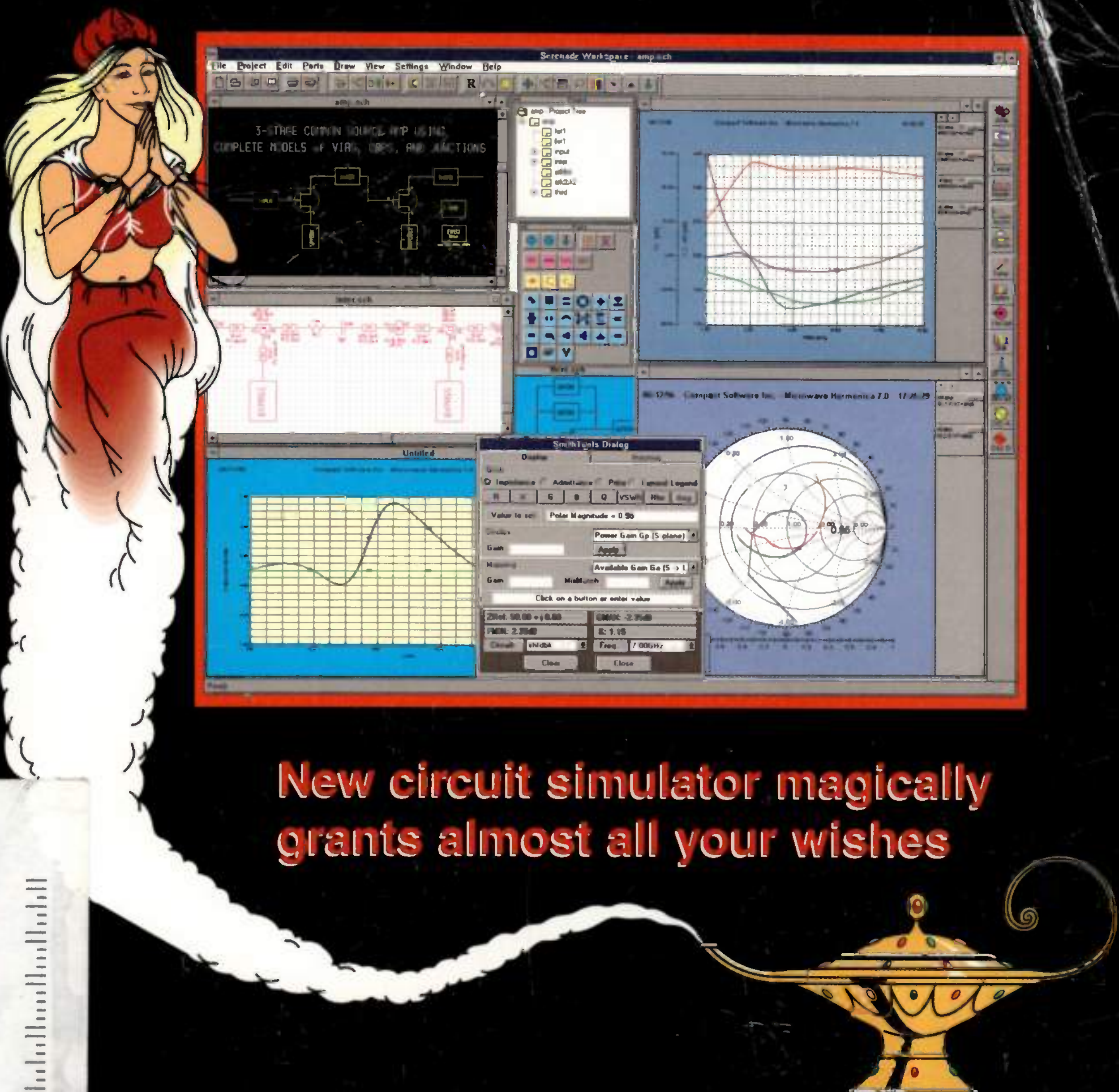
An INTERTEC®/K-III Publication

RF design®

engineering principles and practices

August 1996

WIRELESS 17 YRS LEADERSHIP



New circuit simulator magically grants almost all your wishes

Featured technology—
Antennas

Tutorial—
Coaxial cables

AIRONET™ HAS MORE THAN 325,000 WIRELESS LAN DEVICES INSTALLED WORLDWIDE

Nobody has more spread spectrum radios installed worldwide than Aironet. And nobody offers a broader line of products for creating wireless local area networks.

