -p^2 e^{-j\theta} \end{vmatrix} \tag{11}$$

and the transmission from port 1 to port 4 is

$$T_{41} = \frac{1}{(1+p)^2 e^{j\theta} - p^2 e^{-j\theta}} \tag{12}$$

Let k be the output power ratio between port 2 and port 4 for power input at port 1, then

$$k = \frac{|T_{21}|^2}{|T_{41}|^2} = (2p\cos[\theta] + j2p^2\sin[\theta])^2 \tag{13}$$

$$k = (2\omega L\cos[\theta]/Z_0 - 2\omega^2 L^2 \sin[\theta]/Z_0^2)^2$$

Search for Frequency At Which the Peak of k Occurs

It might seem that (13) together with Z_o = L/C and k = 1 in k = $(\omega L/Z_0)^2$ will provide a solution to design parameters L, C and θ_0 for broadband quadrature hybrid design. However, a closer look at (13) reveals that the peak of k does not coincide with ω_o, the desired center frequency. This is mainly due to the fact that the frequency response curves are not symmetrical with respect to ω_0. To find the frequency at which the peak of the k curve occurs, we express

$$\omega L/Z_0 = \omega\omega_0 L/(\omega_0 Z_0) = (\omega/\omega_0)(\omega_0 L/Z_0) = \omega/\omega_0 = q \qquad (14)$$

$$\theta = \beta\ell = 2\pi\ell/\lambda = \omega\ell/v_c = (\omega_0\ell/v_c)(\omega/\omega_0) = q\theta.$$

where θ_0 is the electrical length of the transmission lines at ω_0, v_c the velocity of light in the propagation medium and ℓ is the physical length of the transmission lines. Then (13) can be expressed as:

$$F(q) = 2q\cos(q\theta_0) - 2q^2\sin(q\theta_0) - \sqrt{k} \qquad (15)$$

where k can be passband ripple if k ⩾ 1 or the desired coupling if k< 1 as is shown in Figure 4.

To find the frequency or q at which the peak of the k curve, F (q), occurs, we simply take the first derivative of (15) with respect to q, and set it to zero. This leads to:

$$\cos(q\theta_0) - q\theta_0\sin(q\theta_0) - 2q\sin(q\theta_0) - q^2\theta_0\cos(q\theta_0) = 0$$

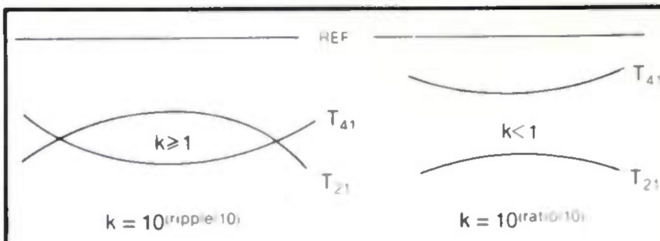


Figure 4: Meaning of k in Amplitude Responses

or (16)

$$\tan(q\theta_0) = \frac{1 - q^2\theta_0}{q(2 + \theta_0)}$$

Given the desired output power splitting ratio k, or passband ripple in a 3 dB design, equations (15) and (16) shall be solved simultaneously to obtain the required electrical length θ_0 of the transmission line and frequency at which the peak of the k curve occurs. Knowing the ratio q of the frequency at which the peak of the k curve occurs to the desired center frequency of operation ω_0, all we have to do is change the designed center frequency of operation by this ratio q, so the peak of the k curve will be coincidental with ω_0.

The missing part from this example is how equations (15) and (16) are solved to obtain θ_0 = 26.247° and q = .7822.

(15) can be re-written as:

Example:

We want to design a broadband quadrature hybrid with a 3 dB average split between the two output ports, and a 0.3 dB ripple in the passband.

If we were to design the two narrow band hybrids according only to the constraints of the first article, ($k = [\omega L/Z0]\ 2$, $Z^2{}_0 = L/C$) with $k = 1$, and $Z0 = 50\ \Omega$ we would have $L = 132.5$ nH, $C/2 = 26.5$ pf at 60 MHz. The solution to (15) and (16), however, indicates $\theta_0 = 26.247$ degrees and $q = .7822$. The θ_0 that we obtain gives us the correct transmission line length, but the q indicates that the maximum of k will occur at 60 MHz x .7822, or 46.94 MHz.

K max can be easily made to fall at 60 MHz by simply designing the narrow band quadrature hybrids at (60 MHz/.7822) = 76.7 MHz. Hence, $L = 103.7$ nH, and $C/2 = 20.7$ pF, and our design is complete.

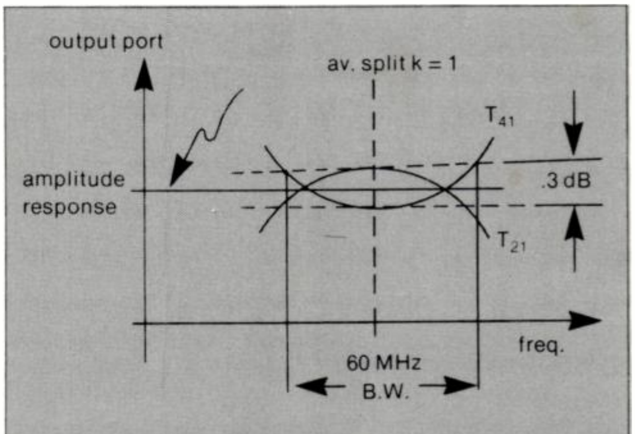


Figure 5. Desired Hybrid Characteristic.

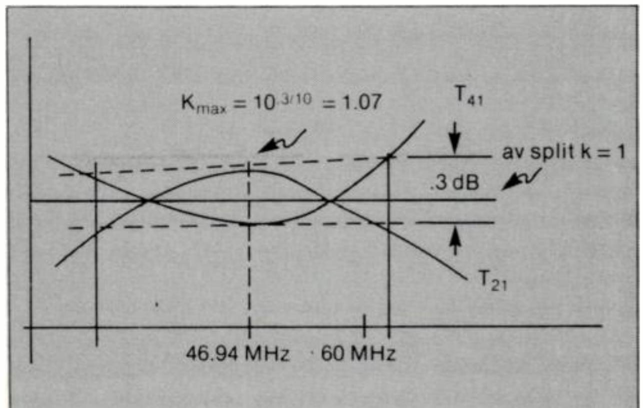


Figure 6. Uncorrected Hybrid Characteristic when Narrowband. ω = 60 MHz.

$$\frac{2q\theta_0 \cos(q\theta_0)}{\theta_0} - \frac{2q^4\theta_0^2 \sin(q\theta_0)}{\theta_0^2} = \sqrt{k} \qquad (17)$$

Substituting $y = q\theta_0$ into (17), we have

$$\frac{2y\cos(y)}{\theta_0} - \frac{2y^2\sin(y)}{\theta_0^2} = \sqrt{k} \qquad (18)$$

Similarly (16) can be re-written as:

$$\tan(q\theta_0) = \frac{1 - q^2\theta_0^2/\theta_0}{2q\theta_0/\theta_0 + q\theta_0} \qquad (19)$$

Substituting $y = q\theta_0$ into (19), we have:

$$\tan(y) = \frac{1 - y^2/\theta_0}{2y/\theta_0 + y} = \frac{\theta_0 - y^2}{y(2 + \theta_0)}$$

or (20)

$$\theta_0 = \frac{y^2 + 2y\tan(y)}{1 - y\tan(y)}$$

Substituting (20) into (18), we obtain

$$\frac{2(1 - y\tan[y])\cos(y)}{y + 2\tan(y)} - \frac{2(1 - y\tan[y])^2\sin(y)}{(y + 2\tan[y])^2} = \sqrt{k}$$

or

$$\frac{2(1 - y\tan[y])\cos(y)(y + 2\tan[y])}{(y + 2\tan[y])^2}$$

$$- 2(1 - y\tan[y])^2\sin(y) = \sqrt{k}$$

or (21)

$$\frac{2(\sin[y] + y/\cos[y])(1 - y\tan[y])}{(y + 2\tan[y])^2} = \sqrt{k}$$

The solution of y in (21) for given k is not as complicated as it looks. Let's define

$$G(y) = \frac{2(\sin[y] + y/\cos[y])(1 - y\tan[y])}{(y + 2\tan[y])^2} - \sqrt{k} \qquad (22)$$

Function G(y) becomes positively infinite for $y = 0$ and is equal to $-\sqrt{k}$ for $y = 1/\tan(y)$ or $y = 49.5$ degrees. Function G(y) is also a continuous function of y for $y\varepsilon(0,49.5]$. Therefore a solution (or more) must exist for ε (0, 49.5]. To find the solution for G(y), conventional bi-section method can be used with the help of a computer of just a hand calculator. After y has been found, θ_0 can be obtained from (20) and q by $q = y/\theta_0$. Using passband ripple as a design parameter, Figure 7 shows the relationship of q and θ_0 to the passband ripple. Figure 8 shows the bandwidth ratio as a function of passband ripple. The design procedures for the broadband quadrature hybrid of Figure 1 are summarized as follows:

Given: Z_0, Passband Ripple, and ω_0

1. Find k by $k = 10^{(\text{ripple [dB]}/10)}$
2. Find y from (22) and θ_0 from (20) and $q = y/\theta_0$ or from Figure 7 and Figure 8.
3. Find the design center frequency of operation $\omega_1 = \omega_0/q$
4. Find $L = Z_0/\omega_1$, and $C = 1/(Z_0\omega_1)$
5. θ_0: electrical length @ ω_1

A computer program has been written for the design of broadband quadrature hybrids of Figure 1, which has incorporated all the design procedures described above. The program will provide the frequency responses for the design or do the analysis when actual values of inductors, capacitors and transmission line lengths are inputted.

