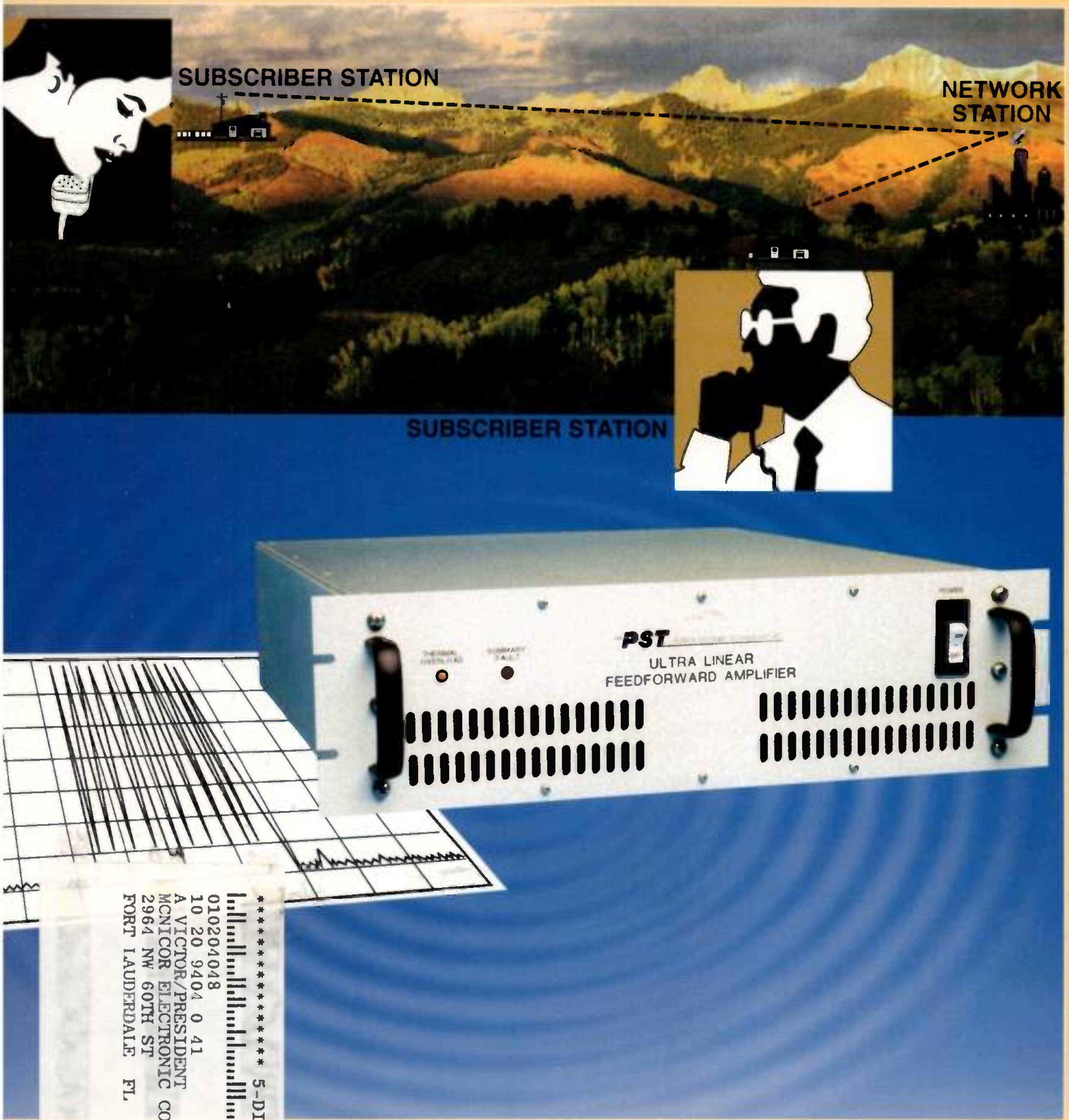
WIRELESS 15 YRS LEADERSHIP

RF design™

engineering principles and practices

July 1994



***************** 5-DIGIT 33309
0102040048 00057
10 20 9404 0 41
A VICTOR/PRESIDENT
MCNICOR ELECTRONIC CORP
2964 NW 60TH ST
FORT LAUDERDALE FL 33309-1735

Cover Story

Power Amplifier Cuts Distortion

Featured Technology

Open-Loop Digital Modulation

A Fast Envelope Detector

New from Loral Microwave-FSI

A COMPLETE LINE OF HIGH PERFORMANCE CER-MET™ DIODES.

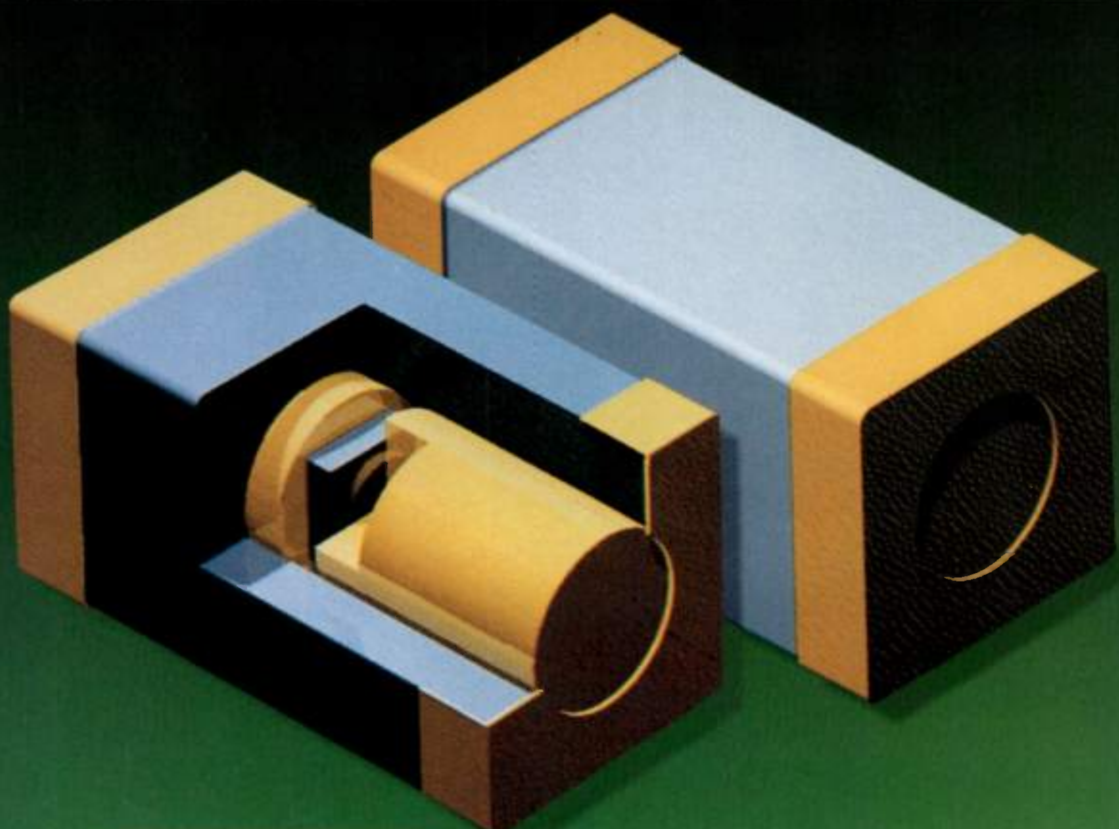
- Surface mount
- High volume manufacturing
- Hermetically sealed
- Full face chip bond
- Double terminal heatsinks

Our PIN diodes are now available with ceramic package/metal electrode technology, designed to meet MIL-STD 19500. High performance specifications include long lifetime, low series resistance, plus reverse voltage rating to 1000 volts.

CER-MET units are readily available in volume for both military and commercial applications. Quantities are already in stock for immediate shipment.

For more information, or to request samples, call or fax, Loral Microwave-FSI, 16 Maple Road, Chelmsford, MA 01824. Tel: (508) 256-4113. Fax: (508) 937-3748.

Part No.	Suggested Case Style	Reverse Voltage Rating (Vr) – min	Total Capacitance (pF) – max F=1MHz Vr=50v		Series Resistance (RS)–ohms F=100 MHz		Carrier Lifetime (Tl) µsec (typ)	Thermal Resistance (Θj)
		Ir< 10µA	M1	M2	If=100mA (max)	If=200mA (typ)	If=10mA	C/W
SM0502	M1 or M2	500	0.45	0.50	0.70	0.55	1.00	35
SM0504	M1 or M2	500	0.55	0.60	0.60	0.45	1.50	20
SM0508	M1 or M2	500	0.85	0.95	0.40	0.25	2.00	15
SM0509	M1 or M2	500	1.00	1.25	0.35	0.20	2.50	12
SM0511	M1 or M2	500	1.30	1.45	0.30	0.15	3.00	9
SM0512	M2	500	N/A	1.50	0.25	0.12	3.50	7
SM0812	M2	800	N/A	1.30	0.40	0.25	4.00	7
SM1001	M2	1000	N/A	1.30	0.35	0.20	4.50	7



Case style	M1 (inches)		M2 (inches)	
Dimension	Min	Max	Min	Max
A	0.08	0.10	0.10	0.12
B	0.12	0.14	0.19	0.21
C	0.01	0.03	0.01	0.03

LORAL
Microwave - FSI

INFO/CARD 1

All the RF pieces to complete your North American Digital Cellular design.

Have you been searching for the right RF ICs to complete a low power digital cellular design? If so, the Philips IS-54 RF Transceiver Chip Set for the North American Digital Cellular system (AMPS/TDMA) is a perfect fit. This highly integrated RF solution consists of four remarkable ICs:

The SA601 RF Front End integrates a high performance LNA and mixer to convert the incoming RF signal to the first IF.

The SA637 Digital IF Receiver down-converts the first IF to a frequency suitable for analog and digital demodulation.

The SA7025 Fractional-N Synthesizer locks both first and second LOs and meets the fast IS-54 switching requirements.

The SA900 I/Q Transmit Modulator completes the chip set with transmit paths for both digital and analog signals.

These ICs are designed to work together, so fewer external components are required. The entire receiver runs at 3V and each IC has a power down mode to extend battery life. Plus our small SSOP-20 and TQFP-48 packages help make your products smaller and lighter.

To solve your next design puzzle, contact Philips Semiconductors for information on our IS-54 RF Transceiver Chip Set.

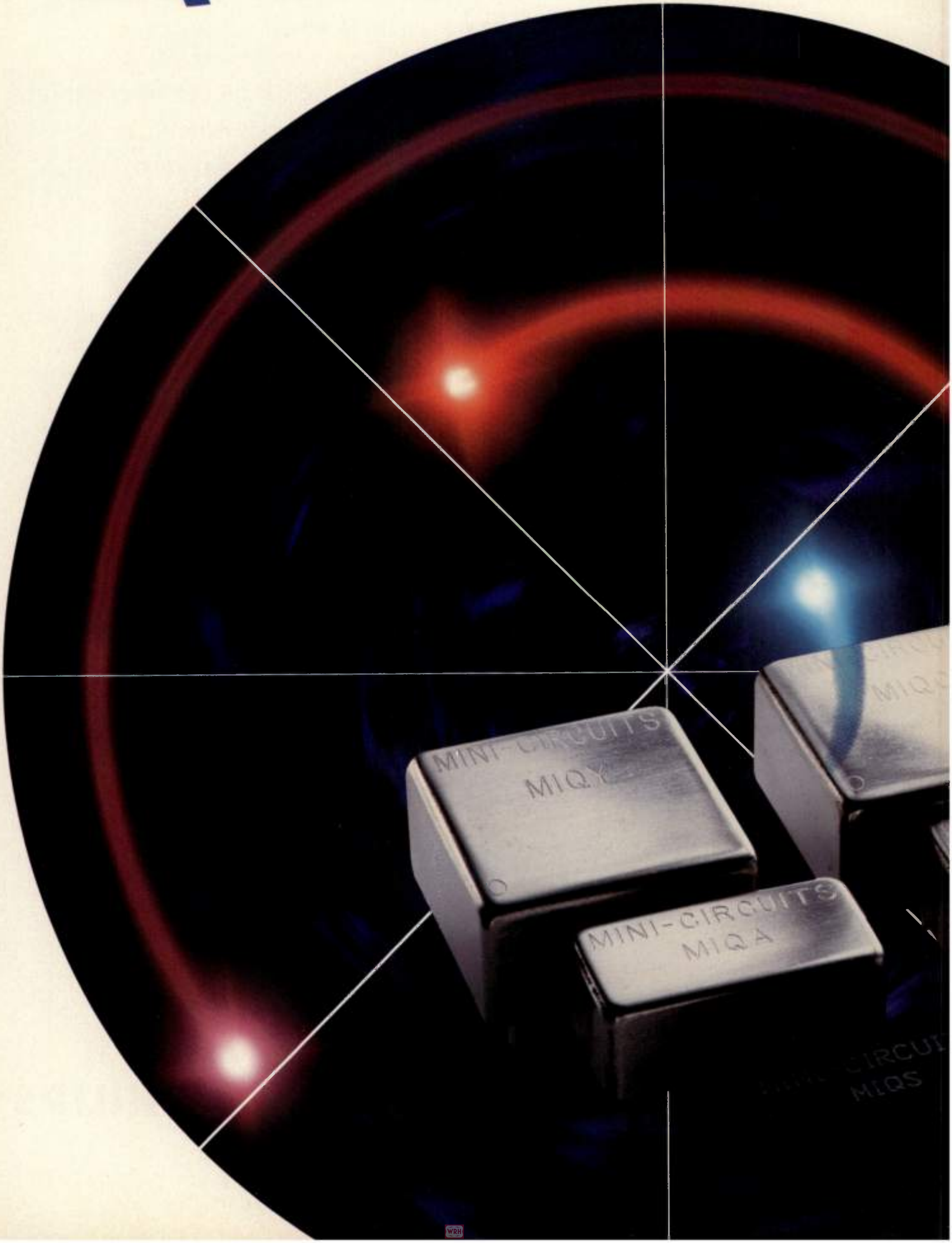
1-800-447-1500 ext. 1083RF

© Philips Electronics North America Corporation, 1994

Philips Semiconductors

PHILIPS

I&Q MODULATORS



DEMODULATORS

1.15MHz to 1880MHz from $19.95

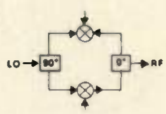
I&Q Modulators and Demodulators...another smart offering from Mini-Circuits that's pushing industry standards to new heights (and prices to new lows)!

Infuse your cellular, radar and communication system project with the powerful new I&Q Modulator and Demodulator, surface mount and plug-in units. Units so reliable, the specified statistical data on performance holds up with rock-solid repeatability unit-to-unit.

For high speed assembly operations, I&Q Modulators and Demodulators are available in tape and reel format, so you can bank on consistent assembly performance for production efficiency time after time...and with prices starting at just $19.95, these powerful and compact units truly are the next generation of value on the market today.

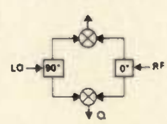
So, call your Mini-Circuits distribution center at a number listed below for guaranteed one week shipment or, turn to our applications department with your special specs for custom units at catalogue prices.

We're redefining what VALUE is all about!



I/Q MODULATORS

MODEL NO	FREQ (MHz) f_L	f_U	CONV LOSS (dB) x	σ	CARRIER REJ (dBc) Typ	SIDEBAND REJ (dBc) Typ	HARM SUPPRESS (dBc) Typ 3xI/Q	5xI/Q	PRICE $ QTY (1-9)
MIQA-10M	9	11	5.8	0.20	41	40	58	68	49.95
MIQA-21M	20	23	6.2	0.14	50	40	48	65	39.95
MIQA-70M	66	73	6.2	0.10	38	38	48	58	39.95
MIQA-70ML	66	73	5.7	0.10	38	38	48	58	49.95
MIQA-91M	86	95	5.5	0.10	38	38	48	58	49.95
MIQA-100M	95	105	5.5	0.10	38	38	48	58	49.95
MIQA-108M	103	113	5.5	0.10	38	38	48	58	49.95
MIQA-195M	185	205	5.6	0.10	38	38	48	58	49.95
MIQC-88M	52	88	5.7	0.10	41	34	52	66	49.95
MIQC-176M	104	176	5.5	0.10	38	36	47	70	54.95
MIQC-895M	868	895	8.0	0.10	40	40	52	58	99.95
MIQC-1785M	1710	1785	9.0	0.30	35	35	40	65	99.95
MIQC-1880M	1805	1880	9.0	0.30	35	35	40	65	99.95
☐ MIQY-70M	67	73	5.8	0.20	40	36	47	60	19.95
☐ MIQY-140M	137	143	5.8	0.20	34	36	45	60	19.95



I/Q DEMODULATORS

MODEL NO	FREQ (MHz) f_L	f_U	CONV LOSS (dB) x	σ	AMP UNBAL (dB) Typ	PHASE UNBAL (Deg.) Typ	HARM SUPPRESS (dBc) Typ 3xI/Q	5xI/Q	PRICE $ QTY (1-9)
MIQA-10D	9	11	6.0	0.10	0.15	1.0	50	65	49.95
MIQA-21D	20	23	6.1	0.15	0.15	0.7	64	67	49.95
MIQC-895D	868	895	8.0	0.20	0.15	1.5	40	55	99.95
☐ MIQY-1.25D	1.15	1.35	5.0	0.10	0.15	1.0	59	67	29.95
☐ MIQY-70D	67	73	5.5	0.25	0.10	0.5	52	66	19.95
☐ MIQY-140D	137	143	5.5	0.25	0.10	0.5	47	70	19.95

☐ NON-HERMETICALLY SEALED
MIQA case .4 x .8 x .4 in.
MIQY case .8 x .8 x .4 in.
MIQC case .8 x .8 x .4 in.
MIQS case .8 x .4 x .2 in.

All Models Available in Surface Mount Package.

Consult Factory for Details.

Mini-Circuits®

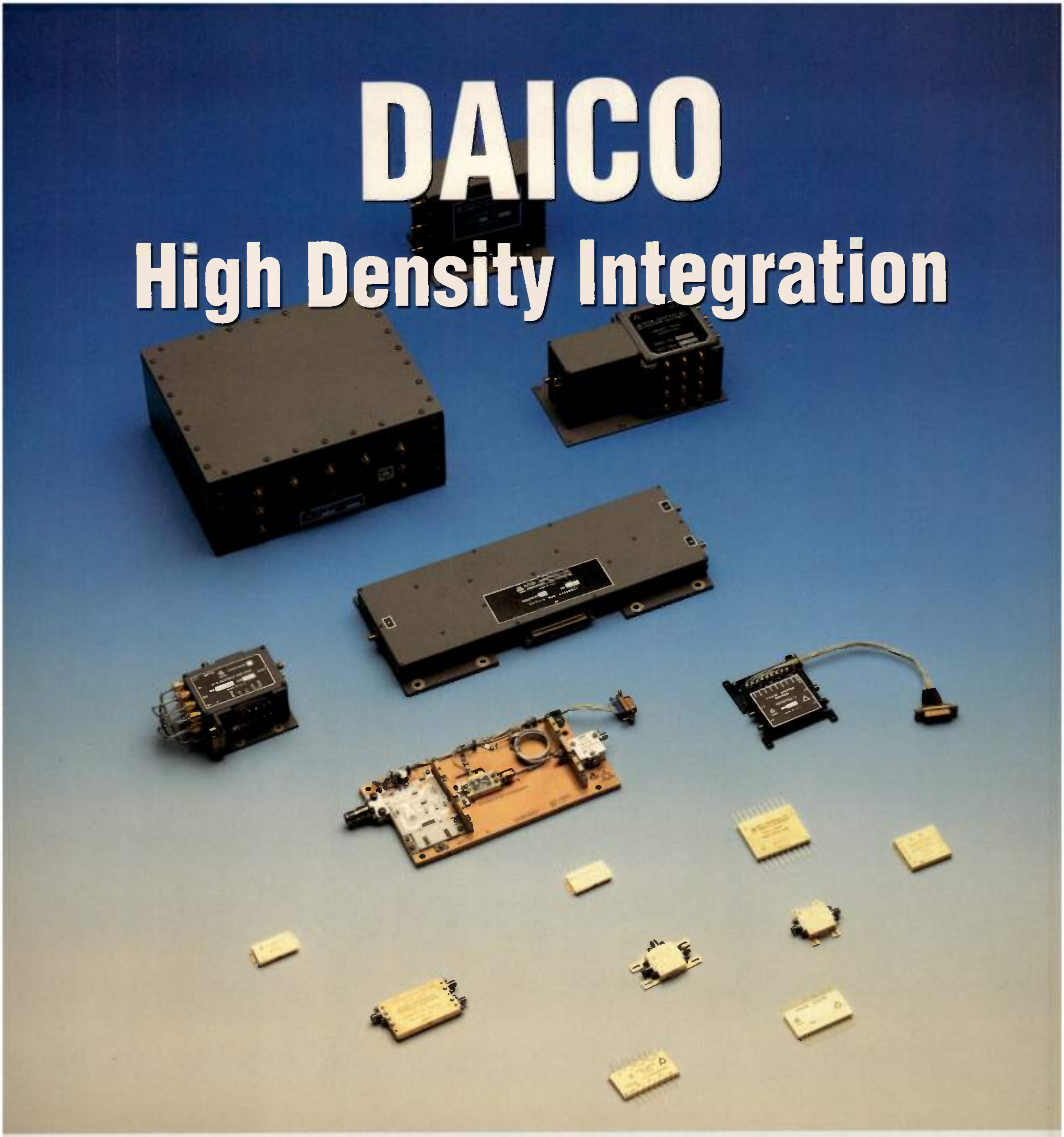
P O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661

For detailed specs on all Mini-Circuits products refer to • THOMAS REGISTER Vol. 23 • MICROWAVES PRODUCT DIRECTORY • EEM • MINI-CIRCUITS' 740-pg HANDBOOK

CUSTOM PRODUCT NEEDS... ***Let Our Experience Work For You.***

INFO/CARD 2

F 156 Rev B



Daico's standard IF/RF and Microwave products include switches from single-throw to forty-throw with insertion losses as low as 0.2dB and isolations as high as 120dB at 5GHz, digitally controlled attentuators with up to 8 bits, phase shifters and voltage variable attenuators. These products serve as an impressive base for higher levels of integration.

By using thin film hybrid technology, GaAs MMICs and diodes (Schottky or PIN) together with mixers, limiters, couplers and power dividers, as well as CMOS, TTL or ECL logic devices, we are able to offer increased reliability and substantially reduced size. High Density Integration also offers significant cost reduction when compared to using conventional discrete packaged devices.

Please call us, we welcome the opportunity to discuss your particular application.

DAICO INDUSTRIES, INC.
2453 E. Del Amo Blvd., Rancho Dominguez, CA 90220
Telephone 310/631-1143 • FAX 310/631-8078

WE ACCEPT VISA AND MASTERCARD

INFO/CARD 3

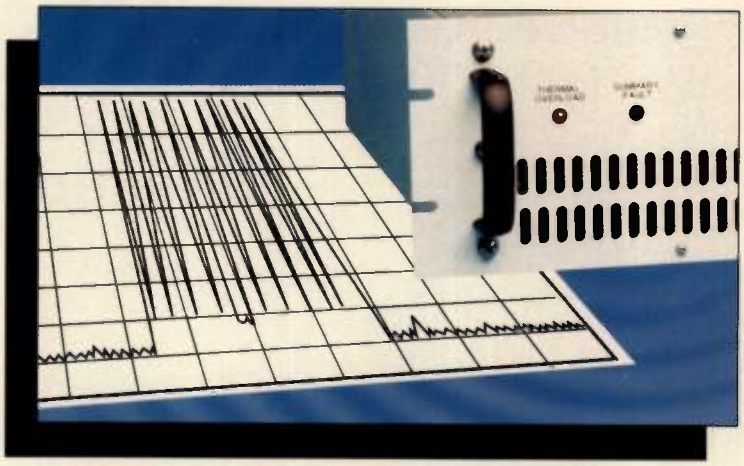
SWITCHES ATTENUATORS PHASE SHIFTERS MMICS BIT DETECTORS COUPLERS MODULATORS AMPLIFIERS

RF design

contents

July 1994

featured technology



departments

cover story

tutorial

RF DESIGN (ISSN:0163-321X USPS: 453-490) is published monthly and semi-monthly in August. July 1994. Vol.17, No. 7. *RF Design* is a registered trademark of Argus Inc. Copyright 1994 by Argus Business, a division of Argus Inc., 6151 Powers Ferry Road, NW, Atlanta, GA 30339, (404) 955-2500. Editorial and advertising offices at 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111, (303) 220-0600. Printed in USA. Second-Class Postage paid at Atlanta, GA and at additional mailing offices. Subscription office: *RF Design*, P.O. Box 1077, Skokie, IL 60076. Subscriptions are $39 per year ($67 for two years) in the United States; $50 (surface mail) or $99 (Air Mail) per year for foreign countries. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $8.00 each (in the U.S.). This publication is available on microfilm/fiche from University Microfilms International, 300 Zeeb Road, Ann Arbor, MI 48106 USA (313) 761-4700. Authorization to photocopy items for internal, personal or educational classroom use is granted by *RF Design*, provided the appropriate fee is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 and provided the number of copies is fewer than 100. For authorization, contact the Copyright Clearance Center at (508) 750-8400. The Transactional Reporting Service fee code is: 0163-321X/94/$3.00. For those seeking 100 or more more copies, please contact the magazine at (303) 220-0600.

SUBSCRIPTION INQUIRIES: (708) 647-0756.

WERLATONE
DECADES AHEAD

HIGH POWER
DUAL DIRECTIONAL
COUPLERS

MULTI-OCTAVE
BANDWIDTH

TYPICAL
SPECIFICATIONS

FREQ. RANGE .... 80-1000 MHz
INS. LOSS .... 0.1 db
FLATNESS ....+/-0.5db
DIRECTIVITY .... 20 db min.
VSWR ML .... 1.2:1max.

MODEL C3240
COUPLING .... 40db nom.
POWER CW .... 200 watts

MODEL C3271
COUPLING .... 50 db nom.
POWER CW ....1500 watts

BROADBAND HIGH POWER
• DIRECTIONAL COUPLERS
• POWER COMBINERS
• HYBRID JUNCTIONS

P.O. BOX 47 • ROUTE 22 • BREWSTER, N.Y. 10509
914-279-6187 • FAX 914-279-7404

INFO/CARD 4

RF editorial

With New Technology, There's Always A Shakeout

By Gary A. Breed
Editor

One of the most fascinating aspects of the so-called "wireless revolution" is the wonderfully creative proliferation of new ideas. Engineering and marketing staffs at RF manufacturing companies have come up with some outstanding capabilities, and their customers (and potential customers) are thinking up new ways that RF linked communications can help them be more cost-effective in their business operations.

New players are getting involved, too. Component manufacturers that did little business in the realm of RF applications are investing millions of dollars to develop RF products. Computer and data communications companies are adding RF capabilities in addition to their twisted-pair or coaxial cable networking expertise. Customers are coming from new directions, too, mainly from the world of computers because the bulk of new ideas are directed toward data transmission.

With many new ideas, the potential market for RF products has grown dramatically. The possibility of a huge boom, similar to the personal computer, seems apparent to most observers (including me). But there is one nagging thought that keeps coming back...

How many of these new RF applications will become successful products?

Debate rages over regulations, standards, and frequency allocations. While resolution of these matters is certainly essential to opening new markets, the ultimate judgement comes from the customers — the "marketplace."

As new RF products go into large-scale production, a shakeout is inevitable. It happens whenever new technology is brought to market. It may be slow, it may be rapid, but it *will* happen. Millions will be made and lost as products are accepted or ignored.

We can look at the personal computer industry for proof. There is no more S-100 bus and no CP/M operating system. Even mainframes and their smaller mini-computer counterparts have been replaced by PCs for many applications.

We have seen similar development within our own industry. GaAs technology, SAW devices and power transistors have all seen huge successes and agonizing failures as the market decided which approaches and which applications needed these products.

Which RF products are going to be as successful as the DOS-based PC? Which will rise and fall like the Commodore 64? Which will die on the loading docks before they even get shipped?

The mystery is part of the fun! It's sad to see innovative companies fail because of a fickle market, or simply because they were a little too early or too late with their product. But, hey, that's how business works.

On the other hand, we are occasionally astounded by the success of a little company that was "in the right place at the right time." It's also fun to watch a product take off when market research never predicted that kind of success.

We will define the RF boom by the success of products that are accepted by customers and generate profits for their manufacturers. But, we need to remember that many innovations, companies, and people will be counted as failures, too. Business is a battleground, and battles always have casualties.

WHAT YOU'VE BEEN WAITING FOR!

Technology of the Future
Available Today

250 Watts CW
.01 - 220 MHz

WORLD'S FIRST

14 Octave 250W
SOLID-STATE RF Amplifier

MODEL 122FC

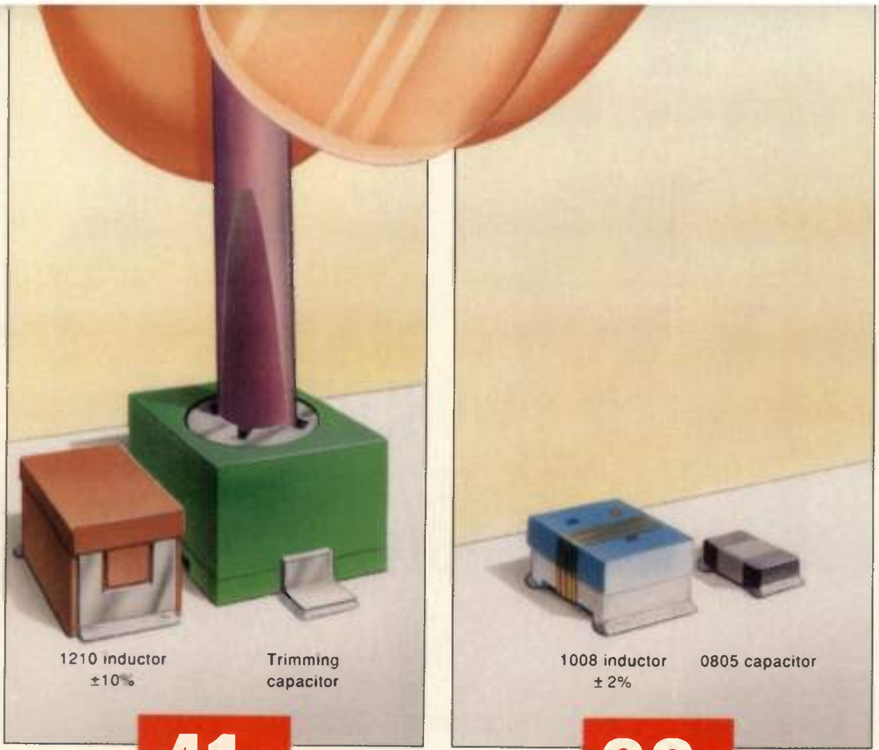
- Instantaneous bandwidth, no warm-up
- Fully protected
- No VSWR shutdown, drives mismatched loads
- ALC gain leveling & power limit set
- All front panel controls available via remote connector
- IEEE488 / RS232 interface capability
- 19" rack mountable, weight 50 kg
- US $19,950.00

KALMUS
ENGINEERING

1-800-344-3341
(206) 485-9000 fax (206) 486-9657
21820-87th S.E. • Woodinville, WA 98072 • USA
Paris, France
phone 1-4645-0945 INFO/CARD 5 fax 1-4645-2403

The World's Most Complete Line of RF Power Amplifiers

More Than 200 Standard Models to Choose From



41¢
PLUS TUNING

22¢

Why your tuned circuits ought to be fixed.

Maybe it's time to rethink the way you design high frequency RF circuits.

Instead of costly tuneable components, why not switch to a fixed LC approach using Coilcraft's tight tolerance chip inductors.

You'll save up to 50% on component costs. Eliminate the time and expense of tuning. Cut board space from 60 to 70%.

And you'll end up with a circuit that's more precise and stable.

We've broken the high price barrier on tight tolerance chip inductors by using a ceramic instead of a ferrite core. Besides having a much higher SRF, ceramic is electrically neutral. So we can turn out a steady supply of 2% parts and sell them at an amazingly low price.

Our 2% inductors come in 1008 (56 nH - 1 µH) and 0805 (56 - 220 nH) sizes. For non-critical applications, our 5 and 10% parts offer maximum savings.

For data sheets or to order one of our Designer's Kits with prototyping samples, call **800/322-2645.**

Coilcraft

INFO/CARD 6

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

1102 Silver Lake Road, Cary IL 60013
800/322-2645 Fax 708/639-1469

RF design

Established 1978

President — Argus Business
Jerrold France

Editorial and Advertising Offices
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111
(303) 220-0600 Fax: (303) 267-0234

Vice President and Group Publisher
David Premo (303) 220-0600

Editor and Associate Publisher
Gary A. Breed (303) 220-0600

Technical Editor
Andrew M. Kellett (303) 220-0600

Consulting Editor
Andy Przedpelski, *The Shedd Group*

Editorial Review Board
Madjid A. Belkerdid, *University of Central Florida*
Alex Burwasser, *RF Products*
Dave Krautheimer, *MITEQ, Inc.*
Ed Oxner, *InterFET Corporation*
Jeff Schoenwald, *Rockwell International*
Raymond Sicotte, *American Microwave Corp.*
Robert J. Zavrel, Jr., *Metricom*

Corporate Editorial Director
Robin Sherman (404) 618-0267

Account Exectives
Jessica Caid (303) 220-0600
Mike Henry (703) 257-1202
Tisha Hill (303) 220-0600
Jeff Peck (303) 220-0600
Dan Rowland (212) 613-9700
Cindy Solomonson (303) 220-0600

Classified Advertising Manager
Carmen Hughes (404) 618-0298

Vice President — Production and Promotion
Cherryl Greenman (404) 618-0302

Production Manager
Jenny Tague (404) 618-0401

Reprints Manager
Vivian Peterson (303) 220-0600

Vice President — Marketing Research Director
Tina D'Aversa-Williams (404) 618-0337

Creative Director
Brian Buxton (404) 618-0108

Art Director
Alan Kohn (404) 618-0368

Circulation Manager
Shawn DeMario (404) 618-0259

List Rental Manager
Etta Davis (404) 618-0266

Argus Business Corporate Offices
6151 Powers Ferry Rd., N.W.
Atlanta, GA 30339-2941
Tel: (404) 955-2500

BPA INTERNATIONAL

ARGUS
A Division of Argus Inc.