From OEM radios for your wireless devices to our patented ARLAN® network architecture, Aironet can be your full line supplier of quality components for a complete, seamless wireless LAN solution.

AIRONET'S WIRELESS OEM PRODUCTS

OEM RADIOS

- 2.4 GHz Direct Sequence Spread Spectrum
- 900 MHz Direct Sequence Spread Spectrum
- 2.4 GHz or 900 MHz Low Power MicroRadios™

OEM WIRELESS LAN MODULES

- 2.4 GHz Frequency Hopping PCMCIA at 1&2 Mbps
- 2.4 GHz Direct Sequence at 1&2 Mbps
- 900 MHz Direct Sequence at 860 Kbps

WIRELESS LAN INFRASTRUCTURE PRODUCTS

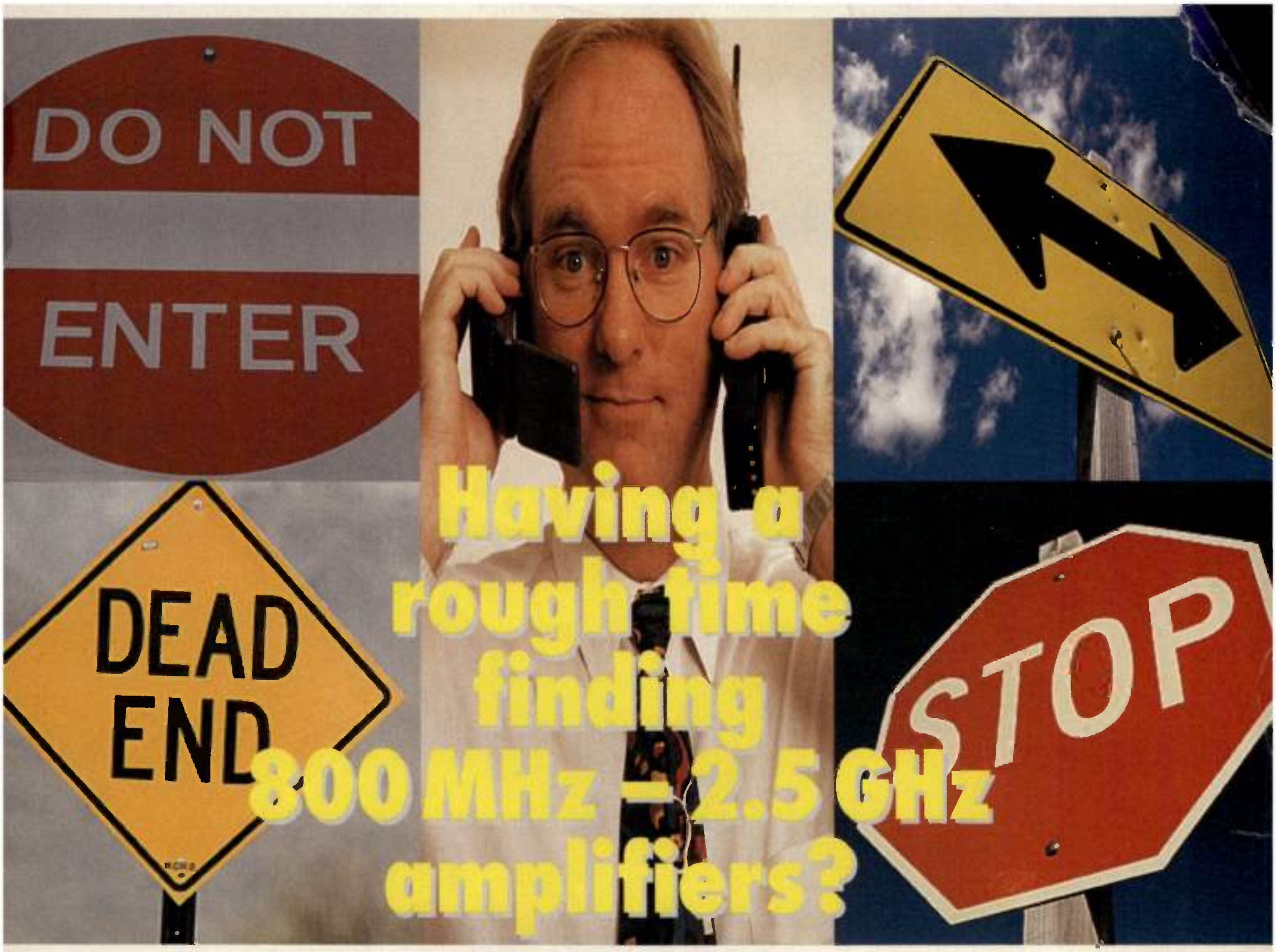
- ARLAN® Patented Wireless LAN Network Software
- Access Points for Ethernet, Token Ring, and LocalTalk
- ISA, Microchannel and PCMCIA LAN Adapters
- Wireless Bridges and Repeaters