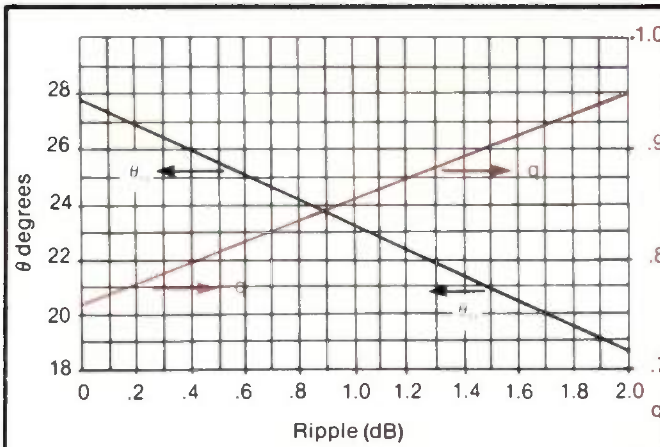


Figure 7. Passband Ripple (dB) vs. Electrical ℓ & Center Frequency Shift.

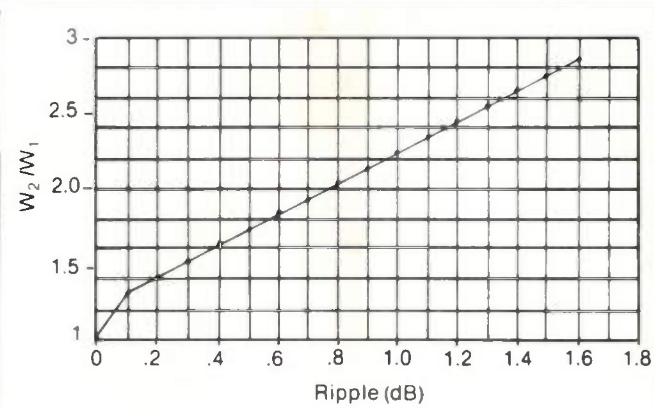


Figure 8. Passband Ripple vs. Bandwidth Ratio.

Experimental Results Of A Broadband Quadrature Hybrid

A broadband quadrature hybrid has been designed using the Computer program with Z_0 = 50 ohm, f_0 = 60 MHz and passband ripple = 0.3 dB. The design parameters of the hybrid are: L = 103.7 nH, C/2 = 20.7 pF and 26.247 degrees @ 76.7 MHz. The inductors are realized using the same techniques as used in Part I and ATC 100 capacitors of 22 pf are used for the capacitors. The 50 ohm transmission lines are microstrip transmission lines printed on 25 mil thick Epsilam-10 substrate material. The inductors and capacitors are soldered on the same substrate. The measured amplitude responses of the example broadband quadrature hybrid are shown in Figure 10, and the return loss and isolation in Figure 11. The phase imbalance of the hybrid is 90° ± 3°. The experimental results show excellent correlation with the theory.

LOWER FREQUENCY = .3000E − 01 GHZ
UPPER FREQUENCY = .9000E − 01 GHZ
CHAR IMP. = 50.0000 OHM
BANDWIDTH RATIO ω2/ω1 = 1.5553
TORID INDUCTANCE = 103.7256 NH
HYBRID CAPACITANCE = 20.7451 PF
PEAK TO PEAK RIP. = .3000 DB
ELECTRICAL LENGTH = 26.2474 DEG AT .0767 GHZ

FREQ	RL	DIR	COUP	ISOL	PHASE
.3000E-01	− 60 0000	− 1 7936	− 4 7066	− 60 0000	− 89 9999
3100E-01	− 60.0000	− 1 8727	− 4 5560	− 60 0000	− 89 9999
3200E-01	− 60.0000	− 1 9505	− 4 4152	− 60 0000	− 89 9999
3300E-01	− 60 0000	− 2 0269	− 4 2837	− 60 0000	− 89 9999
3400E-01	− 60 0000	− 2 1017	− 4 1607	− 60 0000	− 89 9999
3500E-01	− 60 0000	− 2.1747	− 4 0459	− 60 0000	− 89 9999
3600E-01	− 60 0000	− 2.2460	− 3 9385	− 60 0000	− 89 9999
3700E-01	− 60.0000	− 2 3152	− 3 8382	− 60 0000	− 89 9999
.3800E-01	− 60.0000	− 2.3824	− 3 7446	− 60 000	− 89 9999
.3900E-01	− 60.0000	− 2 4474	− 3 6572	− 60.0000	− 89 9999
4000E-01	− 60.0000	− 2 5101	− 3 5758	− 60 0000	− 89 9999
4100E-01	− 60.0000	− 2.5704	− 3 4999	− 60 0000	− 89 9999
4200E-01	− 60.0000	− 2 6282	− 3 4293	− 60.0000	− 89.9999
4300E-01	− 60 0000	− 2.6835	− 3 3637	− 60 0000	− 89.9999
.4400E-01	− 60.0000	− 2 7361	− 3 3030	− 60 0000	− 89 9999
4500E-01	− 60 0000	− 2 7860	− 3.2468	− 60 0000	− 89.9999
4600E-01	− 60.0000	− 2.8332	− 3 1950	− 60.0000	− 89 9999
.4700E-01	− 60.0000	− 2 8775	− 3 1473	− 60.0000	− 89.9999
.4800E-01	− 60.0000	− 2.9188	− 3 1037	− 60 0000	− 89.9999
4900E-01	− 60 0000	− 2.9572	− 3 0640	− 60.0000	− 89.9999
.5000E-01	− 60 0000	− 2 9926	− 3 0281	− 60 000	− 89.9999
.5100E-01	− 60 0000	− 3 0248	− 2 9958	− 60 0000	− 89.9999
.5200E-01	− 60.0000	− 3 0539	− 2 9671	− 60.0000	− 89.9999
5300E-01	− 60.0000	− 3.0798	− 2 9419	− 60.0000	− 89.9999
.5400E-01	− 60.0000	− 3 1023	− 2 9202	− 60 0000	− 89.9999
5500E-01	− 60 0000	− 3 1216	− 2 9018	− 60.0000	− 89.9999
.5600E-01	− 60 0000	− 3 1375	− 2 8867	− 60 0000	− 89.9999
.5700E-01	− 60 0000	− 3 1499	− 2 8750	− 60 0000	− 89.9999
5800E-01	− 60.0000	− 3.1589	− 2 8666	− 60 0000	− 89.9999
5900E-01	− 60.0000	− 3 1643	− 2 8616	− 60 0000	− 89.9999
.6000E-01	− 60 0000	− 3 1661	− 2 8599	− 60 0000	− 89.9999
.6100E-01	− 60.0000	− 3 1643	− 2.8616	− 60 0000	− 89.9999
.6200E-01	− 60.0000	− 3 1587	− 2 8668	− 60.0000	− 89.9999
.6300E-01	− 60.0000	− 3 1495	− 2 8755	− 60 0000	− 89 9999
6400E-01	− 60.0000	− 3.1364	− 2 8878	− 60 0000	− 89 9999
6500E-01	− 60.0000	− 3.1194	− 2.9039	− 60 0000	− 89 9999
.6600E-01	− 60.0000	− 3.0986	− 2 9238	− 60 0000	− 89.9999
6700E-01	− 60.0000	− 3.0737	− 2 9478	− 60 0000	− 89 9999
.6800E-01	− 60.0000	− 3.0449	− 2 9760	− 60.0000	− 89.9999
.6900E-01	− 60.0000	− 3.0120	− 3.0086	− 60 0000	− 89.9999
7000E-01	− 60.0000	− 2.9750	− 3 0459	− 60 0000	− 89 9999
.7100E-01	− 60.0000	− 2.9339	− 3 0881	− 60 0000	− 89 9999
.7200E-01	− 60.0000	− 2.8886	− 3 1356	− 60 0000	− 89 9999
7300E-01	− 60.0000	− 2 8390	− 3 1887	− 60.0000	− 89 9999
7400E-01	− 60.0000	− 2 7851	− 3 2478	− 60 0000	− 89 9999
.7500E-01	− 60.0000	− 2.7270	− 3 3134	− 60 0000	− 89.9999
.7600E-01	− 60 0000	− 2.6645	− 3 3860	− 60 0000	− 89 9999
.7700E-01	− 60.0000	− 2 5977	− 3 4662	− 60 0000	− 89 9999
.7800E-01	− 60 0000	− 2.5266	− 3 5547	− 60 0000	− 89.9999
.7900E-01	− 60.0000	− 2 4512	− 3 6522	− 60 0000	− 89.9999
.8000E-01	− 60 0000	− 2 3714	− 3 7597	− 60 0000	− 89 9999
8100E-01	− 60 0000	− 2 2874	− 3 8781	− 60 0000	− 89 9999
8200E-01	− 60 0000	− 2 1991	− 4 0086	− 60 0000	− 89 9999
8300E-01	− 60 0000	− 2 1068	− 4 1525	− 60 0000	− 89 9999
8400E-01	− 60 0000	− 2 0105	− 4 3114	− 60 0000	− 89 9999
8500E-01	− 60 0000	− 1 9103	− 4 4871	− 60 0000	− 89 9999
8600E-01	− 60 0000	− 1 8065	− 4 6815	− 60 0000	− 89 9999
8700E-01	− 60 0000	− 1 6992	− 4 8972	− 60 0000	− 89 9999
.8800E-01	− 60 0000	− 1 5889	− 5 1371	− 60 0000	− 89 9999
8900E-01	− 60 0000	− 1 4759	− 5 4045	− 60 0000	− 89 9999
9000E-01	− 60 0000	− 1 3605	− 5 7033	− 60 0000	− 89 9999

Figure 9.