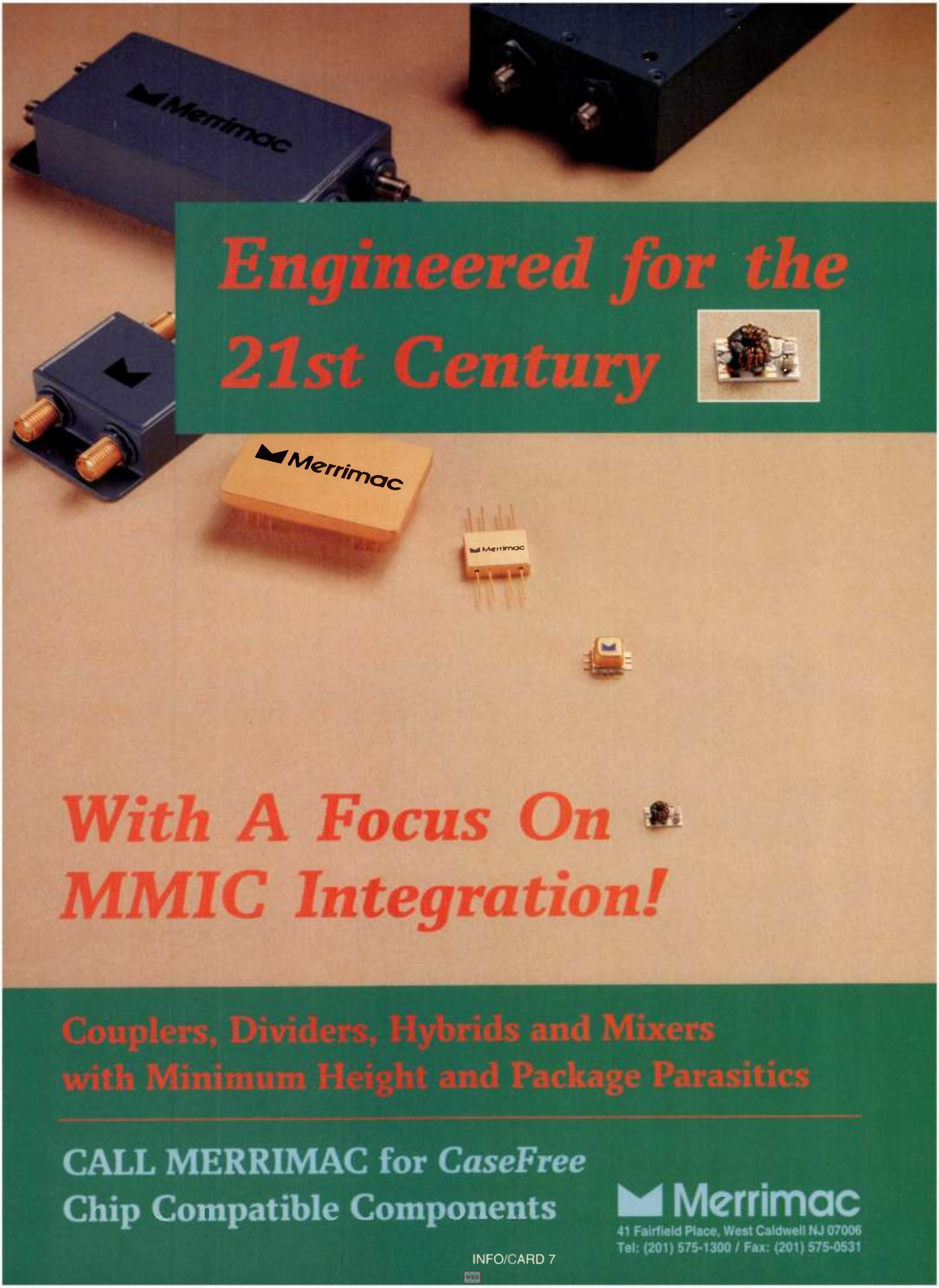
President — Argus Inc.
Scott Smith (404) 618-0286

Vice President, Finance — Argus Inc.
Wayne Otterbourg, C.P.A. (404) 618-0153

Senior Vice President — Argus Inc.
Arthur E. Sweum (404) 618-0109

President — Argus Trade Shows
Dennis Corcoran (404) 618-0485

Subscription inquiries: (708) 647-0756


Engineered for the 21st Century
Merrimac
With A Focus On MMIC Integration!
Couplers, Dividers, Hybrids and Mixers with Minimum Height and Package Parasitics
CALL MERRIMAC for CaseFree Chip Compatible Components
Merrimac
41 Fairfield Place, West Caldwell NJ 07006
Tel: (201) 575-1300 / Fax: (201) 575-0531
INFO/CARD 7

GIGA-TRONICS 6080A & 6082A SYNTHESIZED RF SIGNAL GENERATORS

Giga-tronics Presents The Alternative To $30,000 And $40,000 RF Synthesizers.

Hewlett-Packard makes a couple of very good RF synthesizers. And if you can afford the luxury of paying $30,000 or $40,000 for the name, by all means, call HP right now. They'll be happy to take your order, and your money.

However, if you're looking for an RF synthesizer with outstanding performance and proven reliability for about half the price, you'd better call Giga-tronics.

Here's why:

Performance.
Check the charts. In virtually every category, the Giga-tronics 6080A and 6082A RF Synthesizers meet or exceed the specs of the HP machines. And they use the same GPIB command set, for direct replacement without expensive new software.

Experience.
Granted, Hewlett-Packard has been around a long time. But, Giga-tronics is no Johnny-come-lately.

Giga-tronics has a 14-year history of building test and measurement gear for the most demanding requirements. We've shipped thousands of instruments for use in the testing of radar, EW and communications systems.

Reliability.
Making reliable RF synthesizers is usually no fluke.

However, in this case, it is.

The Giga-tronics 6080A and 6082A RF Synthesizers give you great performance and proven reliability for a lot less money.

© 1993 Giga-tronics Incorporated

Specifications	Hewlett-Packard HP 8642A	Giga-tronics 6080A	Hewlett-Packard HP 8642B	Giga-tronics 6082A
Frequency Range Switching speed	.1 to 1057 MHz <85 ms	.01 to 1056 MHz <100 ms	.1 to 2115 MHz <85 ms	.1 to 2112 MHz <100 ms
Spectral Purity* Spurious Subharmonics	<-100 dBc None	<-100 dBc None	<-94 dBc <-45 dBc	<-94 dBc <-45 dBc
Phase Noise* @ 20 kHz offset	<-134 dBc/Hz	<-131 dBc/Hz	<-125 dBc/Hz	<-125 dBc/Hz
Residual FM* (.3 to 3 kHz BW)	<2 Hz	<1.5 Hz	<5 Hz	<3 Hz
Output Range* Accuracy Reverse Power Protection	+16 to -140 dBm ±1 dB >-127 dBm 50 Watts/50 Vdc	+17 to -140 dBm ±1 dB >-127 dBm 50 Watts/50 Vdc	+16 to -140 dBm ±1 dB >-127 dBm 25 Watts/25 Vdc	+13 to -140 dBm ±1 dB >-127 dBm 25 Watts/25 Vdc
Amplitude Modulation Depth Distortion @ 30%	0–99.9% <2%	0–99.9% <1.5%	0–99.9% <2%	0–99.9% <1.5%
Frequency Modulation Max. Deviation* Distortion	3 MHz <2%	4 MHz <1% @ 50% Dev.	3 MHz <2%	8 MHz <1% @ 50% Dev.
Phase Modulation Max. Deviation*	100 Rad.	40/400 Rad.	200 Rad.	80/800 Rad.
Pulse Modulation On/off Rise/fall time Minimum Pulse Width	>40 dB <400 ns <2 μs	>40/60 dB <15 ns (Typ 7.5 ns) <30 ns	>40/80 dB <400 ns <2 μs	>80 dB <15 ns (Typ 7.5 ns) <30 ns
Internal Modulation Source Level Range Waveforms Programmable	20 Hz to 100 kHz 0 to 3 Vpk Sine Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes	20 Hz to 100 kHz 0 to 3 Vpk Sine Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes
Memory Locations (NVM)	51 Full Function	50 Full Function	51 Full Function	50 Full Function
U.S. List Price	$30,340	$16,950	$41,680	$22,950

The question is not why Giga-tronics is so much less,

but rather, why Hewlett-Packard wants so much more.

*Specifications for both the 6080A and the HP 8642A are at 1GHz. Specifications for both the 6082A and the HP 8642B are at 2GHz. Prices and specifications for the HP 8642A and HP 8642B are from the Hewlett-Packard 1993 catalog. Prices for the Giga-tronics 6080A and 6082A are U.S. list prices.

Both the 6080A and 6082A were originally introduced in 1990 by John Fluke Manufacturing Company. To date, thousands have performed flawlessly in the field.

For added confidence, the instruments incorporate self-testing, internal diagnostics and modular design for easy fault isolation and repair.

Service.

If a problem occurs, Giga-tronics technical support staff can often help you find and fix the problem over the phone.

If you need to return an instrument for repair, we can service it at our factory in California, or at one of our worldwide sales and service centers.

But at Giga-tronics, customer service starts even before you become a customer.

Whether you're looking to buy one unit or one hundred, you'll get the same assistance, including a demonstration at your facility.

Price.

Considering all this, the real question is not why Giga-tronics is so much less, but rather, why Hewlett-Packard wants so much more?

So, if you're interested in paying a lot less for great performance and proven reliability, backed by a worldwide network of service and support, call us toll free at **800 726 GIGA** (4442). We'll send you more information and arrange for a demonstration.

Giga-tronics

Giga-tronics Incorporated
4650 Norris Canyon Road
San Ramon, California 94583
Telephone: 800 726 4442 or
510 328 4650
Telefax: 510 328 4700

INFO/CARD 8

$99.00 OR LESS*

ANY DESIGN KIT

Type	Price, Each Kit
5mm Variable Coil	$99.00
SMD Variable Coil	$99.00
7mm Variable Coil	$59.00
10mm Variable Coil	$59.00
SMD Chip Inductors	$99.00
Molded Coil	$59.00
Leaded Fixed Inductors	$59.00
Multilayer Chip Inductors	$69.00
SMD Spring Coil	$49.00

TOKO

PENSTOCK
WORLD'S LARGEST RF/MICROWAVE DISTRIBUTOR

CALL: 800-PENSTOCK or 408-730-0300, Canada 613-592-6088
FOR OVERNIGHT DELIVERY ON TOKO PROTOTYPING KITS

INFO/CARD 9

*U.S. Dollars

RF calendar

July

4-7 **HF Radio Systems and Techniques**
York, UK
Information: HF '94 Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, UK. Tel: 44-071-344 5478/5477. Fax: 44-071-497 3633.

6-8 **2nd International Conference on ADDA**
Cambridge, UK
Information: ADDA '94 Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, United Kingdom. Tel: 071 344 5478/5477. Fax: 071 497 3633.

August

9-12 **IREECON 1994 - International Electronics and Telecommunications Exhibition**
Melbourne, Australia
Information: TWI, International Exhibition Logistics, 3190 Clearview Way, San Mateo, CA 94402. Tel: (415) 573-6900. Fax: (415) 573-1727.

25-28 **IEEE Electromagnetic Compatibility Symposium**
Chicago, IL
Information: Thomas Braxton, Vice-Chair, AT&T Bell Laboratories, Room 2B-217, 2000 N. Naperville, Road, Naperville, IL 60566. Tel: (708) 979–1299. Fax: (708) 979–5755.

29-1 **Surface Mount International**
San Jose, CA
Information: Institute for Interconnecting and Packaging Electronic Circuits, 7380 N. Lincoln Avenue, Lincolnwood, IL 60646. Tel: (708) 677–2850. Fax: (708) 677–9570.

September

5-8 **The European Microwave Conference 1994**
Cannes, France
Information: Jacqueline Baron, Sales Manager, 24th EuMC, Nexus Business Communications Ltd., Warwick House, Azalea drive, Sawanley, Kent BR8 8HY, UK. Tel: 44 322 660070. Fax: 44 322 667633.

27-29 **16th Piezoelectric Devices Conference**
Kansas City, MO
Information: Electronic Industries Association, 2001 Pennsylvania Avenue, N.W., Washington, DC 20006. Tel: (202) 457–4930. Fax: (202) 457–4985.

October

3-7 **Antenna Measurement Techniques Association**
Long Beach, CA
Information: 1994 AMTA Symposium, School of Engineering and Computer Science, Center for Research and Sciences, California State University, Northridge, 18111 Nordhoff St. - SECS, Northridge, CA 91330. Tel: (818) 885–2146. Fax: (818) 885–2140.

DO YOU KNOW WHO WE ARE?

We've been in the quartz crystal, oscillator and filter business for more than 50 years. . . *and we're probably the best kept secret around.*

Whether you have frequency generating, conditioning or packaging applications, we can fill most of your needs.

CRYSTALS

Choose from a variety of blanks or packaged crystals designed for low frequencies; high frequency fundamental crystal oscillators or wide bandwidth filter applications. Also available are standard and precision AT's up to 250 MHz.

OSCILLATORS

If your application is in communications or instrumentation our complete line of Clocks, VCXO's, TCXO's and OCXO's will give you the highest performance at the lowest total cost.

PACKAGING

As a user of our own glass-to-metal sealed packages, we understand your requirements for hermeticity, solderability and the need to meet MIL-STD testing. We know what our industry requires.

For more information on our products or a catalog, call us at **717-243-5929**. FAX 717-243-0079.

REEVES-HOFFMAN
DIVISION DYNAMICS CORPORATION OF AMERICA
400 W. NORTH STREET
CARLISLE, PA 17013 USA

WE'RE THE BEST KEPT SECRET AROUND

INFO/CARD 10

Introduction to Electromagnetic Compatibility Design Practices
July 7-8, 1994, Milwaukee, WI
Information: University of Wisconsin - Milwaukee, Non-Credit Registration Office, Drawer No. 491, Milwaukee, WI 53293. Tel: (414) 227–3200 or (800) 638–1828. Fax: (414) 227–3146.

Design for Testability and for Built-in Test
July 11-14, 1994, Los Angeles, CA
Wavelet Transform: Techniques and Applications
September 12-16, 1994, Los Angeles, CA
Information: UCLA Extension, Engineering Short Courses, 10995 LeConte Ave., Ste. 542, Los Angeles, CA 90024. Tel: (310) 825-1047. Fax: (310) 206-2815.

Avionics & Weapons Systems Flight Test
August 22-26, 1994, San Diego, CA
Navstar/GPS: Design Applications
August 1-3, 1994, Washington, DC
High Speed & Microwave Devices & Applications
October 24-27, 1994, Boston, MA
Information: University Consortium for Continuing Education, 16161 Ventura Boulevard, M/S C-752, Encino, CA 91436. Tel: (818) 995–6335. Fax: (818) 995–2932.

Applied RF 1
August 22-26, 1994, Los Altos, CA
Wireless Systems
August 29-September 2, 1994, Los Altos, CA
Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel: (415) 949–3300. Fax: (415) 949–4400.

BiCMOS Process Integration and Engineering
August 1-5. 1994. Troy, NY
Information: Rensselaer Polytechnic Institute, Office of Continuing Education, Troy, NY 12180–3590. Tel: (518) 276–8351.

Digital Cellular and PCS Communications - The Radio Interface
October 10-14, 1994, Spain
RF/MW Circuit Design: Linear/Non-Linear, Theory and Applications
October 10-14, 1994, Spain
Active and Passive RF Components: Measurements, Models, and Data Extraction
October 12-18, 1994, Spain
Information: CEI-Europe/Elsevier, Mrs. Tina Persson. Tel: (46) 122–175–70. Fax: (46) 122–143–47.

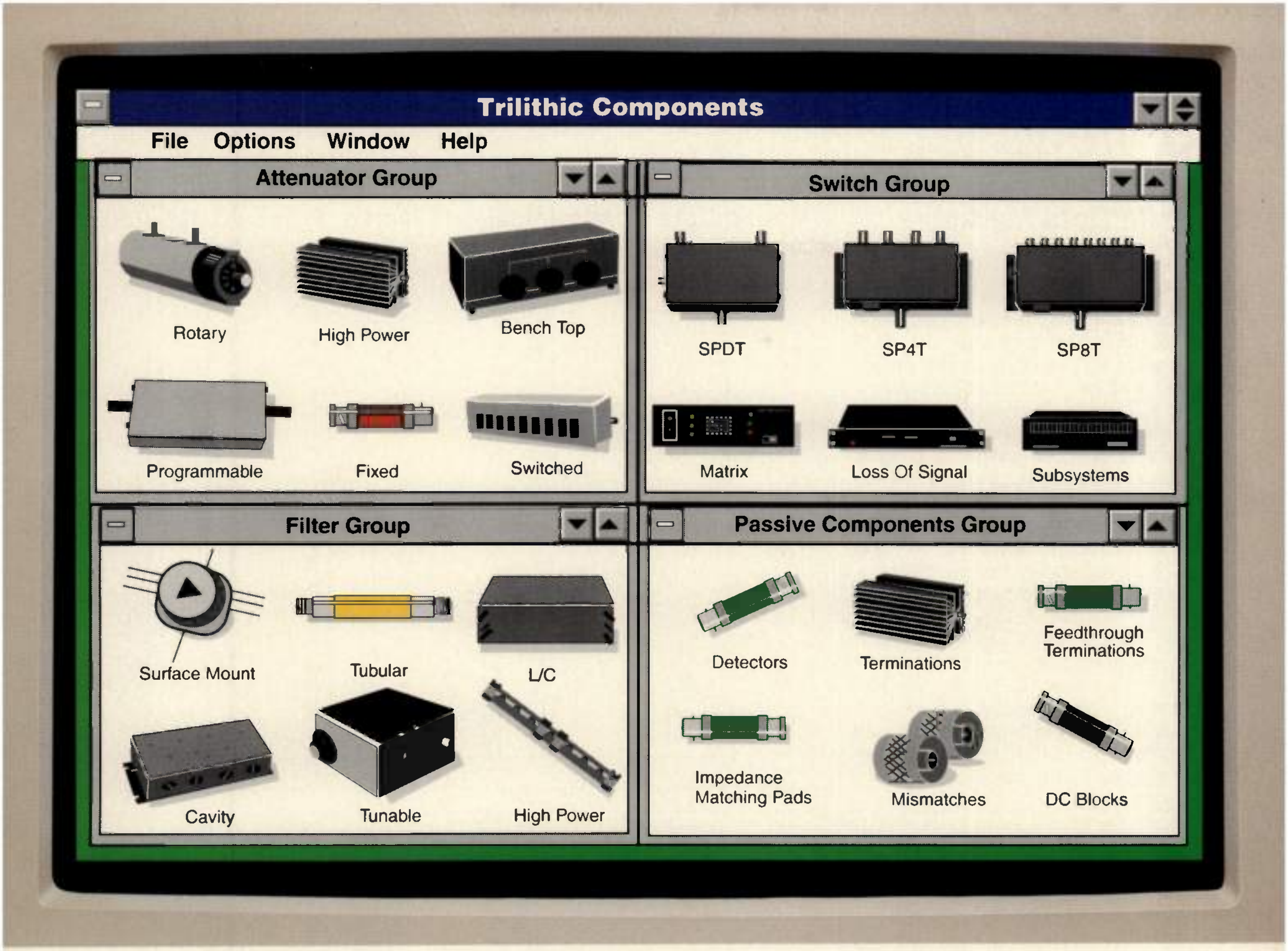
We Do Two Things Greater Than All of Our Competition Combined.

At Norand, ahead of the competition is only one place our unwavering pursuit of technology has taken us. Defining the portable data collection industry, pioneering automated route distribution, and leading the world in RF systems for local area networks... all fruits of our push for innovation. Not to mention the first radio data network, the first RF terminal and integrated bar code printer, the first terminal with portable/mobile capability, and PEN*KEY, the first full function Windows-based hand-held computer. Keeping the technological frontier in clear sight, we approach the next century with still greater plans in mind.

But a sound philosophy is only half our secret. Without a knack for hiring the most talented people in the world, an emphasis on technological innovation could never yield results. In order to perpetuate our record of technological achievement, we plan to continue offering employment opportunities to individuals seeking fulfillment of greater personal and professional objectives. If you perceive yourself as limited in your current position, and possess the vision we seek, a position with Norand will be time well spent. Please investigate Norand's Job Opportunity Hotline (1-800-501-JOBS), or post an inquiry on Internet (HOCHSTAB @NORAND. COM). Fax: (319) 369-3791.

NORAND
Mobile Computing for the REAL WORLD™

INFO/CARD 11



Trilithic ... Today's Icon in RF and Microwave Components

)ouble click on our attenuator group to select units with requency ranges as high as 18 GHz. Types offered include rogrammable step, rotary step, bench top, pushbutton, nechanically switched, or fixed.

- 50 or 75 OHM impedance
- Fixed values from 1 to 60 dB
- Power ratings from 0.5 to 500 Watts
- Dynamic ranges to 127 dB
- Step sizes as low as 0.1 dB

'ull down our switch menu for a diverse assortment of lectromechanical RF switches and switching/control ubsystems. Ideal for RF, video switching and data routing pplications.

- 50 or 75 OHM impedance
- Frequency range of DC to 1 GHz
- Typical isolation is 70 dB
- Voltages of 5, 12, and 24 VDC
- Options of TTL control or latching relays

Return to the filter group and there will be an unsurpassed election of surface mount L/C (first introduced by Trilithic), avity, tubular, tunable and high power filters.

- Highpass, lowpass, bandpass and bandstop
- Power ratings to 2 Kilowatts
- For high reliability, military and wireless communications
- High volume production capability
- Connectorized, PC, or surface mount

INFO/CARD 12

Find help in our passive component group with a useful mixture of detectors, matching pads, high and low power terminations, feedthrough terminations, calibrated mismatches and DC blocks for many production and lab tests.

- Terminations to 1000 Watts
- 50, 75, 93 and 600 OHM matching pads
- 1.0:1 through 5.0:1 calibrated mismatches
- 50 and 75 OHM RF detectors
- Many items available from stock

Call **1-800-344-2412** for our new 93 page catalog and a free copy of TRICAT, a DOS-based filter catalog on a disk for your PC.

TRICAT version 2.1 is now available on a 3 1/2" diskette!

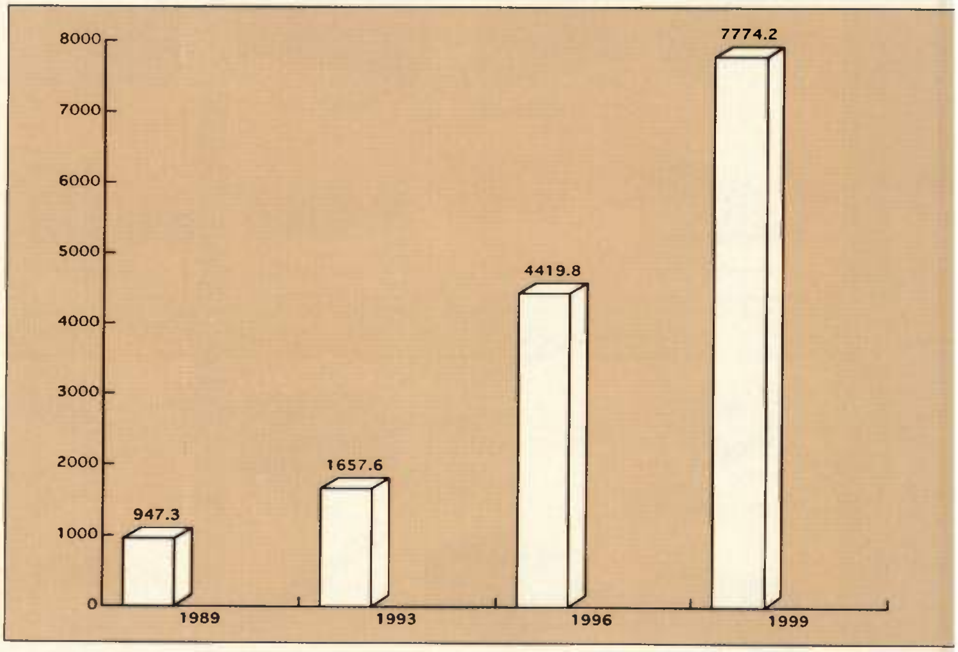
TRILITHIC

9202 E. 33rd Street
Indianapolis, Indiana 46236
(317) 895-3600 (800) 344-2412 FAX (317) 895-3613

Mobile Data Market To Quadruple

According to a forecast by Frost & Sullivan, world markets for mobile data communications services and end-user equipment will more than quadruple from $1.7 billion in 1993 to $7.8 billion in 1999, a 28 percent compound annual growth rate. The firm expects 1996 to be the year of greatest growth, peaking at 48 percent. The firm predicts mobile data will surpass voice as the driving factor. In a report, *World Mobile Data Communications Markets: Market Emerges, Alliances Follow Quickly,* Frost & Sullivan predicted that in most world regions, technology competition will be primarily between cellular and RF data networks, both of which will co-exist with satellite. RF data markets, according to the authors, are shifting from circuit-switched to packet-switched technology, especially suitable for bursty real-time data transmissions.

Mobile Data Communications Market Forecast $Million



Cellular Contracts For Subways And Satellites

Schaeffer Magnetics Builds Satellite Hardware — The Chatsworth, Calif.-based company has completed the design verification model of the solar array drive assemblies that will be used on the IRIDIUM, Inc satellite-based mobile telephone system. The mecha-

nism (photo above) provides two-axis positioning of the satellite's solar panels. Under a $14 million contract, Schaeffer will begin delivery of flight models in May 1995 to Lockheed Missiles and Space Co. The satellite constellation will be comprised of 66 satellites. The global system is scheduled to be fully operational in 1997.

Bell Atlantic Mobile — is expanding its service in Washington to include the subway system. Commuters will have access to cellular phone use in underground stations and while riding the trains. Transmitters will be placed in underground stations. Antennas, provided by Cleveland-based Allen Telecom Group, will be placed in the tunnels. By early 1995, the service will be available in 48 stations and along 55 miles of subway track. The system will use a series of microcells. Initial service is available in six stations covering 3-1/2 subway miles, with 17 additional stations scheduled for startup by April 1995.

Avnet To Acquire Penstock — Subject to applicable regulatory approval, Avnet, Inc. has entered into a contract to acquire all the shares of Penstock, Inc. Sunnyvale, Calif.-based Penstock is a distributes several RF/microwave product lines, mostly to OEM customers in wireless and fibre wireless and fiber optic markets. Sales for the year ending March 31, 1994 exceeded $45 million. Avnet is a $3.5 billion company.

Compact Gets Two Grants — Compact Software has received two Phase I Small Business Innovative Research grants. One is for the development of accurate bias-dependent noise models for Heterojunction Bipolar Transistors (HBTs). HBTs have potential applications in monolithic microwave integrated circuits (MMICs). Existing noise models are based on approximations. The second grant is to develop accurate CAD models for Coplanar Waveguide (CPW) discontinuity structures in MMICs.

Wavetek Licenses HP A-to-D — Wavetek Corp. has licensed Hewlett-Packard Company's patented analog-to-digital conversion technology. Wavetek will use the technology in instruments manufactured by it Calibration Division (formerly Datron Ltd.) in the United Kingdom. The multislope A-to-D conversion technique provides higher speeds than similar conversions at equivalent resolution, according to the company.

No One Supports Motorola's RF Products Better Than Richardson Electronics.

- Inventory
- Technical Assistance
- Delivery
- Design Help

You're Supported by:

- An extensive inventory and off-the-shelf availability of Motorola RF power FETs, power Bipolar, small-signal transistors and power modules.
- A toll-free hotline in the U.S.—**1-800-RF POWER**—to call for technical assistance and design help.

Call **Richardson** today and let us take any RF concerns off your shoulders.

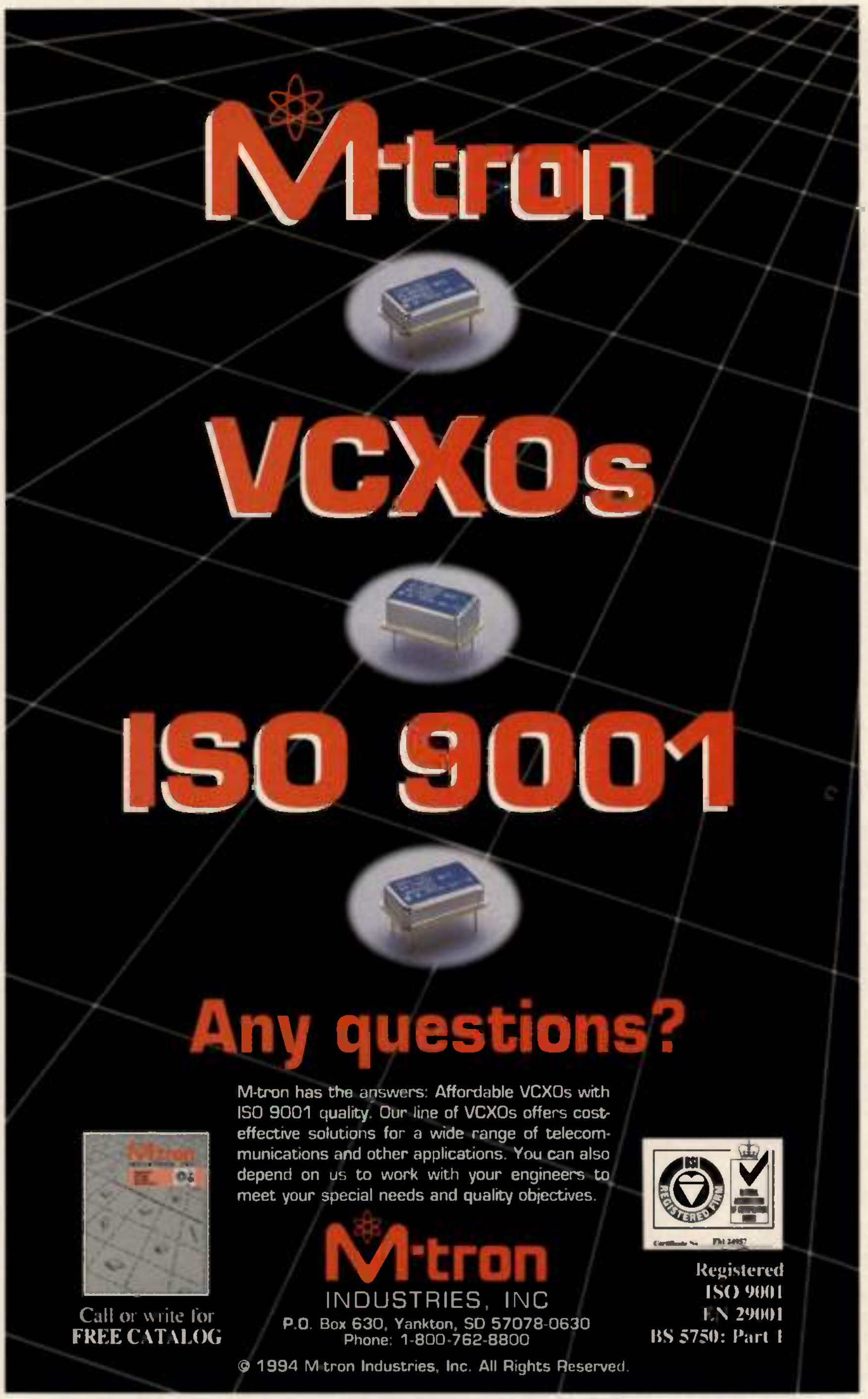
U.S. (800) RF POWER **Canada (800) 348-5580**

MOTOROLA

Richardson Electronics, Ltd.

INFO/CARD 13

AT&T Merges Flash Memory With DSPs — This family of digital signal processors (DSPs) with on-chip flash memory fro AT&T Microelectronics is intended to help consumer electronics manufacturers speed products to market. The ability to load, test and reload development software on the same DSP chip is projected to cut months from a typical development cycle, according to the company. The FlashDSP 1616 processor, with a capacity of 50 million instructions per second (MIPS) at five volts and 30 MIPS at three volts is already being used by several cellular phone manufacturers. The FlashDSP 1616 processor is the first DSP on which the program data storage area can be electronically erased and reprogrammed, eliminating the need for each software version to be permanently coded into a new chip's ROM.



INFO/CARD 14

Scientific-Atlanta DAMA Network In Philippines — International Communications Corporation, one of the Philippines' licensed private telecommunications providers, has selected Scientific-Atlanta to install a demand assigned multiple access (DAMA) satellite network. The network will overlay an existing nationwide network and include a master control earth station and 22 remote sites. The remote sites will include a mixture of eight-channel DDS (digital DAMA System) and two-channel MicroDama chassis for thin to medium rout telephone traffic. The network is scheduled for completion later this summer. Scientific-Atlanta original VSAT hub in 1991.

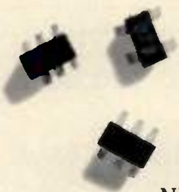
Motorola Expands — Harvard, Ill. will be the site of a new manufacturing, engineering and administrative facility of Motorola Cellular Subscriber Group. The one million square feet is scheduled to be operational by early 1996. Similar to the company's headquarters in Libertyville, Ill., the new facility will create 2,000 to 3,000 new jobs.

Omnipoint and Celeritek in PCS Venture — Omnipoint Corporation and Celeritek, Inc. have agreed to work together in the development of a MMIC chip set for use in Omnipoint's Personal Communication Service (PCS) telephones and base station equipment. Under the joint agreement, Celeritek will provide production quantities of the chip set operating in the 1.9 GHz PCS spectrum. Omnipoint was recently awarded a 30 MHz PCS operator license in the New York Major Trading Area (MTA).

Battelle To Automate Autos — The Federal Highway Administration awarded a $1.7 million contract to Battelle as part of the Department of Transportation plans for an automated highway system. Battelle will focus on systems analysis of malfunction management and safety, operational issues and other topics.

Briefcase Earth Stations — Rockwell Defense Electronics has two briefcase mobile earth station products that offer dial-up voice, fax and data services. The two products are similar; both use the INMARSAT satellite network. One version, the Secure Satcom Terminal provides secure voice, fax and data services.

FINALLY! 3 VOLT RF ICs FOR HANDHELD WIRELESS PRODUCTS



NEC'S NEW LOW CURRENT SILICON ICs not only reduce power consumption in your 3 Volt designs, they reduce the parts count, improve the reliability, and simplify the assembly.

NEC is committed to 3 Volt Silicon technology; these parts are just an introduction.

There are more on the way. Soon.

If 5 Volt ICs are the solution, NEC has a wide selection of them as well, all available right now.

And don't forget NEC's huge family of discrete devices. Many are characterized at 2.5 Volts and they're available in a variety of packages, including a new ultra-small SMD that's a third the size of a SOT 23!

For a ***FREE Product Selection Guide***, call your nearest CEL Sales Office. Or circle the number below.