Aironet™

AIRONET WIRELESS COMMUNICATIONS, INC.

Call: 1-800-3-WIRELESS ▲ 818-361-4918 ▲ Information via fax at 818-837-4341 ext. 291 ▲ Visit our Web site at http://www.aironet.com

Circle 75 for free literature – Circle 76 for immediate requirements.



If it's amplifiers you want? It's amplifiers we've got!

Celeritek has a new family of broadband MMIC amplifiers serving the **800 MHz to 2.5 GHz** frequency range, focusing on your wireless communications needs.

Celeritek's **CSS9132** amplifier is a pin-for-pin replacement for existing amplifiers, while the **CMM2306** amplifier fits in the same socket, but offers higher performance for those applications that require lower current, higher gain and lower noise figure. See how much more design margin you can get at the same price!

Both these low-cost amplifiers offer industry standard features including: Single +3V to +6V Supply; Input and Output Matched to 50Ω, DC Blocked; SOIC-8 Plastic Package in Tape and Reel.

Pick Your Part!

CSS9132 Driver Amplifier or the CMM2306 Performance Amplifier

Only $2.95!
(in 1000 piece quantity)

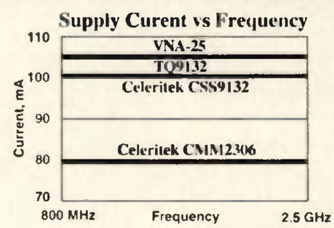
The choice is yours!

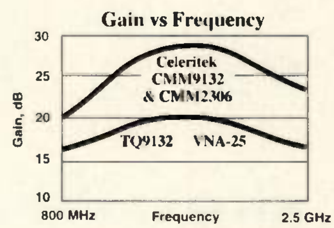
The charts show the performance characteristics of **Celeritek's CSS9132** broadband driver amplifier and **CMM2306** broadband performance amplifier versus two other amplifiers currently available.

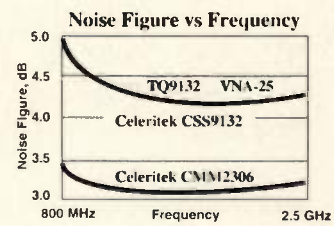
In each case, the **Celeritek** MMICs meet or exceed the performance of the competing devices.

Stop looking all over town for the MMIC amplifiers you need – Celeritek has them in stock! Get more information and **FREE** samples. Call **Celeritek** today!