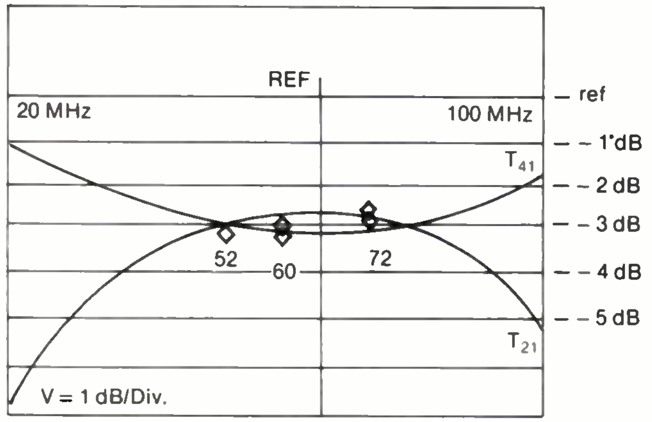


Figure 10: Measured Amplitude Responses.

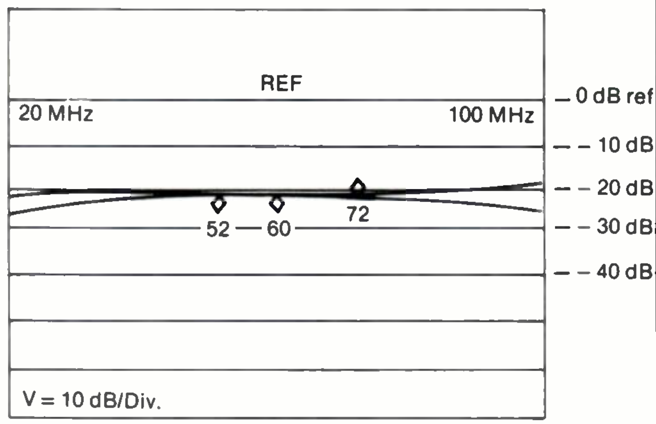


Figure 11: Return Loss & Isolation.

Conclusion

We have derived in detail the equations for the design parameters for a narrow band and a broadband quadrature hybrids. Since each component circuit in the broadband hybrid is a travelling wave circuit, a different approach of analysis using S-parameter matrices and transmission matrices has been used which arrives at identical results with that of the even-mode and odd-mode approach of analysis. Experimental results of a narrow band and a broadband hybrid show excellent agreement with the theory. □

References

1. J. Reed and G.J. Wheller, "A Method of Analysis of Symmetrical Four-Port Networks," *IRE Trans. On MTT.* Vol. 4, pp. 246-252, Oct. 1965.

2. R.E. Fisher, "Broad-Band Twisted-Wire Quadrature Hybrids," *IEEE Trans. On MTT.* vol. 21, pp. 355-357, May 1973.

Directional Couplers

Antonio N. Paolantonio, P.E.
Registered Electrical Engineer
Radio and Communications Consultant

The balanced, parallel-wire transmission line is an electric network which may be used throughout the frequency range from HF through X-Band. Typically, the separation between the parallel lines is large compared with the diameter of the wires. However, if the wires are mounted rather close to each other (for tight coupling), this transmission line may then be used as a directional coupler having broadband characteristics. This coupler has application as a hybrid, power splitter, power adder or a mixer.

Described herein is the procedure for designing directional couplers. In addition, a simplified, down-to-earth practical technique will be given for the design of a five-way RF power divider which utilizes this type of transmission-line directional coupler.

A directional coupler is a bilateral electrical network which may be used as a hybrid, power splitter, power adder or mixer. The design of such a device usually entails the application of somewhat cumbersome mathematical equations. In addition, "classical" mathematical models are not readily adaptable to the solution of coupler designs which require coupling factors below, say, 10 decibels. It would be nice, as well as convenient, if a procedure was available which would both simplify and speed the design process.

The purpose of this monogram is to answer such a need. Hence, a method is given herein which makes use of prepared design charts and eliminates a great deal of the complicated mathematical equations and the attendant tedious computations.

This method is proposed for the do-it-yourself enthusiast who, for either academic reasons or for practical purposes, wants a simplified design procedure.

Simplified Theory

Before commencing a design it would be useful to review some theory. A diagrammatic representation of a directional coupler is shown in Figure 1. This is a three-port device with an internal terminating resistance at the missing 'fourth port.' With RF power launched into Port A, the arrows indicate the direction of power flow in the feedline and out of Port C via the coupled line. The coupling factor for this network is defined as:

Coupling Factor $_{\text{(decibels)}}$

$$= 10 \log \left[\frac{P_A}{P_C} \right] \tag{1}$$

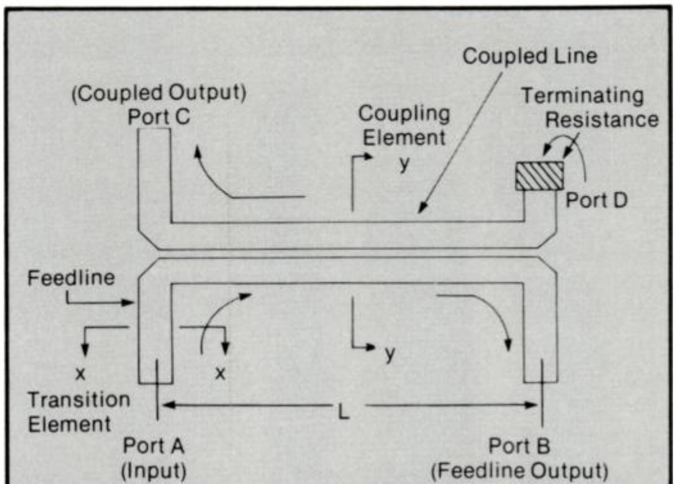


Figure 1. Directional Coupler with Internal Terminating Resistance.

where: P_A = Power into Port A
P_C = Power coupled to Port C

Another basic relation is the directivity, which is given by:

$$\text{Directivity}_{\text{(decibels)}} = 10 \log \left[\frac{P_A}{P_D}\right] \quad (2)$$

where: P_A = Power into Port A
P_D = Power coupled to the internal terminating resistor

This directivity parameter may also be measured. If Port A is properly terminated and power is launched into Port C the output power may be measured at Port B. Then,

$$\text{Directivity}_{\text{(dB)}} = 10 \log \left[\frac{P_C}{P_B}\right] \quad (3)$$

In this discussion, a parallel ground plane structure will be used for illustrative purposes. Sectional views for this type of construction are given in Figure 2, where the transition element, Figure 2(a), and the coupling elements, Figure 2(b), are identified, as they are in Figure 1. In order to achieve broadband operation (i.e., a full octave bandwidth), a quarter-wave coupled device is needed. Referring to Figure 1, the length of the coupled lines is given by:

$$L_{(inches)} = \frac{\lambda_0}{4} = \frac{2952}{\sqrt{f_1 f_2}} \quad (4)$$

where: L = Length of the coupled elements (inches)
λ_0 = Wavelength of the 'design center frequency'
f_1 = Frequency of the lower band limit (Megahertz)
f_2 = Frequency of the upper band limit (Megahertz)

The three-port directional coupler, Figure 1, may be converted to the familiar reflectometer, Figure 3, by simply removing the internal terminating resistor and adding a fourth port. Internal construction and theory of operation remain unchanged. If this device is designed for a coupling factor of 3 dB, it now becomes the well-known hybrid.

It is interesting to note that a hybrid is a special form of 3 dB coupler which is also a symmetrical, non-dissipative, bilateral 4-port network in which the following relations hold.

1. Power launched into *ANY* port splits evenly into each of the two adjacent output ports; i.e., referring to Figure 3, and assuming the input is at Port C:

$$P_A = P_D = \frac{P_C}{2} \quad \text{a 3 dB split} \quad (5)$$

2. "NO" power will appear at Port B (ideally). In

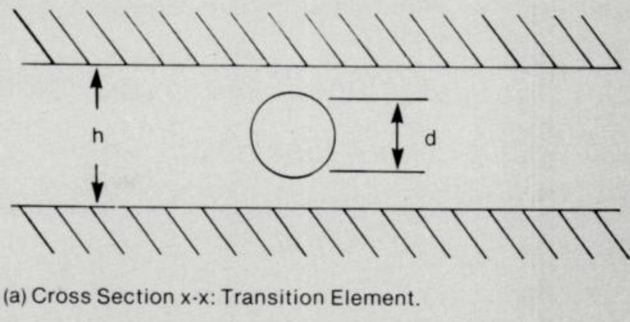


Figure 2. Section Views, showing transmission lines centered between parallel ground planes.

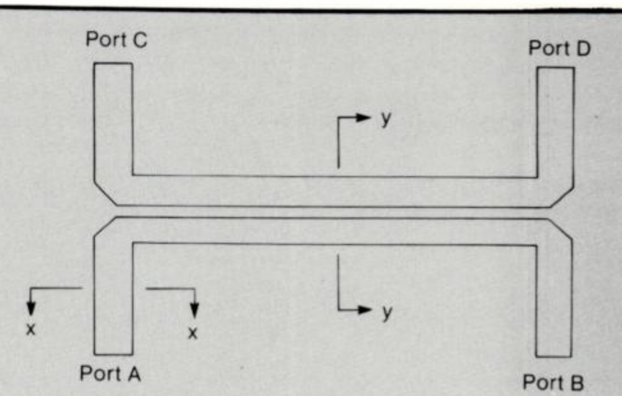


Figure 3. Typical Four-Port Directional Coupler used for Hybrids and Reflectometers.

practice, the isolation between Port B and Port C (opposing ports) is given by:

$$\text{Isolation}_{\text{(dB)}} = 10 \log \left(\frac{P_C}{P_B}\right) \quad (6)$$

In order to construct either a directional coupler, Figure 1, or a hybrid or reflectometer, Figure 3, it is necessary to determine the dimensions of the transition element, Figure 2(a), and the coupling elements, Figure 2(b). The equation for calculating the impedance of the transition element in the main feedline is:

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log \left(\frac{4h}{\pi d}\right) \quad (7)$$

where: Z_o = Characteristic impedance of the transition (ohms)
ϵ = Dielectric constant of the medium
h = Spacing between the two ground planes (inches)
d = Diameter of the transition element (inches)

In actual practice, the impedance, Z, is 'known.' Hence the dimensions of h and d must be determined.