New 3 Volt NEC Silicon ICs

UPC2745
Ultra Broad Band Amplifier
DC to 2.7 GHz
12 dB Gain
-1 dBm PSAT
7.5 mA Icc

UPC2747
Broad Band Low Noise Amplifier
100 MHz to 1800 MHz
12 dB Gain
3.3 dB NF, 5 mA Icc

UPC2746
High Gain Amplifier
DC to 1500 MHz
19 dB Gain
0 dBm PSAT
7.5 mA Icc

UPC2748
High Gain Low Noise Amplifier
200 MHz to 1500 MHz
19 dB Gain
2.8 dB NF
6 mA Icc

UPB1502
Frequency Divider
0.5 to 2.2 GHz
Divide by 64/65, 128/129
6 mA Icc

UPB587
Frequency Divider
50 to 1000 MHz
Divide by 2/4/8
5.5 mA Icc

...plus dozens of Bipolar Transistors characterized at 2.5 Volts, including:

f = 1500 MHz	*f = 2.5 GHz*	*f = 1000 MHz*
NE68519	**NE68030**	**NE68039**
1.3 dB NF	1.90 dB NF	1.0 dB NF
10.0 dB GA	7.2 dB GA	11.6 dB GA
@ only 3 mA Ic	*@ only 3 mA Ic*	*@ only 1 mA Ic*

Surface Mount packages shown actual size

...and a wide variety of 5 Volt RF ICs including:

UPC2708
Wide Band Amplifier
DC to 2.9 GHz
15 dB Gain
10 dBm PSAT

UPC2710
Wide Band Amplifier
DC to 1000 MHz
33 dB Gain
3.5 dB NF

UPC2713
Wide Band Amplifier
DC to 1200 MHz
29 dB Gain
3.2 dB NF

UPC2723
AGC Amplifier
100 MHz to 1100 MHz
38 dB AGC
13 dB Gain

UPC2721
Down Convertor
RF=0.4 to 3.0 GHz
IF=50 - 600 MHz
Conversion Gain=15 dB

UPC2726
Differential Amplifier
400 MHz to 1400 MHz
15 dB Gain

NEC

Typical Performance at 25°C, Frequency Range is 3dB Bandwidth

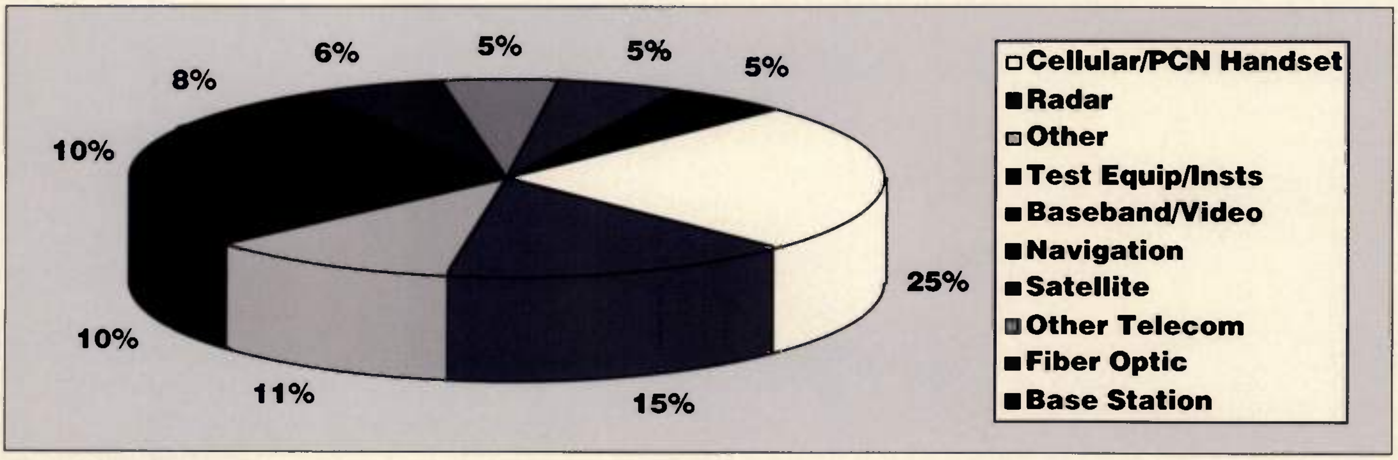
California Eastern Laboratories

CEL Headquarters, 4590 Patrick Henry Drive, Santa Clara, CA 95056-0964; (408) 988-3500 FAX (408) 988-0279 ❑ Santa Clara, (408) 988-7846 ❑ Los Angeles, CA (310) 645-0985 San Diego, CA (619) 467-6727 ❑ Bellevue, WA (206) 455-1101 ❑ Richardson, TX (214) 437-5487 ❑ Olathe, KS (913) 780-1380 ❑ Woodridge, IL (708) 241-3040 ❑ Cockeysville, MD (410) 667-1310 Peabody, MA (508) 535-2885 ❑ Hackensack, NJ (201) 487-1155 or 487-1160 ❑ Palm Bay, FL (407) 727-8045 ❑ Snellville, GA (404) 978-4443 ❑ Nepean, Ontario, Canada (613) 726-0626

© 1993 California Eastern Laboratories

INFO/CARD 15

1993 U.S. GaAs MMIC Market By Application



GaAs MMIC Market To Grow — Over the next five years, the market for gallium arsenide monolithic microwave integrated circuits will grow 25 percent annually, according to Allied Business Intelligence of Oyster Bay, N.Y. The company produced a report titled "Amplifiers: U.S. Markets, Applications & Competitors: 1993 to 1998 Analysis." Low cost wireless telecommunications products are projected to grow substantially, prompting the growth of the GaAs MMIC market. The firm predicts the greatest opportunities at 5.8 GHz, 2.4 GHz and above 30GHz. The report includes sales and market share figures for 39 amplifier 24 transistor and 21 MMIC manufacturers. The analysis was conducted according to end use, selling prices, operating frequencies, output power, device technology, packaging type and bandwidth. The research firm predicts growth and lower prices in wireless telecommunications in both commercial and consumer markets. (Data for the graph above was provided by Allied Business Intelligence, Inc.)

INFO/CARD 16

CIRCUIT BOARD PROTOTYPES

RF/Microwave Prototypes Produced at Your Desk!

Video available.

Quick Circuit Model 7000

SYSTEM FOR ENGRAVING, DRILLING, & ROUTING PROTOTYPE CIRCUIT BOARDS

- EASY — Works with files from your existing CAD package.
- QUICK — Most boards can be made in less than an hour so projects don't get delayed.
- FLEXIBLE — FR4, G10, Duroid™, PTFE, and Ceramic materials can all be used.
- VERSATILE — Analog, Digital, RF, and Microwave boards are easily produced.
- NO CHEMICALS — Uses no chemicals, so there are no odors or disposal problems.
- TUNED CIRCUITS — Tuned microwave circuits are easily produced and adjusted - at your desk!

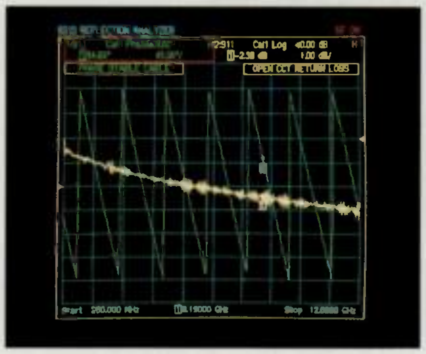
DESIGNED AND MANUFACTURED IN THE USA

T-Tech, Inc.
5591-B New Peachtree Road - Atlanta, GA 30341
TEL (404) 455-0676 FAX (404) 455-0970

INFO/CARD 17

Marconi's 6200 Family of Microwave Test Sets have been making microwave scalar measurements to 46 GHz and providing high-speed, high-resolution fault location for coax lines & waveguide runs.

Now a powerful & economical new addition to the family, the **6210 Reflection Analyzer** is here. It uses the highly accurate "6-port coupler" technique to measure phase and amplitude characteristics of network inputs (S_{11}). The Test Set thus provides accurate return-loss measurements, vector

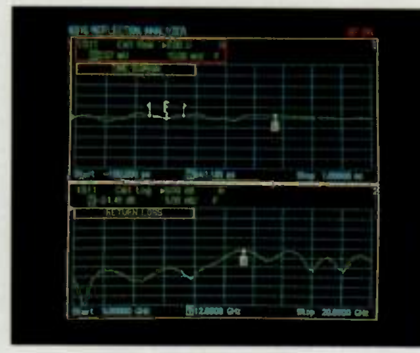


measurements, and time domain measurements. The frequency range of the Model 6210 starts at 250 MHz and extends to 26.5 GHz (or as limited by the host 6200 Series Microwave Test Set).

The Reflection Analyzer is housed in an add-on adaptor that fits below the 6200 Series Microwave Test Set thereby retaining its compact profile for portable and field use. This adaptor technique also provides an easy upgrade route for users of the 6200 Test Set now and at any time in the future. All existing features of the 6200 Series Test Set are retained.

Key features of the 6210 include:

- Higher accuracy and wider range reflection measurements as compared to the RF bridge technique.
- Both vector and time domain analysis so that the causes of reflections can be diagnosed. Especially useful with fault location.
- Smith Chart presentation for easier impedance matching adjustments.



- Simultaneous time domain and frequency domain measurements for full characterization of an input port.

For more information or to arrange a demonstration contact:

Marconi Instruments, Inc.
3 Pearl Court
Allendale, NJ 07401
1-800-233-2955
201-934-9050

Microwave Reflection Analysis Made Easy.

Marconi
Instruments

Marconi

In Canada, contact Canadian Marconi at 514-341-7630, X 4695.

Antenna Technology Takes on the Challenge of Wireless Applications

By Gary A. Breed
Editor

Radio signals must have an antenna in order to radiate and be received. Depending on the application, the antenna may be simple or complex, efficient or inefficient, large or small. For new wireless communications equipment, the requirements are often contradictory, requiring tradeoffs or unusual design solutions.

The first consideration is physical. What is the shape and volume of the device, is it fixed, handheld, or body-worn. Is it going to be well-treated or must it survive rough handling.

The next consideration is system performance. What range is required? How sensitive is the receiver, what is the transmitter power, and what are the signal-to-noise specifications? What is the frequency of operation?

With a picture in mind, an antenna is selected from available products, or uniquely designed to fit the requirements. The rest of this report will look at some of the antenna solutions that have been developed for wireless products.

Dipoles and Monopoles

The common "whip" antenna is still in widespread use in those cases where the protrusion of a slender rod or mast can be accommodated. This has been the most common antenna used in traditional mobile radio, both for vehicular installation, and for handheld equipment. Antennas for handheld products are often physically shortened by the use of a loading inductance: the well-known "rubber ducky" antenna.

Because they are widely used, the cost of this type of antenna is low. Adaptation from standard products is also possible. For example, Part 15 devices operating in the 902-928 MHz band can use antennas designed for cellular telephones with little or no modification.

Collinear arrays, like the common cellular vehicle antenna with its distinctive phasing coil, can be used when greater antenna gain is useful. In particular, such antennas can provide increased range in locations where the path losses are significant.

At frequencies of 900 MHz and above, a dipole or monopole may be included within the structure of a products. In one case, a 915 MHz dipole has been incorporated into the plastic enclosure of a notebook computer.

Other Configurations

Besides the simple dipole or monopole configurations, loop and patch antennas are commonly used. Each has physical characteristics that may be used to advantage.

Some pagers make use of loop antennas comprising an etched copper trace around the perimeter of the unit's circuit board. This allows the small belt-worn units to avoid external antennas that might break or get in the way. At the VHF frequencies most often used, the loop will be smaller than the full wavelength of a resonant loop, and matching is required. As reported by Dr. Ian Dilworth at RF Expo West 1994, the compensation for a short electrical length can be accomplished by capacitive, linear or inductive loading, including inductance contributed by ferrite materials.

Patch antennas are well-known in radar and some satellite applications. As such, they have thoroughly analyzed and characterized. Physically, a patch antenna constructed on common glass-PTFE substrate material will be most useful at frequencies above 2 GHz. However, some high-dielectric-constant ceramic substrates have been used to make compact antennas for GPS at in the 1.5-1.6 GHz range.

Diversity antennas are another family, where sufficient physical separation is present to combat fading due to multipath. At 2.4 GHz, two antennas can be placed in a single compact package, but a lower frequencies, other solutions are required. One is to actually use two antennas located at least one-quarter wavelength apart. Another option is to use polarization diversity, which can be easily accomplished by mounting two dipoles or monopoles at right angles to one another. Polarization diversity, in general, is not as effective as spatial diversity, but it can provide a dramatic improvement over a single antenna.

Future Applications

If development of products continues as expected, new antennas must be developed for severe environments, reduced size, and flat form factors. For applications involving Part 15 devices in the microwave ISM bands at 3.4 and 5.7 GHz, multipath is more severe and diversity becomes much more important. Shorter wavelengths at microwave frequencies can be an advantage, allowing full-size resonant structures to be constructed within a product's package.

It may be necessary for new antennas to cover more than one frequency, if multiple-use products appear. For example, a PCS cordless phone operating at 1.9 GHz may be combined with 900 MHz cellular circuitry in the same unit. Other products may utilize two or more of the unlicensed ISM bands in a single product, as well.

By definition, wireless RF products radiate and receive signals! To get the job done efficiently, the advanced circuitry inside a product needs a properly-designed antenna. In today's competitive market, no weak links can be tolerated. *RF*

Antenna Manufacturers

The following companies make antennas for personal communications:

Company	Info/Card No.
Ace Antenna Company	187
Antenna Research Associates	188
Antenna Specialists	189
Celwave	190
Centurian International	191
Cushcraft Corp.	192
Kintronic Labs	193
Larsen Antennas	194
M/A-COM, Antenna & Cable Div.	195
Synetcom Digital	196
Teledyne Microwave	197
Telewave	198
Toko America	199

New Windows Version ! ! !

Compact Software's new SUPER-SPICE® time-domain simulator is now available for PCs running Microsoft Windows™!

SUPER-SPICE is a powerful time-domain simulator for RF, Microwave, and high speed digital applications. SUPER-SPICE combines a high performance time-domain simulation engine with an easy-to-use graphical interface and special models for high frequency applications. SUPER-SPICE is integrated with the Serenade Schematic Editor to provide a complete solution for design capture and analysis.

SUPER-SPICE provides accurate simulation of signal propagation in various transmission media. High accuracy models are included for different media including microstrip, stripline, coplanar waveguide, multiple coupled lines and discontinuities including bends, tees, steps and crosses. SUPER-SPICE also includes a unique electromagnetics module that computes electromagnetic coupling between traces in complex multi-layer media. Designers can use SUPER-SPICE to quickly and accurately model crosstalk effects in high-speed digital designs. Fast time-domain calculations of layout-related factors provide valuable insight into the operation of high-speed PCBs, MCMs and device packages.

SUPER-SPICE is available for popular UNIX-based workstations and IBM PCs running the Microsoft Windows operating environment.

Compact Software, Inc. • 201 McLean Boulevard • Paterson, NJ 07504, USA
Tel: (201) 881-1200 • Fax: (201) 881-8361

INFO/CARD 19

Open Loop Modulation of VCOs for Cordless Telecommunications

By Daniel E. Fague
National Semiconductor Corporation

Cordless telecommunications systems are rapidly emerging, and low cost radio front ends are paramount to their success. Frequency modulation (FM) has traditionally been the choice for low cost radio systems, and indeed it is used in today's cellular telephones and analog cordless phones. The Digital European Cordless Telecommunications (DECT) standard specifies the use of a digital FM technique, Gaussian filtered Frequency Shift Keying (GFSK). A relatively simple technique to implement the modulator for DECT is open loop modulation of a VCO. This article will examine the concept of open loop modulation as used in DECT. Measured results from a hardware implementation of the technique for a full frequency (2 GHz) VCO are presented to demonstrate its robustness. Also, measurements from a half frequency VCO implementation are used to show open loop modulation's performance in an actual DECT phone.

Frequency modulators are the current choice for most mobile telephones. Two reasons for this include the low cost of both the modulator and demodulator (limiting amplifier and FM discriminator) and the relative ease of implementation of FM systems. While both analog cellular and analog cordless telephones utilize FM methods, the complexity of the modulators and radio front ends is different. Cordless applications typically can use less complex modulator structures because they operate in less "radio-hostile" environments. The less complex modulators (and radio front ends) translate directly to lower cost telephones. Since digital communications methods are emerging as the solution for future telecommunications systems, the need to find low cost implementations of high performance modulators is ever greater.

The pan-European DECT standard combines a high bit rate (1.152 Mb/s), high frequency operation (2 GHz), and fast switching between frequencies (~30 ms). A digital cordless telephone sold in the United States will have similar constraints to the DECT system. These stringent requirements must be met while keeping the overall cost of the radio low enough to be competitive in the consumer market.

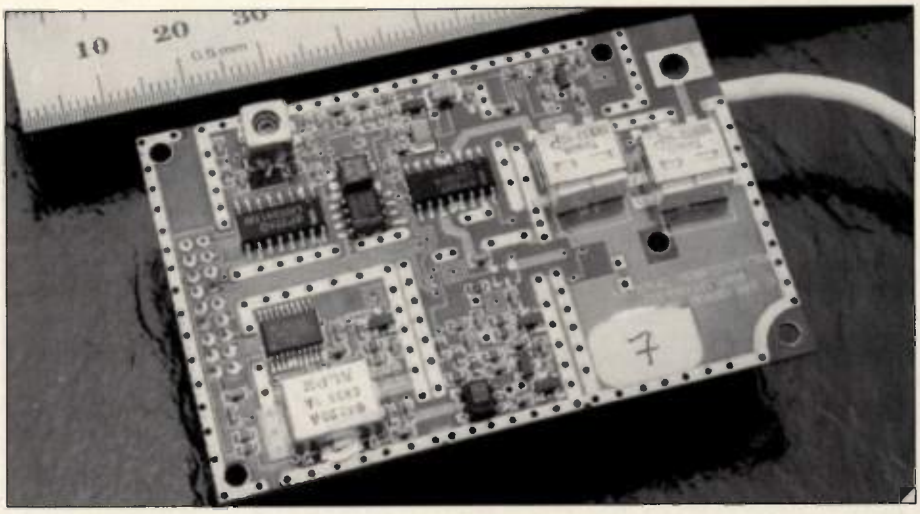


Photo of the test circuit utilizing an open-loop modulated half-frequency VCO, plus a frequency doubler.

The DECT standard calls for a (digital) FM technique. This allows the use of FM discriminators in the receiver, but other requirements in the DECT system preclude the use of conventional FM modulators. A solution to the design of a simple FM modulator for cordless systems such as DECT is open loop modulation of a VCO. Open loop modulation simplifies the modulator because the loop filter in the phase locked loop will not affect the modulation, since the PLL is actually opened, or unlocked, when the modulation is applied.

Several key factors allow for the loop to be opened. First, the DECT bursts are short (approx. 0.5 ms). This reduces the time available for the VCO to drift. In addition, very low leakage charge pumps in PLL integrated circuits such as

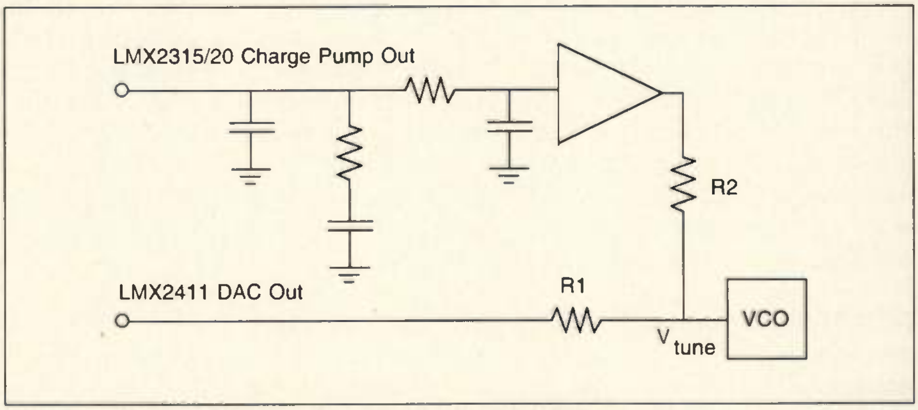
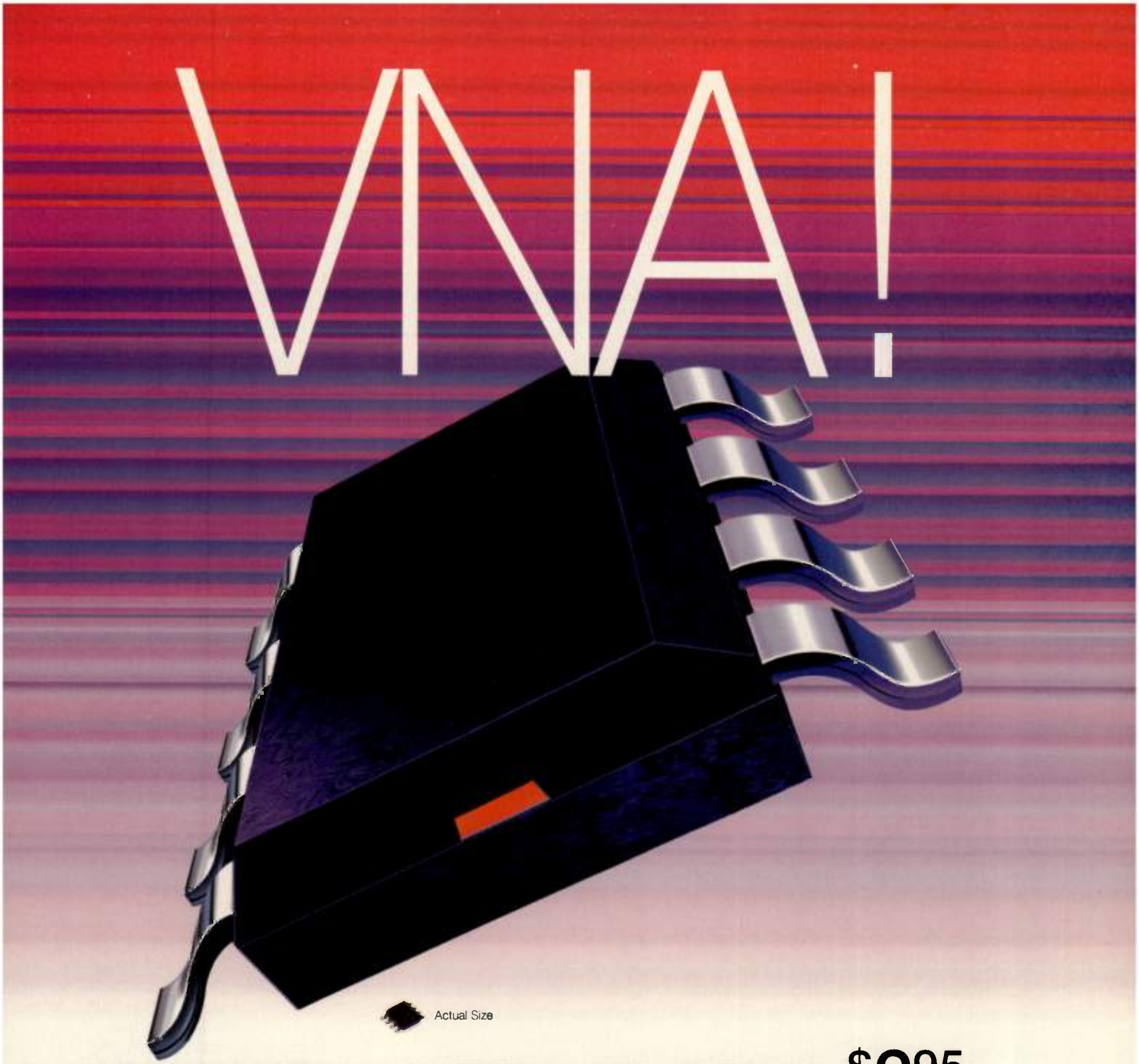
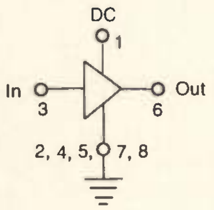


Figure 1. Block diagram of open loop modulation.



VNA Amplifiers +17.5dBm, 0.5 to 2.5GHz only $2.95 (1000 qty.)

Very New Amplifiers...at a very affordable price, from Mini-Circuits! Yes, VNA-25 RF amplifiers are very small, yet incredibly powerful (+17.5dBm typ. output at 1dB compression). The SOIC-8 pin surface mount units operate directly from a +3V to +5V single DC supply with 18dB typ. gain and cover the popular 0.50-2.50GHz wireless band. These units are very easy to use because all capacitors are internal and RF/DC connections are separate, eliminating the need for both external coupling capacitors and an RF choke. You can buy these very new amplifiers for the low price of just $2.95 ea., qty.1000. Development qty.10, only $4.95ea.! So, call Mini-Circuits today for immediate off-the-shelf availability and guaranteed 1 week shipment.



Freq.(GHz)	.5-.8	.8-1.0	1.0-2.0	2.0-2.5
Gain (dB) typ.	14.0	17.0	18.0	16.0
Max. Output (dBm) @1dB Comp. typ.	+18.0	+18.5	+17.5	+17.0
IP 3rd Order (dBm) typ.	+27	+27	+27	+27
VSWR Output typ.	1.5:1	1.7:1	1.7:1	1.5:1
VSWR Input typ.	6.4:1	2.8:1	2.0:1	1.4:1

DC Power.: +5.0V for specified performance.
Current,(mA): 85typ., 105 max.
Thermal Resistance. Junction-to-case: 125°C/W
Price ($) ea. : 2.95 (qty. 1000), 4.95 (qty. 10).

- All specs at 25°C (case temp. 35°).
- Available in Tape and Reel.
- MTTF at 150°C max. junction temp.: 3×10^7 hrs.typ. "Case" is defined as mounting surface of leads.

Mini-Circuits...we're redefining what VALUE is all about!

Mini-Circuits®

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661

For detailed specs on all Mini-Circuits products refer to • THOMAS REGISTER Vol. 23 • MICROWAVES PRODUCTS DIRECTORY • EEM • MINI-CIRCUITS' 740- pg. HANDBOOK.

*CUSTOM PRODUCT NEEDS...**Let Our Experience Work For You.***

F 180 Rev Orig

INFO/CARD 20

the National Semiconductor Corp. (NSC) LMX2315 and LMX2320 prevent the loop filter voltage from sagging during unlocked bursts. Finally, any limitations that can occur with open loop modulation can be overcome. This article investigates those limitations and concentrates on methods to remove them. Measured results of these solutions are provided to illustrate their effectiveness. These results include measurements from both a full frequency (1.9 GHz) and half frequency (950 MHz) VCO implementation.

Open Loop Modulation

The DECT system uses a Time Division Multiple Access/Time Division Duplex (TDMA/TDD) access method. There are 24 time slots in a 10 ms frame, or 420 ms per time slot. Ten frequency channels are available, each spaced 1728 kHz apart. This means a total of 120 full duplex channels are available for use. The modulation method for DECT is Gaussian filtered frequency shift keying (GFSK) with a pre-modulation lowpass filter bandwidth of half the bit rate ($B_bT = 0.5$) and nominal peak frequency deviation of a quarter of the bit rate (±288 kHz). Because this is a frequency modulation technique, a voltage controlled oscillator (VCO) can be directly modulated by the baseband signal.

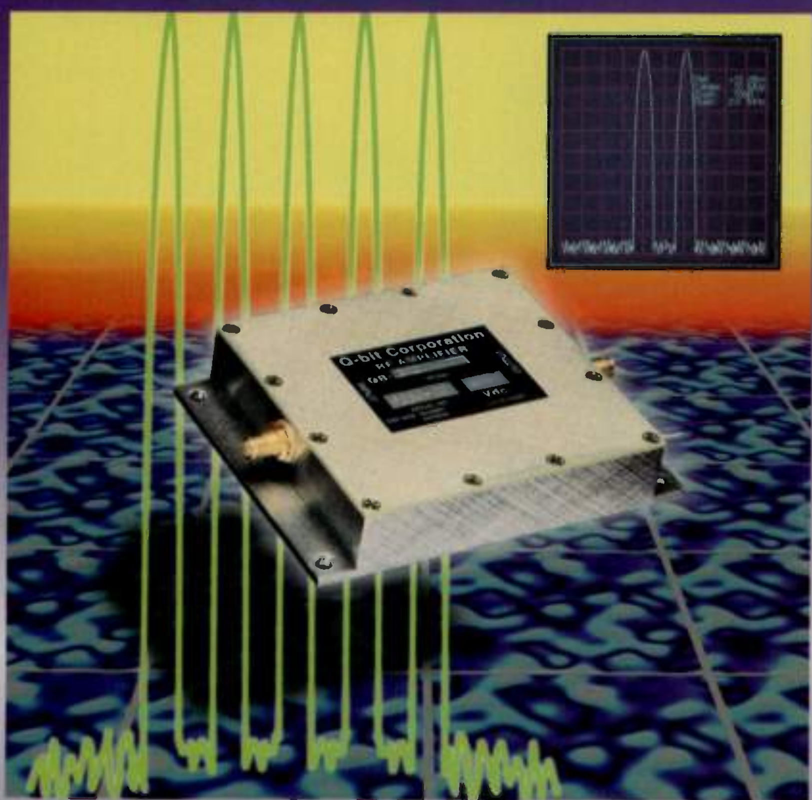
There are several techniques that can be used to modulate a VCO. The most common are modulation "in the loop" and modulation "over the loop". In general, modulation in the loop can be used when the output signal is narrowband with respect to the loop filter. Modulation over the loop can be used when the time required to switch frequencies is relatively long.

In DECT, however, neither of these conditions is valid. The lock times of the phase locked loop must be very short (~30 ms) to avoid a blind slot, and the output signal's spectrum is much wider (approximately 50 times) than the loop filter bandwidth. In certain radio architectures such as single conversion receivers [3,4], there is a need for wideband VCOs to cover the IF bandwidth plus the system bandwidth. In DECT, this amounts to a 130 MHz bandwidth at 1.77-1.90 GHz. Open loop modulation is an exciting technique that allows for fast switching speeds and wide output signal bandwidths while delivering high performance at the 130 MHz spread.

In open loop modulation, the PLL is actually unlocked ("opened") for a brief time to allow the modulation to occur. The modulating voltage is added to the loop filter voltage (at the center frequency) at either a modulation port or the tuning port (via a resistive adder). Figure 1 shows a block diagram of open loop modulation. One of the key reasons that open loop modulation can be used in DECT is that the time slots are of very short duration (420 ms), so the loop is open only for that short time.

The sequence for open loop modulation is as follows: Just prior to transmission, the loop is closed to lock the VCO to the correct carrier frequency. The modulating signal is then turned on, and the loop remains closed to re-lock to the center frequency.

At this point, the modulation signal is simply the mean DC point of the modu-



Typical HF High Dynamic Range Amplifiers

AMPLIFIER MODEL	FREQ. (MHz)	GAIN (dB)	VSWR	NF (dB)	P1dB (dBm)	3rds/2nds (dBm)
QB-101	2-70	22	1.5:1	4.5	31	55/110
QB-102	2-32	12	1.5:1	6.2	28	50/100
QB-105	2-32	22	1.5:1	4.5	37	50/90
QB-7205	2-70	22	1.5:1	4.0	27	51/65
QB-7223	2-32	22	1.5:1	4.5	33	50/65
QBS-101	2-70	12	1.5:1	4.0	20	60/100

Q-bit®

Q-bit Corporation

2575 Pacific Avenue NE • Palm Bay, Florida 32905

Main 407/727-1838 • Sales 800/226-1772 • Fax 407/727-3729

VISA

INFO/CARD 21

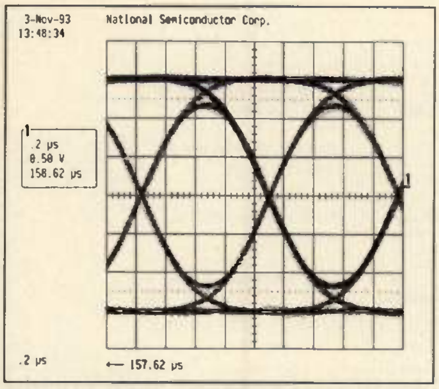


Figure 2. Eye diagram of the demodulated output of the open loop VCO (full frequency), modulated by Gaussian filtered data.

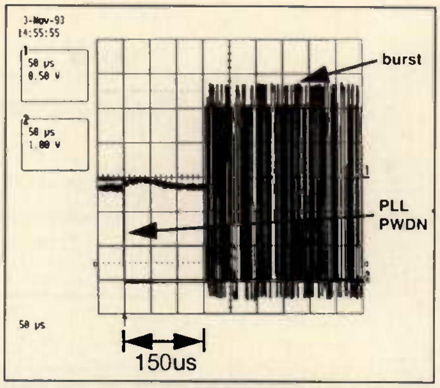


Figure 3. Demodulated output of the open loop VCO (full frequency), modulated by Gaussian filtered data.

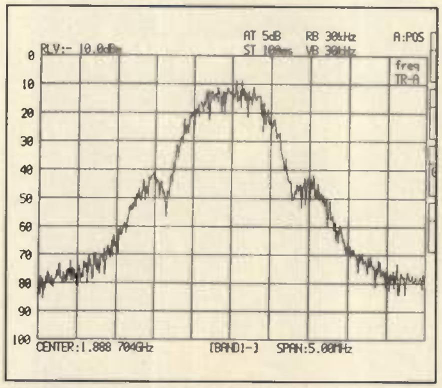


Figure 4. Plot of the open loop modulated DECT signal in burst mode as taken by a time gated spectrum analyzer.

lation. The loop is then opened, and modulation by the transmit data occurs. Once the modulation is finished, the loop can be closed again, and the PLL tuned to the receive frequency.

Since KV of a wideband VCO is on the order of 70 MHz/V for a 3 V VCO, it is important that the loop have very low drift since relatively small voltage changes can have a big impact on the center frequency.

There are some elements of open loop modulation that can limit performance, as listed below:

- Frequency pushing: A change in VCO output frequency caused by a change in the VCO supply voltage.
- Load pulling: A change in VCO output frequency that is caused by a change in the load that the VCO output buffer sees.
- Frequency drift: A change in the VCO output frequency that is caused by RF coupling or by droop in the VCO tuning voltage. Droop in the VCO tuning voltage can be caused by leakage from the PLL charge pump, the loop filter components, or the resistive adder at the tuning port.

Full Frequency Experimental Setup

The circuit used for the full frequency open loop modulation measurements utilized the LMX2320 2.0 GHz PLL with a TRI-STATE™ feature on the charge pump output, a 130 MHz wideband VCO, a 3.0 V regulator, and the Gaussian filter ROM-DAC on the LMX2411 to shape the transmit data. The data rate used was 1.152 Mb/s (DECT bit rate).

The carrier frequencies that were used to demonstrate open loop modulation performance were DECT channels 0, 5, and 9. The circuit was implemented on a printed circuit board. The power amplifier load was simulated by a 10 ohm resistor and a P-channel switch (for current draw), and a PIN diode and 220 ohm resistor to ground (for load impedance change). Measurements were made by using a Rohde and Schwarz CMT-55 DECT system tester to demodulate the output of the circuit (from the PIN switch), and the frequency offsets

HF LINEAR AMPLIFIERS - BROADBAND TRANSFORMERS

HF AMPLIFIERS per MOTOROLA BULLETINS
Complete Parts List for HF Amplifiers Described in the MOTOROLA R.F. Device Data
AN758 300W $154.15 — EB63 140W $ 89.65
AN762 140W $ 95.15 — EB27A 300W $136.80
AN779L 20W $ 83.79 — EB104 600W $371.65
AN779H 20W $ 93.20 — AR305 300W $346.82
AR313 300W $366.00
NEW!! 1K WATT 2-50 MHz Amplifier
MOTOROLA AR347 $1,100.95
POWER SPLITTERS and COMBINERS 2—30MHz
600 Watt PEP 2—Port .... $ 69.95
1000 Watt PEP 2—Port .... $ 79.95
1200 Watt PEP 4—Port .... $ 89.95

2 METER VHF AMPLIFIERS
35 Watt Model 335A .... $ 79.95 Kit
75 Watt Model 875A .... $119.95 Kit
Available in kit or wired/tested

100 WATT 420-450 MHz PUSH-PULL LINEAR AMPLIFIER — SSB-FM-ATV
KEB67—PK (Kit) $159.95
KEB67—PCB (PC Board) .... $ 18.00
KEB67—I (Manual) .... $ 5.00
We also stock Hard-to-Find parts
CHIP CAPS—Kemet/ATC
METALCLAD MICA CAPS—Unelco/Semco
RF POWER TRANSISTORS
MINI—CIRCUIT MIXERS
SBL—1 (1—500Mz) .... $ 6.50
SBL—1X (10—1000Mz) .... $ 7.95
ARCO TRIMMER CAPACITORS
VK200—20/4B RF Choke .... $ 1.20
56—590—65—3B Ferrite Bead .... $ 20
Broadband HF Transformers
Add $4.00 for shipping and handling.

For detailed information and prices, call or write for our free catalog.

VISA
CCI Communication Concepts Inc.
508 Millstone Drive • Beavercreek, OH 45434-5840 • (513) 426-8600
FAX (513) 429-3811
MasterCard

INFO/CARD 22

EDC
FREQUENCY PRODUCTS
ELECTRO DYNAMICS CRYSTAL CORP.

Crystals
- Microprocessor
- Military Spec/QPL
- Communication
- Custom Crystals

Oscillators
- Hybrid Clock
- TCXO
- VCXO
- Custom Oscillators

9075 Cody Overland Park KS 66214
Phone (800) EDC-XTAL Fax (913) 888-1260

INFO/CARD 23

Turn your shielded room into a reverb chamber

at frequencies from 30 to 1000 MHz.

Our Cavitenna® cavity-exciter uses the wall or ceiling as its groundplane, and delivers field strengths you usually associate with antennas bigger than your room.