(408) 986-5060 Ext. 275







CELERITEK

3236 Scott Blvd.,Santa Clara, CA 95054
FAX: (408) 986-5095

INFO/CARD 1

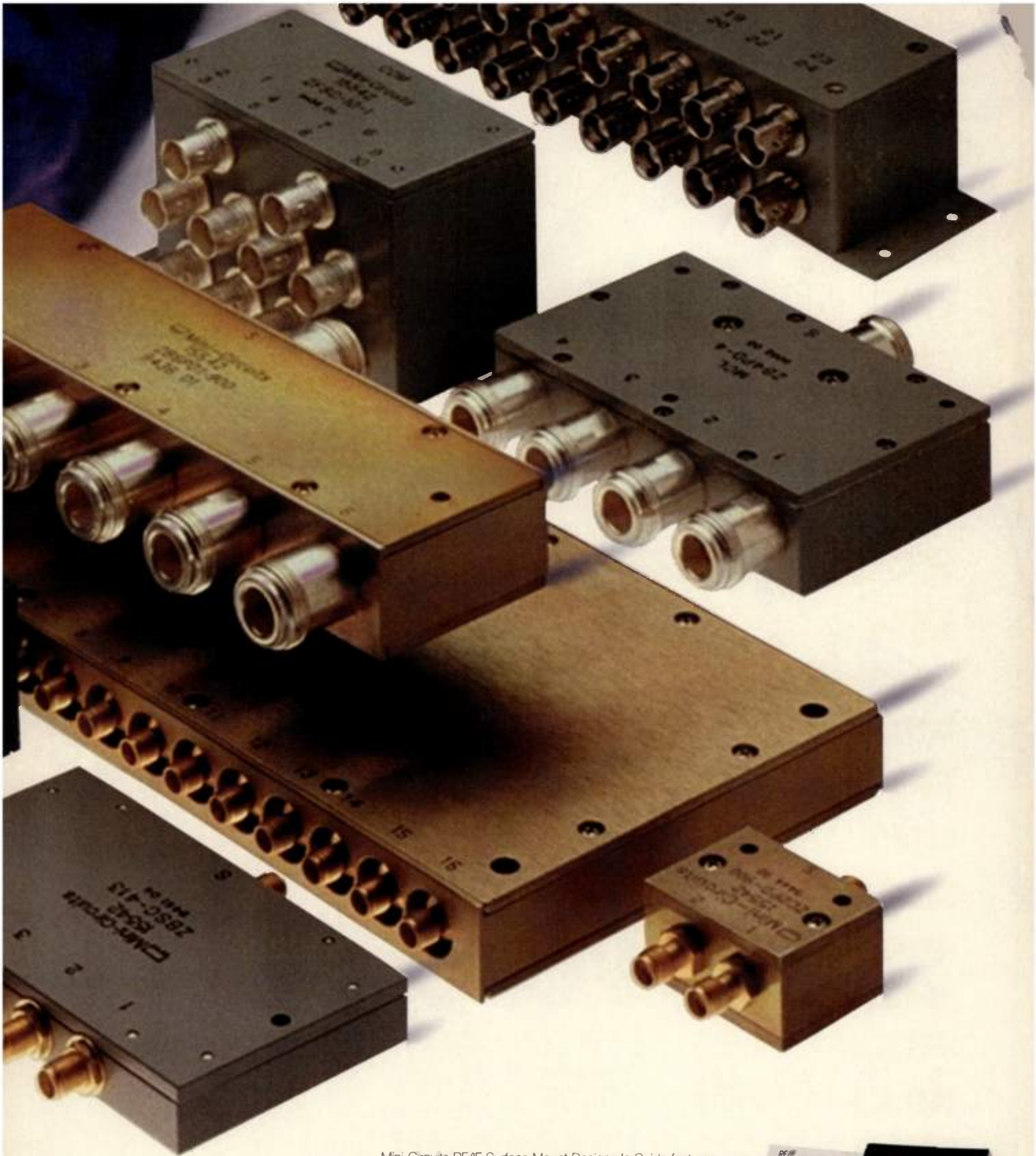
THE WORLD'S LARGEST SELECTION

POWER SPLITTERS/ COMBINERS

2kHz-10GHz *from* $2.95

Choose from over 480 standard off-the-shelf models from 2-way to 48-way; 0°, 90° and 180°; 50 and 75 ohms; covering 2kHz to 10GHz. Mini-Circuits will also supply your special needs such as wider bandwidths, higher isolation, lower insertion loss, and phase matched ports...all at catalog prices with rapid turnaround time. Models include surface mount, plug-in, flat-pack and standard connectorized designs such as SMA, N, TNC, C, and F connectors as well as custom designs. Ultra-miniature surface mount units provide excellent solutions in cellular communications, cable systems and countless wireless applications. All units come with a 1year guarantee and "skinny" 4.5 sigma repeatability unit-to-unit and production run to production run. Catalog models are guaranteed to ship within one week.

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



Mini-Circuits RF/IF Surface Mount Designer's Guide features 48 pages of the most up-to-date and complete product and specification information about Mini-Circuits surface mount components. The RF/IF Microwave Handbook is packed with 740 pages of articles, selection guides and detailed specifications for Mini-Circuits components.

Call, write or fax for your free Surface Mount Designer's Guide and Handbook today!