Without attempting to suggest any theoretical 'proofs,' the dimensions of the coupling bars may be determined with the aid of Figures 4 and 5. In these curves, it is assumed that all four ports of the device are matched to 50-ohm impedances. As stated in the introduction, above, 'classical' mathematical models do not provide useful design results for this type of structure. The curves shown in Figures 4 and 5 were prepared with the aid of measured empirical data.

General Procedure

The general procedure for designing either a directional coupler, a hybrid or a reflectometer involves the following steps:

1. Select an appropriate ground plane spacing, equation (7).
2. Calculate the length of the coupling elements, equation (4).
3. Determine the dimensions of the transition elements; Figure (4) and (5) and,
4. 'Pick off' the cross-sectional dimensions of the coupling elements and the gap spacing.

Design Example

Now we are ready to jump into a full-blown design of a five-way RF power splitter. Suppose we start with some specifications for this device, as follows:

1. Frequency range: 1000 to 2000 MHz.
2. Input and Output Impedances: 50 ohms (all ports).
3. Power Split: Equal power split at all output ports.
4. Number of Output Ports: 5.

(Continued on page 45.)

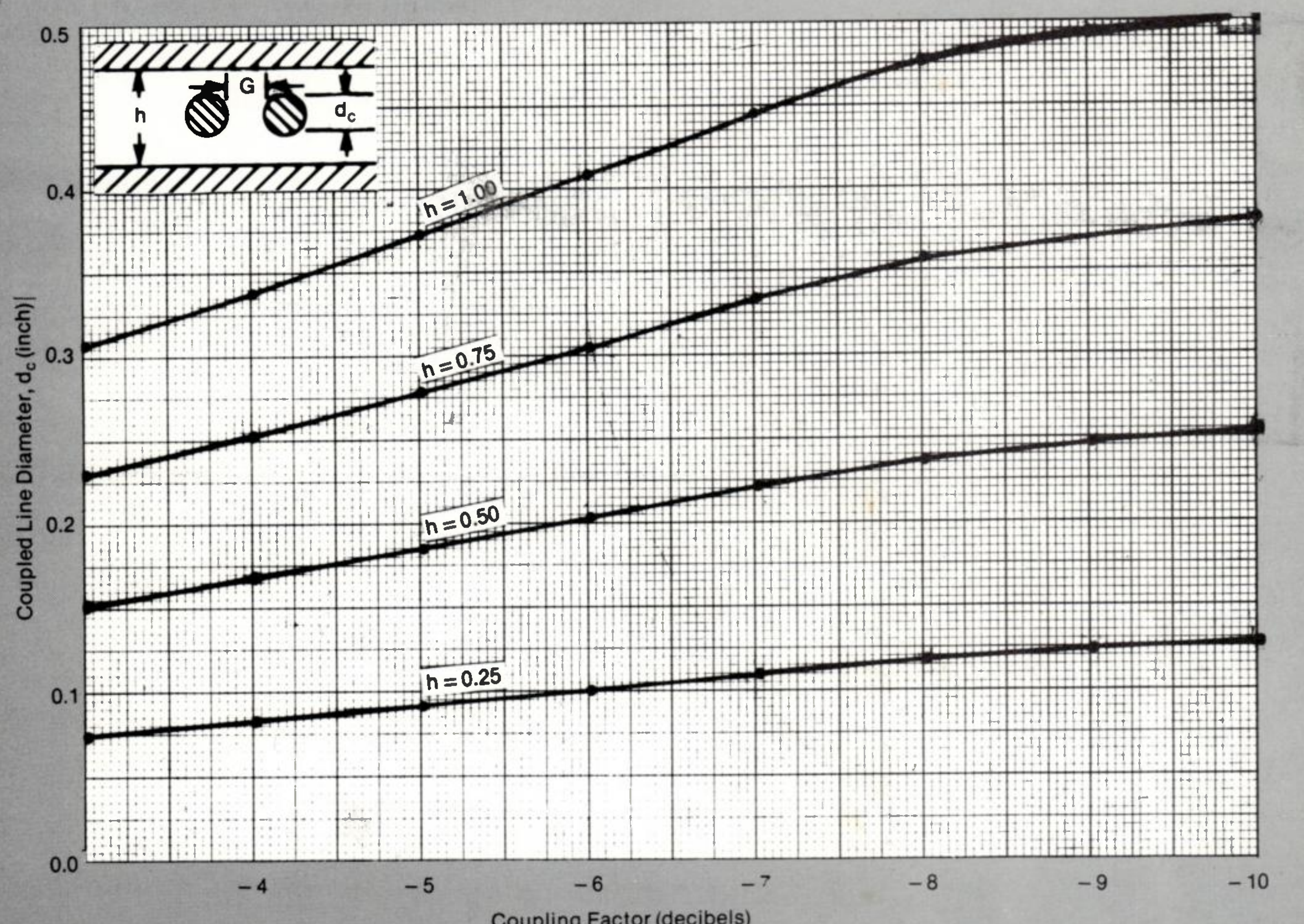


Figure 4. Parametric Curves of Coupled Line Diameter vs. Coupling Factor.

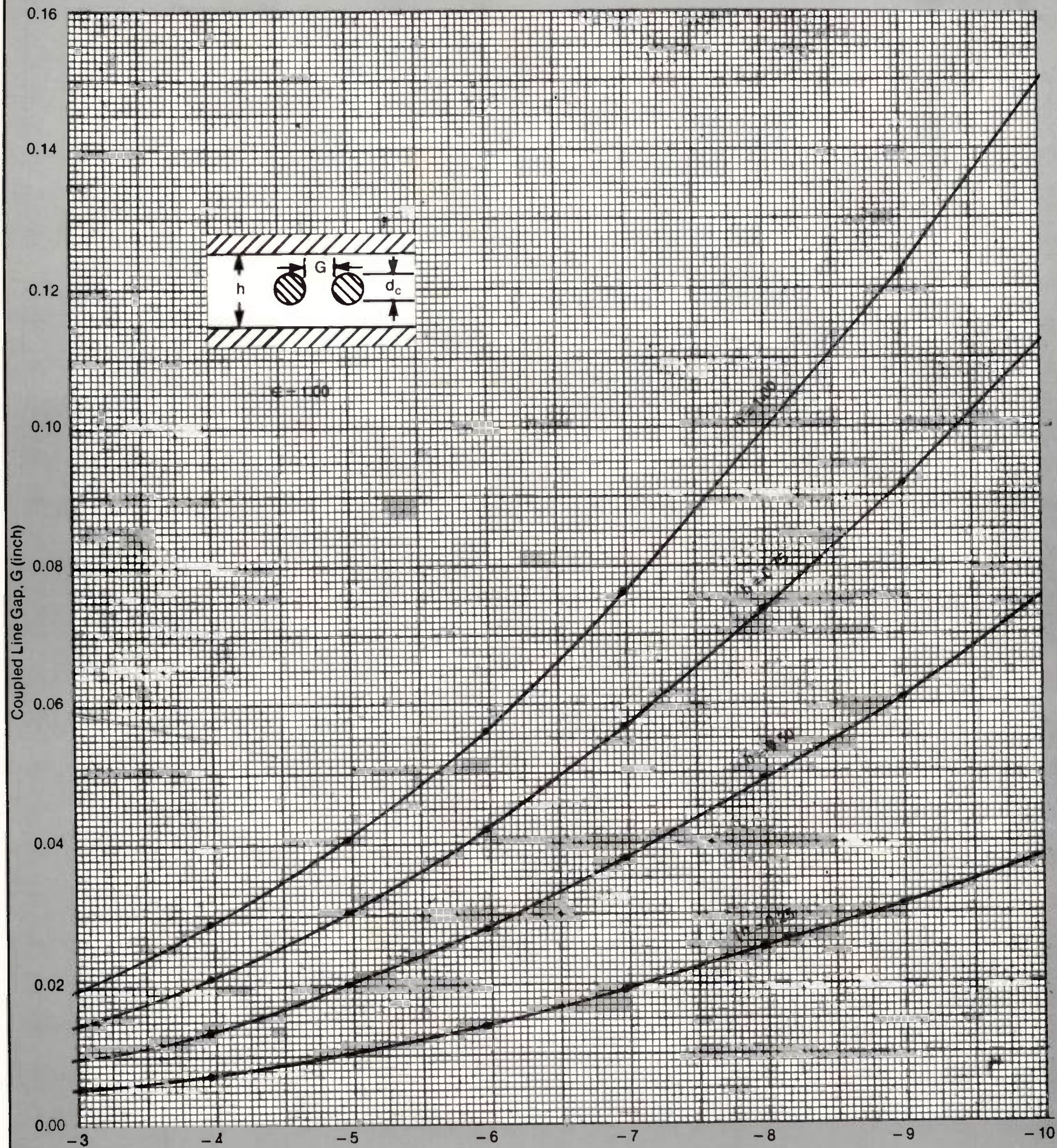


Figure 5. Parametric Curves of Coupled Line Gap vs. Coupling Factor.

A sketch of the five-way power splitter is shown in Figure 6.

Before the individual couplers may be designed, it is necessary to determine the coupling factor for each coupler along the main feedline. The power coupled to each of the five output ports is equal and given by the relation:

$$\frac{P_{(in)}}{N} = P_i(out) \qquad (8)$$

where N = total number of output ports

The coupling factor for each of the four directional couplers is

$$C_k = \frac{1}{(N + 1 - k)} \text{ for } k \leqslant (N - 1). \qquad (9)$$

Design Details

Step Number 1: Select appropriate ground plane spacing. Let us assume that we will use Type-N Input and Output Port connectors. These connectors are rugged and have good RF characteristics. This will also more easily permit the choice of a ground plane spacing of *0.375 inch* (connector 'fit' and feedline size easily machined on a bench lathe).