This 4-foot-wide top-loaded monopole, with typical gain over 5 dB, is especially welcome in the "difficult" mid frequencies between 30 and 150 MHz, where other fractional-wavelength antennas don't measure up. Accepting input power as high as 3500 watts, the Cavitenna cranks out well over 700 volts per meter at 100 MHz, and even more at 200 MHz.

Magnetic mounting clamps make installation and relocation in the shielded room fast and easy. Easy, too, is the price.

You should talk volts/meter and rf power with someone who knows your language and most often knows your problems. That's one of our applications engineers, who'll pick up the phone when you call, toll-free, **1-800-933-8181.**

amplifier research

160 School House Road
Souderton, PA 18964-9990 USA
215-723-8181 • Fax 215-723-5688

For engineering assistance and service throughout Europe, call

EMV GmbH • Munich • 89-612-8054
EMV Ltd. • London • 908-566-556
EMV S.A.R.L. • Paris • 1-64-61-63-29

1670

INFO/CARD 24

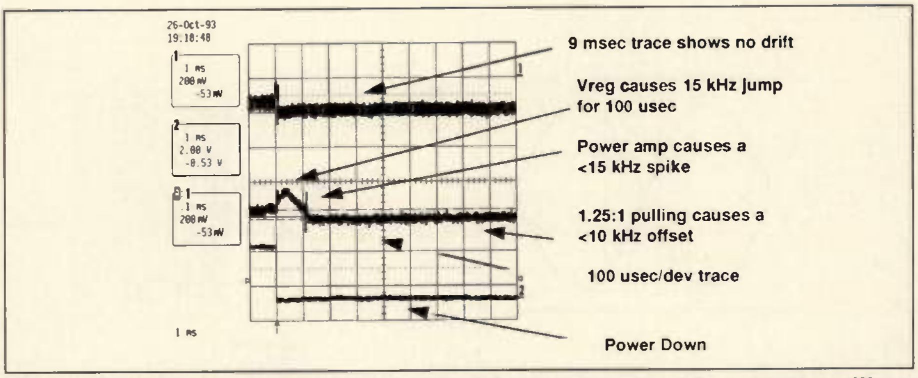


Figure 5. Measurement of open loop frequency pushing, load pulling, and frequency drift for DECT channel 0 at 25° C.

were determined from the demodulated signal on a digitizing oscilloscope.

The circuit featured the National Semiconductor LMC6482 CMOS rail-to-rail operational amplifier that was used to control leakage due to the resistive adder at the tuning port. The low output impedance of the op amp allowed the summing node to be a simple resistive adder. An RF buffer with good reverse isolation (>30 dB) was used at the output of the VCO to effectively control the load pulling caused by the power amplifier and T/R switch. An NSC LP2951 low dropout voltage regulator was used to supply the 3.0 V V_{cc} to the components, and this regulation of the input battery voltage plus power supply filtering limited noise and frequency pushing.

Full Frequency Experimental Results

The first set of measurements shows the experimental results of modulating a full frequency (i.e., 1770 to 1900 MHz) VCO. The performance is seen to be very good. Figure 2 shows the demodulated eye diagram of the open loop modulated DECT signal. The virtually perfect eye diagram of Gaussian B_bT= 0.5 filtered data can be seen. Figure 3 shows a time domain view of the demodulated signal after the loop was opened. A small 15 kHz jump that settles out can be seen in this time domain plot. Figure 4 shows the open loop modulated DECT signal operating in burst mode (i.e., TDMA/TDD operation). The measurement was taken with a time gated spectrum analyzer to capture a number of bursts. Note that the output spectrum of the signal is a DECT-compliant GFSK signal.

The next three plots show the small imperfections that can occur in open loop modulation. Figure 5 shows open loop frequency pushing, pulling, and drift at 25° C on Channel 0 in the DECT band (~1.9 GHz). The lower trace is the power down signal sent to the PLL to TRI-STATE the charge pump. The upper trace shows that there is imperceptible frequency drift over a 9 ms burst. The middle trace is a 10x zoom of the upper trace, and it shows a 15 kHz pushing jump while the voltage regulator recovers from the PLL powering down. This lasts about 100 msec. The (simu-

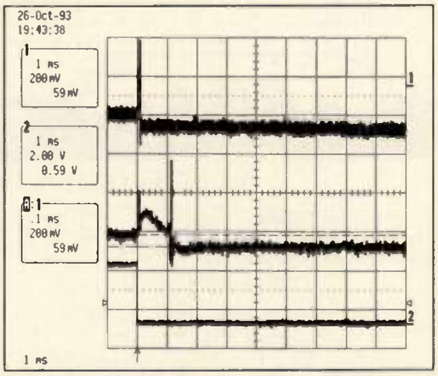


Figure 6. Measurement of open loop frequency pushing, load pulling, and frequency drift on DECT Channel 0 at –20° C.

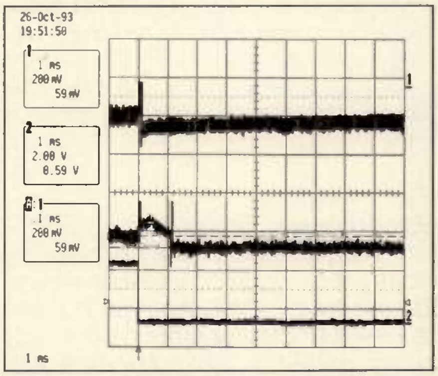


Figure 7. Measurement of open loop frequency pushing, load pulling, and frequency drift for DECT channel 0 at 60° C.

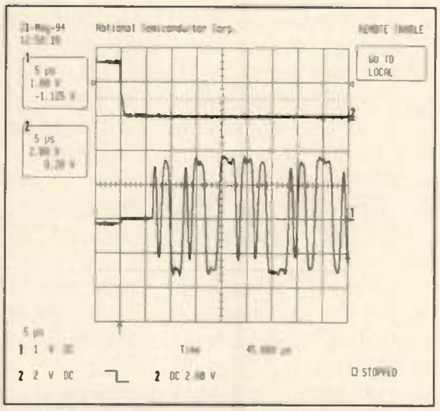


Figure 8. Beginning of a demodulated DECT burst. Note small (30 kHz) jump after power amplifier power up signal goes low (upper trace). Horiz. 5 ms/div., vert. 200 kHz/div.

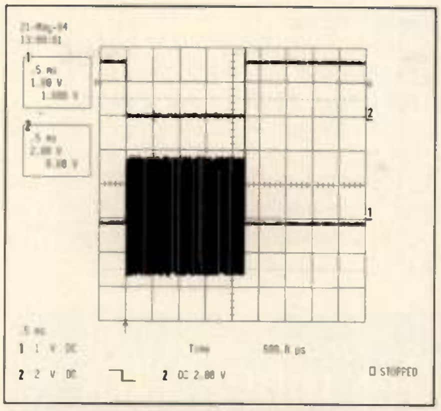


Figure 9. Complete demodulated DECT burst. There is no center frequency drift, and the deviation is about 588 kHz (peak-to-peak). Horiz. 0.5 ms/div. (expanded 5× to 0.1 ms/div.), vert. 200 kHz/div.

lated) power amplifier turning on causes a 15 kHz pushing spike, and 1.25:1 load pulling causes a <10 kHz offset. Similar curves are seen at Channel 9, the lower end of the DECT band (~1.88 GHz).

Figure 6 shows the performance of open loop modulation at –20°C. It can be seen that the only difference in performance is that the power amplifier pushing creates a slightly larger spike at the beginning of the burst, but the rest of the performance is nearly identical to that of 25° C. Figure 7 shows the performance at 60° C. In this case, the power amplifier pushes a slightly smaller spike. However, a small frequency drift is now noticed, and this is due to a small leakage from the charge pump to the VCO.

Half Frequency Experimental Results

In a second experiment, a half frequency VCO and doubler circuit was implemented. This variation was tested because a half frequency VCO has a greater inherent immunity to RF radiation than the full frequency VCO. This higher tolerance for RF radiation exists because the VCO operates at half the frequency that the power amplifier radiates, and thus is less likely to couple to the power amplifier's output. A standard balun was used, although a printed balun can be used to save cost. The next three figures show the performance of the half frequency VCO open loop modulation used in the DECT phone.

Figure 8 shows the start of a demodulated burst from the DECT phone. After the power amplifier is powered up (top trace), a small (30 kHz) jump is seen to occur. Then, the demodulated random data appears with no further drift. The entire demodulated burst is shown in Figure 9. Here, it can be seen that the frequency deviation is approximately 588 kHz (peak to peak). Both Figure 8 and Figure 9 have vertical scales of 200 kHz/div. Finally, the received eye diagram is shown in Figure 10, and it can be seen that the demodulated signal is Gaussian filtered (B_bT= 0.5) data. A photograph of the 950 MHz RF front end board is shown on the first page of this article.

Summary

As demonstrated in this article, the principle of open loop modulation for wideband VCOs can be implemented and used in a practical and cost-effective manner. The measured results show that the methods used to reduce

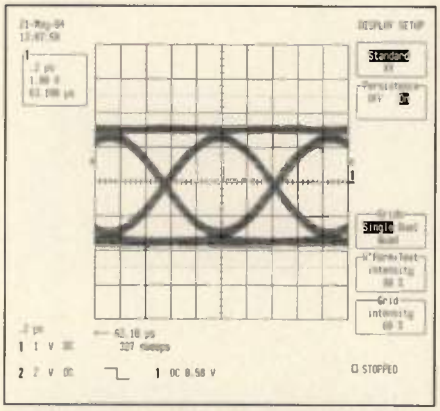


Figure 10. Received eye diagram from the DECT phone. Bit rate is 1.152 Mb/s.

INFO/CARD 25

or eliminate frequency pushing, load pulling, and frequency drift are effective. These methods are also robust, as the circuit shows virtually no degradation in performance over a wide range of temperatures. Open loop modulation can therefore provide a proven, low cost solution to designers who are implementing digital FM modulators in systems with short data burst durations. *RF*

References

1. ETSI, Final Draft - prETS 300 175-2, Specification for DECT, Part 2: Physical Layer, May, 1992, Cedex, France.
2. D.E. Fague, A. Dao, and C. Karmel, "Techniques for Open Loop Modulation of a Wideband VCO for DECT", *Conference Proceedings*, RF Expo West, San Jose, CA, March 22-24 1994, pp. 274-277.
3. D.E. Fague, A. Dao, B. Madsen, and C. Karmel, "Performance Evaluation of a Solid State, Low Cost Radio Front End for DECT", *Proceedings of the 44th Vehicular Technology Conference*, Stockholm, Sweden, June 7-10, 1994.
4. Madsen, Benny, and Fague, Daniel E., "Radios for the Future: Designing for DECT", *RF Design*, April, 1993, pp. 48-53.
5. LMX2411 Baseband Processor for Radio Communications Data Sheet, National Semiconductor Corp., Lit. #108550-001, September, 1993.
6. LMX2320 2.0 GHz Frequency Synthesizer for RF Personal Communications Data Sheet, National Semiconductor Corp., Lit. #108535-001, January, 1993.

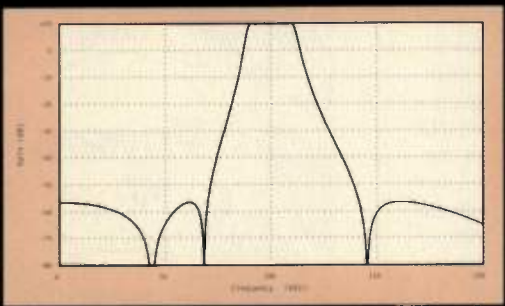
Note: TRI-STATE is a trademark of National Semiconductor Corporation.

About the Author

Daniel E. Fague obtained his BSEE in 1989 at Gonzaga University and his MSEE (Signals and Systems) in 1991 at the University of California at Davis. Since 1991, he has worked at National Semiconductor Corporation in the Wireless Communications Group, specifying integrated circuits for radio transceivers and building radio boards with them. He is a member of the IEEE, and his interests include digital radio modems, indoor and outdoor propagation for mobiles, and digital signal processing. He can be reached at National Semiconductor Corporation, P.O. Box 58090, M/S A-1500, 2900 Semiconductor Drive, Santa Clara, CA 95052-8090.

Complex active filter subsystems can now be designed in-house!

AFDPLUS The integrated design environment chosen by commercial active filter vendors just got even better...



AFDPLUS Benefits
• Time savings
• Cost savings
• Immediate payback
• Guaranteed performance

AFDPLUS Features
• Every filter type
• 14 built-in response types
• 8 built-in circuit topologies
• Synthesis to poles/zeros
• Synthesis to arbitrary response
• Transfer function math
• PLL synthesis & analysis
• Component sensitivity & worst-case analysis
• Complete frequency & time domain graphical analysis
• Interfaces to SPICE and leading RF simulators
• Standalone nodal circuit analysis
• Unrestricted noise capability

AFDPLUS is the integrated engineering environment for the active filter designer. Complex filter requirements can now be handled in-house. From comprehensive network synthesis to built-in manufacturability analysis, AFDPLUS guarantees a new level of independence!

AFDPLUS now includes standalone audio/RF/microwave nodal analysis with unrestricted noise capability! $995.

Engineering Software

WEBB LABORATORIES
13731 W. Capitol Drive • Suite 260
Brookfield, WI 53005
TEL 414•367•6825 FAX 414•367•6824

INFO/CARD 26

Remember!

RF Expo East
November 15-17, 1994
Orlando, Florida

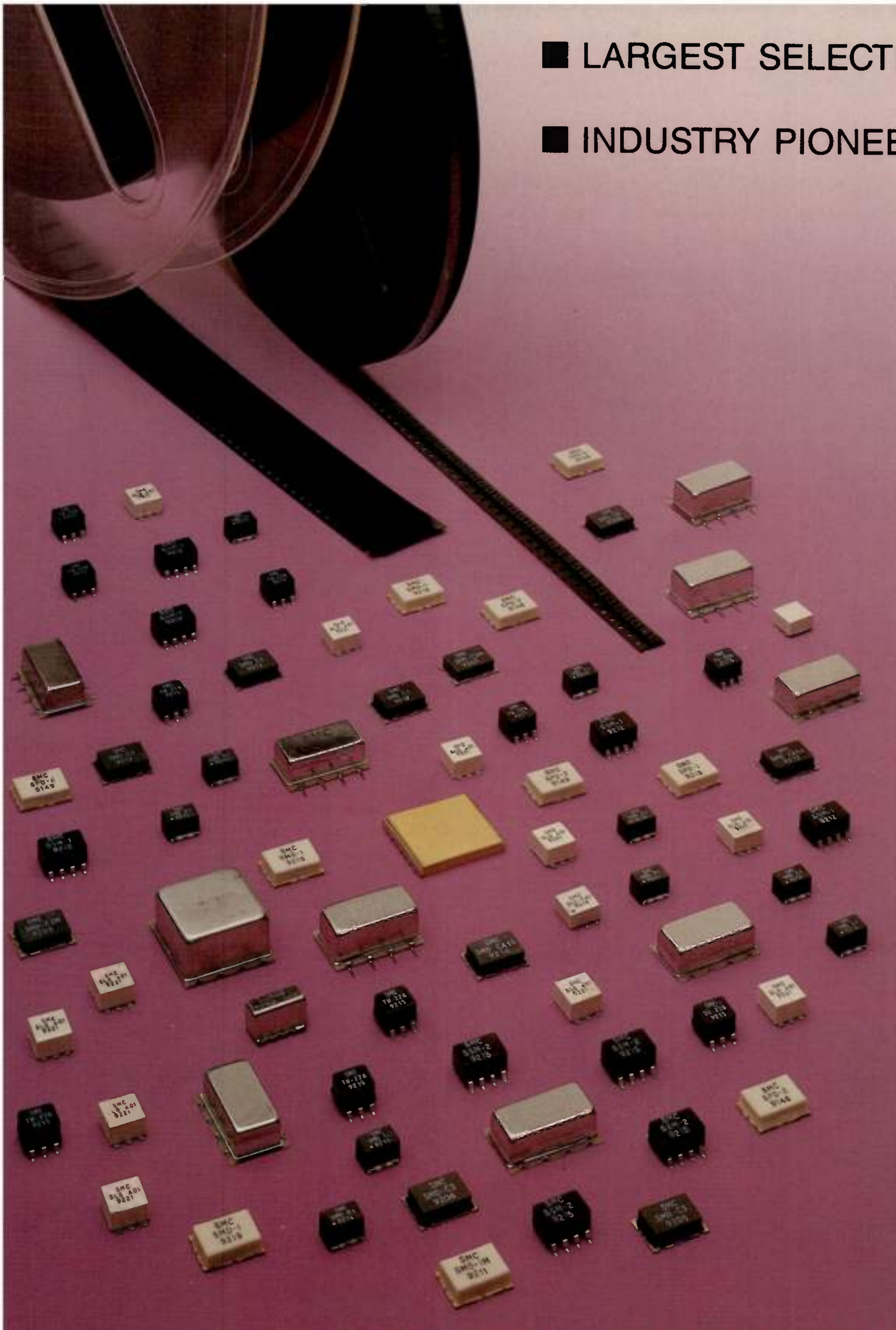
RF Expo West
January 30 - Feburary 1
1995
San Diego, California

Make your plans now!
Call 1-800-828-0420

■ LARGEST SELECTION

■ INDUSTRY PIONEER

SURFACE MOUNT



MIXERS • POWER DIVIDERS • COUPLERS • FILTERS
I/Q MOD. & DEMOD. • PHASE DETECTORS • PHASE SHIFTERS
ATTENUATORS • VECTOR MODULATORS and more...

SYNERGY®
MICROWAVE CORPORATION

483 McLean Boulevard • Paterson, New Jersey 07504 • (201) 881-8800 • Fax: (201) 881-8361

INFO/CARD 27

A Fast Envelope Detector

By Dominic J. Ciardullo
Brookhaven National Laboratory

Traditional AM demodulating methods include both synchronous (product detector) and non-synchronous (rectification) techniques. While each has its merits, both methods require some amount of filtering to accomplish their goal of envelope detection. In certain applications, the resulting circuit delays present severe limitations to the system's response time, (for example, when the detection scheme is utilized within a feedback loop). This paper describes a wideband, active envelope detector with a response time on the order of 1 μs. The circuit described has a demodulation bandwidth of DC-350 kHz, and provides a high degree of linearity over a dynamic range in excess of 40 dB. The device is designed for broadband carrier operation (1 MHz to 5 MHz), but can easily be adapted to demodulate carriers in other ranges (up to VHF).

The circuit described was developed to provide a real-time monitor for an amplitude modulated RF signal swept in frequency from 1 to 5 MHz. Although the specific accuracy, linearity and dynamic range requirements could have been satisfied using more conventional detector techniques, its inclusion as part of a feedback loop within a larger system was the ultimate motivation for developing this circuit. Standard envelope detectors generally utilize a signal rectification/filtering combination which requires a time constant much greater than one RF period (at the lowest carrier frequency) to maintain reasonable amplitude accuracy.

Most product (or synchronous) detectors use a non-linear detection scheme which requires filtering to extract the "DC" term from its output to obtain the original modulation waveform. Like the rectifier approach, this filtering adds significant delay to the response time of the detector; This technique was therefore determined unsuitable for our particular application.

To circumvent the problem of response delay. a vector addition technique is used tc convert an RF sinusoid directly into a "DC" modulation signal, with minimal RF processing of the carrier. This method is easily implemented using currently available high speed analog transconductance multipliers. It achieves amplitude demodulation at frequencies approaching that of the carrier, without the long time constants typical of other detection methods.

Basic Theory

Since minimizing delay is a primary concern, it is desired to use a detection method which does not depend on low pass filtering to extract the modulation signal. To do this, we will first split the modulated carrier into two equal parts, each of which contains both the intelligence signal and the carrier RF. These elements may then be combined in such a manner as to null out the RF while leaving the modulation waveform intact. The trigonometric identity

$$\sin^2(\omega t) + \cos^2(\omega t) = 1 \qquad (1)$$

shows that it is indeed possible to accomplished this task if the two components are made to be 90° apart in phase. The functional block diagram of such a detection technique is shown in Figure 1.

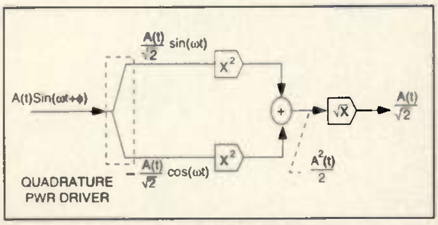


Figure 1. Envelope detector functional block diagram.

An incoming RF carrier is decomposed into two equal amplitude, quadrature phase components (I and Q):

$$\text{I component: } \frac{A(t)}{\sqrt{2}}\sin(\omega t) \qquad (2)$$

$$\text{Q component: } -\frac{A(t)}{\sqrt{2}}\cos(\omega t)$$

where A(t) is the amplitude of the carrier as a function of time (i.e., the modulation waveform) and ω is the carrier frequency. Note that we have assumed here the use

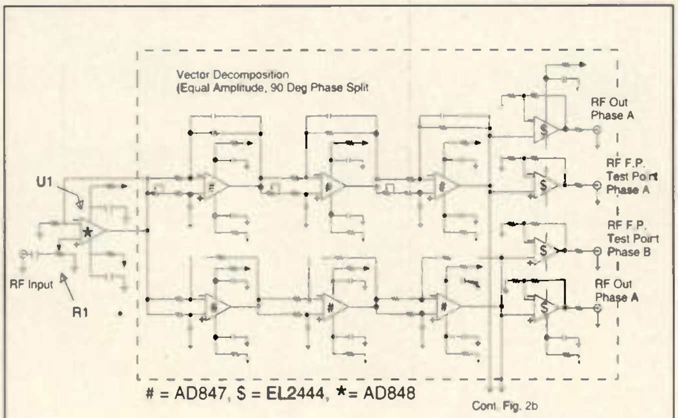


Figure 2a. Functional diagram of the demodulator. Portion of circuit in dotted box performs vector decomposition.

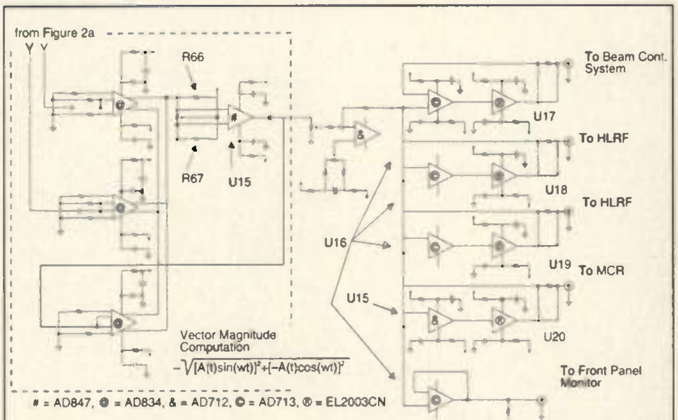


Figure 2b. Continuation of functional diagram. Circuitry in dotted box performs vector magnitude computation.

TRANSMITTERS

Video/Digital Transmitters and Telemetry/Digital Transmitters

Up to 10 MHz Analog Bandwidth
Up to 15 MB/Sec Digital Bit Rate
Up to Eight Bit Rates (User Specified and Field Selectable)

Telemetry/Digital

Exhibiting at International Telemetering Conference

OTHER PRODUCTS:

Receivers • Beacon Transmitters
Command Encoders & Decoders
Amplifiers • VCOs
(Rack Mount Available)

AVAILABLE IN ANY COMBINATION OF THE FOLLOWING FEATURES:

- Video/Digital or Telemetry/Digital
- Up to Eight Bit Rates (User Specified and Field Selectable)
- Automatically Selects Optimal Pre-Mod Filter
- Automatically Selects Optimal Deviation
- 2, 5, or 10 Watts
- Single Frequency or Channelized
- AC or DC Coupled
- Frequency Bands:
  - D1 = 1435 to 1540 MHz (L Band)
  - D2 = 1710 to 1850 MHz (L/S Band)
  - E1 = 2200 to 2299 MHz (Lower S Band)
  - E2 = 2300 to 2400 MHz (Upper S Band)
- SMA, N, or TNC RF Connector
- 20 Cubic Inches (3.50" x 2.50" x 2.25")
- **Options:** Extended Temperature, Pre-Emphasis, Telemetry Subcarrier

Call our engineers with your specific requirements

EMHISER RESEARCH, INC.

2705 Old Highway 40 West
P.O. Box 189
Verdi, Nevada 89439-0189 USA

TEL: (702) 345-2705
FAX: (702) 345-2484

Since 1978

INFO/CARD 28

VISA MasterCard

of a power divider to obtain the quadrature phase split, with some insertion phase ϕ (which is dependent upon the RF frequency). The vector sum of the two components is explicitly carried out to obtain a linearly scaled version of the amplitude modulating function, A(t).

To obtain the vector sum, both components of the original carrier are squared, then added together. The square root of the sum of the squares is then computed in real-time to obtain:

$$\sqrt{\left[\frac{A(t)}{\sqrt{2}}\right]^2 \sin^2(\omega t) + \left[-\frac{A(t)}{\sqrt{2}}\right]^2 \cos^2(\omega t)} = \frac{A(t)}{\sqrt{2}} \qquad (3)$$

using the trigonometric identity of equation 1. An important consequence of this result is the fact that there is no RF term in the solution; Although we started out with two RF (amplitude modulated) sinusoids, the result is a scaled version of the modulation waveform only. The significance of this outcome is two-fold; First, even though two non-linear operations were involved, no filtering is required to separate the carrier from the original modulation waveform. Since no filtering is required, there are no long time constants to slow down the overall detector's response time. In addition, the modulation frequency can approach the actual carrier RF, since there is no need to allow room for filter "skirts". The second implication of this result is one of practicality; Any analog processing which follows this portion of the electronics need only operate at the modulation frequency (as opposed to at RF). Time delay and slew rate now become the chief design considerations from this point on in the circuit, rather than RF bandwidth.

Implementing The Block Diagram

A schematic for the envelope detector as constructed is shown in Figures 2a and 2b. The drawing is divided into three basic sections; vector decomposition, vector magnitude computation and post processing gain/offset/distribution. Amplifier U1 is used to scale the maximum amplitude of the modulated RF to 2 Vpp. This upper limit is a constraint imposed by the maximum input voltage to the vector magnitude section (the vector decomposition section has unity gain). Potentiometer R1 is calibrated such that the peak carrier voltage applied to the input of the circuit results in +1 Vpk at the output of U1. This adjustment matches the input signal to the AD834s to make full use of their dynamic range.

Quadrature Phase Division

The 90° phase split can be accomplished using a good quality quadrature power divider, many of which are available commercially. Using such a device provides a quick, easy solution for frequencies above approximately 100 kHz, particularly if wideband carrier reception is not a main concern. Active all-pass networks [1] are a good choice for carriers in the HF frequency range and below, especially for applications where a 90° splitter doesn't exist "off the shelf" or when its cost is prohibitively expensive. The advantage to using an active all-pass network as opposed to a passive one is the amplitude match afforded by using operational amplifiers. The use of

ICM®

948 Years Experience!

When reliability and accuracy count, call us. 948 years of combined employee crystal experience and 43 years of service to businesses like yours translates into our dedication to the quality products and customer satisfaction that you deserve.

- ENGINEERING AND DESIGN SUPPORT
- EXPERIENCED SALES STAFF
- CRYSTAL ANALYSIS
- EXPEDITE SERVICE
- CUSTOM CRYSTALS TO YOUR SPECS
- MICRO-BALANCED/LAB CRYSTALS
- SOON TO BE ISO 9001 CERTIFIED
- LIFETIME CRYSTAL GUARANTEE

Call or FAX for more information about Crystals, Elements, Oscillators and Accessories.

WHEN QUALITY COUNTS. . .

INTERNATIONAL CRYSTAL MANUFACTURING CO., INC.

PHONE 1-800-725-1426 • 24-HOUR FAX 1-800-322-9426

P.O. BOX 26330 • OKLAHOMA CITY, OK 73126

INFO/CARD 29

THE INDUSTRY STANDARD FILTER DESIGN SOFTWARE.

S/FILSYN™

The Most Powerful and General Filter Design Program

- Passive LC
- Crystal
- Microwave
- Active RC
- Switched Capacitor
- IIR and FIR Digital Filters

...is still unsurpassed by any other filter-design program in existence.

New 3.0

New Version 3.0 is now available with New Features, New Manual and New LOW Prices.

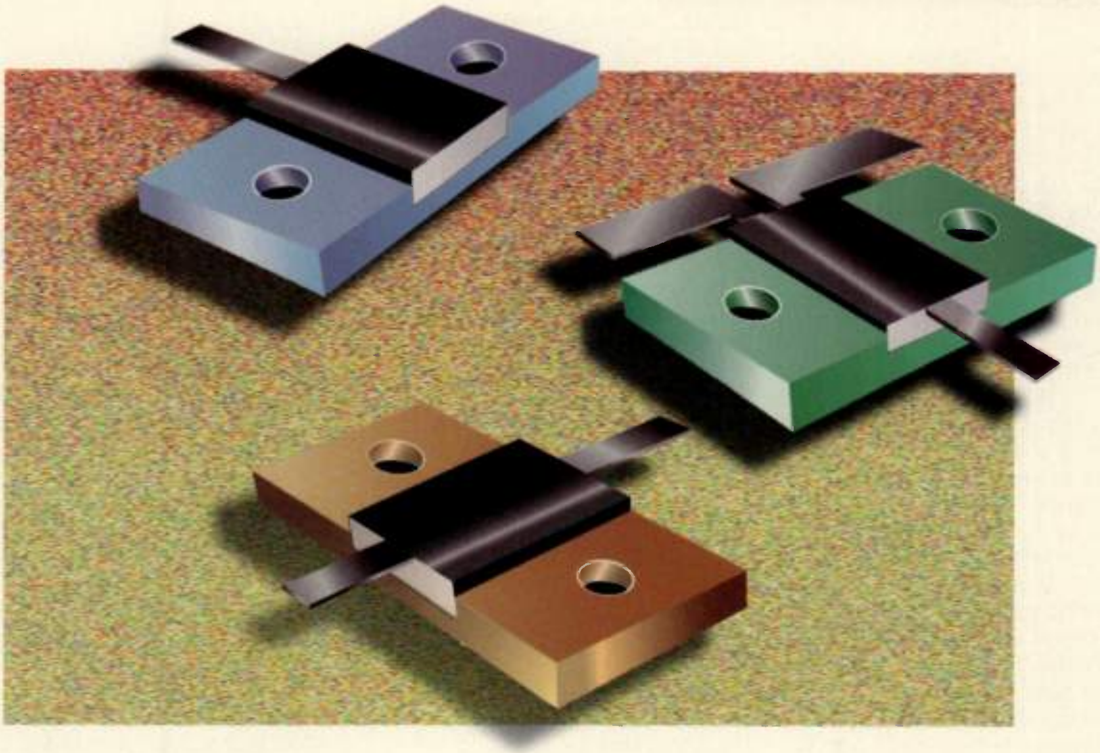
The program that provides more options, more accuracy, more implementations and more efficient solutions–S/FILSYN

For information, brochures & prices 415/325-4373

DGS ASSOCIATES, INC. FAX 415/325-7278

INFO/CARD 30

QUALITY
Reliability
EXCELLENCE
PERFORMANCE
Innovation



125 - 150 - 250 and 500 Watt
50 and 75 Ohm
DC-3 GHz

We Are The
Last Word In Hybrid
Attenuators, Terminations
& Resistors

JFW 15 YEARS OF QUALITY

JFW Industries, Inc.
5134 Commerce Square Drive
Indianapolis, Indiana 46237
Tel. 317-887-1340
Fax 317-881-6790

INFO/CARD 31

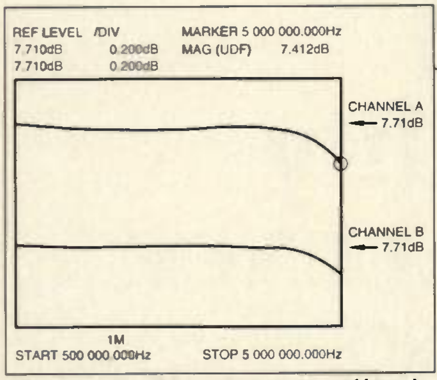


Figure 3. Absolute amplitude response of both quadrature outputs.

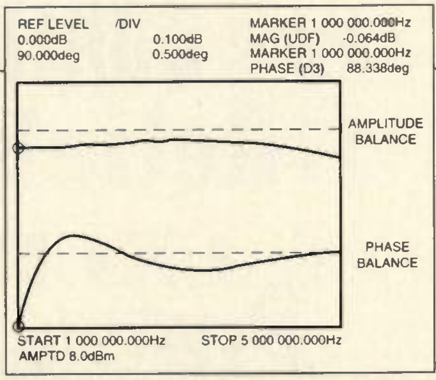


Figure 4. Relative amplitude and phase balance of the two quarature outputs.

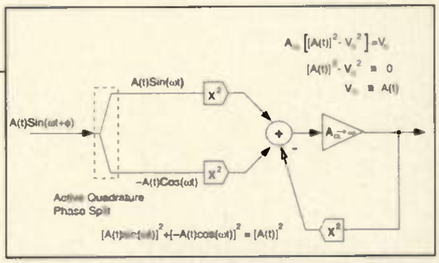


Figure 5. Block diagram of detector showing squaring function in feedback loop which performs square root extraction.

feedback provides a very flat amplitude response, resulting in a broadband amplitude balance between quadrature outputs that is difficult to match using passive networks. An active phase split also provides gain to preserve the original amplitude of the input signal, eliminating the $1/\sqrt{2}$ scaling factor associated with a power divider. Broader-band operation can be accomplished by simply cascading additional sections, without incurring an appreciable loss in carrier signal or a significant increase in amplitude ripple.

The decision of which 90° phase shifting technique to use was based upon amplitude balance, cost and frequency range requirements. The detector circuit shown in Figure 2 uses AD847 high speed op-amps to realize a pair of three section active all-pass networks, which provide quadrature outputs over a frequency range of 1 to 5 MHz. The AD847 is a voltage feedback operational amplifier, selected for its high speed at unity gain, as well as its amplitude and phase characteristics at the carrier frequencies of interest. Figure 3 shows the absolute amplitude response of both quadrature outputs. The constant level shift between the two plots is primarily due to the non-exact component value match of the resistors used for reverse termination of each output. Note the response flatness out to just above 3 MHz, where the plots begin a slight roll off. Though down by only 0.3 dB at 5 MHz, this translates directly into a 0.3 dB amplitude error for the overall detector. The vector sum circuitry cannot distinguish between a change in amplitude at the input to the detector or changes in the response characteristic of the quadrature splitter. For this reason, it is important to minimize both the absolute response ripple and the relative amplitude imbalance between outputs of the splitter within the desired band of operation, especially if the envelope detector is to be used in a high accuracy application.

The relative amplitude imbalance and deviation from quadrature phase for the active splitter outputs is shown in Figure 4. The worst-case phase deviation is ≅1.7° at 1 MHz, the low end of the frequency band of interest. In general, deviations from 90° of a few percent will have minimal effect on the vector sum [2,3] (and hence on the overall envelope detection error).

Sum of Squares Function

The next step in implementing the block diagram of Figure 1 involves squaring each of the quadrature modulated carriers. It is desirable to use variable transconductance type multipliers (as opposed to RF mixers) to carry out this function, to eliminate any need for filtering unwanted harmonics at the output. Each carrier is applied to both inputs of its associated multiplier. The resulting outputs are then

$$[A(t)\sin(\omega t)]^2 = \frac{A(t)^2}{2}\,[1-\cos(2\omega t)] \qquad (4)$$

$$[-A(t)\cos(\omega t)]^2 = \frac{A(t)^2}{2}\,[1+\cos(2\omega t)]$$

where the modulation function A(t) is greater by a factor of $\sqrt{2}$ than in equation 3; This is a consequence of using an active 90° phase split as opposed to a power divider. As can be seen by equation 4, the multiplier chosen should be capable of operating at twice the carrier frequency. In addition it should be a four quadrant device, since both inputs must be capable of accommodating a bipolar signal.