Mini-Circuits®

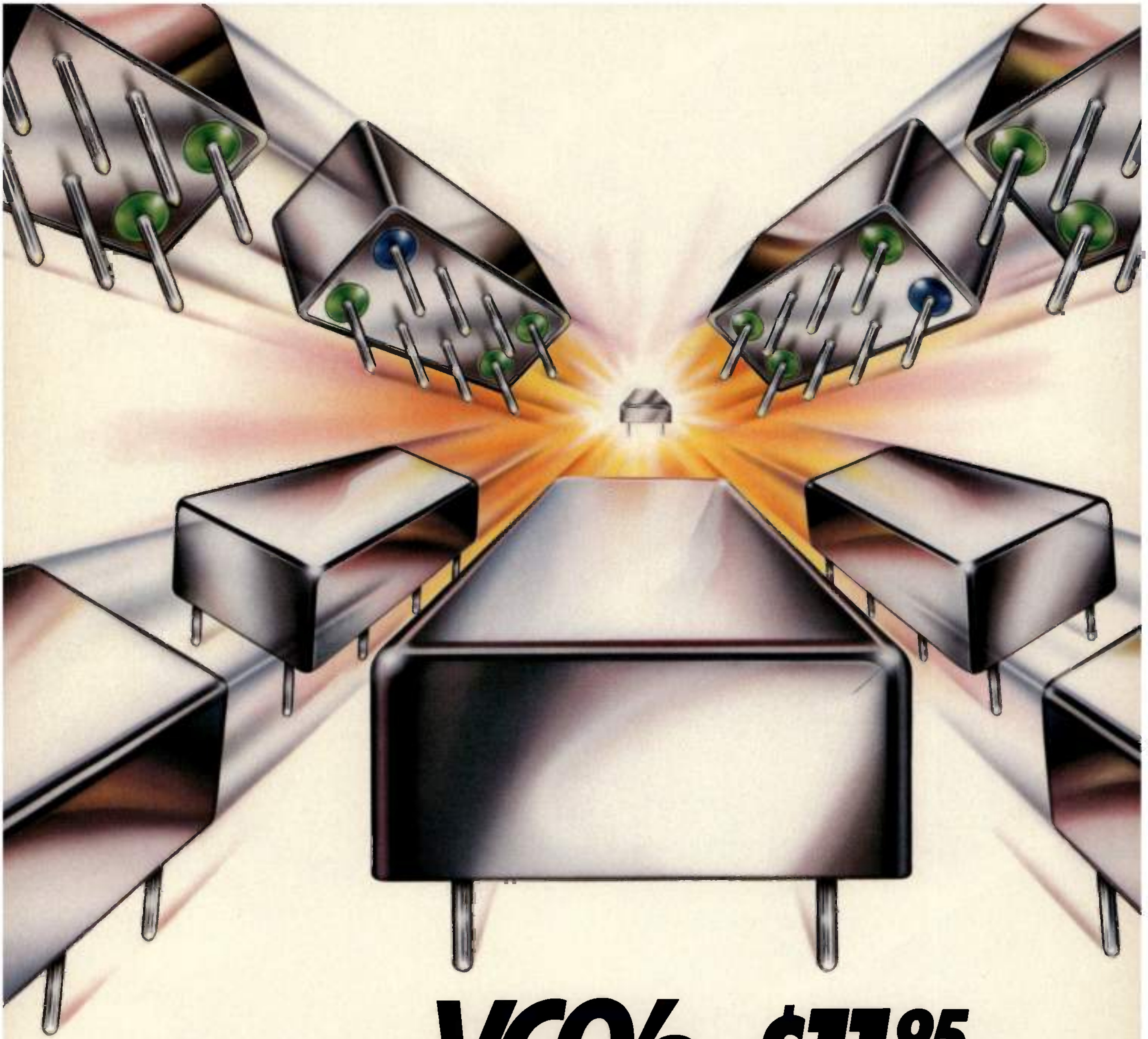
US 3 INT'L 66
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www. minicircuits. com

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EI

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

F 194 Re



25 to 2000MHz VCO's from 11^{95} (5-49)

It's a fact! With Mini-Circuits new POS family of shielded, laser sealed voltage controlled oscillators, you pay less and get more...Superior Performance, Top Notch Quality, and Value Pricing. Features include wide band models with typically octave bandwidths and linear tuning. Low SSB phase noise characterized at 100Hz to 1MHz offsets. Excellent harmonic suppression typically more than 30dB below. RF power output of +7dBm, excellent for driving level 7 mixers. Miniature size occupying only 0.4"x0.8" board space. Hermetically sealed and ruggedly constructed for tough environments. And best of all, these extremely reliable, high performance VCO's are affordably priced from only $11.95 each (qty.5-49). Call Mini-Circuits today for guaranteed shipment within one week.