Step Number 2: Calculate the length of the coupling elements. Using equation (4):

$$L = \frac{2952}{\sqrt{(1000 \times 2000)}} = 2.09 \text{ inches} \qquad (4)$$

This dimension will be the same for all four directional couplers.

Step Number 3: Determine the dimensions of the transition elements. Using equation (7)

$$d = (4h/\pi)(10^{-Z_0\sqrt{\epsilon}/138}) = (4(.375)/3.14)(10^{-50\sqrt{1}/138}) = .207 \text{ in}$$

One detail which should not be forgotten is the use of dielectric supports along the main feedline. These will be made of teflon, which has a dielectric

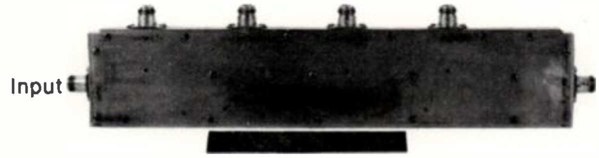


Figure 7. Completed Five-Way Power Splitter.

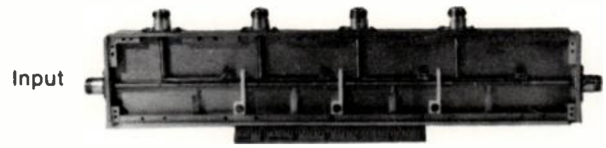


Figure 8. Power Splitter with cover removed.

constant of 2.1. Again using equation (7) we get d = .142 in. The transitions must, therefore, be undercut to this diameter for distance equal to the width of the support.

Step Number 4: 'Pick off' the cross-sectional dimensions of the coupling elements and the gap spacing. There are 4 directional couplers in this device (see Figure 8); hence, we take one at a time.

Coupler Number 1: First, use equation (9) to determine the coupling factor:

$$C_k(dB) = -10 \log (N + 1 - k) \qquad (10)$$

substituting numbers,

$$C_1 = -10 \log (5 + 1 - 1)(dB) = -7.0 \text{ dB}$$

The diameter of the coupler lines may be determined with the aid of Figure 4. Start on the abscissa at a coupling factor of −7.0 dB; go up to the point at which h = 0.375 inch; turn left to find d_{c_1}. *Result:* D_{C_1} = 0.166 inch. Now use Figure 5 to find the gap

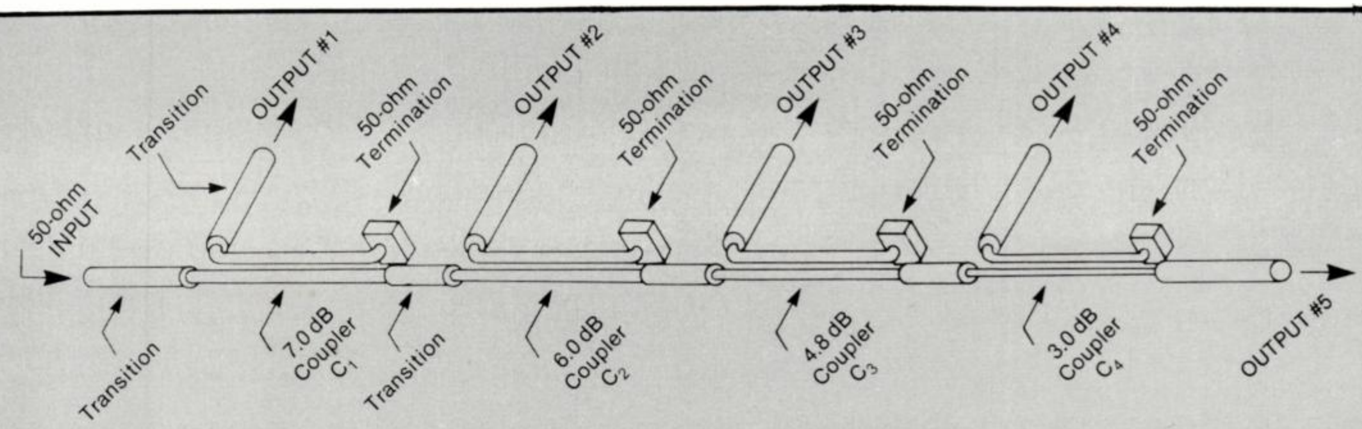


Figure 6. Diagrammatic View of Five-way RF Power Divider.

spacing. Enter abscissa where the coupling factor is equal to −7 dB; go up to h = 0.375; turn left to find G_1. *Result:* G_1 = 0.029 inch. The same procedure is followed for C_2, C_3 and C_4.

The results of the calculations and 'curve picking' are summarized in Table I.

Finished Product

This writer fabricated and assembled a five-way power splitter based upon the design described above. A photograph of this device is shown in Figure 7. Upon removing one of the cover plates the 'guts' of the power splitter can be examined, as shown in the photograph given in Figure 8. By referring to the drawing, shown in Figure 6, the internal parts of the power splitter may be identified.

The cover plates, ends, sides and termination mounting blocks are made of aluminum; and, all parts of the main feedline and all four directional couplers were machined from solid brass stock. The teflon supports for the feedline may readily be recognized; however, the four nylon 'tuning screws' (for adjusting the gaps in the directional couplers) may not be as clearly visible as would be desirable. Standard, silver-plated brass connectors were used for all six ports.

Measured Test Data

Theory, design calculations and, even, photographs of finished products do not, of themselves, yield convincing evidence of good working devices. The 'proof-of-the-pudding' exists in the measured performance data.

There are two factors which are of importance in evaluating the performance of this five-way RF power

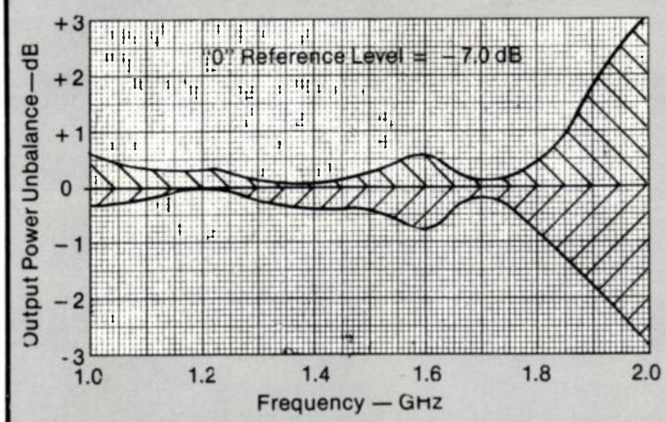


Figure 9. Curve of Output Power Split Unbalance vs. Frequency.

splitter, namely: (a) RF Power Balance (i.e., does the Input Power divide equally at the five Output Ports?; and, (b) What is the SWR at all Ports?

The measured data for the Coupling Factor as a function of Frequency is given in Figure 9. This curve actually shows the Output Power Split Unbalance. The nominal relative output power is −7.6 dB (referred to the Input Power), with a maximum output power unbalance of ±0.75 dB (at any port) over 80 percent of the 1000 to 2000 MHz band. Minimum directivity = 15 dB (any port).

A curve of the SWR as a function of frequency is given in Figure 10. The SWR for the Input Port is quite good — i.e., less than 1.5 over the entire frequency band. At the Output Ports, the SWR is not quite as good, approaching a maximum of 3.0 at the upper end of the band. For many applications, however, this represents performance almost equal

Table I. Summary of Dimensions for the Five-Way Power Splitter.

Name Of Element	Ground Plane Spacing h (inch)	Diameter of Transition Element d (inch)	Coupled Element Parameters: Length L (inch)	Coupling Factor C_k (dB)	Diameter d_c (inch	Gap G (inch)
Transition Element ∈ = 1.00	0.375	0.207	——	——	——	——
Transition Element (Teflon Supports) ∈ = 2.10	0.375	0.141	——	——	——	——
Coupler Number 1	0.375	0.207	2.09	−7.0	0.166	0.029
Coupler Number 2	0.375	0.207	2.09	−6.0	0.152	0.021
Coupler Number 3	0.375	0.207	2.09	−4.8	0.137	0.014
Coupler Number 4	0.375	0.207	2.09	−3.0	0.116	0.007

Notes:
1. f_1 = 1000 MHz and f_2 = 2000 MHz.
2. $Z_{in} = Z_{out}$ = 50 OHMS (all six ports).
3. RELATIVE OUTPUT POWER = −7.0 dB (equal power output at all five output ports).