The Analog Devices AD834 transconductance multiplier was selected for this application due to its excellent combination of accuracy, dynamic range and DC to 500 MHz bandwidth. The AD834 also has differential current outputs which can be paralleled with one or more similar devices, providing a convenient method of summing their outputs. Since current addition is inherently wideband, use of these multipliers eliminates the need for an additional DC coupled broadband summing device. Adding the outputs from both AD834s we obtain

$$408\text{mV}\left[\frac{A(t)^2}{2}\,[1-\cos(2\omega t)] + \frac{A(t)^2}{2}\,[1+\cos(2\omega t)]\right] = 408\text{mV}[A(t)]^2 \qquad (5)$$

where the 408 mV scaling factor is a result of the +4 mA output current of the AD834 (from its transfer function) through 51Ω resistors R66 and R67 in the schematic of Figure 2.

The differential nature of the AD834 outputs requires the use of a difference amplifier (e.g. an op-amp or an instrumentation amplifier) to convert the "sum of squares" into a single-ended voltage. The amplifier chosen for this purpose need not be capable of operation at the RF frequency; equation 5 illustrates that once the squares of the quadrature carriers are added together, all that remains is a scaled version of the square of the modulation term, devoid of any RF. Selection of an appropriate differential amplifier depends upon the delay and common mode input voltage handling of the amplifier, as well as on the slew rate and the bandwidth of the modulation. As indicated in the circuit schematic of Figure 2, an Analog Devices AD847 operational amplifier was chosen for this task.

Inspection of the circuit schematic in Figure 2b reveals that each AD834 is configured to output the negative of the square of its input. This is done as a practical matter to reduce crosstalk between the input and output pins. Since the same technique is applied to all three devices which contribute differential current to the summing node, only the sign

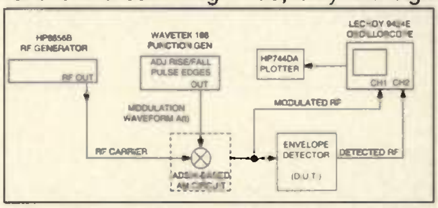


Figure 6. Test set-up for time domain performance evaluation.

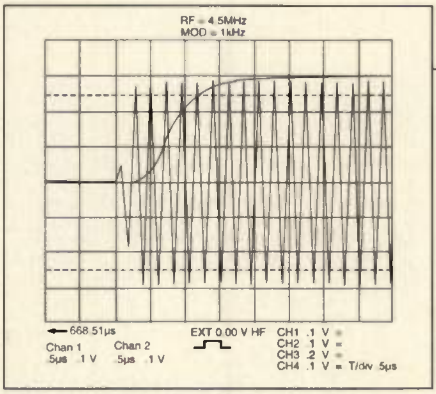


Figure 7a. Risetime of the constructed envelope detector.

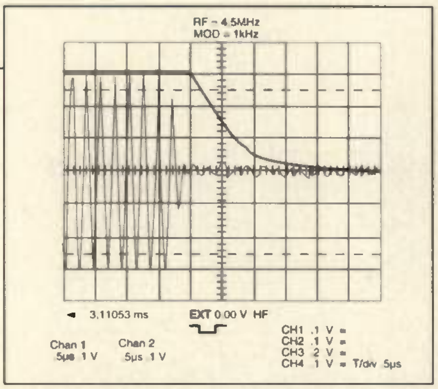


Figure 7b. Falltime of the constructed envelope detector.

of the final result is affected. The reader is directed to references [5] and [6] for information regarding the practical aspects of circuit design with the AD834 multiplier.

Square Root Function

To complete the analog vector sum computation (and hence reconstruct the modulating waveform A(t)), it is necessary to take the square root of the result found in equation 5. Several analog computational ICs capable of performing this calculation are available commercially. One should note, however, that this computational step presents significant limits on both the dynamic range and time delay specifications for the overall envelope detector. For example, a 40 dB dynamic range at the output of the square-root function (the output of the detector) necessitates an 80 dB range at its input. In addition, the device selected needs to have sufficient bandwidth to accommodate both the expected modulation frequency and the overall delay specifications for the circuit.

For the constructed envelope detector, a squarer is placed in the feedback loop of an operational amplifier to approximate the square root function shown in Figure 1 [4]. This particular computational method was selected because it allows us to further capitalize on the benefits of the current summing technique used to implement the "sum of squares" in equation 5. In this case, a third AD834 multiplier operates as the squaring device. The output of the third AD834 is simply paralleled with the outputs from the two previous multipliers, but with its two output pins reversed. This has the effect of subtracting the differential output current of the third AD834 from the sum of the other two. [Note, however, that the common mode currents of all three multipliers still add]. The difference voltage across the summing node is amplified by the full open loop gain of the AD847 operational amplifier, which changes its output voltage until the voltage at both its inputs are equal (i.e., the differential summing node nulls to zero). A simplified block diagram representation of this feedback loop is illustrated in Figure 5. This diagram is meant as a generalized illustration of the envelope detector. As such, the scaling details of the AD834s used to effect the squaring function blocks have been left out for clarity. (It can be seen from the schematic of Figure 2b that each multipli-

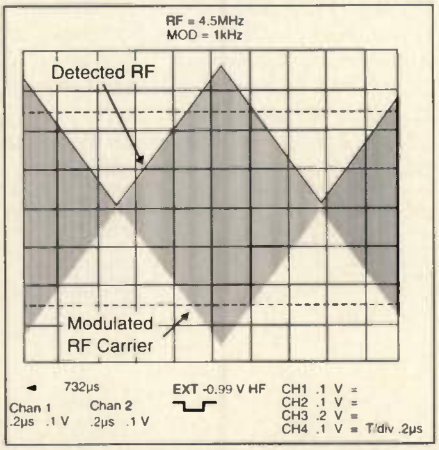


Figure 8a. Overlay of modulated carrier and detected RF.

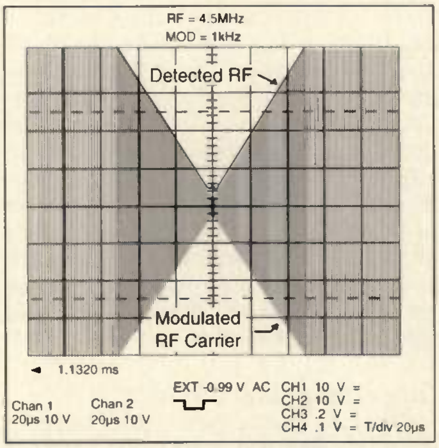
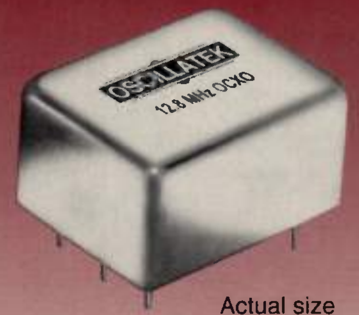


Figure 8b. Expanded view of modulated carrier and deteced RF.

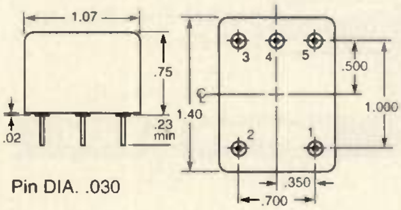
LOW COST OCXO



Actual size

Oscillatek manufactures OCXO's in a wide assortment of packages. This SMALL PACKAGE OCXO is available from:

1.0 to 50.0 MHz



Pin DIA. .030

PIN	1	2	3	4	5
Function	OUT	GND	VCO-IN	VCO-REF	SUPPLY

Output	TTL, HCMOS or SINE
Stability	To 1×10^{-8} 0° to 50°C
	or 5×10^{-8} -40° to +85°C
Supply	+5, 12, 15 or 24.0 VDC
Supply	<3 watts at turn-on
Tuning	Electrical

Oscillatek manufactures a complete line of military, aerospace and commercial:

OCXO's & OVCXO's
TCXO's & VCXO's
HYBRID CLOCKS
QPL CLOCKS

OSCILLATEK

A DOVER TECHNOLOGIES COMPANY

620 NORTH LINDENWOOD
OLATHE, KS 66062
FAX (913) 829-3505
PH. (913) 829-1777

INFO/CARD 32

Radio Links

- Eliminate leaseline and wireline costs
- Aggressively priced with quantity discounts available
- Transmitter and receiver links in VHF, UHF and 900 MHz are designed specifically for high-performance data transmission
- Utility data system accommodates audio inputs (modem tones) or TTL-level digital inputs
- RS-232 radio modems available in VHF, UHF and spread-spectrum (unlicensed) frequencies
- A two-way radio manufacturer for more than 30 years

Repco Aerotron-Repco Sales, Inc.
1-800-950-5633
2400 Sand Lake Road
Orlando, Florida 32809

Dealer Inquiries Invited

INFO/CARD 33

CERAMIC RF CAPACITORS
C-D/SANGAMO
MICA RF CAPACITORS

JENNINGS
VACUUM CAPACITORS
VACUUM RELAYS

SURCOM ASSOCIATES, INC.
2215 Faraday Avenue, Suite A
Carlsbad, California 92008
TEL (619) 438-4420
FAX (619) 438-4759

INFO/CARD 34

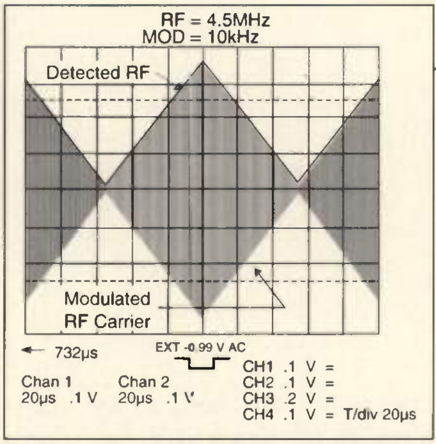


Figure 9a. Overlay of modulated carrier and detected RF.

er is actually configured to output a scaled version of the negative square of its input).

As shown in the diagram, the output of the summing junction is multiplied by the open loop gain of the amplifier, resulting in

$$A_{OL}\left\{\left[A(t)\sin(\omega t)\right]^2 + \left[-A(t)\cos(\omega t)\right]^2 - V_0^2\right\} = V_0 \tag{6}$$

If the open loop gain is assumed to be large ($A_{OL} \cong 70$ dB for the AD847), then

$$(A(t)\sin(\omega t))^2 + (-A(t)\cos(\omega t))^2 - V_0^2 \Rightarrow 0 \tag{7}$$

where each term on the left side of the equation represents the differential output from one of the three multipliers. Substituting equation 5 into 7 and solving for V_0 results in

$$A(t)^2 - V_0^2 \approx 0 \tag{8}$$

$$V_0 \approx A(t)$$

The voltage appearing at the output of the AD847 is thus "the square root of the sum of the squares", which is essentially the DC-coupled vector sum of the quadrature amplitude modulated carriers. This approximation also holds true when using the AD834s to effect the squaring functions in Figure 5; The high open loop gain of the AD847 OP-AMP is more than enough to compensate for the 0.408 scaling factor of the multipliers (±4 mA full scale output into 102Ω, as compared with their ±1 V input amplitude).

Other Peripheral Circuitry

One half of amplifier U15 is used to adjust the gain and offset of the detected RF (this particular adjustment is application specific). U15-U20 serve to buffer and distribute the detected RF, with each

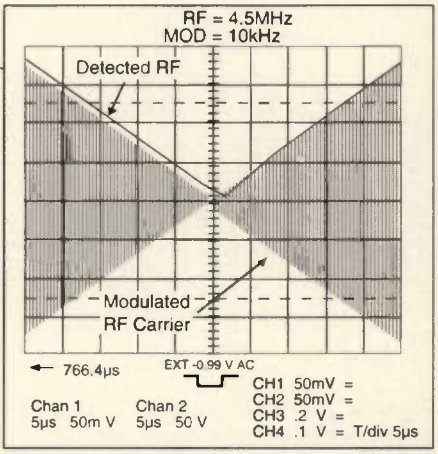


Figure 9b. Expanded view of modulated carrier and detected RF.

output capable of driving a 50Ω load. A regulated supply is important for this circuit because the AD 834s have current source outputs.

Results

To evaluate the performance of the constructed envelope detector it is necessary to have some method of amplitude modulating an RF carrier. The performance of the modulator must meet or exceed that of the envelope detector if the test results are to be meaningful. For the results presented here, the device used to accomplish this task is a circuit based on the AD834 multiplier.

Figure 6 shows the test set-up used for the time domain plots of Figures 7a and 7b. The Wavetek function generator is first set to output a square pulse as the amplitude modulating function A(t) for the purpose of measuring the rise and fall times of the envelope detector. The RF source is set to output a carrier frequency of 4.5 MHz at the maximum amplitude acceptable to the modulator. Figure 7(a) shows the rise time of the envelope detector to be on the order of 1 µs (10%-90%); The plot also indicates an additional propagation delay time from input to output of about 400 nsec. The fall time of the detector under test is shown in Figure 7(b) to be approximately 1.5 usec.

Next, the function generator is set to output a triangular waveform at a modu-

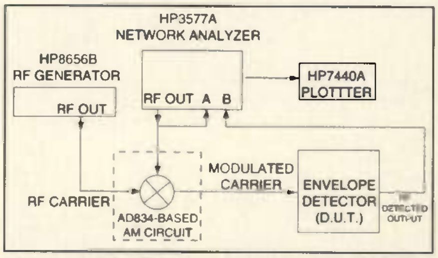


Figure 10. Test set-up for network analyzer based measurements.

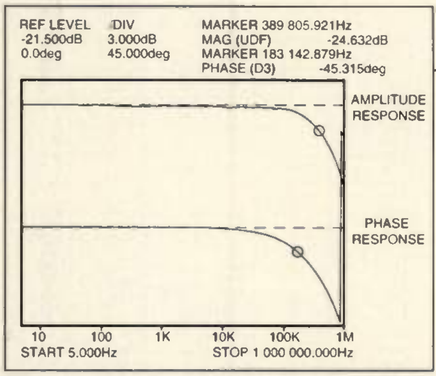


Figure 11. Comparison of detected RF with modulation signal.

lation frequency of 1 kHz. The amplitude of the waveform is adjusted to achieve close to 100% modulation of the carrier. Figure 8(a) shows the oscilloscope traces of both the modulated 4.5 MHz carrier and the detected RF (both traces overlay one another). Figure 8(b) is an expanded view, showing the amount of "failure to follow" distortion at low signal levels. These plots give a rough indication of the linearity and dynamic range for the detector, and can be used for initial circuit alignment. The lower bound on the dynamic range is minimized by adjusting the "zero input offset" potentiometer. Post processing gain and offset adjustments are determined by the particular application requirements for the circuit. Figures 9(a) and 9(b) are similar plots, at a modulation frequency of 10 kHz.

Figure 10 illustrates the set-up used to obtain the plots in Figures 11 through 14.

For these measurements, an HP3577A network analyzer is used to modulate the RF with a swept sinusoid. The output of the envelope detector is then compared with the original modulating waveform to determine its accuracy under a variety of carrier conditions. For the tests that follow, the AD834-based modulating circuit shown in the diagram is adjusted to provide approximately 20% carrier modulation. The reader should note that the following results represent the performance of the modulator/envelope detector pair, since the modulator is in fact inside the measurement loop of the network analyzer. The delay performance of the modulator is expected to be better than that of the detector because of its 30 MHz bandwidth. Amplitude accuracy and dynamic range, however, are expected to be similar, based upon these specifications for individual components utilized in the modulator circuitry.

The plot of Figure 11 shows the amplitude and phase response of the envelope detector for a single carrier frequency of f_{rf}=4.5 MHz, with the modulating signal swept from 5 Hz to 1 MHz. The top trace is the amplitude response (3 dB/div), indicating a −3dB bandwidth of just below 390 kHz. A high degree of amplitude accuracy is indicated by the response flatness, which is shown to be better than 0.5 dB (+0.25 dB) up to a modulation frequency of 100 kHz. For those applications requiring the detector to reside within a feedback loop, trace 2 is the phase response (45°/div) of the detector. The circuit exhibits 45° of phase shift at a modulation frequency of approximately 180 kHz.

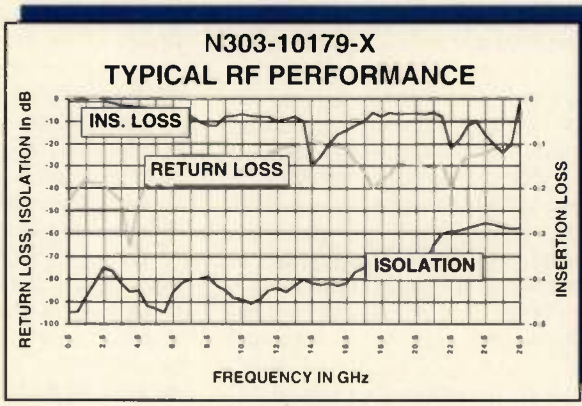
Figure 12 consists of 10 individual amplitude response plots, overlaid on the same graph. The plots are intended to show the dynamic range of the detector with respect to the amplitude of the carrier signal. Each of the traces results from a 5 dB decrease in carrier amplitude. [In each case, the carrier has approximately 20% amplitude modulation]. The demodulation bandwidth does not start to significantly decrease until

SWITCH TO ARROWSMITH!

For All Your Microwave Switch Needs – The N-Series Microwave Switches from Arrowsmith Shelburne

DESIGN IN HIGH QUALITY AND SUPERIOR PERFORMANCE AT A REASONABLE COST

The N series switches are available with 50 or 75 ohm impedance SMA, SMB, BNC, TNC, F, and N type connectors. Custom voltages are available. Other options include TTL compatability, self de-energizing, indicator circuitry and suppression diodes. Please contact a sales representative for price and availability today.



ARROWSMITH Shelburne, Inc.

2085 Shelburne Road • Shelburne, Vermont 05482
802-985-8621 • FAX: 802-985-1042

INFO/CARD 35

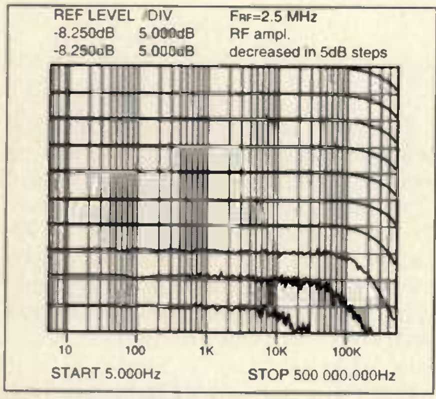


Figure 12. Detected RF vs. modulation frequency for various carrier amplitudes.

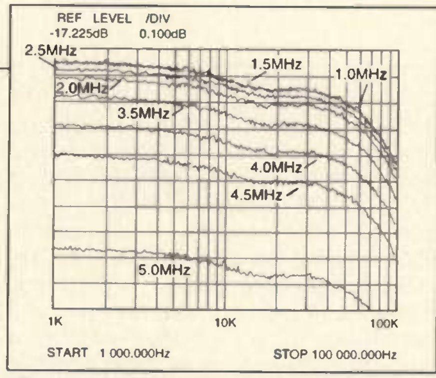


Figure 13. Envelope detector output versus modulation frequency at different carrier frequencies.

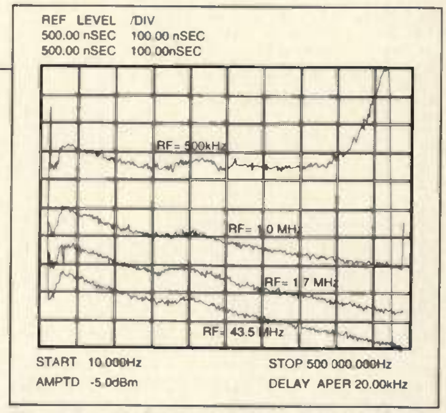


Figure 14. Time delay for various carrier frequencies.

the carrier is approximately 35 dB down from its maximum amplitude. The detector circuit is still observed to be usable to –45 dB, but with modulation bandwidths only up to 10 kHz.

It is also desired to evaluate the envelope detector at different carrier frequencies, since the circuit constructed was designed to operate with carrier frequencies over a span of 1 MHz - 5 MHz. The results of such a measurement are shown in Figure 13. For this test, the modulation frequency is swept from 1 kHz to 100 kHz. Since we are looking for small (on the order of tenths of a dB) changes, the upper modulation frequency was limited to 100 kHz for the purpose of expanding the scale per division of the plot. Each trace in the figure represents a different carrier frequency, ranging from 1.0 MHz to 5.0 MHz in 500 kHz increments.

Note that the shape of all nine plots are similar. From the graph, carrier frequencies from 1 to 3 MHz are clustered within 0.07 dB of one another. Significant amplitude errors begin to be observed above approximately 3 MHz, some of which can be accounted for in Figure 3 (the amplitude response of the quadrature phase split circuitry). It should be noted here that the device used to modulate the RF in the test set-up (the AD834-based modulator in Figure 10) has as part of its circuitry a low pass filter with a nominal cutoff frequency (–3dB) of 6 MHz. The response roll-off of this LPF is believed to be predominantly responsible for the relatively large apparent decrease in amplitude accuracy as the carrier frequency is increased above 4.5 MHz. In other words, the envelope detector is actually responding to the soft portion of the LPF's roll-off.

The final plot, presented in Figure 14, shows the delay of the circuit for various carrier frequencies. In this measurement, the modulation frequency is swept from 10 Hz (the lowest frequency available from the network analyzer) to 500 kHz. The upper modulation frequency and lower carrier frequency were purposely chosen to coincide. It is interesting to note that the envelope detector is capable of demodulating frequencies approaching that of the carrier; this is possible because no explicit filtering is used during the AM detection process.

Conclusion

An envelope detector circuit has been developed which operates over a carrier range of 1 MHz to 5 MHz. Specific delay requirements prevented the use of classical rectifier or product detector techniques, which depend on low pass filtering to extract the modulation signal. To minimize the overall response time of the envelope detector, a vector addition technique is used to null the carrier while keeping the modulation intact. The circuit presented is implemented using currently available high speed analog transconductance multipliers, and achieves amplitude demodulation at frequencies approaching that of the carrier, without the long time constants usually associated with other detection methods. The specific RF carrier bandwidth is easily modified by replacing the active all-pass section of the circuit with a 90° power divider, appropriately selected (or designed) to effect the desired overall detector amplitude accuracy.

Test results for the envelope detector constructed have been presented to evaluate the device under varying conditions of modulation frequency, carrier amplitude and carrier frequency. In addition to its µs response time, use of the vector processing method allows the device to provide accurate envelope detection over a wide dynamic range. The dynamic range of the device is measured to exceed 35 dB for modulation signals up to 100 kHz (45 dB for modulation below 10 kHz).

Acknowledgments

The author wishes to express his appreciation to Dr. J.M. Brennan for his consultation and incitement throughout the design of this circuit, and for his review of the manuscript. This work was performed under the auspices of the U.S. Department of Energy. *RF*

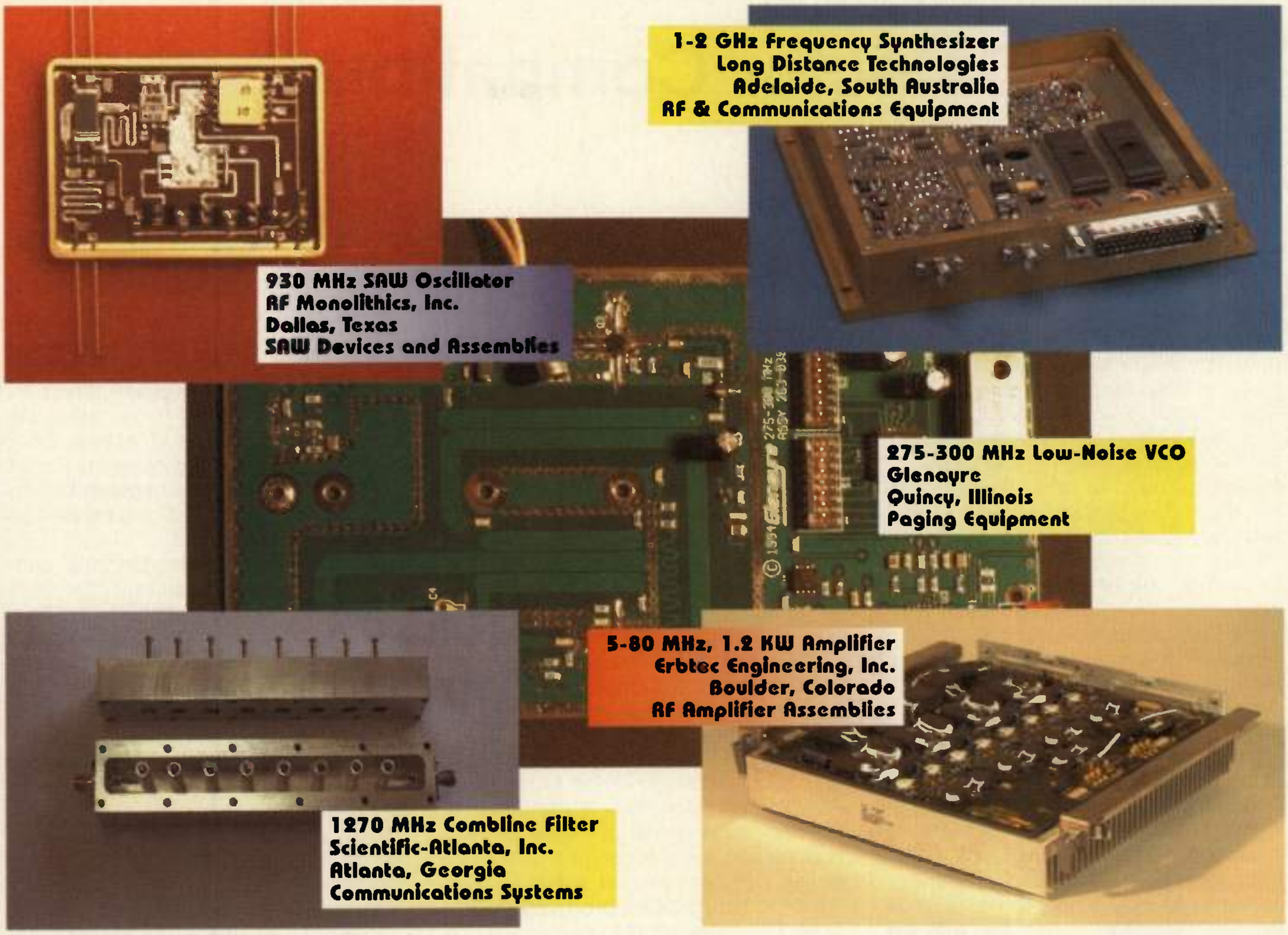
References

1. Williams, A.B., and Taylor, F.J., *Electronic Filter Design Handbook: LC, Active, and Digital Filters*, 2nd. ed., McGraw-Hill Book Company, New York, 1988.
2. Tuckman, M., "I-Q Vector Modulator-The Ideal Control Component?," *MSN & CT*, May 1988, pp.105-115.
3. Ciardullo, D.J., "A High Accuracy Phase Shifter Based On A Vector Modulator," *RF Design*, October 1993, pp. I06-114.
4. Sheingold, D.H., ed., *Nonlinear Circuits Handbook*. Norwood, MA: Analog Devices Inc., January 1976.
5. Elbert, M. and Gilbert, B., "Using the AD834 in DC to 500 MHz Applications: RMS-to-DC Conversion, Voltage-Controlled Amplifiers, and Video Switches," Analog Devices Application Note #AN-212.
6. *1992 Special Linear Reference Manual*, Analog Devices Inc.
7. Clarke, K.K., and Hess, D.T., *Communication Circuits: Analysis and Design*, Addison-Wesley Publishing Company, Reading Massachusetts, 1978.
8. Couch, L.W., *Digital and Analog Communication Systems*, second edition, Macmillan Publishing Company, New York, 1987.

About the Author

Dominic J. Ciardullo is a Research Engineer in the Low Level RF group at Brookhaven National Laboratory. He received an Associates Degree in Engineering Science from Nassau Community College, BSEE from Rensselaer Polytechnic Institute and MSEE from the Polytechnic University. He is on the adjunct staff in the Ens./Phy./Tech. department at Nassau Community College. He can be reached at Brookhaven National Laboratory, Building 911B, Upton, NY 11973

WHAT DO THESE PRODUCTS HAVE IN COMMON?



THEY WERE DESIGNED WITH SYSTEM 32 SOFTWARE!

Every day thousands of Eagleware customers worldwide use our state-of-the-art software to design state-of-the-art products. Join this elite group who look to Eagleware for a wide range of accurate and easy-to-use programs and direct factory support with no annual fees.

YOU SELECT PROGRAMS AND OPERATING SYSTEMS

MS DOS

MICROSOFT. WINDOWS.

MICROSOFT. WINDOWS NT.

M/FILTER
=OSCILLATOR=
=MATCH=
=FILTER=
=SuperStar=
HIGH-SPEED SIMULATOR
=SCHEMAX=
UTILITIES

System 32 programs run under DOS, Microsoft Windows and Windows NT. Windows programs are 32-bit for fast and robust multi-program operation. User created files in all operating systems are exchangable for sharing with coworkers and painless future upgrading.

SAME PRICES INTERNATIONALLY
DIRECT SALES & USER SUPPORT
BY FAX, PHONE OR LETTER

EAGLEWARE

Eagleware Corporation ★ 1750 Mountain Glen ★ Stone Mtn, GA 30087 ★ USA
TEL (404) 939-0156 ★ FAX (404) 939-0157

INFO/CARD 36

An AM Detector Compatible With SSB-SC

By Chase P. Hearn
NASA

A recent article [1] presented an AM detection circuit which is basically a correlation detector. The local oscillator (LO) signal was generated with a zero-crossing detector driven from the input signal, which is basically an amplitude-limiting operation. The carrier phase of an AM signal is (ideally) unaffected by the sidebands, so ideal limiting produces a constant-amplitude signal which is phase coherent with the carrier. This LO signal actuated an analog gate to perform the required multiplication operation. This implementation produced the desired linear relationship between the input signal and the demodulated output over a 50 dB dynamic range.

Another approach to correlation detection is diagrammed in Figure I. The LO is also derived from the input signal, but the carrier is extracted by a passive narrowband filter ($B_c < 0.1\ B_{IF}$) prior to limiting. This extends linear operation to input signal-to noise ratios (SNRs) lower than is possible with the usual envelope detector. This approach avoids the acquisition problems associated with a phase-locked-loop (PLL) carrier filter. The original application involved post-detection filtering of discrete sidebands in a bandwidth much less than B_{IF}. The design goal was linear detection at SNRs in B_{IF} as low as zero dB, and a dynamic range of 60 dB. These goals were fully met.

This approach is also applicable to the detection of single sideband-supressed carrier (SSB-SC) signals if there is sufficient residual carrier to be regenerated and maintain at least a 7-8 dB carrier-to-noise ratio (CNR) in the carrier-filter bandwidth, B_c. This was found to be possible except with very weak signals or unusually high carrier suppression. Carrier bandwidths between 300 and 30 Hz were evaluated, which provided CNR improvements of 14 to 24 dB with B_{IF} = 8 kHz. When the CNR in B_c becomes too low, the detected audio quality suffers, and better performance is obtained with an independent LO signal, as normally used for SSB detection.

The operational behavior of this circuit is noticeably different from a diode AM detector. The difference between correct and incorrect tuning is more prominent, and is characteristic of the locking of a PLL demodulator. This is attributed to the narrow bandwidth of the carrier filter and the frequency-dependent differential phase shift between the signal and LO inputs to the multiplier produced by that filter. The detection gain of a correlation detector is dependent on that phase difference, so a phase-trim adjustment may be needed in one path to set the phase difference at the detector inputs to 0 or 180 degrees with the carrier centered in B_c.

Also, care should be taken to minimize level dependent phase shift (AM-PM conversion) through the limiter. In SSB reception, sideband energy can fall within B_c if it is too wide, and produce sideband-dependent phase modulation of the regenerated carrier when the resulting carrier-to-interference ratio is much less than 10 dB. This modulation dependent LO "phase jitter" affects the demodulation process in the same way additive input noise affects a diode envelope detector: the optimum (coherent) phase relationship between the signal and LO is corrupted, and the demodulated output degraded.

A detailed circuit diagram of a "compatible linear demodulator," or CLD, operating at 500 kHz is shown in Figure 2 [2]. The CA-3089E is a multi-function IC designed as a quadrature FM detector; only the limiter and product detector are used in this application. The source-follower input amplifier was added to provide an input resistance compatible with vacuum tube circuitry. The carrier bandpass filter consisted of two series resonant crystals coupled capacitively to produce a B_c of approximately 75 Hz. A bandwidth of 300 Hz and a single-pole response was found satisfactory for AM operation, but smaller bandwidths and steeper skirt selectivity produced better SSB reception at the expense of more critical tuning. This is appreciated by noting that with B_c=30 Hz, a receiver (LO) drift of 15 Hz would produce a large signal-LO differential phase shift at the demodulator inputs.

Circuit evaluation consisted of quantitative dynamic range and distortion measurements and listening to AM broadcast, radio amateur and short-

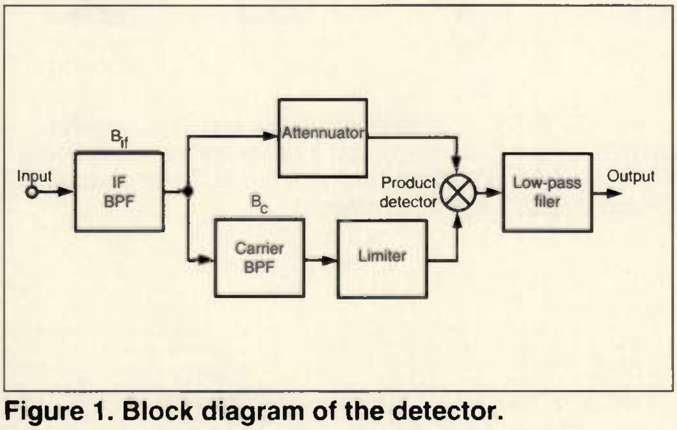


Figure 1. Block diagram of the detector.