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

	Model	Freq. Range (MHz)	Phase Noise (dBc/Hz) SSB @10kHz Typ.	Harmonics (dBc) Typ.	Current (mA) @ +12V DC Max.	Price (Qty.5-49) $ ea.
	POS-50	25-50	-110	-19	20	11.95
	POS-75	37.5-75	-110	-27	20	11.95
	POS-100	50-100	-107	-23	20	11.95
	POS-150	75-150	-103	-23	20	11.95
	POS-200	100-200	-102	-24	20	11.95
	POS-300	150-280	-100	-30	20	13.95
	POS-400	200-380	-98	-28	20	13.95
	POS-535	300-525	-93	-26	20	13.95
	POS-765	485-765	-85	-21	22	14.95
	POS-1025	685-1025	-84	-23	22	16.95
NEW	POS-1060	750-1060	-90	-11	30*	14.95
NEW	POS-1400	975-1400	-95	-11	30*	14.95
NEW	POS-2000	1370-2000	-95	-11	30*	14.95

*Max. Current (mA) @ 8V DC.
Notes: Tuning voltage 1 to 16V required to cover freq. range. 1 to 20V for POS-1060 to -2000. Models POS-50 to -1025 have 3dB modulation bandwidth, 100kHz typ. Models POS-1060 to -2000 have 3dB modulation bandwidth, 1MHz typ.
Operating temperature range: - 55°C to +85°C.

DESIGNER'S KITS:

K-POS1 $124.95 (contains 1ea. all models except POS-1060 to -2000).
K-POS2 $79.95 (contains 1ea. all models except POS-75,-150,-300, -1060 to -2000)
K-POS3 $79.95 (contains 2ea. models POS-1060,-1400,-2000).

Mini-Circuits®

US 7 INT'L 77
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www. minicircuits. com

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

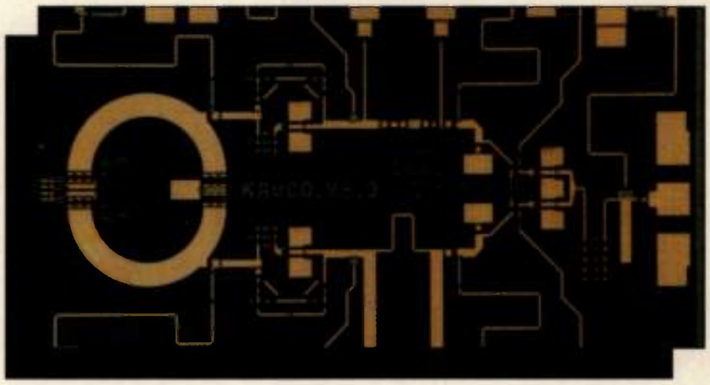
CUSTOM PRODUCT NEEDS...Let Our Experience Work For You.

F 229 Rev Orig

RFdesign

contents

August 1996



cover story — p. 56

Coming in September

- Microstrip techniques
- RF connector tutorial

RF editorial

Spectrum fuels RF product boom

By Don Bishop
Editorial Director

In what could be a replay of its sweeping reorganization of UHF-TV allocations in the 1970s, the FCC may free as much as 54 MHz of RF spectrum for telecommunications development. Once the matter of whether to auction the spectrum has been resolved, the commission may act to relocate 100 TV stations from channels 60–69, interspersing them among stations already on channels 2–59.

As you can imagine, such a plan raises political considerations of nightmarish proportions, and it could throw into turmoil the strategies of telecommunications service providers with business plans based on current spectrum allocations. Broadcasters hate to lose spectrum, and they carry political clout. Wireless communications carriers that have bid billions of dollars for a limited supply of spectrum may find the value of that resource undermined by an increase in supply.

Remember what grew out of the previous reallocation of channels 70-83 for telecommunications use: cellular, paging, specialized mobile radio (SMR), narrowband personal communications services (NPCS) and public safety radio networks, to name a few. The reallocation helped to fuel a boom in RF-based telecommunications products. Another frequency reallocation of this size would pay off for RF equipment designers in ways that can't even be imagined.