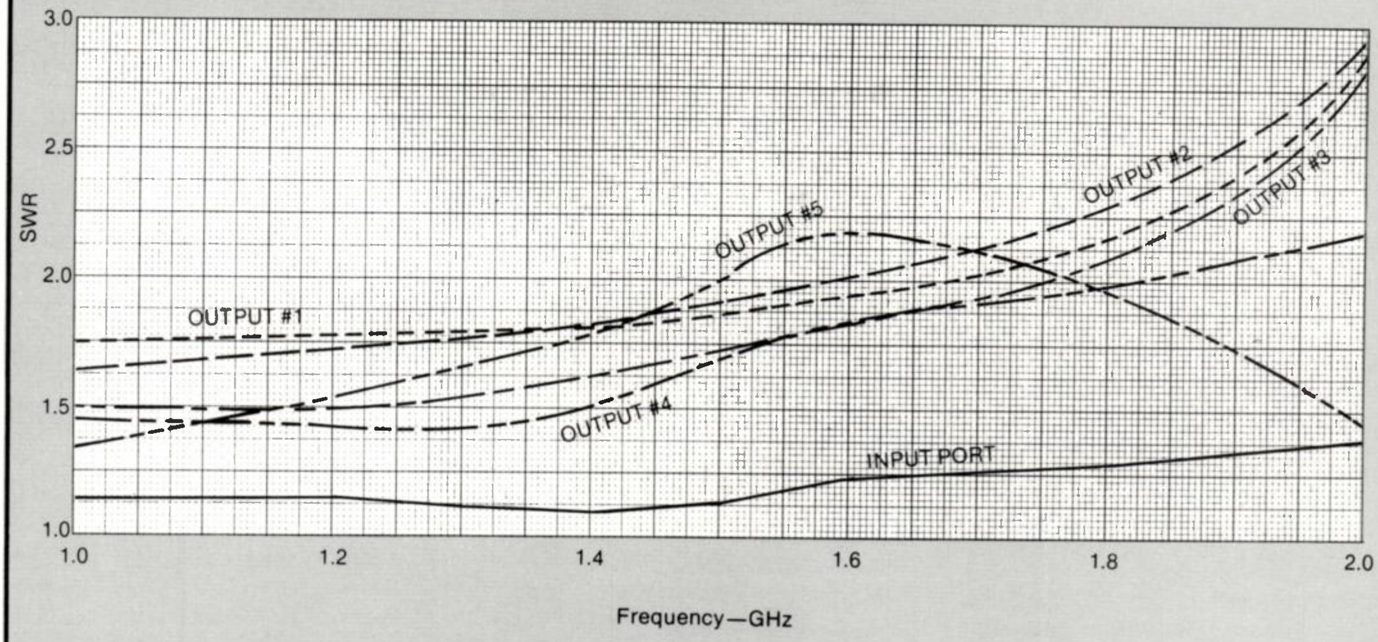


Figure 10. Curves of SWR vs. Frequency.

to custom designs of devices which operate over much smaller frequency bandwidths.

Conclusions

The design of a power splitter — has been given. This design procedure makes use of prepared design charts, coupled with a minimum of simple mathematical computations, to determine the physical parameters of the finished device. Photographs of the completed product, together with measured performance data, should assure the reader that he, too, may 'make his own.' All that is needed are some materials, a drill press (or hand drill), a bench lathe and willingness to do a little work with your hands. □

Advertiser Index

Anderson Laboratories, Inc. 19
Bright Electronics 59
Communications Specialists 2
Communications Transistor Corp . . . 13
Erik A. Lindgren & Associates 34
Hewlett-Packard Co. 11, 15
IIT Research Institute 57
JFD Electronics Comp 35
John fluke Mfg. Co. Inc 54-55
Mag Radiation Labs 34
Microwave Filter Co., Inc 49
Midcon '79 51
Mini Circuits 5
Opto Electronics 56
Plessey Semiconductors 27, 29, 31
Programmed Test Sources, Inc 10
Rockwell International 46
Solid State Microwave
Div. of Thomson-CSF 3
Solitron Devices, Inc 10
Standard Communications 23
Tech Systems Corp 14
Tektronix, Inc 6-7
Teledyne Relays 60
Texscan Corp 8
Wavetek Indiana, Inc 16
Weinschel Engineering 36-37

Automated Scalar Network Analyzer Covers 10 MHz to 18 GHz Range

The Wiltron 5610 Automated Scalar Network Analyzer establishes a new level of accuracy, simplicity and cost savings for microwave measurements over the 10 MHz to 18 GHz range. Under desktop computer control, the system makes automated measurements of transmission loss or gain, return loss (SWR), and absolute power. A preprogrammed cartridge accompanies each system. By entering a few simple inputs, the operator obtains hard-copy test data over a 66 dB (+16 dBm to −50 dBm) dynamic range. Special versions are available for operation up to 40 GHz.

The system introduces several recent advances:

- SWR measurements with better than 40 dB directivity from 10 MHz to 18 GHz.
- One sweep generator govering the 10 MHz to 18.5 GHz range.
- Digital memory techniques which substantially improve measurement accuracy.
- Calibration techniques which correct for variations caused by frequency response variations and test port mismatch errors.
- Refreshed display of memory-corrected measurement results.

As impressive as the system's performance and low cost ($45,215) is the simplicity with which measurements are made. Software is structured not only to make automated measurements with hard-copy output, but it also provides a CRT display of memory-corrected measurement results. This visual display allows adjustment or calibration of the device under test (DUT) and assures the operator that the test setup is functioning properly. Upon completion of the DUT adjustments, the push of a button initiates an automated data-taking sequence that produces accurate, easy-to-read hard-copy output in either tabular or graphical form (or both).

The exceptional return-loss accuracy of 5610 is made possible by a new GPC-7 SWR Autotester that has a directivity of 40 dB from 10 MHz to 18 GHz.

Accuracy is also improved by using memory to remove errors contributed by the measurement system. During calibration, system residuals that would otherwise introduce errors are stored in memory. Residual frequency-response characteristics are stored for later correction of transmission loss or gan data. The average of reflections from an open and short is computed and also stored for correction of return loss data. The resulting normalized data represents the true characteristic of the test device.

Tabulated data and/or curves of transmission loss or gain, power and return loss are prepared for any portion of the 10 MHz to 18 GHz range.

For more information, contact Walt Baxter, Wiltron Company, 825 East Middlefield Road, Mountain View, Calif. 94043. Tel: (415) 969-6500, TWX: 910-379-6578. Circle INFO/CARD #139.

LSI Chip Guaranteed For Life Used in New 99 Hundred Counter Series

A new lifetime guarantee was recently announced by Racal-Dana Instruments Inc. on the LSI chip utilized in the wide range of new 99 Hundred Series counters. An industry first, this new gurantee demonstrates the high reliability of the counters.

The guarantee, follows accelerated life tests on the dedicated bipolar LSI chip conducted by the manufacturers, Ferranti Electronics Ltd. Tests on LSI devices show a chip life in excess of 20 years under normal operating conditions.

"Our own experience, using 10,000 such chips over the last few years without a single failure recorded, confirms this high reliability," said Webb Scroggin, president of Racal-Dana. "World-wide feedback has indicated that customers value reliability. Our new 99 Hundred Series, with a range of 13 instruments, also incorporates a host of other improved features demanded by users. The result is the widest choice of counters available in the world from any single manufacturer."

All instruments in the 99 Hundred Series feature a two-year warranty on all other parts. They range from economy counters for general purpose use to highly sophisticated instruments designed to meet stringent military specifications. Five universal counters range from a basic 30 MHz version for general lab use to an all purpose 1100 MHz model for communications users.

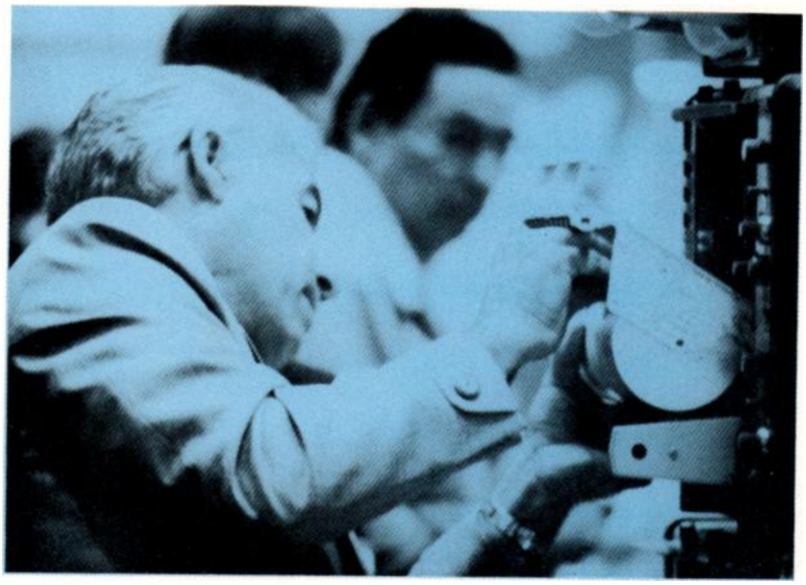
The eight frequency counters provide precision measurements up to 3 GHz in the HF/VHF and UHF bands. The new range provides complete capability for measuring frequency, period, time interval, ratio, time interval average and for totaling. There are models for bench, systems, and battery portable applications.

Every counter in the new series uses the custom designed bipolar chip manufactured to Racal-Dana's specifications using the Ferranti CDI (Collector Diffusion Isolation) process. The chip has the power of a microprocessor, but can operate at far greater speeds — even above 60 MHz.

Among the many new features available on various counters in the 99 Hundred Series are increased bandwidths, improved overload protection, automatic gain control, a new pulse mode, a range of excellent high stability time bases, and conformance to new international safety standards.

Contact Norbert Laengrich, Racal-Dana Instruments Inc., 18912 Von Karman Ave., Irvine, Calif. 92715. Circle INFO/CARD #138.

Midcon—the electronic touch in Chicago



Touch, study, and explore the products, systems and ideas that will influence all our lives in the 1980's. Midcon is really *four electronics shows* in one, offering *500 exhibits* in four distinct groupings:

1. Instrumentation and control systems
2. Mini and micro computers and EDP peripherals
3. Components, microelectronics, and fiber/electro-optic communications
4. Production, packaging, and test equipment

Plus, more than *120 Professional Program presentations* on technical and career topics to tell you what you need to know.

Take advantage of the special pre-Midcon registration offer and save $2 over regular admission. Fill out the registration coupon below and mail it with your check for $3, before October 15, to: Midcon, 999 North Sepulveda Boulevard, El Segundo, California 90245. We'll send you an embossed admission badge in plenty of time before Midcon. No fuss. No waiting in line. You'll spend *all* of your time at Midcon examining and listening. And touching.

Midcon is a hands-on experience. Get the feel of it.