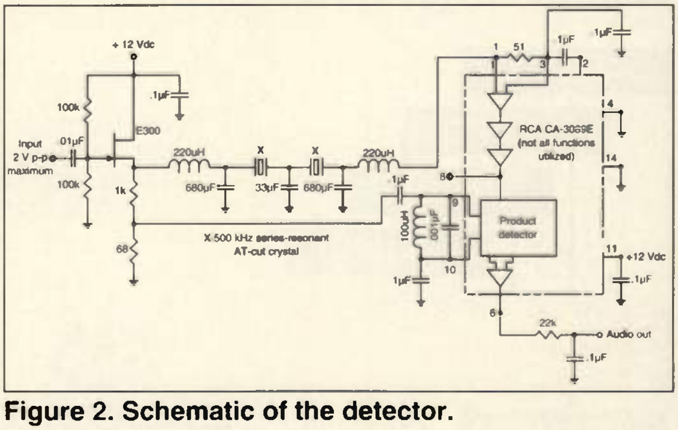
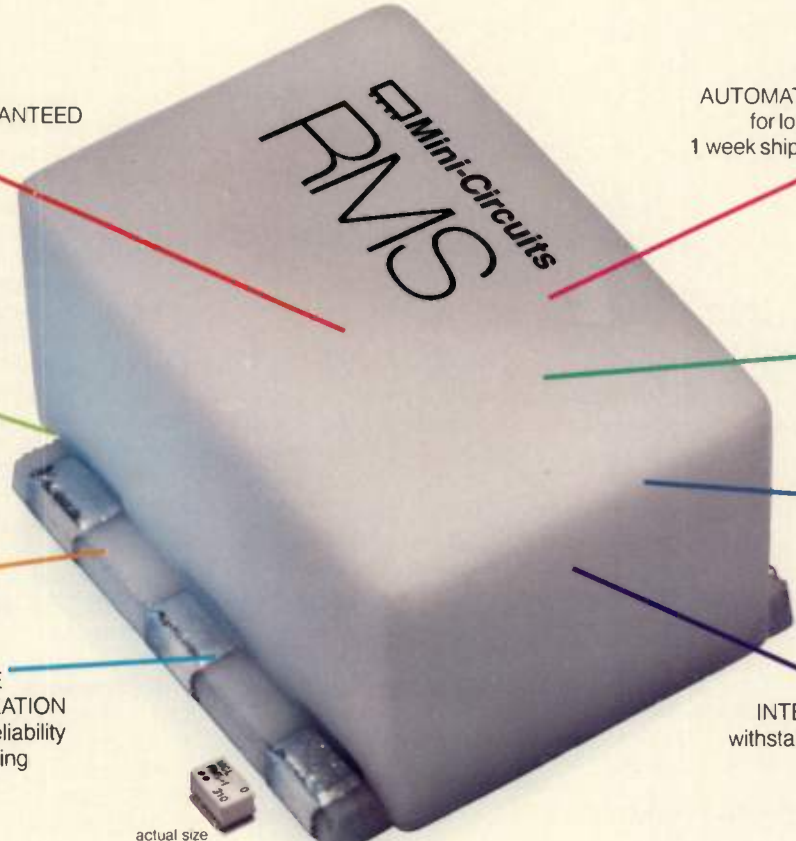


Figure 2. Schematic of the detector.

MIXERS UNPRECEDENTED IN VALUE.



4.5 SIGMA
REPEATABILITY GUARANTEED

AUTOMATED ASSEMBLY
for low-cost and
1 week shipment guaranteed

ALL-CERAMIC PACKAGE
cover pull strength
in excess of 20 lbs.

ULTRA•REL™ MIXERS
5 YEAR GUARANTEE

RUGGED CONSTRUCTION
passes MIL-M-28837
shock and vibration tests

SURFACE MOUNT
board area .25 x .30"
tape and reel available

SOLDER PLATE
OVER NICKEL METALIZATION
improves solder reflow reliability
and eliminates leaching

ALL-WELDED
INTERNAL CONSTRUCTION
withstands up to 240°C for 5 minutes

actual size

ALL-CERAMIC 5 to 3000MHz from $3.95 (10-49 qty)

Now you can buy very low-cost, high-performance commercial mixers with the ruggedness and reliability required for military applications. That's value! ...Only from Mini-Circuits.

Model	LO (dBm)	Freq. (MHz) LO,RF	Freq. (MHz) IF	Midband, dB Conv. Loss	Midband, dB Isol L-R	Midband, dB Isol L-I	$ ea. (10-49)
RMS-11X	+7	5-1900	5-1000	7.1	29	31	3.95
RMS-11F	+7	350-2000	DC-400	5.5	31	30	4.95
RMS-30	+7	200-3000	DC-1000	6.5	26	22	6.95
RMS-25MH	+13	5-2500	5-1500	7.5	32	32	7.95

finding new ways...
setting higher standards

Mini-Circuits®

WE ACCEPT AMERICAN EXPRESS AND VISA

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661

Distribution Centers / NORTH AMERICA 800-654-7949 • 417-335-5935 Fax 417-335-5945 EUROPE 44-252-835094 Fax 44-252-837010

For detailed specs on all Mini-Circuits products refer to • THOMAS REGISTER Vol. 23 • MICROWAVES PRODUCT DIRECTORY • EEM • MINI-CIRCUITS' 740-pg HANDBOOK.

CUSTOM PRODUCT NEEDS... ***Let Our Experience Work For You.***

F166 REV. ORIG.

INFO/CARD 37

AT&T Job Opportunities

We currently have immediate opportunities available at our AT&T Microelectronics locations in North Andover, Massachusetts and Northern New Jersey for the following Engineering positions:

The following positions will be located in North Andover, Massachusetts:

Crystal Oscillator & Piezoelectric Engineers:

Opportunities available for candidates with expertise in one or more of the following areas:

- SAW Filter Design
- BAW Resonator Design
- Custom Mixed Mode CMOS and/or Bipolar ASIC Design
- SAW Based Product Design
- BAW Based Product Design

Educational requirements include an MS, or PhD in Physics, and Electrical or Mechanical Engineering.

The following positions will be located in Northern New Jersey:

RF Engineers:

- Design and manufacture of large wireless telecommunications systems
- Experience in RF System design and/or manufacture (i.e., cell-site equipment)
- BSEE required

Electrical Engineers:

- Design and manufacture of large RF wireless telecommunications systems
- Focus on chassis, including power distribution, RF and wiring
- BSEE and experience in the above areas are required

Technicians:

- Support of product development and manufacture of large RF wireless systems
- AASET, or equivalent experience, is required

System Architects/System Engineers:

- Architecture and system specification of large RF wireless telecommunications systems
- Experience in large telecommunications systems definition and architecture are required (i.e., cellular applications).

Qualified candidates are invited to send their resumes, indicating position of interest, to: AT&T, Dept. 787/0725/94, Room 325, P.O. Box 636, Murray Hill, NJ 07974. An equal opportunity employer.

AT&T
The right choice.

INFO/CARD 38

wave transmissions, and subjectively comparing the performance to the internal diode detector in a military R-388 receiver.

The experimental detector was usable with AM inputs less than 10 µV to 0.1 volt, a dynamic range of more than 60 dB. Total harmonic distortion (THD) was at least −40 dB. The unusual tuning characteristic of the CLD was not found to be an operational problem; no further adjustment was necessary once the signal was properly "tuned in".

The CLD was judged to be marginally better when an AM signal was very weak and noticeably superior when strong selective fading was present. The detection linearity of a diode detector should be inferior to the CLD, but no linearity measurements were made on the R-388 diode detector.

Reception of SSB with the CLD was better with a 30 Hz filter bandwidth, probably because of sideband-induced phase jitter; however, the increased tuning sensitivity necessitated more operator attention and "tweaking" after the initial set-up than the R-388 detector. The SSB performance of the CLD degraded relative to the R-388 when the input signal was very weak, and the regenerated LO became excessively noisy. Detection of SSB with the R-388 was accomplished in the CW detection mode, using the CW beat oscillator, no AGC, maximum AF gain and minimum RF gain. In conclusion, this circuit was judged to be an excellent AM detector, but inferior to a good SSB demodulator with an independent LO for SSB reception. ***RF***

References

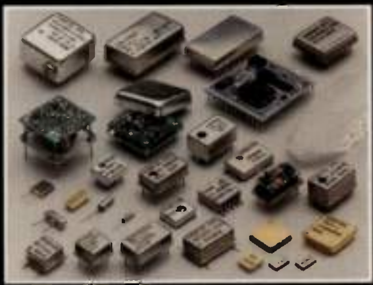
1. Reiser, James E, High Dynamic Range AM Detector, *RF Design*, June 1992, p. 69.
2. Hearn, Chase P., Demodulator for AM and SSB-SC Signals, *NASA Tech Briefs*, Winter 1983, p. 174.

About the Author

Chase P. Hearn has been a Research Engineer with NASA since 1961. His work there has involved analysis, design and development of circuits and systems spanning VLF to microwaves, and microwave measurement theory and practice. He has been a radio amateur since 1954 and currently enjoys "homebrewing", working with vacuum-tube equipment and the discrete-component technology of the fourties and fifties. He can be reached at 104 Glenwood Dr., Williamsburg, VA 23185.

RF PRODUCT SHOWCASE

CRYSTAL OSCILLATORS
AND THICK FILM HYBRID CUSTOMIZATION



- FREQUENCY RANGE 1Hz TO 1GHz.
- ECL, XO, VCXO, ECL, PECL, MECL, ECL in PS, 10K, 100K DIFFERENTIAL OUTS FOR SONET, LAN, ATM, DDS, AND OTHER DATA RECOVERY APPLICATIONS.
- HIGHER LIMIT (HIGH FREQUENCY CLOCK OSCILLATORS) CMOS, HCMOS, TTL, SINEWAVE TYPE OUTPUTS, UP TO 230MHz (VARY WITH OUTPUT LOGIC).
- TCXO'S, VCXO'S, TCVCXO'S ALL LOGIC OUTPUTS INCLUDING SINEWAVE IN DIP (.8" X .5" X .4") AND (1" X 1" X .5") PACKAGES.
- CLIPPED SINEWAVE TCXO, VCXO, TCVCXO FOR CELLULAR RADIO COMMUNICATION.
- CUSTOMIZATION TO YOUR REQUIREMENTS.

HYBRIDS INTERNATIONAL LTD
311 N. LINDENWOOD DRIVE / OLATHE, KANSAS 66062
PHONE: (913) 764-6400 • FAX (913) 764-6409

INFO/CARD 65

RF POWER AMPLIFIERS

200 W • 150-200 MHz • 55% Efficiency • 35dB Gain

1 MHz-2GHz 1W-1KW

- Small Size • High Efficiency • Durable
- Module and Rack Mount Systems
- Customization Available

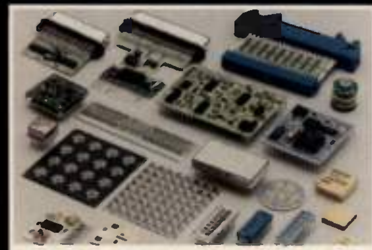
LCF ENTERPRISES
RF POWER AMPLIFIERS

651 Via Alondra, #712
Camarillo, CA 90312 USA
TEL: (805) 388-8454
FAX: (805) 389-5393

INFO/CARD 66

HYBRIDS INTERNATIONAL LTD
311 N. LINDENWOOD DRIVE / OLATHE, KANSAS 66062
PHONE: (913) 764-6400 • FAX (913) 764-6409

CUSTOM HYBRIDS-MCM TURN KEY MANUFACTURING
FAST TURNAROUND



- DIP'S, SIP'S, Custom Packages, Coating Choices. Any schematic with Resistors, Capacitors, Inductors, Diodes and other active components. Production and testing any volume. SMD Turn Key Assembly
- Hybrids, Die Attach, Wire Bond
- Laser Trimming Services

HYBRIDS INTERNATIONAL LTD
311 N. LINDENWOOD DRIVE / OLATHE, KANSAS 66062
PHONE: (913) 764-6400 • FAX (913) 764-6409

INFO/CARD 67

YOUR PRODUCT PHOTO

Don't miss the opportunity to have your product featured in the **NEW** RF PRODUCT SHOWCASE. Achieve results with four-color impact!

Call Carmen Hughes
1-800-443-4969

MTI MILLIREN TECHNOLOGIES, INC.

OCXO

Ultra Stable

2.00 x 2.00 x 1.52"
51 x 51 x 39 mm

260 Series

Model Number	260-0503	260-0502	260-0504
Frequency	5 MHz	10 MHz	5 MHz
Stability (-30/70°C)	2×10^{-9}	2×10^{-10}	2×10^{-10}
Aging (per day)	5×10^{-10}	3×10^{-10}	5×10^{-11}
Phase Noise			
1 Hz	-85 dBc	-95 dBc	-110 dBc
100 Hz	-140 dBc	-145 dBc	-150 dBc
10 kHz	-150 dBc	-160 dBc	-160 dBc

Two New Pasture Road, Newburyport, MA, 01950, USA
Tel: (508)465-6064 Fax: (508)465-6637

INFO/CARD 68

DIGITAL WIRELESS CORPORATION

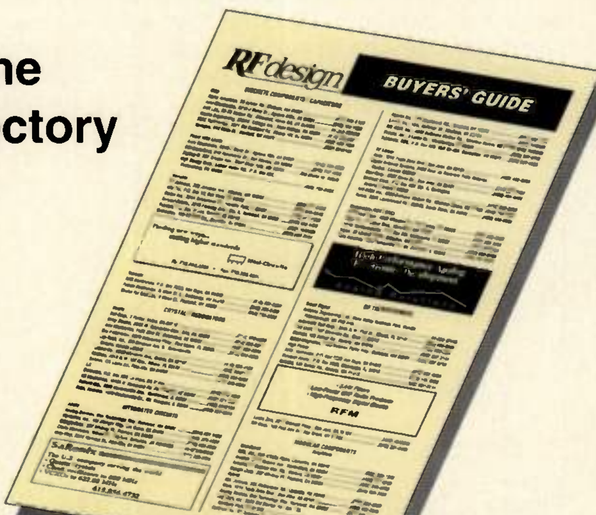
WIT 915
SPREAD SPECTRUM OEM TRANSCEIVER

- *Recombinant Spread Spectrum* prevents multipath fades.
- Ideal for OEM integration - only 2.3" x 2.9" x .8".
- 300 to 38.4 Kbit/s data rates, synch/asynch serial interface.
- 21 frequency channels in unlicensed 902-928 MHz band.
- Up to 1 Watt transmit power
- Full/half duplex, point-to-point or multi-point CSMA networks.

TEL (404) 325-4843 FAX (404) 315-6809

INFO/CARD 69

RF design
Introduces the Yellow Page Directory Section



CALL
1-800-443-4969
FOR
DETAILS ON
AN EXCITING
INTRODUCTORY
OFFER!

RF design
Classified Department
6151 Powers Ferry Road NW
Atlanta, GA 30339-2941
(404) 955-2500 Fax: (404) 618-0342

RF cover story

A High Power, Low Distortion Feed-Forward Amplifier

By Walter Koprowksi
Power Systems Technology Inc.

The use of sophisticated radio technology to provide basic telephone service has created a need for cost-effective high power amplifiers. The technical requirements are that each amplifier will handle 1-24 RF channels and provide high peak power output with low intermodulation products (–55 dBc). For this application, multiple amplifiers are installed in an unattended station that provides wireless telephone service to isolated subscribers and emergency services, and offers new choices for telephone service in developing countries.

Solid state amplifier technology has been in existence for over thirty years. The common design procedure is to choose the highest gain and power capability for the output transistors and then select the necessary driver stages for the overall gain required. A typical block diagram is shown in Figure 1.

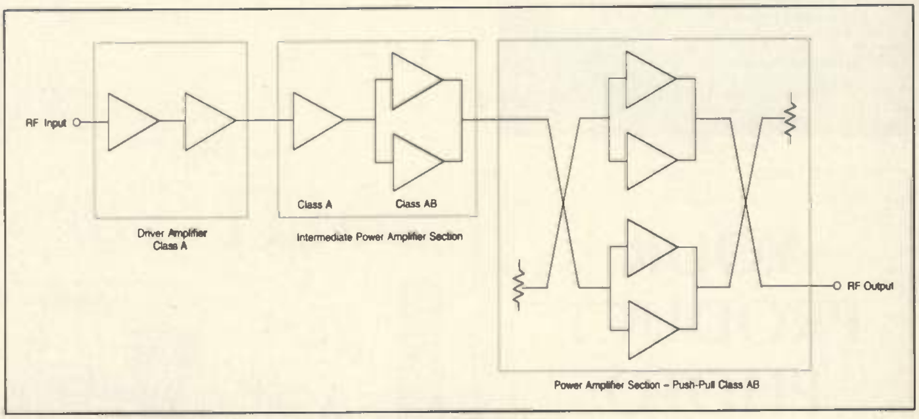


Figure 1. Standard high power amplifier design.

The driver stages are class A biased, low cost, high performance hybrid amplifiers. These amplifiers were specifically designed for low distortion and wide dynamic range performance required in the CATV industry. The output capability of the hybrid amplifiers is approximately 0.5 watt. Internally matched at both the input and output to 50 ohms, these amplifiers offer the design engineer a distinct advantage over the discrete transistor approach.

In the intermediate amplifier section are two discrete bipolar transistors. The first stage biased class A, and the second stage is a push-pull device biased for class AB operation.

The PA section of a standard high power amplifier is designed utilizing two push-pull transistors biased class AB which are connected together using a 3 dB quadrature hybrid for balance and good input/output VSWR. The advantage of using class AB is improved power output capability at a lower power consumption than a class A. However, the disadvantage is lower linearity performance. Typical performance of a class AB amplifier under two-equal-tone conditions is –30 dBc, as shown in Figure 2.

When confronted with a specification of –55 dBc intermodulation distortion at a given power output, the designer must either use a very large class A biased amplifier, or use some means of distortion cancellation.

Feed-Forward Cancellation

The concept of feed-forward cancellation has been used by manufacturers of hybrid CATV amplifiers for many years. The technique is to isolate the distortion of the power amplifier and re-inject it 180 degrees out of phase to cancel the distortion at the output. A standard feed-forward amplifier system is shown in the block diagram of Figure 3.

The RF input signals are equally split by means of a two-way divider. Half of the signal power goes into the power amplifier, and half goes through a delay

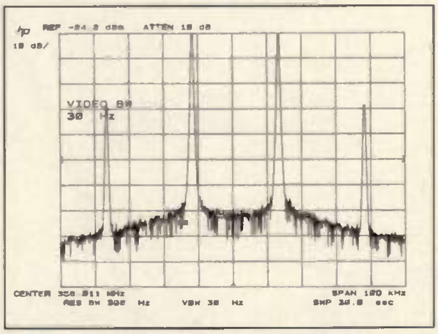


Figure 2. Typical 2-tone IMD performance of a standard amplifier.

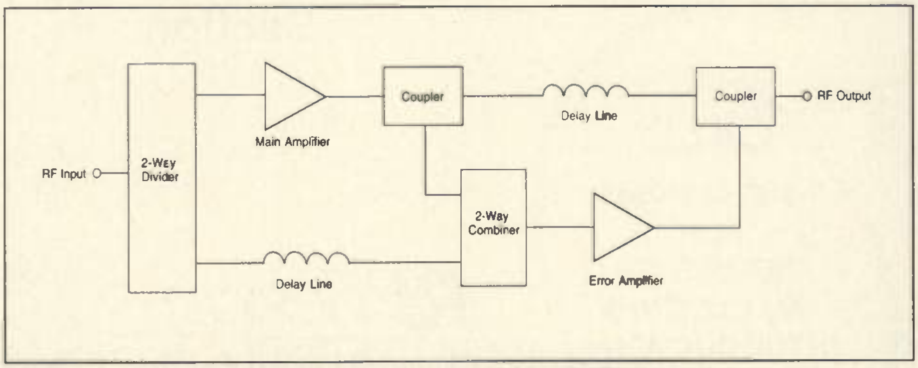


Figure 3. Standard feed-forward system block diagram.

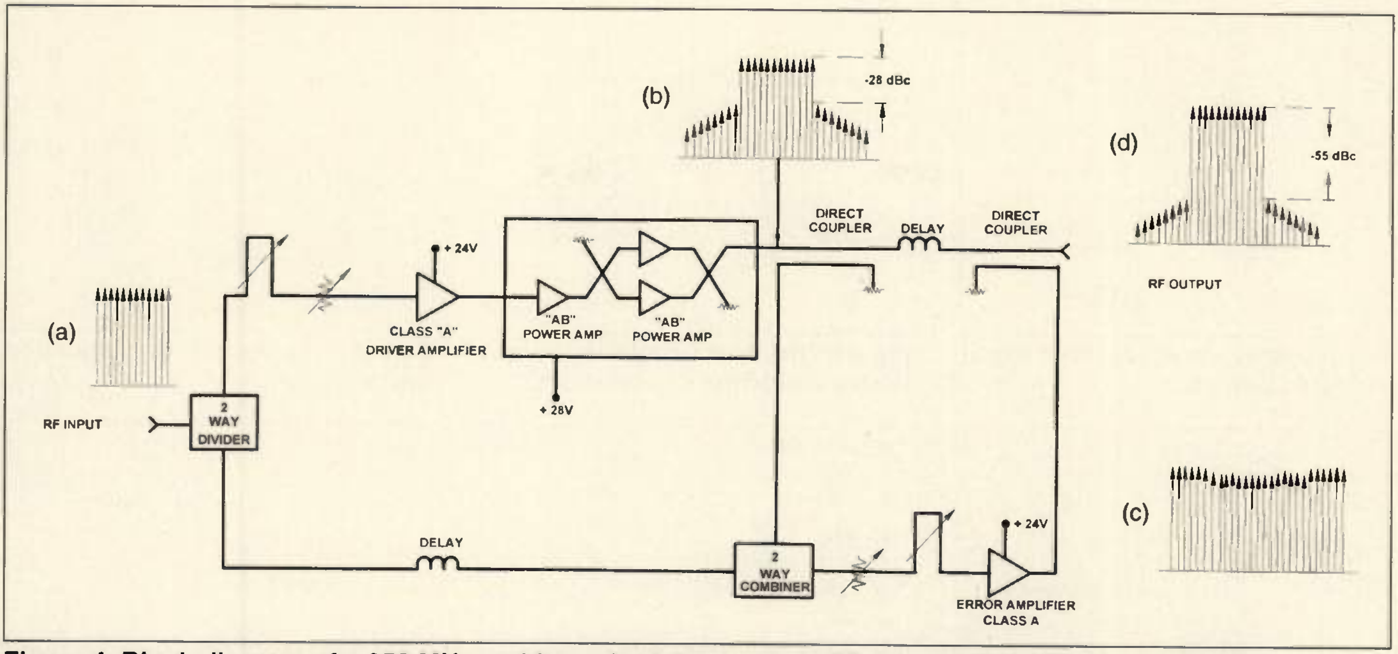


Figure 4. Block diagram of a 358 MHz multitone feed-forward amplifier for 24 carriers spaced 25 kHz.

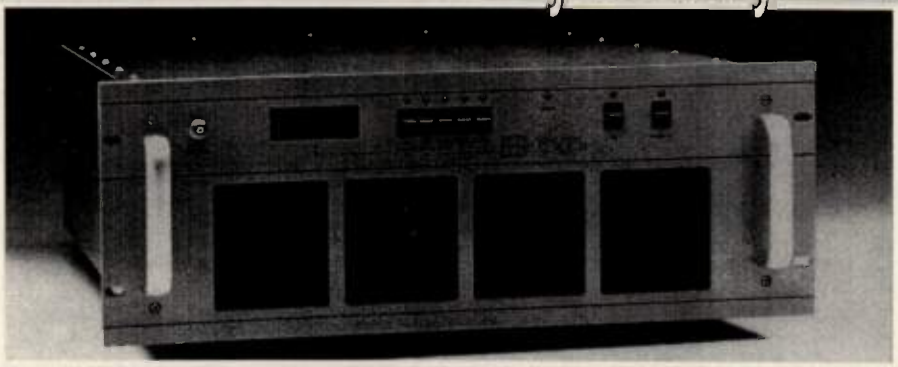
line. The multiple tones are amplified in the main amplifier, which also generates a certain amount of intermodulation distortion. A directional coupler is used to obtain low-level sample of the signal and its distortion, and provide it to one of the inputs of a two-way combiner that is part of the error signal path.

The 0 degree two-way combiner will algebraically sum the signals as long as both inputs are of equal phase and amplitude. The purpose of the delay line between the input divider and the error signal combiner is to assure that the input carriers and the sampled main amplifier carriers arrive at the two-way combiner at the same time and 180 degrees out of phase. Fine amplitude and phase adjustment is accomplished via an attenuator and phase shifter in the main amplifier section. The signal carriers are canceled, and the output of the combiner, which now contains only the distortion products, is fed into the error amplifier. The error amplifier is a class A ultra-linear design, and its function is to amplify the distortion required in the cancellation loop to cancel the intermodulation products. The error amplifier output is connected to a directional coupler used for distortion cancellation. The choice of coupling factor is important so as to maintain minimum main line loss as well as to limit the power capability of the error amplifier. For proper cancellation to take place at the output, it is imperative that the signals are equal in amplitude and 180 degrees out of phase when they reach the coupler. The delay line in the output main line compensates for propagation time in the error amplifier. Fine phase and amplitude adjustments are accomplished using a phase shifter and attenuator in the error amplifier.

Feed Forward Correction System

A feed-forward amplifier used for mul-

1000W - 100 to 200 MHz - 30 day delivery - Guaranteed



Silicon Valley POWER AMPLIFIERS
The RF People
Custom configurations available:
For *FREE* catalogue *CALL* 1-800-986-9700
FAX 408-986-1438

INFO/CARD 39

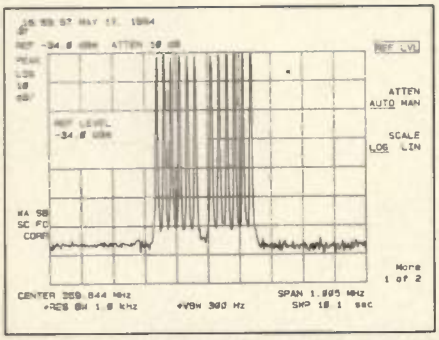


Figure 4(a). Multi-carrier input signal to amplifier.

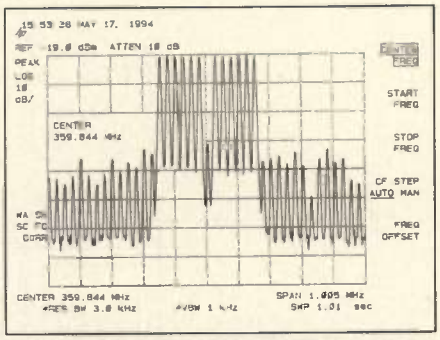


Figure 4(b). Main amplifier output before distortion cancellation.

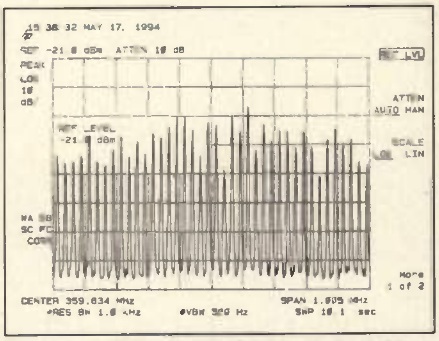


Figure 4(c). Amplifier distiortion (error signal).

Frequency Range:	300-400 MHz
Gain:	54 dB ±0.5 dB
Number of Channels:	1-24
Channel Spacing:	25 kHz
Power Output:	12 watts (average)
Intermodulation Distortion:	–55 dBc maximum
Dynamic Range:	30 dB
Stability:	Unconditionally stable for any source and load impedance
Environmental:	0 to +50° C
DC Power:	–42 to –54 VDC, 6 A maximum
Size:	15 x 21 x 5.25 nches

Table 1. Feed-forward amplifier specifications.

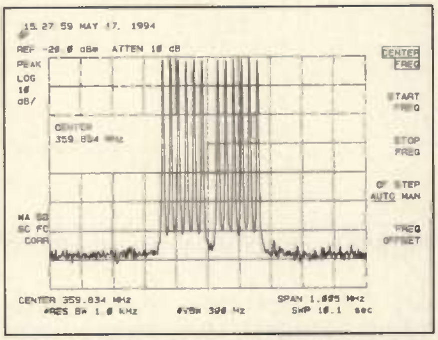


Figure 4(d). Output after feed-forward cancellation.

titone amplification of signals at 358 MHz is shown in Figure 4. The RF input accepts up to 24 carriers which are spaced 25 kHz apart. The input signals, shown in Figure 4(a), are divided in power to provide the drive to the main amplifier, and to the delay line that feeds the two-way combiner. The intermodulation distortion of the main amplifier is –28 dBc, shown in Figure 4(b). The carriers are canceled in loop 1, and the residual distortion is amplified by the error amplifier. Figure 4(c) shows the distortion that feeds the output directional coupler used for final cancellation. The final output shown in Figure 4(d) is the result of a feed-forward cancellation which exceeds –55 dBc.

The amplifier system is housed in an enclosure 15x21x5.25 inches designed for rack mounting. The system contains internal heat sinks and fans that draw air from front to rear and provide proper cooling. Power is supplied by two high efficiency DC-DC converters. A fault/alarm board provides local and remote identifications of amplifier overdrive and excessive output load VSWR. Specifications for the amplifier are contained in Table 1.

Conclusion

This article describes the overall operation of a multitone high power amplifier. The use of feed-forward cancellation techniques allows for significant intermodulation distortion improvements and encourages the use of class AB linear power amplifiers for applications in wireless communications equipment.

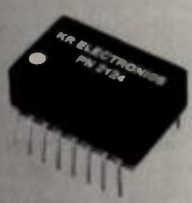
Readers may obtain more information about this amplifier by contacting the author at the address below, or by circling Info/Card #201. ***RF***

About the Author.

Walter Koprowski is Vice President, Amplifier Engineering at Power Systems Technology Inc., 105 Baylis Road, Melville, NY 11747. He can be reached at (516) 777-8900, or by fax at (516) 777-8877.

FILTERS

High Performance Filters



Low Cost Solutions

KR Electronics designs and manufactures all types of LC Filters for the OEM market. Linear phase anti-aliasing, phased matched bandpass and group delay equalized video filters with sin(x)/x correction are a few of our specialties.

KR Model 2124 lowpass filter balances cost, size, and performance. Ideally suited for many video applications.

- ❑ Passband Ripple <0.15 dB to 5.5 MHz
- ❑ Group Delay Ripple <20 nsec to 5.0 MHz
- ❑ Stopband >40 dB by 8 MHz
- ❑ DIP Package **0.60" x 0.87" x 0.30"**

Choose one of our standard filters or let us design one to your specifications. Call or fax for a fast response.

Quality Filters for Over 20 Years

KR Electronics, Inc.
91 Avenel Street, Avenel, NJ 07001
Phone: (908) 636-1900 • Fax: (908) 636-1982

INFO/CARD 40

RF products

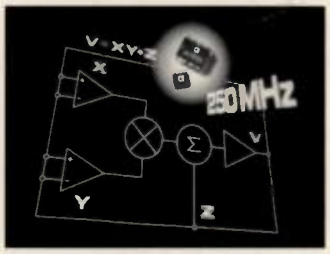
Network Analyzers Upgraded

Hewlett-Packard has upgraded the performance and reduced the price on two of its high-performance network analyzers, the HP 8753 and 8752. The HP8753D now has an integrated S-parameter test set, improved dynamic range, TRL and LRM calibration, power specified at the test port and added power control features, 30 kHz start frequency, and an optional high-stability frequency reference. In addition, the HP 8753D has a new disk drive which supports both LIF and DOS formats, a new CPU which is 67% faster, and improved data and port-handler interfaces. Dynamic range is improved in both the standard 3 GHz source and optional 6 GHz source by eliminating a doubler. Dynamic range for the 6 GHz source has been improved 25 dB to 105 dB, and the 3 GHz source has been improved 10 dB to 110 dB. The HP 8752C now has an optional 6 GHz source, built-in step attenuator and a 67% faster CPU. Base price of the HP 8753D RF network analyzer is $34,500. Base price for the HP 8752C is $22,000. Until November 30, 1994, HP offers customers a 20% discount on the HP 8753D and a 15% discount on the HP 8752C for any working vector network analyzer with an operating frequency that includes 1 GHz.

Hewlett-Packard Co.
INFO/CARD #250

Four-Quadrant V_{out} Multiplier

Analog Devices has announced the industry's first 250 MHz, four-quadrant voltage-output monolithic analog multiplier. The AD835 can generate a linear product of its "X" and "Y" input voltages with a 3 dB bandwidth of 250 MHz. Small-signal rise-time is 1.0 ns; full-scale (–1 to +1 V) rise and fall time is 2.5 ns (with 150 Ω loads). Settling time to within 0.1% of full scale is typically 17 ns. High gains are achieved over wide bandwidths with low



noise contribution (44 nV/√Hz). Few external components are required to apply the AD835. Its differential multiplication (X,Y) and summing (Z) inputs are high impedance nodes that do not require signal conditioning. Likewise, its low-impedance output signal needs no additional buffering to drive ±2.5 V into loads as low as 50 Ω. The AD835 is priced at $7.95 in 1000s and packaged in 8-pin mini-DIPs and 8-lead SOICs.

Analog Devices
INFO/CARD #249

GPS Antenna Module

Toko America has introduced the AMG series, a complete antenna module for GPS applications. This miniature module includes the antenna element, bandpass filter, and low noise

amplifier, sealed in a 38mm square package. The antenna is centered at 1575.42 MHz for GPS receivers, and operates on 4 to 5.25 V over the temperature range of –40 to +85 °C. The module provides excellent gain and directivity. Typical antenna gain is 4 dBi at 90° angle of elevation, –4 dBi at 0°. The maximum axial ratio is 3 dB. Typical gain of the low noise amplifier is 26 dB, with maximum current consumption of 25 mA and typical noise figure of 1.6 dB. The module can be provided with or without a radome. A cable and connector are also provided, and can be customized upon request. Samples are available from Toko America for $150.

Toko America, Inc.
INFO/CARD #248

SMT Inductors

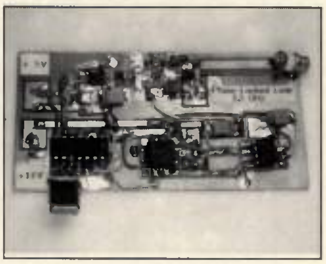
The 1008CX series from Pulse Engineering contains surface mount RF inductors with inductances from 4.7 nH to 4700 nH. The inductors are characterized at high frequencies and have high Q and high self resonant frequencies. The 1008CX series comes in the industry standard 1008-size footprint, with spot welded wire bonds that will not open under severe reflow conditions. Gold terminations are standard, with other types available.

A sample kit is available for $99 plus shipping and handling. An 0805-sized series will be available for sampling in September, with low-profile 1008-sized and ferrite core series to follow shortly afterward.

Pulse Engineering, Inc.
INFO/CARD #247

Prototyping System

The Wainright Solder-Mount-System allows "freehand" construction of experimental circuits of all kinds – without the the need for tools or services. Only diagonal cutting pliers and a soldering iron are needed. Solder-Mounts are self adhesive pieces of print-



ed circuit material (epoxy glass) with an etched and tinned pattern of soldering points – each laid out for one or more component types. To build a circuit, components are soldered to a suitable Solder-Mount, the paper cover removed from the adhesive, and the Solder-Mount with the component is then placed on a copper-clad and tinned groundplane. No layout or wiring plan is needed. The metal surface of the groundplane serves as electrical ground, providing a definite ground potential at every point in the circuit. Stray capacitance to ground is very small and can be compared to a printed circuit board.