Miniaturization

Success for many electronic products depends on miniaturization. For some products, a smaller size means faster computing. For wireless communications products, smaller size often means greater consumer appeal. Oddly enough, miniaturization with some cellular telephones has reached the point where the size of the electronics no longer requires a case large enough to extend from the ear to the mouth. Some cellular phones use an extension to enlarge the product profile just to make it more similar to the familiar desktop telephone handset.

Even greater miniaturization for computer chips has been achieved by researchers at Bell Labs, where an electron beam has been used in place of ultraviolet light to create circuits separated by 0.08 microns. Most chips have circuits spaced at 0.35 microns, and it is said that using ultraviolet to imprint a circuit design onto silicon has a practical limit of 0.10 microns.

Spectrum wall chart

If you have had difficulty ordering the National Telecommunications Information Administration spectrum wall chart previously mentioned in this column, here is some more detailed information that may be helpful. The product name is "1996 Spectrum Wall Chart," stock No. 003-000-00652-2, $3.25.

Orders can be placed by mail to U. S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

Inquiries and orders can be placed by telephone and facsimile; Tel. 202-512-1800; Fax 202-512-2250. Fax-on-demand orders can be placed with U.S. Faxwatch at 202-512-1716.

Kalmus: A Tradition of High Performance, Value-Packed RF Amplifiers

"When Kalmus began designing and manufacturing RF amplifiers in 1971, the vision was to produce the best high performance product possible for the best possible price."

"As we address the needs of the engineering community in the 21st century, we never lose sight of this tradition. At the same time, however, we are taking our operations to an unprecedented level of engineering and manufacturing excellence."

"For example, our engineering and design capability enables us to respond rapidly to customer requirements. And with improved order handling and production capability, we are continually reducing delivery times."

"With the resources of Thermo Voltek behind us, Kalmus is committed to producing technically advanced RF amplifiers upon which customers can depend, and to expanding its leadership position."

Colin I. W. Baxter, President
Kalmus

Straight Talk About RF Power Amplifiers.

Kalmus offers over 120 ruggedly built RF amplifiers for use in EMC testing, medical, communications and general laboratory applications. A comprehensive line of RF amplifier modules and custom amplifier options are also available.

RF AMPLIFIERS

- **Stock and Custom Amplifiers and Modules**
- **Meets RF Immunity Standards, including IEC 1000-4-3 and 1000-4-6**

EMC Test Amplifiers

- RF power levels from 1 to 3000 Watts
- Covering the frequency spectrum from 10KHz to 1GHz

Communications Amplifiers

- RF power levels to 1000 Watts
- Covering communications bands to 1GHz

Pulsed Amplifiers

- RF power levels to 12 KW
- Fast rise and fall times, high efficiency

Dual Band Amplifiers

- RF power levels to 100 Watts
- Offers operator convenience and cost savings without technical/capability compromise

Distributed Tube Amplifiers

- RF power levels to 2000 Watts
- Cover 14 octaves from 10KHz to 220MHz with rise and fall times of better than 3 nanoseconds

O.E.M. Amplifier Modules

- RF power levels from 1 to 250 Watts
- Many stock and custom modules can be tailored for specific O.E.M. applications

For detailed information about the full line of Kalmus RF amplifiers, please contact: **1-800-344-3341**

KALMUS

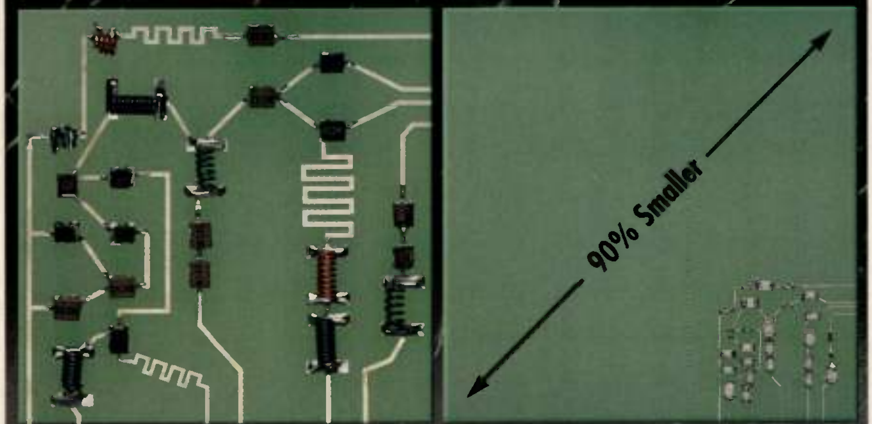
Kalmus • 21820 - 87th S.E. • Woodinville, WA 98072 USA
Tel: (206) 485-9000 • Fax: (206) 486-9657