O'Hare Exposition Center/Hyatt Regency O'Hare • Chicago • November 6-8, 1979

Midcon/79

PERSONS UNDER 18 YEARS OF AGE NOT ADMITTED

Midcon/79
CHICAGO
Electronic Show and Convention/Nov 6 8
O Hare Exposition Center Chicago

ENCLOSE $3 CHECK WITH THIS COUPON FOR PRE-REGISTRATION

Please PRINT as you want shown on badge.

Name

FIRST OR INITIALS LAST

Position

Telephone (OPTIONAL)

AREA CODE NUMBER

Company/Organization

Address: Bus or Home

City, State, Zip Code

STATE ZIP CODE

RF

CIRCLE ONE LETTER IN EACH BLOCK		
YOUR POSITION	A	Corporate/technical management
	B	Design/specifying engineer
	C	Engineering/manufacturing technician
	D	Engineering services
	E	Sales/Marketing
	F	Purchasing/Procurement
	G	Educator/Student
AREA OF MAIN PRODUCT INTEREST	H	Active components
	I	Passive components
	J	Hardware
	K	Tools & production equipment
	L	Computers
	M	Computer peripherals
	N	Control systems & components
	O	Electro-optical components
	P	Enclosures
	Q	Instruments indicating
	R	Instruments control
	S	Mechanical components
	T	Microwave components & systems
	U	Power sources
	V	Wire cable & connectors

Sponsored by Chicago and Dallas Sections, Region IV and V, IEEE; Mid-USA Council, Chicagoland and Southwest Chapters, ERA.

INFO/CARD 22

Subsystems

0.1 dB Step Attenuators

An improved, miniature 1 dB rotary step attenuator with 0.1 dB steps for those jobs requiring very precise attenuation has just been announced.

Telonic Berkeley model 8123 with 50 ohm impedance and model 8133 with 75 ohm impedance, have a frequency range from DC to 500 MHz, and ±0.02 dB accuracy. Contact the Marketing Department, Telonic Berkeley, 2825 Laguna Canyon Road, P.O. Box 277, Laguna Beach, Calif. 92652. Telephone (714) 494-9401, or toll free outside of California (800) 854-2436. INFO/CARD #80.

Phase Shifter

A new in-line phase shifter, which provides two inches of line length adjustment, has been introduced by Sage Laboratories, Inc.

The model FPS 2438 utilizes SMA connectors, but Sage can supply type N, TNC, BNC, SC, C or HN series connectors if the customer desires. Contact Tony Cieri, sales manager, Sage Laboratories, Inc., 3 Huron Dr., Natick, Mass. 01760, (617) 653-0844, TWX (710) 346-0390. INFO/CARD #78.

Variable Attenuator

Model 50R variable attenuators feature small size, wide frequency range, extremely flat frequency response and long life. Standard models 50R-002 and 50R-003 cover DC-1250 MHz with attenuation ranges of 0 to 130 in 10 dB steps and 0 to 100 in 10 dB steps respectively.

This series has been designed with flexibility built in and can be adapted to special attenuation ranges, special frequency ranges or mechanical configurations. Contact JFW Industries, Inc., P.O. Box 226, Beech Grove, Indiana 46107. INFO/CARD #77.

Tone Squelch

Selectone Corporation announces an entirely new series of field tunable CTCSS tone units for two-way radio tone squelch applications. Compact, solid-state design permits easy mounting in almost any portable, mobile, or base station radio. Frequency tuning from 67 to 250 Hz requires only a screwdriver and a frequency counter. Frequency stability and operating performance exceed all EIA specification, and there are no exotic hybrids or sole-source custom circuits to complicate servicing. Contact Selectone Corporation, 26203 Production Ave., Suite 6, Hayward, Calif. 94545, (415) 887-1950. INFO/CARD #75.

HF Multicoupler

The WJ-7431 HF Multicoupler, a signal distribution unit covering the 0.5 to 30 MHz frequency range, has been introduced by Watkins-Johnson Limited. The multicoupler accepts an incoming signal from an antenna system and splits it eight ways, with a nominal 4 dB gain from input to output.

The most significant feature of this new, all-solid-state design is the extremely low level of intermodulation products achieved by the use of a new amplifier incorporating VMOS field-effect transistors.

Complete details on the WJ-7431, including price and delivery, are available from Watkins-Johnson Limited, Shirley Avenue, Windsor, Berkshire, SL4 5JU, England. Telephone Windsor 69241. Telex 847578. INFO/CARD #82.

Narrow Band FM, IF IC

Micro Power has introduced a new product, the MPS5071 FM IF circuit that is designed to replace the Motorola MC3357. In addition to being pin-compatible with the MC3357, the MPS5071 has a higher gain and a better stability, over a wider temperature range. Applications for the new IC include: Voice Communication Scanning Receivers, Wireless Extension Telephones, Land Mobile Radios, Weather Radios, Pocket Pagers, and Ham Radios.

The MPS5071 achieves improved gain, temperature stability, and noise immunity by using a special advanced high-value monolithic thin film resistor process. The monolithic thin-film process keeps the gain variances, within each batch, to a minimum.

Contact Robert Sabo, Product Marketing Manager, (408) 247-5350, ext. 322, or Victor Herrick, Victor Advertising, 1565 Kooser Road, San Jose, Calif. 95118. (408) 267-7081. Circle INFO/CARD #137.

Variable Attenuators

Model 50R variable attenuators feature small size, wide frequency range, extremely flat frequency response, and long mechanical life. Standard models cover DC to 250 MHz with a range of 0 to 130 dB. This series has been designed with flexibility in mind and can easily be adapted to special attenuation ranges, special frequency ranges or mechanical requirements.

Contact JFW Industries, Inc., P.O. Box 226, Beech Grove, Indiana 46107. Circle INFO/CARD #136.

Instruments

Portable Oscilloscopes 100 MHz

The Tektronix 465B offers flexible vertical mode controls, simultaneous trigger view with zero delay, 2ns maximum magnified sweep speed, low noise IC technology for sharper trace, LED panel indicators 100 MHz at 5 mV/div, dual trace, delayed sweep, the DM44 differential time DMM option, and a sharp, bright 8 cm x 10 cm CRT.

The "push-push" vertical mode selection buttons on the 465B allow the operator to choose channel 1 and/or channel 2, differential, and A trigger view in any combination. The ability to look at both channels, their sun, and the external trigger simultaneously provides a complete picture of the measurement. Contact the marketing communications department, delivery station 76-260, Tektronix, Inc., P.O. Box 500, Beaverton, Ore. 97077. INFO/CARD #140.

Portable Digital Capacitance Meter

The Model 820 portable digital capacitance meter, which is now available from B&K-Precision Dynascan Corporation, is a compact instrument capable of measurement over the wide capacitance range of 0.1pF to 1 Farad. Accuracy greatly exceeds the tolerance of most capacitors. The unit features a bright 4 digit LED display for easy-reading in laboratories, product lines of field applications. For additional information, contact B&K Precision, Sales Department, 6460 West Cortland Street, Chicago, Ill. 60635. (312) 889-9C87. Please circle INFO/CARD #134.

Frequency Counters

An ovenized time base with 0.03 ppm stability (0-40°C) is being featured by Leader Instruments Corp. with its new 520 MHz and 250 MHz digital frequency counters.

The Model LDC-824S, 520 MHz counter is the latest addition to Leader's line of "Easy-Reader" digital units. This unit and its 250 MHz counterpart, the Model LDC-823S, feature a standard temperature stability of 1 ppm. The 0.03 ppm temperature stability rating is optional at $325 additional. Contact Mr. George Zachman, Marketing Manager, Leader Instruments Corp., 151 Dupont Street, Plainview, N.Y. 11803. (516) 822-9300. Please circle INFO/CARD #131.

Oscilloscope Probes

Leader has augmented its line of test instruments with four general application probes for use with oscilloscopes. They are: Model LP-16AX, Model LP-17Ax. For further details contact Mr. George Zachman, Leader Instruments Corp., 151 Dupont Street, Plainview, N.Y. 11803 (516) 822-9300. INFO/CARD #130.

Radiation Monitor

A new Electromagnetic Radiation Monitor which measures up to 10W/cm² for the "H" field and 2W/cm² for the "E" field is now available from The Narda Microwave Corporation, Plainview, New York. Narda's Model 8609 provides true readings of mean squared field strength in $(V/m)^2$ over the frequency range of 100 MHz to 3 GHz (E-field) or in $(A/m)^2$ between 10 and 300 MHz (H-field). Contact The Narda Microwave Corporation, 75 Commercial Street, Plainview, New York 11803; or call (516) 433-9000. INFO/CARD #128.

35 MHz Oscilloscope

The B&K-Precision product group of Dynascan Corporation has just announced the introduction of a 35 MHz dual-trace triggered scope. The 1535 is usable to an even greater bandwidth and is typically down only 3 dB at 40 MHz.

Many options for trigger source selection are featured on the 1535, including channels A or B or an external source. An alternate triggering mode can also be selected, which uses either channel A or channel B as a trigger source on alternate sweeps.

For more information write B&K-Precision, Sales Department, 6460 W. Cortland, Chicago, Ill. 60635. 312/889-9087. INFO/CARD #127.

Instruments Catalog

A number of new oscilloscopes, frequency counters and audio and video instruments, are among the products featured in a newly published, 60 page, full line catalog issued this week by Leader Instruments Corp. of Plainview, N.Y.

For further details contact Mr. George Zachmann, Marketing Manager, Leader Instruments Corp., 151 Dupont Street, Plainview, N.Y. 11803. (516) 822-9300. INFO/CARD #126.

Test Instruments Catalog

New products, a new look and new features highlight the largest catalog ever from Continental Specialties Corporation.

This new 32-page catalog, entitled "1979 CSC," features the company's signal generators, electronic test instruments, logic probes, frequency counters, solderless breadboards, digital troubleshooting instruments and IC test clips.