Wainwright Instruments, Inc.
INFO/CARD #246

SIGNAL SOURCES

Miniature Oscillator

The Wenzel Associates Miniature Oscillator (WAMO) provides power consumption of less than 1 W at 25° C. At 1.33 x 1.33 x 1.33 inches, this 10 MHz oscillator rivals the performance of larger oscillators with temperature stability of ±5 x 10^{-9} over 0 to 50° C and phase noise of –160 dBc/Hz at 1 kHz offset. Pinout is compatible with industry standard miniature designs. The WAMO is available as a MIL, Space or Commercial grade unit.
Wenzel Associates, Inc.
INFO/CARD #245

SC-Cut OCXO

Model 2930200 from Piezo Crystal Company utilizes Piezo's World Class "SC" cut crystals. The frequency range is from 80 to 110 MHz. Typical phase noise at 100 MHz is –90 dBc/Hz at 10 Hz, –120 dBc/Hz at 100 Hz, –140 dBc/Hz at 1 kHz and –153 dBc/Hz at 10 kHz. Frequency stability is ±2 x 10^{-8} from 0 to +50° C, and the size of the 2930200 is 2.00 x 2.00 x 1.00 inches. The approximate price is $350 to $450 in quantities of 500 pieces.
Piezo Crystal Company
INFO/CARD #244

Low Profile OCXO

Piezo Technology has introduced its model XO5008, which features a maximum height of 0.75 inches, with a footprint of 1.5 x 1.5 inches. The standard center frequency is 10 MHz, with frequencies available from 3 MHz to 50 MHz. The unit features temperature stability of ±0.08 ppm over –40 to +85 °C, sinewave output, five minute warm-up, and moderate current consumption.
Piezo Technology, Inc.
INFO/CARD #243

SMT VCOs

A series of surface mount, voltage controlled oscillators is available from ST Microwave. The new design utilizes silicon bipolar

transistors with high-Q silicon varactor tuning diodes on advanced thin-film hybrid microwave integrated circuit substrates. GaAs FET buffer amplifiers are included to insure stable operation. Models are available at 2 to 6, 6 to 12, and 12 to 18 GHz, with power output of +10 dBm on the two lower frequency units and –5 dBm on the higher frequency unit. The packages measure 0.45 x 0.45 x 0.16 inches. Production quantities are available in 60 to 90 days.
ST Microwave Corp.
INFO/CARD #242

SIGNAL PROCESSING COMPONENTS

Miniature Mixer

The ZP-11A mixer from Mini-Circuits offers space-saving miniature construction plus high reliability backed by a five-year guarantee. The RF and LO ports can operate from 1400 to 1900 MHz, while the IF operates from 40 to 500 MHz. Conversion loss specifications are statistically controlled to better than 4 5σ from mean. Conversion loss is flat (0.6 dB typ.) over the full range, and 1 dB compression is 1 dBm typ. A miniature connectorized package houses the mixer.
Mini-Circuits
INFO/CARD #241

Threshold Detector

Daico Industries introduces a flatpack threshold detector to its detector series. Model CTDO8014 has an operating frequency of 10 to 3000 MHz. Detection is over the dynamic range of –25 to –10 dBm, with 1.2 dB hysteresis. Transition time is 300 µs, (10%/90% RF). Input flatness is ±1.5 dB with VSWR of 1.5/1. The detector is comes in a 14-pin flatpack.
DAICO Industries
INFO/CARD #240

Bandpass and Lowpass Filters

In three different diameters, this new series of coaxial tubular filters offers either bandpass or lowpass characteristics from 30 MHz to 5000 MHz. The filters provide rejection of 70 dB and greater while VSWR is maintained at 1.5:1 or better. A wide choice of connectors is offered,

including SMA, N, TNC and BNC types as well as pins for PCB mounting.
Atlantic Microwave Ltd.
INFO/CARD #239

INMARSAT Phase Shifters

Vectronics introduces several phase shifters in the INMARSAT band for phased-array applications. Three-bit and four-bit units are available in switched-line designs (individual bit values vary linearly vs. frequency). All units feature low insertion loss and excellent phase accuracy. A number of different internal TTL driver options are available with switching times as low as 200 ns.
Vectronics Microwave Corp.
INFO/CARD #238

Diplexer

The GLDI-001 diplexer is a high performance, low cost solution to diplexing in the 30 to 152 MHz range. Maximum insertion loss is 0.7 dB, minimum isolation is 40 dB and VSWR is maintained at or below 1.5. The diplexer meets or exceeds military environmental requirements. Prices start at $135 each in quantities of one to five.
Geoffroy Labs
INFO/CARD #237

AMPLIFIERS

Feedforward Amp

Model PA09005200-01R, a 200 W PEP, wideband, feedforward cellular base station amplifier provides intermodulation products of –60 dBc. This is accomplished over a 25 MHz instantaneous bandwidth at 20 W multichannel output power. Gain is 53 dB and the power requirement is 26 V, 9.5 A.
AML Communications
INFO/CARD #236

Broadband Amplifiers

EM Research Engineering introduces its line of broadband modular amplifiers. These linear amplifiers have an instantaneous bandwidth of 10 to 1000 MHz and output powers ranging from 100 mW to 10 W with an input of 0 dBm. Variable gain control is available as an option in these amplifiers. Pricing starts at $485 for a 1 W amplifier in small quantities (1 to 4).
EM Research Engineering, Inc.
INFO/CARD #235

4W UHF Amplifier

ENI's model 604L power amplifier produces 4 W of linear class A output over 0.5 to 1000 MHz. With a gain of 40 dB, the 604L features harmonics more than 18 dBc below the fundamental and low intermodulation distortion. Other features include unconditional RF stability, +13 dBm overdrive protection, and infinite maximum load VSWR. The 604L is available for 30-day delivery at a cost of $2850.
ENI
INFO/CARD #234

25-100 MHz, 100 W Amplifier

Model A005 from LCF Enterprises has an output power level of 100 W CW and operates from 25 to 300 MHz. The module measures 6.0 x 2.0 x 1.0 inches (excluding mounting feet and connectors), and delivers a minimum gain of 35 dB. Operation is from a 24 VDC supply. Customization to other frequencies and output powers is available.
LCF Enterprises
INFO/CARD #233

Broadband, 100 W Amplifier

Model 7100LC is an instantaneous broadband RF power amplifier especially designed for

European EMC testing. Power output of 100 W CW covering 80-1000 MHz will offer solutions for many different applications. An IEEE-488 /RS-232 interface kit, model KEI IF-488, is available. Price for the 7100LC is $19,500.
Kalmus Engineering Inc.
INFO/CARD #232

10W Cellular Amp

The QBS-227 is a 10 W, 1 dB compression point, linear power amplifier operating over the 800 to 960 MHz frequency range. Having minimum gain of 40 dB, the QBS-227 uses a 24 V supply with an operating case temperature range of –20 to +70° C. With a +50 dBm third order intercept point, the QSB-227 has –40 dBc third order intermod product levels when two one watt tones are being amplified.
Q-bit Corp.
INFO/CARD #231

SEMI-CONDUCTORS

SOT-143 NPNs

A family of NEC devices from California Eastern Laboratories is designed as an alternative to other manufacturers devices in mixers, oscillators and LNA applications. The NE85639R has f_T of 7 GHz and I_{Cmax} of 100 mA, NE68139R has f_T of 9 GHz and I_{Cmax} of 65 mA, NE68039R has f_T of 10 GHz and I_{Cmax} of 35 mA, and NE68539R has f_T of 12 GHz. A range of performances are available from the family; noise figures from 1.1 dB at 1.0 GHz, insertion power gain to 15 dB at 1.0 GHz and outstanding low voltage/low current operation from VHF to 2.5 GHz.
California Eastern Laboratories
INFO/CARD #230

Evaluation Kits

A series of MMIC evaluation kits from Richardson Electronics contains the MMIC devices most widely used for low-noise amplifiers, general medium power applications, upconverter/downconverter and antenna switching for cellular, PCN and other applications. The kits are marketed as the RF Gain, Ltd. MMIC Evaluation Kits.
Richardson Electronics, Ltd.
INFO/CARD #229

IF ICs

AT&T Microelectronics has introduced a line of general purpose intermediate frequency (IF) integrated circuits. Included in the offering are a quadrature modulator, a programmable AGC amplifier and two quadrature demodulators with integrated AGCs. The W2009 quadrature modulator has I/Q input bandwidth of 4 MHz. The W1466 amplifier provides up to 45 dB gain in selectable 3 dB steps; its 3 dB bandwidth is 100 MHz. Both the W1452 and W1575 combine a quadrature demodulator with digitally programmed IF AGC amplifier. Production quantities of the IC are available now, with pricing of $2.50 for the W1466, $4.50 for either the W1452 or W1575, and $3.40 for the W2009.
AT&T Microelectronics
INFO/CARD #228

Power MOSFET

Motorola is announcing a new surface mount RF power MOSFET designed for broadband commercial and industrial applications at frequencies to 520 MHz. The MRF5003 device supplies up to 3 W output power at 7.5 V with minimum gain of 9.5

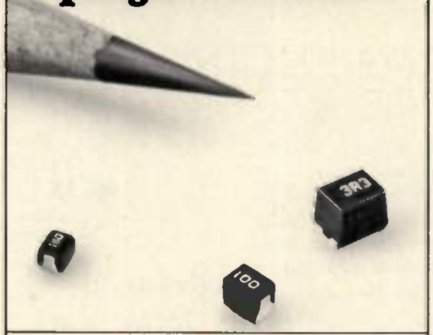
dB at 512 MHz. The MOSFET has low feedback capacitance (C_{rss} = 4.4 pF typical) and can withstand 20:1 load VSWR at any phase angle when properly mounted. Pricing for the MRF5003 is $7.91 in low volumes.
Motorola Semiconductor Products Sector
INFO/CARD #227

TEST EQUIPMENT

Synthesizers

The 68000B synthesized CW generators and 68100B synthesized sweep generators are available in six models covering different frequency ranges from 0.01 to 40 GHz. The 68000B delivers precise CW and digitally-stepped

Sprague-Goodman



Surfcoil®
SMT Inductors

- Inductance from 10 nH to 1 mH
- 8 model series in 3 sizes:
  2.5 x 2.0 x 1.6 mm (0.098" x 0.079" x 0.063")
  3.2 x 2.5 x 2.2 mm (0.126" x 0.098" x 0.087")
  4.5 x 3.2 x 3.2 mm (0.177" x 0.126" x 0.126")
- Shielded, unshielded, ferrite core and nonmagnetic models
- Operating temp: -20° to +85°C
- Carrier and reel standard
- Fully encapsulated

Phone, fax or write today for Engineering Bulletin SG-800B.

SPRAGUE GOODMAN

134 Fulton Ave Garden City Park, NY 11040
Phone: 516-746-1385 • Fax 516-746-1396

INFO/CARD 42

Filmtrim®
Single Turn Plastic Trimmer Capacitors

- Cap ranges: 1.0-5.0 pF to 25-500 pF
- Q to 5000 at 1 MHz
- Operating temp:
  PTFE, Polycarbonate, Polyimide: -40° to +85°C
  Polypropylene: -40° to +70°C
  High temp PTFE: -40° to +125°C
- 6 sizes from 5 mm to 16 mm
- More stable with temperature than other single turn trimmers

Phone, fax or write today for Engineering Bulletin SG-402E.

SPRAGUE GOODMAN

134 Fulton Ave., Garden City Park, NY 11040
Phone: 516-746-1385 • Fax: 516-746-1396

INFO/CARD 47

signals for LO substitution and stimulus applications. The 68100B adds analog sweep capability and external AM/FM/squarewave modulation for network analysis applications. Prices start at $20,500.
Anritsu Wiltron
INFO/CARD #226

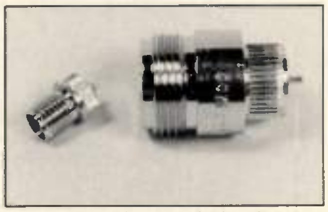
Synthesizer/Sweeper

Giga-tronics has introduced 2 to 20 GHz models of its GT 9000 microwave synthesizer and GT 9000S synthesized microwave sweeper. Both the GT 9000 and 9000S have –95 dBc/Hz phase noise at 10 kHz offset from 2 GHz and output power of +13 dBm or greater. Internal pulse modulation is standard, while built-in amplitude, frequency and scan modulation are available options. The 9000S adds analog and digital sweep of both frequency and power. U.S. list prices for the 2 to 20 GHz GT 9000 and GT 9000S are $22,950 and $24,950, respectively.
Giga-tronics, Inc.
INFO/CARD #225

CABLES & CONNECTORS

Press-In Connectors

Delta Electronics' line of press-mount coaxial receptacle is designed to require only one through hole in the housing, as



opposed to the one hole plus two or four tapped holes for flange-mounted jacks. Delta's press-mount receptacles are currently available in type N and SMA series, and can be provided with tab, slotted, or solder pot contact ends.
Delta Electronics
INFO/CARD #223

TNC Jack

COAXICOM has announced the release of a "pre-assembled" TNC bulkhead jack for RG402 (0.141 dia.) semi-rigid cable. Model 4539CC-430-1 is directly soldered to the cable jacket after stripping back the cable's center contact and plugging it into the captive female contact at the rear of the connector. Part number 4539CC-431-1 is available for RG405 (0.085 dia) semi-rigid cable.
Coaxial Components Corp.
INFO/CARD #222

High Isolation Cables

A line of cables from Storm Products offer improved isolation over traditional RG cables and are well suited for extended frequency use through 5 GHz. Shielding effectiveness is –85 dB at 1 GHz with an insertion loss as low as 0.15 dB/ft. These RG equivalents use standard, commercially available connectors.
Storm Products Co.
INFO/CARD #224

Foam Cable Connectors

Custom made UHF and Type N coaxial connectors that are designed to fit the full range of RG low-loss foamed cables are available from Tru-Connector. Both male and female connectors designed for use with 1/2-, 3/4- and 7/8-inch low-loss foamed cables. Field serviceable without special tools, they are designed for applications up to 200 MHz.
Tru-Connector Corp.
INFO/CARD #221

Low-Loss Cable

Both the 7/8 inch LMR-1200 and 1-1/4 inch LMR-1700 cables use a bonded aluminum tape and overbraid outer conductor, making them more flexible and less prone to kink than corrugated cables. LMR-1200 cable has 1.26 dB/100 ft. loss at 900 MHz and is priced at $4.75/ft. LMR-1700 cable provides 0.94 dB/100 ft. loss at 900 MHz and is priced at $7.65/ft.
Times Microwave Systems
INFO/CARD #000

Proven Performance:
Hi-Rel Airborne RF Transmitters and Receivers

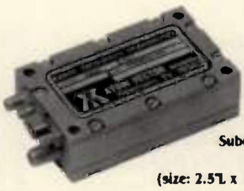
Don't Settle for Less

- Miniature & Rack Mount
- UHF/VHF/TV Bandwidths
- Fixed Frequency/Synthesized Multichannel
- 2 to 200 Watts Power Output
- Standard Military Frequency Ranges
- Off-the-Shelf/Custom Design
- Meets Latest IRIG Specifications
- Command Control/Flight Termination Applications
- Used in Virtually Every Major Aerospace Program
- MIL-STD-2000 and WS-6536 Workmanship and Special Parts Screening Available

The Highest Quality Available, at an Affordable Price

RCC-300
L/S Band
Wide Band
Video Receiver

For Full Details CALL 215-968-4271



T300 Series
Subminiature UHF
Transmitter
(size: 2.5"L x 1.5"W x .75"H)

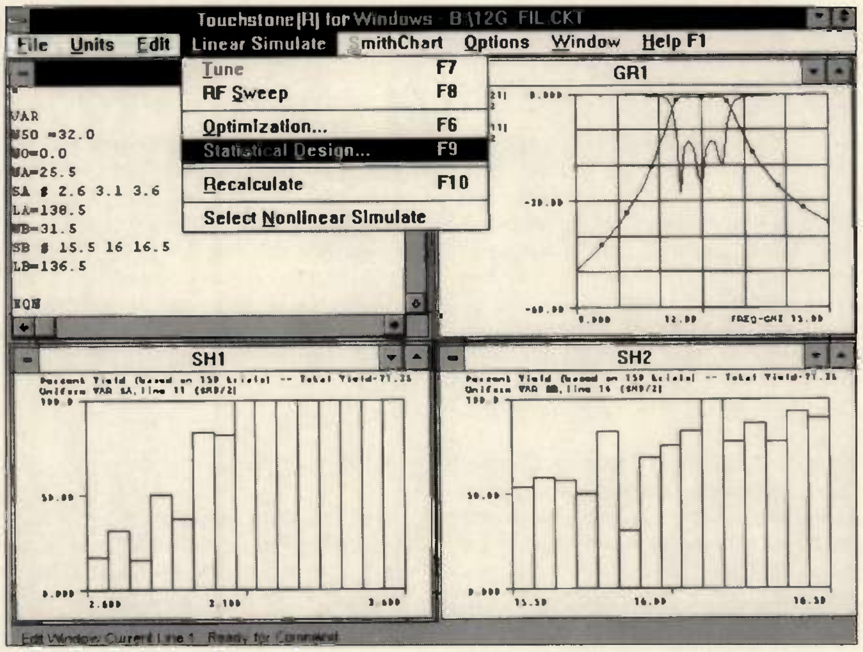
AYDIN VECTOR
Aydin Vector Division • P.O. Box 328 • Newtown, PA 18940-0328 • TEL: 215-968-4271 • FAX 215-968-3214
In Europe: Aydin International U.K. • 1/3 Hunting Gate • Hitchin, Herts SG4 OTJ • England TEL: 44-0462-434555 FAX: 44-0462-420727

INFO/CARD 43

.....LAST CHANCE....ENTRY DEADLINE IS JULY 29.....

RF Design Awards Contest

GRAND PRIZE! — Touchstone/Libra for Windows



The 1994 Grand Prize provided by **Hewlett-Packard Company,** through their MDS group and their new EEsof operation.

Touchstone linear analysis and Libra non-linear analysis provide valuable tools for RF designers. Our winner will be able to spend even more time being creative, letting this software accurately simulate a circuit, taking away most of the trial-and-error associated with prototyping and design revision.

The personal computer version of Touchstone and Libra will be awarded — allowing the winner to use these powerful programs on a 386/486 PC platform, operating under the popular Microsoft Windows operating system.

Official Rules

1. Entries shall represent RF functions operating at frequencies from tens of kHz to 3 GHz.
2. Entries may be circuits, circuit design methods, test procedures, or design software programs.
3. If the entry is a circuit, it shall have a complexity equivalent to that of a circuit using 8-10 discrete active devices or 6-8 integrated circuits. The circuit may be a portion of a larger system.
4. If the entry is a design method, it must include an example of a circuit designed using the method described.
5. If the entry is a test method, it must include actual results of the measurement described.
6. If the entry is a computer program, it must operate on either an MS-DOS or Apple Macintosh system. It must be provided in a form that can be operated directly, without additional software (e.g., compiled). Programs must be submitted on disk, with supporting documentation provided in printed form.
7. Entries shall be the original work of the entrant, not previously published or publicly distributed. If developed as part of the entrant's employment, entries must have the approval of the entrant's employer.
8. Only one entry per person is permitted. An entry may have two or more co-authors.
9. Submission of an entry implies permission for publication in *RF Design*, and distribution of software submissions by the RF Design Software Service.
10. Winners are responsible for any taxes, duties, or other assessments which result from the receipt of their prizes.
11. Entries must be postmarked no later than July 29, 1994 and received no later than August 8, 1994.
12. All entries will remain confidential until publication of contest results in the November 1994 issue of *RF Design*.

Judging Criteria

The single objective of the judging is do determine which entry makes the most significant contribution to the advancement of the art and science of RF engineering. Specific judging criteria include:

- *Engineering* — identifying a problem and developing a solution
- *Documentation* — completeness of the entry submission
- *Usefulness* — practicality or wide applicability
- *Technical Merit* — difficulty or magnitude of the work
- Other criteria as deemed appropriate

Send entries to:

RF Design Awards Contest
***RF Design* magazine**
6300 S. Syracuse Way, Suite 650
Englewood, Colorado 80111

Transmission Line Fundamentals

By Andy Kellett
Technical Editor

Transmission lines are among the blackest of RF "black magic". At first glance, a transmission line appears to be nothing more than an RF garden hose, piping RF energy from one place to another. However, transmission lines exhibit a complex behavior which enables them to be used as impedance transformers and even filters. The purpose of this article is to quickly arrive at a few basic equations from which we can derive the quantities and formulas most often used in transmission line problems.

Figure 1 demonstrates the notation used in this article and most books. The distance between the end of the cable and some point along the cable is called x. The distance from the load end of the cable to the same point along the cable is called d. The total length of the cable is s so that x+d=s. The impedance the cable sees looking toward the signal generator is Z_g, and the impedance the cable sees looking into the load is Z_l. Quantities having to do with the end of the line connected to the signal source use the subscript s (for sending or source end), for instance, the potential at the sending end is called E_s. Quantities relating to the end of the line connected to load are denoted with the subscript r (for receiving). The potential on the line at the load-end of the line is called E_r.

The electrical model for a section of transmission line used in this article is illustrated in Figure 2. This model assumes that the line we are working with propagates the EM wave along the axis of the line, with the magnetic and electric fields perpendicular to the axis. This is called the TEM mode. For the cables used in RF work, it is hard for anything but the TEM mode to be transmitted down the line because the only dimension in RF cables that approaches the wavelength of RF signals is the cable's length.

The model, as drawn here represents an unbalanced line, but the same quantities and results are obtained when the impedance and current are shared by both conductors.

The quantity, "z", in Figure 2 is the impedance per unit length of line, and "g" is the unit admittance. Both of these quantities are complex, being made up of real and imaginary parts as shown in equations 1 and 2.

$$z = r + j\omega l \qquad (1)$$

$$y = g + j\omega c \qquad (2)$$

The real part of the impedance is the resistance of the line, the imaginary part is the familiar expression for inductive reactance. The admittance is made up of a conductance (the real part) and the inverse of the capacitive reactance (the imaginary part).

At the source end of the line there exists a potential E between the conductors and a current I flowing through a point at that end. On the other end there will be a potential E+ΔE and a current I+ΔI. If a transmission line were really like a garden hose, ΔE and ΔI would be zero, but it turns out they are not. The impedance per unit length, z, is responsible for dropping the potential, while the admittance is responsible for shunting some of the current. The amounts of these drops are given in equations 3 and 4.

$$\Delta E = -I(z\Delta x) \qquad (3)$$

$$\Delta I = -(E + \Delta E)(y\Delta x) \qquad (4)$$

Dividing both equation 3 and 4 by Δx and taking the limit as Δx goes to zero we get the derivatives describing the changes in voltage and current for an infinitesimal section of cable:

$$\lim_{\Delta x \to 0}\left[\frac{\Delta E}{\Delta x} = -Iz\right] \to \frac{dE}{dx} = -Iz \qquad (5)$$

$$\lim_{\Delta x \to 0}\left[\frac{\Delta I}{\Delta x} = -(E + \Delta E)y\right] \to \frac{dI}{dx} = -Ey \qquad (6)$$

We can eliminate I from equation 5 and E from equation 6 by differentiating again with respect to x to get:

$$\frac{d^2E}{dx^2} = -\frac{dI}{dx}z \qquad (7)$$

$$\frac{d^2I}{dx^2} = -\frac{dE}{dx}z \qquad (8)$$

and substituting the expressions for dI/dx and dE/dx from equation 5 and 6 into the the right side of equations 7 and 8. The result is a set of differential equations:

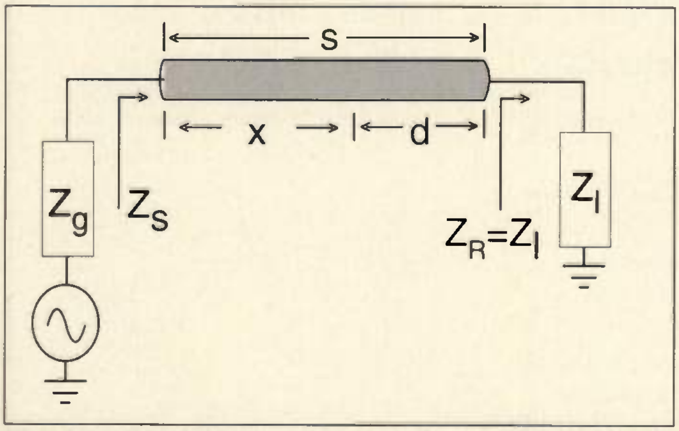


Figure 1. Diagram showing notations used to identify positions along cable of length s.

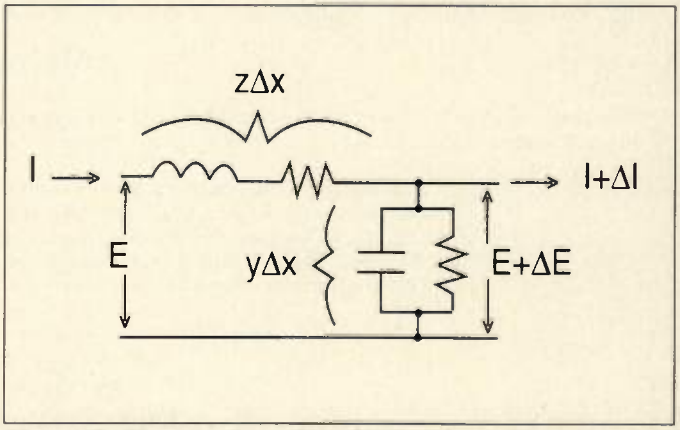
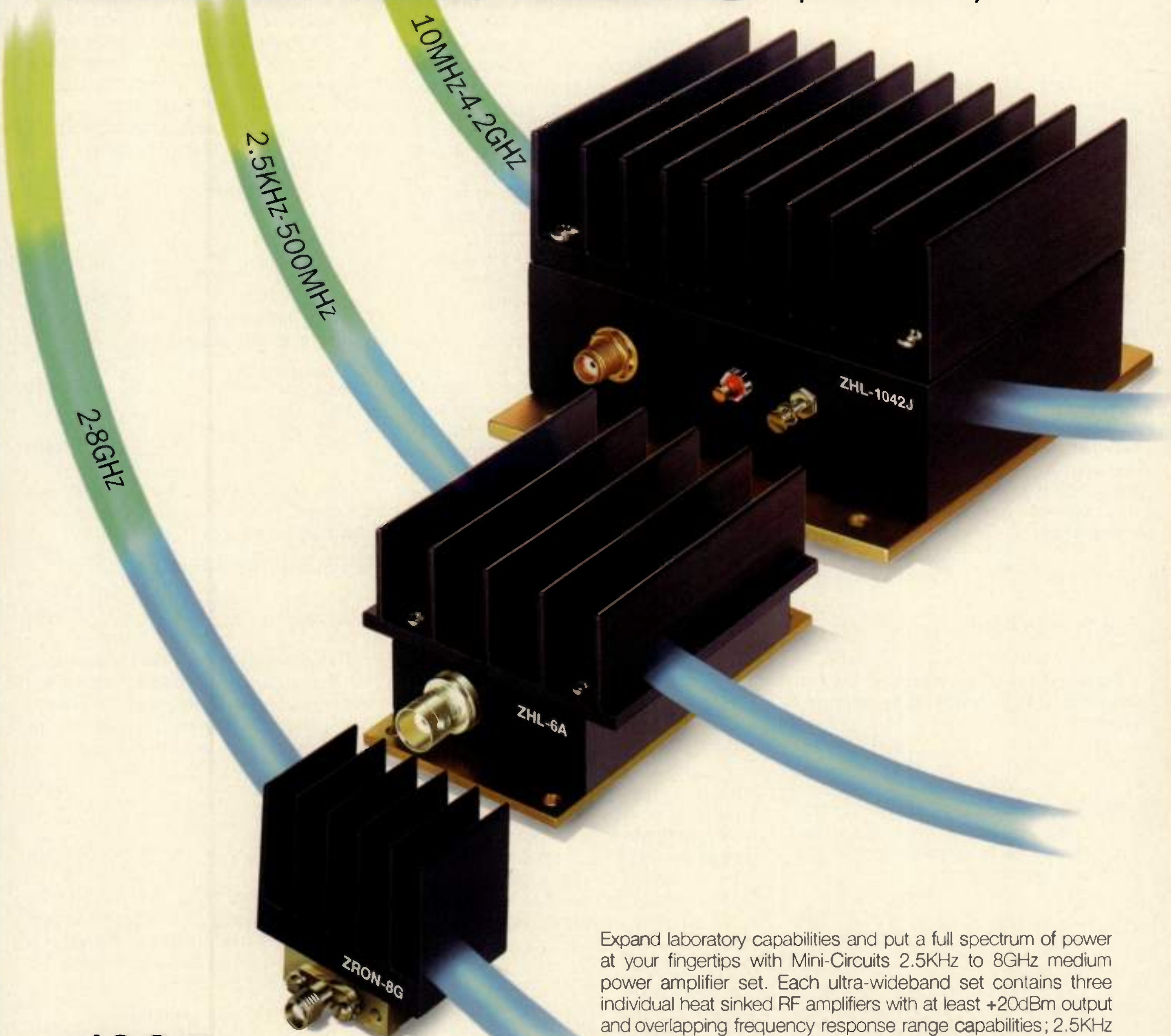


Figure 2. Electrical model of a section of lossy transmission line transmitting a signal in the TEM mode.

2.5KHz to 8GHz AMPLIFIERS

(3 Piece Set)



only $1095 (Set of 3 1-9 qty.)

+20dBm Power Output, 20dB Gain

Model :	Freq. (MHz)	Gain (dB)	Power Output, dBm @ 1dB Compression	DC Power Volt V	DC Power Current mA	Conn. Type	Indiv. Price ($) (1-9 qty.)
ZHL-6A	.0025-500	21	+23	+24	350	BNC	199
ZHL-1042J	10-4200	25	+20	+15	330	SMA	495
ZRON-8G	2000-8000	20	+20	+15	310	SMA	495

Set of 3 Amplifiers # KZHL-318: $1095 (1-9 qty.)

Expand laboratory capabilities and put a full spectrum of power at your fingertips with Mini-Circuits 2.5KHz to 8GHz medium power amplifier set. Each ultra-wideband set contains three individual heat sinked RF amplifiers with at least +20dBm output and overlapping frequency response range capabilities; 2.5KHz to 500MHz, 10MHz to 4.2GHz and 2GHz to 8GHz. Applications for these amplifiers include increasing the signal levels to power meters, spectrum analyzers, frequency counters and network analyzers as well as boosting signal generator outputs.

You can buy these amplifiers individually at Mini-Circuits already low prices, or own the full spectrum set for the money saving price of only $1095 (1-9 qty.) ! To order from stock with a guarantee to ship within one week, call Mini-Circuits today !

Mini-Circuits...we're redefining what VALUE is all about!

Mini-Circuits®

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661

For detailed specs on all Mini-Circuits products refer to • THOMAS REGISTER Vol. 23 • MICROWAVES PRODUCTS DIRECTORY • EEM • MINI-CIRCUITS' 740- pg. HANDBOOK.

CUSTOM PRODUCT NEEDS...Let Our Experience Work For You.

INFO/CARD 44

F 176 Rev A

$$\frac{d^2E}{dx^2} = Eyz \quad (9)$$

$$\frac{d^2I}{dx^2} = Iyz \quad (10)$$

This form of differential equation has solutions :

$$E = Ae^{-\sqrt{zy}x} + Be^{\sqrt{zy}x} \quad (11)$$

$$I = A'e^{-\sqrt{zy}x} + B'e^{\sqrt{zy}x} \quad (12)$$

Plug these solutions into the differential equations to verify them. So much for the easy part, the calculus, the rest of the work is messy algebra.

The parameters A, B, A' and B' are to be determined by the boundary conditions imposed on the particular transmission line situation, but ohm's law links the parameters of equation 11 with the parameters of equation 12, so one set must be solved in terms of the other. To solve A' and B' in terms of A and B, differentiate equation 11 and substitute that derivative and equation 12 into equation 5:

$$A\left(-\sqrt{zy}\right)e^{-\sqrt{zy}x} + B\left(\sqrt{zy}\right)e^{\sqrt{zy}x} = -\left(A'e^{-\sqrt{zy}x} + B'e^{\sqrt{zy}x}\right)z \quad (13)$$

Equating the coefficients in front of identical $e\pm\sqrt{yz}x$ terms in equation 13 yields:

$$-A'z = -A\sqrt{zy} \quad (14)$$

$$-B'z = B\sqrt{zy} \quad (15)$$

These can each be solved in terms of the primed parameters:

$$A' = \frac{A}{\sqrt{\frac{z}{y}}} \quad (16)$$

$$B' = -\frac{B}{\sqrt{\frac{z}{y}}} \quad (17)$$

The boundary conditions encountered by the line determine what form the constants A and B take. Even non-uniform lines can be described with these equations if they are piece-wise uniform, i.e. made up of segments of uniform line. Equations 11 and 12 are the starting point from which we derive all the really useful tools in transmission line analysis such as reflection coefficient and VSWR.

Picking Familiar Parameters out of the Equations

At this point we should examine the results of our work and condense some notation into commonly used parameters. Because transcendental functions (such as exponentiation) must have unitless solutions, it is clear that the units for the parameters A and B in equation 11 should have units of voltage. Transcendental functions also have unitless arguments, and working out the units of $\sqrt{(zy)}x$ shows that this is the case for our solution. The quantity $\sqrt{zy}$ is commonly given the symbol γ and called the propagation constant. γ has both real and imaginary components:

$$\gamma = \sqrt{zy} = \alpha + j\beta \quad (18)$$

The real part, (α), describes the attenuation in the line, while the imaginary part, (β), is the factor that determines how quickly the phase of the transmitted signal changes with the distance it travels down a line. The quantity $\sqrt{(z/y)}$ is the characteristic impedance of the line, commonly called Z_0. Examining the units in $\sqrt{(z/y)}$ should make this seem plausible. Equations 11 and 12 using the new quantities are written as

$$E = Ae^{-(\alpha+j\beta)x} + Be^{(\alpha+j\beta)x} \quad (19)$$

$$I = \frac{A}{Z_0}e^{-(\alpha+j\beta)x} - \frac{B}{Z_0}e^{(\alpha+j\beta)x} \quad (20)$$

Before we continue, it must be pointed out that the equations derived so far have only shown variation in space. The time variation will be added later, but for now quantities that do not depend on frequency will be developed.

From now on, unless otherwise noted, losses will be ignored, that is we will let α of equations 19 and 20 equal zero so that:

$$E = Ae^{-j\beta x} + Be^{j\beta x} \quad (21)$$

$$I = \frac{A}{Z_0}e^{-j\beta x} - \frac{B}{Z_0}e^{j\beta x} \quad (22)$$

Removing losses makes the math much easier, and is an accurate assumption for short lengths of line. When this is done, γ becomes $j\omega\sqrt{(lc)}=j\beta$ and Z_0 becomes $\sqrt{(l/c)}$. Calculations that require loss terms are most commonly done using a computer or the Smith Chart.

Impedances

A signal source looking into the end of a transmission line sees some impedance. The impedance seen depends on both the characteristic impedance of the line and the impedance connected to the load end of the transmission line. To find the impedance at the source end of the cable (or at any other place along the cable) we need to find the ratio of voltage to current at that point.

At the receiving end of the cable, x = s and equations 21 and 22 become:

$$E_R = Ae^{-j\beta s} + Be^{j\beta s} \quad (23)$$

and

$$I_R = \frac{A}{Z_0}e^{-j\beta s} - \frac{B}{Z_0}e^{j\beta s} \quad (24)$$

Solving these equations for A and B yields (after lots of algebra)

$$A = \frac{I_R}{2}(Z_R + Z_0)e^{+j\beta s} \quad (25)$$

$$B = \frac{I_R}{2}(Z_R - Z_0)e^{-j\beta s} \quad (26)$$

Which, when plugged back into 21 and 22 gives, (remember s=d+x, and e^{ja} = cos a + j sin a).

$$E = E_R\cos(\beta d) + jI_RZ_0\sin(\beta d) \quad (27)$$

$$I = I_R\cos(\beta d) + j\frac{E_R}{Z_0}\sin(\beta d) \quad (28)$$

This expression is useful for determining the voltage and current along the transmission line in terms of the voltage and current at the load. Similarly, for x=0, A and B can be solved to get:

$$A = \frac{E_s + I_sZ_0}{2} \quad (29)$$

$$B = \frac{E_s - I_sZ_0}{2} \quad (30)$$

Plugging these back into 21 and 22 gives an expression for voltage and currents along a line in terms of the voltage and current at a distance x from the sending end of the cable.

$$E = E_s\cos(\beta x) - jI_sR_c\sin(\beta x) \quad (31)$$

$$I = I_s\cos(\beta x) - j\frac{E_s}{Z_0}\sin(\beta x) \quad (32)$$

Equations 27 and 28 can be used to find the impedance seen at the sending end of the cable. Using the expressions for I and E at the sending end (d=s) in the relation Z = E/I, we get

$$Z_s = \frac{E_s}{I_s} = \frac{E_R\cos(\beta s) + jI_RZ_0\sin(\beta s)}{I_R\cos(\beta s) + j\frac{E_R}{Z_0}\sin(\beta s)} \quad (33)$$

dividing through by $I_R \cos \beta s$ yields the familiar equation

$$Z_s = Z_0 \frac{Z_R + jZ_0 \tan(\beta s)}{Z_0 + jZ_R \tan(\beta s)} \tag{34}$$

This relation is the basis for the quarter wave transformer. A length of line one-quarter a wavelength long has an input impedance given by:

$$Z_s = \frac{{Z_0}^2}{Z_R} \tag{35}$$

By selecting a quarter-wavelength line with the appropriate characteristic impedance, the input impedance of the transmission line/load combination can be tailored to any desired impedance.

Another special case of equation 34 puts $Z_R = Z_0$ yielding:

$$Z_s = Z_0 \frac{1}{1} = Z_0 \tag{36}$$

Which means that any line and load whose impedances match always present that impedance at the sending end of the line, no matter the length.

Time Variation

A true wave solution contains variations in both space and time. Substituting the expressions for A and B in equations 25 and 26 into equation 21 gives:

$$E = \frac{I_R}{2}(Z_R + Z_0)e^{j\beta(s-x)} + \frac{I_R}{2}(Z_R - Z_0)e^{-j\beta(s-x)} \tag{37}$$

Because s–x=d, this can be rewritten as:

$$E = \frac{I_R}{2}(Z_R + Z_0)e^{j\beta d} + \frac{I_R}{2}(Z_R - Z_0)e^{-j\beta d} \tag{38}$$

(remember d is a measure of distance from the *load end* of the line to some particular point.)

Assuming I_R has the form:

$$I_R = \hat{I}_R e^{j\omega t} \tag{39}$$

(where I_R hat is a complex constant). The result is:

$$E = \frac{\hat{I}_R}{2}(Z_R + Z_0)e^{j(\omega t + \beta d)} + \frac{\hat{I}_R}{2}(Z_R - Z_0)e^{j(\omega t - \beta d)} \tag{40}$$

This is a solution to the wave equation. It may seem dubious that we arrive at a solution to the wave equation (a partial differential equation) without starting with the wave equation, (equations 9 and 10 are ordinary differential equations in x). However, had we started the derivation in a way that led to the wave equation (as is done in many texts [1,2]) and used separation of variables to solve it, equations 9 and 10 pop out as the ordinary differential equations in x that must be solved. The ordinary differential equations in time that arise have solutions of the form given in equation 38.

The two terms in equation 40 represent two waves travelling in opposite directions. You can verify this by seeing how d has to change to keep the argument of each exponential term constant, (the argument of the exponential in each term is the phase of the wave it represents).

RF design

REPRINTS!

RF Design offers a convenient reprint service to accommodate your promotional needs. Articles and advertisements appearing in *RF Design* are available as reprints in quantities of 100 or more.

- Increase your company's visibility
- Enhance your corporate image
- Position your company as experts in the field
- Provide your personnel with expert information

Increase sales and profits by investing in REPRINTS.

For information and orders, phone our Reprints Department

(404) 618-0481

1,239,580 Filters

America's Filter Specialist since 1956

0.1 Hz to 3000 MHz -

1,239,580 standard filter types □ Miniature and subminiature sizes □ Passive and active types □ Stock filters □ Gaussian, Butterworth, Chebyshev designs □ Call or write for free catalog today.

TTE®

TTE, Inc.
2251 Barry Avenue
Los Angeles, CA 90064
Fax (310) 445-2791
Tel (800) 776-7614

FREE CATALOG

INFO/CARD 46

For example, take the second term on the right hand side of equation 40. The real part of that term is (ignoring the factor in front of the exponential):

$$\cos(\omega t - \beta d) \qquad (41)$$

When the argument, ωt-βd, equals zero, equation 41 is at its maximum. Using the maximum as a "tracking point" we see what happens as t gets bigger (as time does when it moves forward). In order to maintain the argument's zero value as t gets larger, d must also get bigger. This means the maximum occurs at a point where d is larger, i.e. further from the load end of the line. Of course any other reference point besides the maximum could have been chosen and the results would be the same.

Applying this type of verification to the other term in equation 40, it can be seen that there are two waves, each traveling in opposite directions. The wave traveling away from the source end is called the incident wave, and the wave traveling away from the load end is called the reflected wave.

Phase velocity

As in the last section, we will follow a particular point on a wave to determine phase velocity, which is the speed at which the wave travels along the transmission line. Because we are following a fixed point on the waveform (again use the crest for a mental example), we set the phase equal to a constant:

$$(\omega t - \beta d) = \text{const.} \qquad (42)$$

Taking the derivative of this with respect to time we get:

$$\frac{d}{dt}(\omega t - \beta d) = \frac{d}{dt}\text{const.} = 0 \qquad (43)$$

$$\omega + \beta\frac{d(d)}{dt} = 0$$

The quantity d(d)/dt is the velocity we are looking for, so solving for that quantity we get:

$$\frac{d(d)}{dt} = \frac{\omega}{\beta} \qquad (44)$$

This is the phase velocity. Notice if we select the phase of the other term to set constant, the absolute value of the phase velocity is the same, but the sign is reversed, again demonstrating that the two terms represent waves travelling in opposite directions.

Reflection Coefficients

While the existence of two waves has been established, the amplitudes of the waves relative to each other has not been discussec. The reflection coefficient is the ratio of the reflected and incident wave amplitudes *at the load end* of the line:

$$\Gamma = \frac{E-}{E+} \qquad (45)$$

Where E+ represents the incident wave voltage and E– represents the reflected wave voltage. Generally, Γ is a complex number. The magnitude of each wave is given by the coefficients in front of each exponential term in equation 38. Plugging these coefficients into equation 45 results in :

$$\Gamma = \frac{\frac{I_R}{2}(Z_R - Z_0)}{\frac{I_R}{2}(Z_R + Z_0)} = \frac{(Z_R - Z_0)}{(Z_R + Z_0)} \qquad (46)$$

Some special cases help demonstrate Γ. If $Z_R = Z_0$, $\Gamma = 0$, which means there are no reflections in a line terminated in its characteristic impedance. For $Z_R=0$, (a short circuit), and $Z_R=\infty$, (an open circuit), the magnitude of $\Gamma = 1$, indicating the incident and reflected waves are equal. Figure 3 demonstrates the relationship between the two current waves in a short-circuited line.

Standing Waves, VSWR

Except for lines terminated in open and short circuits, the reflected and incident waves do not have equal amplitudes, meaning there will never be total cancellation of the two waves (see Figure 4). The ratio of the maximum voltage amplitude along a line to the minimum voltage amplitude along the line is called the voltage standing wave ratio (VSWR), (because voltage and current are proportional, the ratio of currents can also be used):

$$\rho = \frac{|E_{max}|}{|E_{min}|} = \frac{|I_{max}|}{|I_{min}|} \qquad (47)$$

The maximum amplitude occurs when the maximum of the reflected wave coincides with the maximum of the incident wave, and the minimum amplitude occurs when the maxima are 180 degrees apart, so that :

$$\text{VSWR} = \frac{|E+| + |E-|}{|E+| - |E-|} \qquad (48)$$

Notice that if both the numerator and enominator on right hand side of equation 48 is divided by |E+|, the result is:

$$\text{VSWR} = \frac{1 + \left|\frac{E-}{E+}\right|}{1 - \left|\frac{E-}{E+}\right|} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (49)$$

Conclusion

Of course nobody goes about solving a transmission line problem by starting with differential equations. This tutorial only touched upon the really useful tools in transmission line analysis, such as reflection coefficient and VSWR. However, it is hoped that this tutorial has helped to make use of those tools more intuitive and less mechanical by illustrating the principles that lead up to them. *RF*

Bibliography

1. King, Ronold, W.P., Rowe, Mimno, Harry Rowe, Wing, Alexander H., *Transmission Lines, Antennas and Wave Guides*, Harvard University, Cruft Laboratory Notes, McGraw-Hill, 1945.

2. Sinnema, William, *Electronic Transmission Technology*, 2nd ed., Prentice Hall, 1988.

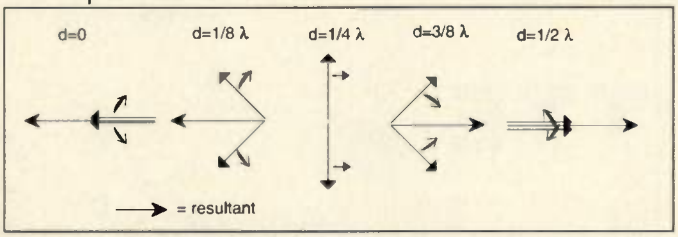


Figure 3. Phase relation between equal incident and reflected current waves as a function of distance from short-circuited end.

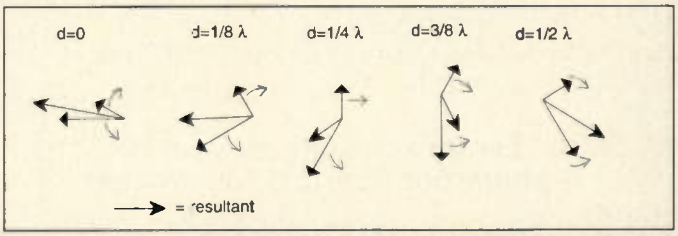


Figure 4. Incident and reflected waves at different distances from an arbitrary complex load. Notice phase of resultant changes gradually.

RF product forum

Crystal Filters

Product Forum is a new feature starting this month in RF Design. *Replacing the RF Product Report, the Product Forum is a collection of comments from manufactures about the markets and technology for a selected product. It is written by the manufactures themselves, with no editing, (except for grammar and length), by the editors of* RF Design.

Raltron Electronics Corp.

Raltron's line of low cost standard and custom RF filters is currently enjoying about 25% a year growth, and is expected to continue expanding linearly for at least the next two years.

Driving applications include beepers, cordless and cellular phones, satellite and other systems for wide area voice and data transmittal. These forms of wireless communication employ superheterodyne radio receiver techniques with intermediate frequencies (IF) in need of filtering. Popular frequencies include 10.7 MHz, 21.4 MHz, 70 MHz and 90 MHz.

Since half the world's growth in beepers right now is in China, and the Chinese are very political in their business dealings, developments in Chinese politics greatly affect Raltron's sales of crystal filters, and will probably continue to do so in the future.

Technological developments of smaller components, higher frequencies and wider bandwidths also affect Raltron's sales.

Low cost, low insertion loss, wide selection and superior Raltron service all contribute to faster time to market, and greater market growth for Raltron.

For more information on Raltron's crystal filter products circle INFO/CARD #199

Piezo Technology, Inc.

The crystal filter market includes two different technologies, discrete and monolithic crystal filters. PTI is a major supplier of both. The biggest market for traditional discrete crystal filters is military – guided weapons, navigation, radar, and EW – and it's no secret that demand for these systems is shrinking. The monolithic crystal filter market is primarily communications systems, and this market is exploding.

The "communications highway" consists of land mobile communications, cellular telephone systems, and now "wireless" systems. The traditional 10.7 MHz and 21.4 MHz IFs have migrated toward new standards of 45 MHz and 70 MHz, with some IFs being above 100 MHz. Expanding demand here has saturated some suppliers, with lead times of six months or more. In this area, PTI is a technology leader, and is capable of supporting requirements, including fundamental mode devices, to 200 MHz and beyond.

For more information about PTI's crystal filter products circle INFO/CARD #198 *RF*

To get your hands on *RF DESIGN's* most popular books, simply check below.

__❐ #R-1
Oscillator Design Handbook . . . more than 20 top RF engineers as they share their expertise on oscillator theory, design and applications.
80 pages.......**$25.00**

__❐ #R-2
Filter Handbook: Volume 1 – Applications . . . see how the best engineers solve their design problems. Essential information on active, passive, lumped element, microstrip, helical and SAW filters will help make your filter design tasks easier. **80 pages**.......**$25.00**

__❐ #R-3
Filter Handbook: Volume 2 – Design . . . fundamental and advanced material on classic Butterworth, Chebyshev and elliptic filters, plus notes on filter implementation, including filter performance with real, not ideal components. **82 pages**.......**$25.00**

__❐ #R-4
RFI/EMI/EMC: A Designer's Handbook . . . the best design-for-compliance articles from RF DESIGN and EMC TEST & DESIGN.
80 pages.......**$25.00**

__❐ #R-5
Power Amplifier Handbook . . . loaded with practical circuits for power amplifiers operating from HF through L-band, from a few watts to over a kilowatt, with clear explanations of how these circuits were designed. **80 pages**.......**$25.00**

__❐ #R-6
Frequency Synthesis Handbook . . . phase locked loops and direct digital synthesis are the main focus of this handbook.
80 pages.......**$25.00**

__❐ #R-7
Wireless Communications Handbook . . . topics include spread spectrum systems, Part 15 devices, digital modulation, demodulation, transmission, reception and signal propagation.
80 pages.......**$25.00**

__❐ #R-8
Test & Measurement Handbook . . . covers general RF test information, specific test procedures and circuits for test applications.
80 pages.......**$25.00**

Payment enclosed $____
Bill My: ❐ MC ❐ VISA ❐ AMEX
Card #____ Exp ____
Signature____
Name ____
Title ____ Phone ____
Company____
Address ____
City/State/Zip____
Country____

Amount Spent	Shipping Charge
$0-25.00	$4.00
$26-50.00	$6.00
$51-100.00	$8.00
$101-150.00	$10.00
$151-200.00	$14.00
$201-250.00	$18.00
$251-300.00	$20.00

All additional amounts, please combine above.

Outside U.S. TRIPLE Shipping Charges

RD HANDBOOKS Special Set Prices

#R-21 Any 4 for $69
#R-22 Any 5 for $84
#R-23 Any 6 for $98
#R-24 Any 7 for $110
#R-25 Any 8 for $122

Mix and match the RF Handbooks and . . . **SAVE!**

Send to: Argus Book Department • 6151 Powers Ferry Road, NW • Atlanta, GA 30339-2941 • (404) 618-0398 • Fax (404) 618-0347

RF marketplace

Classified display ads are available at $115 per column inch. Frequency rates available for multiple insertions. Please call for further information, 1-800-443-4969, ask for Carmen Hughes. Or fax your ad copy for a rate quote to (404) 618-0342.

PRODUCTS & SERVICES

A-COMM ELECTRONICS
Refurbished Test Equipment
DC-26ghz HP GR Wavetek Tektronix
Send for Catalog listing
7198 S. Quince Street
Englewood, Colorado 80112
303 290 8012 Fax 303 290 8133

INFO/CARD 70

COAXIAL CONNECTOR SOCKET

Designed to reach between tightly packed Coaxial connectors, this socket is the perfect tool for tightening coaxial connectors to specific torque values. The socket fits a standard 1/4" drive wrench.

KCR PRODUCTS 800-283-6368 or 904-238-7295

INFO/CARD 71

RF Design
1-800-443-4969

ANALOG & RF MODELS
SPICE models from DC to 10 GHZ
Full non-linear models including:
RF pin diodes, class C, opto, & logic.
We also do measurements and consulting.
Give us a call at **(602) 575-5323**

INFO/CARD 72

It's Here . . .
PRODUCT SHOWCASE
See page 47 for details

- *Voltage Controlled Oscillators*
- *Phase Locked Oscillators*
- *Frequency Synthesizers*
- *Radar Receivers*
- *Subsystems*
- *Integrated Assemblies*

delphi Components, Inc.
A Division of Aura Systems Inc.
27721-A La Paz Road
Laguna Niguel, CA 92677
Ph: 408.280.7073 Fax: 408.280.1633

INFO/CARD 73

NOLAN LABORATORIES, INC.
Consulting, Design, Test and Manufacture
FOR
RF, Microwave, Antennas,
Electromagnetics, EMI/RFI,
Bioelectromagnetic Sensors
Design and Support for Manufacturability
James A. Nolan, MSEE — PO Box 567
President — Conifer, CO 80433-0567
(303) 838-0057

INFO/CARD 74

SPECTRUM PROBE
EMC RFI
This low circuit loading **scope probe** produces a 60 dB **spectrum analyzer** display on your inexpensive scope

AC Power line - FCC limited	*computers*
Field Strength - E field	*medical*
Conducted Radiation - current	*avionic*
Radiation Sources - voltage	*automotive*
EMI Sources,and leak sniff	*ind.process*
Ultrasonics Infrared	*TV remotes*
Remote (line) Controllers	*household*

Ask for these application notes,specifications, sales & warranty information.

255 Spectrum Probe 30 KHz to 2.5 MHz $279
107 Probe 1 to 100 MHz $249 ($279 extra shielding)
Accessory Current Adapters: IA5 $19 IA7 $29

Technical tips show how scope amplitude allows estimating field strength 300 µV/M to100 V/M, to find and reduce RF radiation per FCC part 15,18;VDE. You can sniff and find that radiation!

Other tips show current adapters (40 µA to 100 mA) with typical calibration curves. Useful for RTCA/DO-160, MIL-STD461 requirements. Good also for capacitor, board and IC lead currents.Computer switching power supply servicing is speeded by current measurements.

An unusual tip shows how you can connect standard low cost components within an outlet strip. These outlets then allow operation of your equipment well isolated from power line RF noise.Included is the FCC line (LISN) network, allowing you to measure conducted EMI from your equipment per FCC part 15,18;VDE.
— Fix conducted EMI !

SMITH DESIGN
207 E.Prospect Ave,N.Wales, PA 19454 **(215) 661-9107**

INFO/CARD 75

RSG-10
SIGNAL GENERATOR
The $2495 profit generator
Quality crafted in the USA

Finally, a synthesized signal generator that's designed to help you generate more than just signals. The Ramsey RSG-10, is the signal generator you can afford, the signal generator that's designed to do what a signal generator is meant to do- provide a very stable, accurate, easy to control signal from 100 Khz to 1.0 Ghz.

For the price, you wouldn't expect any more. But, there is more to the RSG-10. An intelligent microprocessor controlled/programmable memory, for example, can store up to 20 of your most commonly used test set-ups. And unlike other units, just one touch of the memory exchange button is all it takes to quickly shift from one test set-up to another. You get more work done, easier and faster.

At $2495, the Ramsey RSG-10 is your profit generator.

RAMSEY
RAMSEY ELECTRONICS
793 CANNING PARKWAY, VICTOR, NY 14584
Fax: (716) 924-4555
TELEX: 466735 RAMSEY CI
ORDER DIRECT—CALL 1-800-446-2295
VISA MasterCard

INFO/CARD 76

KTS ELECTRONICS
"Where your dreams turn into reality."

- STD. 5 AND 10 MHZ OCXO
- TCXO • VCXO • TC-VCXO
- VCO's • CLOCK OSCILLATORS
- CUSTOMIZED CRYSTAL FILTERS STD. 10.7 MHZ, 21.4 MHZ and 45 MHZ
- L/C FILTERS
- STANDARD IF FREQUENCYCRYSTALS
- SURFACE MOUNT AND LEADED PACKAGE

Call or Fax requirements.
16406 N. Cave Creek Rd. #5
Phoenix, AZ 85032-2919
Phone & Fax (602) 971-3301

INFO/CARD 77

FREQUENCY CONTROL PRODUCTS

CRYSTAL OSCILLATORS	CRYSTAL OVENS
VCXO's	M05
TCXO's	M18
OCXO's	M43

- LOW PROFILE
- TIGHT STABILITIES
- SINE OR SQUARE WAVE
- PHASE LOCKING INPUTS
- INTERNAL SMD CONSTRUCTION

ISOTEMP RESEARCH, INC.
P.O. Box 3389 Charlottesville VA 22903
(804) 295-3101 FAX (804) 977-1849

INFO/CARD 78

Products & Services

PCFILT

L-C and transmission line filter design and analysis for your PC compatible

- 7 years in development.
- Internal analysis and optimization.
- Pole placers or lowpass reference scaling.
- Practical and flexible.

ALK Engineering
1310 Emerson Ave.
Salisbury, Maryland 21801
(410) 546-5573 Fax (410) 860-9069

INFO/CARD 79

CAL CRYSTAL LAB., INC. • COMCLOK, INC.

Need Clock Oscillators or Crystals? Call 1-800-333-9825 • 714-991-1580

Quartz Crystals 50Khz to 200Mhz
TTL Clock Oscillators 250Khz to 70Mhz
HCMOS Clock Oscillators 3.5Mhz to 50Mhz

Tri-State, Half Size and Surface Mount also available on request

Fast Service - 3 weeks or less
Special frequencies our specialty

1142 N. Gilbert Anaheim CA 92801 • FAX 714-491-9825

INFO/CARD 80

WHAT CAN

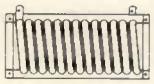
KINTRONIC LABS, INC.

OFFER YOU?

HIGH QUALITY, AFFORDABLY PRICED

DESIGN / FAB / TEST / SUPPORT

OF WHAT?



RF Components (LF, MF & HF Bands)

Custom Antennas (VHF, UHF & Microwave Bands)

RF Components (LF, MF & HF Bands)	Custom Antennas (VHF, UHF & Microwave Bands)
•Inductors •RF Switches •RF Patch Panels •RF Chokes •Mica Capacitors* (Cornell Dublier) •Vacuum Capacitors* (Jennings) •Rigid Transmission Line & Accessories *In Stock Ready For Immediate Delivery	•High Gain, Vertically Polarized, Series Fed Arrays •Wide Band, Omnidirectional, Vertically Polarized Biconicals •Tunable Discones Utilizing A Patented Design •Covert Designs For Indoor Or Outdoor Applications

Kintronic Laboratories, Inc.
P.O Box 845
Bristol, TN. 37621-0845
Phone: 615-878-3141
Fax: 615-878-4224

INFO/CARD 81

Professional Services

RF POWER CONSULTING

Engineer with over 20 years of experience in high power HF-VHF designs is available for consultation.
(Recently retired from a major semiconductor manufacturer).

Specialties: MOSFETs, amplifiers (classes A-D), power combiners, RF transformers, filters, PC lay-outs, directional couplers, ETC.

Modern RF lab is available at the premises.

H.O. Granberg
Phone: 602-943-0401 Fax: 602-944-5019

INFO/CARD 82

RF Design
1-800-443-4969

Career Opportunities

The CellNet Breakthrough

We've created CellNet™, a state-of-the-art communication system designed to help electric utilities automate their entire power distribution networks. The CellNet system is a scalable, bi-directional network capable of real-time communications that enable utilities to remotely monitor and manage every point in the distribution system.

This is *electrifying* work, with the challenge of creating progressive solutions that foster positive environmental impact and more efficient use of our existing resources. If you are a talented RF professional ready to make a breakthrough of your own, send us your resume today.

RF Services Manager

Take charge of FCC licensing activities and developing cell planning strategies. More specifically, you will oversee cell planning for all CellNet installations and RF related activities, including the design of RF networks for each site and managing RF Field Engineers. Selected candidate will have 5-8 years of experience in the cellular or related industry and 3+ years in management. You must be knowledgeable about RF propagation theory/practice/application, antenna design, FCC regulations and cellular rollout planning.

Sr. RF System Engineer

You will provide technical leadership and detailed expertise for the planning, design and development of WAN and LAN radio systems. Requires at least 7 years of experience with digital and radio communication systems development, as well as DSP and RF circuit design. Familiarity with narrowband and spread spectrum modulation is also necessary, as is exposure to digital circuitry for microcomputers.

Sr. RF Design Engineer

Responsible for concept design, prototyping, RF layout development and project management of a 900 MHz wireless radio product. We require 7+ years of high volume commercial product design experience with oscillators, synthesizers, receivers and transmitters. CAE experience is a must; RF ASIC preferred. Oversight of subcontracted projects is a definite plus.

RF Product Engineer

Improve quality margins, reduce costs and increase product functionality as champion of release products. You must have 8 years of experience in electronics manufacturing including product/process engineering, as well as an emphasis on RF products.

All positions require a BS/MSEE or equivalent.

We offer some *powerful* reasons for joining us: a challenging work environment, competitive salary, and a comprehensive benefits package. For immediate consideration, please send your resume, indicating position of interest, to CellNet, Professional Staffing, Dept. RF0794, 75 Shoreway Road, San Carlos, CA 94070 or FAX it to (415) 592-6858. EOE. CellNet is a trademark of CellNet Data Systems.

CELLNET
DATA SYSTEMS

INFO/CARD 83

CLINICOM, the leader in Information Solutions for Better Patient Care, has current openings for the following positions:

▼ Hardware Services Engineers ▼

Provide technical services to perform RF site surveys and maintenance, CliniCom hardware troubleshooting, and provide an engineering interface to the customer. BSEE or equivalent with at least 2 years RF communication system installation and troubleshooting are required. Excellent written and verbal skills and the ability to manage multiple projects in a high stress environment are necessary.

CliniCom

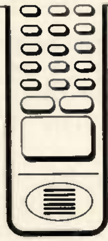
the leader in information solutions for better patient care

Please send resume and salary requirements to (*NO phone calls, please*):

Attention: HR
4720 Walnut Street
Boulder, Colorado 80301
EOE

INFO/CARD 84

For more information CALL 1-800-443-4969 Carmen Hughes



Cellular Engineers: Design/develop RFand analog circuits for high capacity cellular systems. Requires minimum of 2 years experience in any of the following: DSP, ASIC Design, Cae Development, Digital Modulation, Digital Mobile Communications, Channel Equalizers, Transmitter-Receiver Synthesizer or Audio Design, Digital Signal Processing.

...YOUR CAREER

Spread Spectrum Design: Responsible for design development and test of RF circuits and systems for spread-spectrum wireless systems. Designed 1.8/2.4 GHz wideband frequency synthesizer and VCO and GAAS linear power amplifiers. Analyzed and simulated communications system performance. Assisted in producibility redesign and system integration.

Product Marketing Manager: Our client, a well known microwave firm, seeks an experienced professional to perform classical marketing functions for a product line: i.e., develop short and long term business plan, determine marketplace, etc. Excellent compensation package along with executive benefits.

Digital ASIC Design Engineer: Will be responsible for the design of high speed CMOS digital circuit on a gate and a component level. Requires BS/MS in EE with 3 to 5 years experience in high speed CMOS digital ASIC design in its entirety; design with testability; simulation; timing analysis; test vector. Also requires design experience with FPGAs for prototyping. Must be familiar with Verilog HDL on SUN platform with UNIX. Experience designing circuit with low power techniques is highly desired.

RF/Synthesizer Design: Positions available for candidates experienced in the design and development of communication receiver/transmitter systems and subsystems. Experience in RF synthesizer design, RF circuitry, low power circuit design and GaAs/Silicon MMIC design is desirable. At least a BS degree in Engineering is required.

RFIC Design: MS or PhD in Electrical Engineering with minimum 5 years related experience preferred. The candidate should have a good knowledge and experience in Linear Bipolar High Frequency IC design and measurement techniques in design IC's like Amplifiers, Mixers, Oscillators, VCO's, Prescalers, Synthesizers, Limiting Amplifiers, etc. operating up to 2 GHz in Bipolar or BiCMOS technologies.

MMIC Design Engineer: Develop L/S band GaAs MMIC power amplifiers for commercial wireless communications. Requires: M.S. or BSEE, +2 years experience with GaAs MMIC design, simulation, packaging and test.

Sr. RF Systems: Responsible for design and integration of RF subsystem on a component level basis in hand-held cellular phone applications; link budget analysis system performance budget; PCB layout support. Also responsible for supporting system integration. Requires BS/MS in EE, minimum of 8 years related RF circuit and system design experience. Broad knowledge of RF circuit in wireless communication portable products is essential. Should be familiar with digital signal processing theory and its applications. Experience in RF subsystem design and overall system familiarity with Digital and/or Analog Hand-held Cellular environment is highly desired.

MICRO COMMUNICATIONS EXECUTIVE SEARCH

800 Turnpike St. • North Andover, MA 08145

We specialize in the placement of communications both nationally and internationally.

FOR THESE AND OTHER OPENINGS
CALL COLLECT: TEL: 508-685-2272 FAX : 508-794-5627

INFO/CARD 85

We'll Supply The Way. You Supply The Means.

When it comes to technological innovation, Norand has been a leader in more ways than one. Just as we refuse to acknowledge limits to technology itself, so our scope remains wide, as evidenced by the impact we've had on portable data products and solutions. Our current record of achievement includes innovations in automated route distribution, portable data collection systems/products, RF Systems, radio data networking, RF terminals and integrated bar code printers, terminals with portable/mobile capability, and PEN*KEY, our most recent release. Join us, and lend your talents to the pursuit of still higher technology, focusing on Wireless Data Solutions & Technologies, Software and Hardware, SNMP, ODI Drivers, EtherNet, Novell Protocols, C & C++ languages, Windows Programs/Drivers, ASIC, DSP, and other disciplines key to pursuing the next generation. We currently need technology leaders for:

MANAGEMENT POSITIONS OPEN WIRELESS SYSTEMS

- NETWORKING S/W DEVELOPMENT
- CONTINUATION ENGINEERING

ENGINEERING POSITIONS

- SR. ENTERPRISE NETWORKING DEV. ENGINEER
- SR. CONSULTING ENGINEER-RF
- LEAD ENGINEER; DIGITAL/DSP
- RF TECHNICAL LEAD ENGINEER
- OPEN SYSTEMS TEST ENGINEER
- S/W DEV. ENGINEER/LIBRARIAN

The above positions represent some of the current opportunities which are available at Norand. They require a minimum 4-year degree in a relevant discipline, a minimum 3-5 years' development and/or design experience, and a desire to be challenged. If you perceive yourself as limited in your current position, and possess the vision we're seeking, please investigate the Norand Job Opportunity Hotline (1-800-501-JOBS), or post an inquiry on Internet (HOCHSTAB @NORAND.COM). Fax: (319) 369-3791.

NORAND®
Mobile Computing for the REAL WORLD

550 Second Street S.E.
Cedar Rapids, IA 52401

INFO/CARD 86

Wireless Communications Products

Rockwell has been the leader in wireline communications devices for some 15 years. Eighty percent of the worldwide fax machine installed base and more than sixty percent of personal computer data and data/fax modems use Rockwell technology.

Today, as we enter the new era of wireless systems communications, we plan to remain at the forefront. All the technologies required for the "communicate-anywhere-at-any-time" era are being developed at Rockwell Telecommunications, including:

- **Digital Cellular and Cordless Telephony**
- **Packet Data**
- **Wireless LAN**
- **Personal Communications Systems**

The skill sets required for these programs include:

- **Advanced signal processing algorithms and communications protocols**
- **Miniaturized low power RF transceiver design**
- **RF systems integration architectures and device implementations**
- **Digital modulation schemes and multiple access technologies**

Immediate employment opportunities are available in all the above product and technology areas for:

RF TECHNICAL GROUP LEADERS
RF SYSTEMS DESIGN ENGINEERS
RF CIRCUIT DESIGN ENGINEERS

If you would like to know more about becoming part of our vision of the wireless future, and you have experience with any of the technologies listed above, apply today. Positions may be in Newport Beach, CA or other locations in the country. For immediate consideration, fax your resume to (714) 833-6793, Attn: RFD-0794-DG or mail to: Rockwell Telecommunications, Attn: RFD-0794-DG, 4311 Jamboree Road, P.O. Box C, Newport Beach, CA 92660-3095. Equal Opportunity Employer M/F/D/V.

Rockwell *Telecommunications*

CAREER OPPORTUNITIES

RF DESIGN ENGINEER

A Southeastern Cleveland, OH corporation is seeking an engineer to design and develop RF based products. The development role will range from the conception of new products through first production run. Responsibilities include product cost estimation, RF and analog design, and testing of designs. Requirements: BSEE or equivalent, 7-10 years experience in the design of RF transmission line products at power levels up to 5kW, and frequencies up to 2500 MHz. Candidates must have a thorough knowledge of RF transmission line fundamentals, and direct experience in the design of radio frequency filters, directional couplers, and other products of this nature. Candidates must also be familiar with stripline and microstrip design techniques, as well as coaxial transmission line configurations of the above devices. Familiarity with CAD tools for design of the above, as well as good mechanical ability, is desired.

Please respond to: Argus Business
RF DESIGN, P.O. Box 76828
Atlanta, GA 30328
ATTN: Carmen Hughes

An Equal Opportunity Employer

INFO/CARD 88

DSP Without Tears™

Learn DSP and put your knowledge to work IMMEDIATELY!

ΩΞ
ψ

COMING TO A CITY NEAR YOU
Atlanta San Jose
Salt Lake City
Washington D.C.
Toronto Austin
Scottsdale, AZ

Call Z Domain Technologies, Inc.
800-967-5034
404-587-4812

Hours 9-5 EST.
Ask for a brochure

Our 2-Day Advanced Course is ready. Call for more info.

By taking this 3-Day Course you will really learn DSP. Guaranteed!

INFO/CARD 89

MARKETPLACE

404•618•0217

Electronics Instructor:

B.S.E.E. or B.E.T. or related degree. 2 years experience in directly related field. Good communication and presentation skills required.

Starting Date: August 1, 1994

Send resume and transcripts to:

Dr. Veldon L. Law
John Wood Community College
150 South 48th Street
Quincy, Illinois 62301
Phone: 217/224-6500, Ext. 164
FAX No. 217/224-4208

INFO/CARD 90

RECRUITMENT

Leader in the placement of RF Professionals
Call Toll Free 800-433-2160 FAX 817-599-4483

TECHNICAL

1. **CH. Des.** – HDW test des. & dev. Broadband – Sprv. 9 To 85K
2. **Cell. Sys. Engrs. (sev.)** – Dev. new srvs, ntwk pl., Freq. Coord., Intl. & USA Loc., 50-75K
3. **App. Eng.** – Anal. & Dig. Sys. for video & data ntwks BSEE, S. Loc. 50's
4. **Test Eng.** – RF test eqp. – FL Loc. To 40K
5. **Proj. Eng.** – Modules & Hybrids MW Loc. – 50's
6. **RF Des. Eng.** – CATV & LAN Prod. – S.E. To 55K
7. **RF Des. Eng.** – RF Amps & Hybrid Oscill S. Loc. 55K
8. **Sr. RF Des.** – Telecom. Prod. – Must know C & C++ 60's S. Loc.
9. **Jr. RF Eng.** – BSEE 1 + yr exp. N.E. 40's
10. **Microwave test Tech** – Test microwave radios High 30's TX Loc.
11. **Sr. R&D Eng.** – Fiber & Broadband LAN 5 yrs. N.E.Loc. Sal. open
12. **RF Des.** – EMC Prod. – 8 Loc's – Sal. 35-60K

SALES AND MARKETING

1. **Reg. Sales Mgr.** – Components – 70-90K + Comm.
2. **Nat. Sales Mgr.** – EMC Prod's Sal. Open + Comm.
3. **South Amer. Sales Mgr.** – Must be bilingual comp. Sal. Neg.+ Comm.
4. **Acct. Rep.** – Sys. Block & Sub Assemblies – To 85K + Comm.

Please call about our many other positions domestic and international for full details.

JIM YOUNG & ASSOCIATES
One Young Plaza 1235 Ranger Highway Weatherford, TX 76086
Call for information about these and many other opportunities nationwide

INFO/CARD 91

RECRUITMENT

RF/MICROWAVE — IOWA MIDWEST — WIRELESS

WORK WITH AN RF ENGINEER IN YOUR MOVE TO THE MIDWEST!

My clients need top-notch RF Design Engineers and Managers, 3 to 10+ years experience, HF to 3.0 GHz, Receivers, Transmitters, Power Amplifiers, Synthesizers, Spread Spectrum, ASIC/MMIC Design, Modems, Communications DSP.

DON GALLAGHER MSEE

Phone: 319-895-8042 Fax: 319-895-6455
1145 LINN RIDGE RD. MT. VERNON, IA 52314

40 YEARS OF RF ENGINEERING, MANAGEMENT, AND PLACEMENT OF ENGINEERS

INFO/CARD 92