Copies of the new catalog are available through reader service inquiries, CSC distributors, or by contacting Continental Specialties Corporation toll-free 1-800-243-6077. INFO/CARD #125.

Test Instrument Catalog

A B&K-Precision industrial test instrument catalog, BK-180, featuring more than forty instruments, is now available from Dynascan Corporation. The 44-page catalog features a broad range of high-quality test instruments for engineering, production line, MRO and other industrial applications. Each catalog product description includes a detailed specification section and helpful applications information. Contact B&K-Precision, Dynascan Corporation, 6460 West Cortland Street, Chicago, Ill. 60635; (312) 889-9087. INFO/CARD #124.

Frequency Counters to 1.2 GHz

A new family of frequency counter/timers has been announced by Kontron Electronic, Inc. Designated the series 6000, the family consists of three instruments: Model 6001, a 110-MHz auto-ranging and programmable counter/timer; model 6002, a 600-MHz frequency counter; and model 6003, a universal counter/timer, which, with options can operate to 1.2 GHz.

Model 6001 is a general purpose instrument that offers all the measurement capabilities associated with counter/timers in its price range. The 6001 is unique, however, in that it offers true auto-ranging in all modes.

The model 6003 is an ultra-low cost, metal-cased, universal counter/timer that features a latched, 7-digit display and an accuracy not commonly found in its price range.

Rounding out Kontron's 6000 series are models 6002 and 6002-1, frequency counters of 600 MHz and 1.2 GHz respectively, each with a 10-MV input sensitivity at 50-ohm input. Contact Pease/Brough Associates, Inc. Public Relations, 151 University Avenue, Palo Alto, Calif. 94301. (415) 326-6141. INFO/CARD #122.

Packaging

Flexible Coaxial Cable

Crush-resistant, low-loss flexible coaxial cable assemblies for microwave and RF use are available from Adams-Russell Company, Inc., Antenna and Microwave Division, of Amesbury, Massachusetts. Adams-Russell FM20F Cable Assemblies provide a 48 dB/100' loss and 1.4 to 1 maximum VSWR at 18 GHz. Connectors include SMA, TR (TK-compatible), OSSM, TNC, ETNC (18 GHz TNC), and N. Contact Adams-Russell Company, Inc., Antenna and Microwave Division, David W. Ryan, Director of Marketing, Haverhill Road, Amesbury, Mass. 01913. (617) 665-2750. INFO/CARD #115.

Electrically-Conductive Bearings

A polyphenylene sulfide alloy with electrically-conductive properties has been introduced by the Tribol Industries Division of the Fluorocarbon Company. Designated Milkon 573, the material is designed to be utilized for the production of non-metallic, self-lubricating bearings for industries such as computer and instrumentation which are plagued with the problem of electro-static discharge. Contact Robert Alvarez; the Fluorocarbon Company; 3310 W. MacArthur Blvd.; Santa Ana; Calif. 92704; telephone (714) 754-1441. INFO/CARD #133.

Components

Environmental Connectors

SAE builds in high quality from the initial precision engineering, through meticulous assembly, to rigorous environmental testing under strict white room conditions.

Do you have a connector problem to challenge us with? Do you want more details on our fast growing line of environmental connectors?

Connector filters.
General application filters.
High performance filters.

SAE applications experts are as close as your phone to help you select a standard filter to meet your mechanical and electrical requirements. And they'll be glad to help you with special requirements to bring you up to date on newly designed SAE filters, too.

Call or write: SAE, Stanford Applied Engineering, 340 Martin Avenue, Santa Clara. Calif. 95050, (408) 243-9200. INFO/CARD #135.

Engineering said these new counters were the best values in the industry.

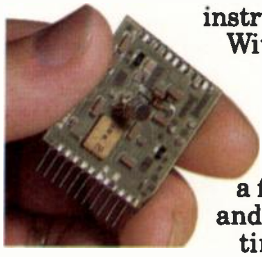
We said "prove it."

They did.

You'd expect our design engineers to be biased in favor of these new counters. But when we challenged them, they convinced us by going back to basics:

"Face it, in a counter, basically two elements determine whether or not you can get accurate repeatable readings: the input amplifier and the crystal oscillator.

In these new counters we've used new thick film hybrid circuits to control input amplifier circuit characteristics and reduce instrument costs.



With these new hybrids we get excellent sensitivity, a flat response and, at the same time, we have reduced the effect of parasitics.

As a side benefit, with hybrids the parts counts are less. This means there are fewer components to fail.

The new ovenized oscillator options were designed especially for these new counters. That means you get better temperature spec's, aging rates, and better short term stability than with either free air crystals or TCXO's.

As a result, measurement accuracy is improved and calibration cycles can be extended.

And because these low-power ovens can operate from batteries, there's no time wasted in the cal lab waiting for the oscillator to warm-up. More importantly, cal lab accuracy is preserved when you take the instrument back to the bench."

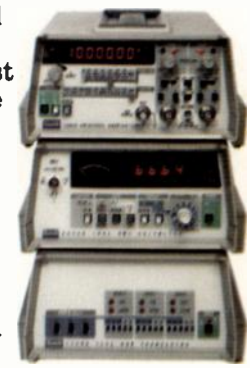
The engineers went on and on. For example, to reduce false triggering

due to noise, they incorporated stainless steel RFI shields. They're standard on all models.

We're convinced. You won't find a better value in counters.

IEEE-488 Compatible, of course

Fluke solved the problem of putting low-cost products on the IEEE-488 bus with the Model 1120A IEEE Translator. With it, you can use any of these new counters with a number of other Fluke instruments in compact, portable IEEE-488 mini-test systems.



It's Performance That Counts

For design engineering and R&D, the Models 7260A and 7261A are full-feature universal counter-timers. Both are 125 MHz models with options to 1300 MHz.**

		7250A	7260A	7261A
Frequency		80 MHz	125 MHz	125 MHz
Frequency Options			520 MHz	520 MHz
			1300 MHz**	1300 MHz**
Sensitivity (RMS)	50 MHz	10 mV	10 mV	10 mV
	100 MHz	15mV(80MHz)	15 mV	15 mV
	125 MHz	—	35 mV	35 mV
Period		×	×	×
Period Average		×	×	×
Time Interval		100 ns	100 ns	10 ns
Time Interval Average			×	×
Phase Modulated Time Base Option				×
Ratio, Totalize, CPM		×	×	×
Autoranging		×	×	×
RFI Shield		×	×	×
Oven Time Base Options		×	×	×
IEEE Option		×	×	×
Price		$675*	$850*	$995*

*U.S. prices only.
** 1300 MHz available soon.

With the 7261A you get 10 ns resolution and a phase modulated timebase option. This option eliminates time interval averaging errors caused by input signal/timebase phase coherence.

The 7250A is an autoranging 80 MHz counter. It's a true price/performance leader for bench and production applications.

Compare their performance features for yourself.

In the U.S. CALL TOLL FREE (800) 426-0361. (For residents of Alaska, Hawaii, and Washington, the number is (206) 774-2481.)

In Europe, contact:
Fluke (Holland) B.V.,
P.O. Box 5053,
5004 EB Tilburg,
The Netherlands,
Telephone (013) 673973.
Telex: 52237.

FLUKE®

RFD 9/79

John Fluke Mfg. Co., Inc.
P.O. Box 43210 M/S 2B
Mountlake Terrace, WA 98043

Yes, I'd like some proof too.

_____ **Please arrange a demo.**
_____ **Send 7260A/7261A Information.**
_____ **Send 7250A Information.**
_____ **Send 1120A Translator Information.**

Name ____________________
Title ____________________
Company ____________________ Mail Stop ________
Address ____________________
City ____________________ State ________ Zip ________
Phone ( ) ____________________

For Technical Data Circle INFO/CARD 23

Components Con't.

Toroidal Inductors

A new design of toroidal inductors has been announced by Delevan Division of American Precision Industries Inc. Identified as series 2020, these new modular toroidal inductors are available in 25 sizes in an overall inductance range from .10 to 10.0 micro-henries. Contact Delevan Division of American Precision Industries Inc., 270 Quaker Road, East Aurora, New York 14052 or call (716) 652-3600. INFO/CARD #49.

Precision Resistors

Julie Research Laboratories announces availability of their new Type PC Oil-Filled, Miniature, Low-Profile, Precision Resistors for Printed-Circuit Applications. Terminal pin configurations fit the standard 0.1" grid, for direct automatic or manual insertion into printed circuit boards. Contact Julie Research Laboratories, Inc., 211 West 61st Street, New York, N.Y. 10023. Attn: Mrs. Ora Julie, General Manager. Telephone: (212) 245-2727. INFO/CARD #48.

Transistors for 2 GHz Designs

Two new small signal NPN bipolar transistors, both using a rugged 70-mil diameter alumina package have been introduced by Hewlett-Packard.

Optimized for designs at 2 GHz, the HXTR-2102 is a general purpose transistor with minimum tuned gain (guaranteed) of 13 dB. In addition, its typical linear output power of 100 mW (20 dBm) makes this versatile transistor suitable for use in driver or output amplifier steps.

The economical HXTR-6106 is a low noise device with a guaranteed noise figure of 2.7 dB maximum at 2 GHz. With an associated gain of 11.5 dB typical at 2 GHz and characterization from 500 MHz to 6 GHz.

Contact Inquiries Manager, Hewlett-Packard Company, 1507 Page Mill Road, Palo Alto, Calif. 94304. Circle INFO/CARD #58.

Carbon Film Resistors

Stackpole's Electronic Components Division, in conjunction with Sprung/Nussbaum, is featuring its domestically-manufactured carbon film resistors. The 1/4-watt units are available in standard values from 4.7 ohms to 4.7 megohms with tolerances of ±5 percent. Contact James Sennett, Stackpole Carbon Company, Kane, Pa. 16735. INFO/CARD #54.