Distributor:
KeyTek • One Lowell Research Center • Lowell • MA 01852-4345 USA
(800) 753-9835 • Tel: (508) 275-0800 • Fax: (508) 275-0850

http://www.thermovoltek.com

Thermo Voltek

COMTEST BENELUX • COMTEST ITALIA • COMTEST UK • KALMUS • KEYTEK • VERIFIER • UVC



RF design

Established 1978

Editorial offices
5660 Greenwood Plaza Blvd., Suite 350
Englewood, CO 80111
303-793-0448; Fax 303-793-0454

Don Bishop, *Editorial Director*, 913-967-1741
Gregg V. Miller, *Technical Editor*
Patricia Werner, *Associate Editor*
Valerie J. Hermanson, *Art Director*
Ernest Worthman, *Contributing Editor*

Editorial Review Board
Andy Przedpelski, The Shedd Group, *Chairman*
Madjid A. Belkerdid, Univ. of Central Florida
Alex Burwasser, RF Products
Dave Krautheimer, MITEQ
Ed Oxner, InterFET
Raymond Sicotte, American Microwave
Robert J. Zavrel, Jr., IBM

Intertec Publishing offices
9800 Metcalf Ave.
Overland Park, KS 66212-2215
913-341-1300; Fax 913-967-1898

Raymond E. Maloney, *President and CEO*
Cameron Bishop, *Senior Vice President*
Mercy Contreras, *Group Publisher*
Darren Sextro, *Associate Publisher*
Tom Cook, *Senior Managing Editor*
Carl Bentz, *Directories Manager*
Nick Cavnar, *Vice President – Circulation*
Michele Bartlett, *Senior Circulation Manager*

Advertising Representatives
Midwest and West
AR, IA, IL, IN, KY, MI, MN, MO, ND, SD, NE, WI, AL, LA, MS, TN, AK, CO, ID, KS, MT, NM, NV, OK, OR, TX, UT, WA, WY, CA, AZ, HI, Ontario and Western Canada
Janell Count, 303-220-4291; Fax 303-793-0454
East
CT, DE, MA, ME, NH, NJ, NY, PA, RI, VT, OH, VA, WV, DC, MD, FL, GA, NC, SC, Quebec and Eastern Canada
Mike Henry, 703-257-1202; Fax 703-257-3215
Classified
Terri Stenson, 303-220-4288; Fax 303-793-0454

Barbara B. VanSickle, *Print Services Manager*
Sarah Barnes, *Advertising Production Coordinator*, 303-220-4275
Jennifer Vogt, *Senior Advertising Coordinator for classified*, 913-967-1820
Dee Unger, *Director Advertising Services*
Ed Laborwit, *Reprints Manager*, 770-618-0499
Lori Christie, *List Rental Manager*, 913-967-1875

Back issues printed since April 1996 are available for $10 postpaid from Intertec Publishing customer service. Call 800-441-0294 or 913-341-1300; Fax 913-967-1899. Photocopies are unavailable from the publisher.

Photocopies of individual articles and of entire issues can be ordered from UMI Information Store, 800-248-0360 or 415-433-5500 ext. 282; Fax 415-433-0100.

This publication is available on microfilm and microfiche from UMI, 300 N. Zeeb Road, Ann Arbor, MI 48106-1346. 800-521-0600 or 313-761-4700; Fax 313-677-0108.

Customer Service
800-441-0294

Subscription inquiries
847-647-0756; Fax 847-647-7543

BPA INTERNATIONAL

INTERTEC PUBLISHING
A K-III MEDIA COMPANY

AS MANY PLL CHOICES AS YOU HAVE IDEAS.

BUILDING THE BEST SOLUTION

You have great wireless design ideas and stringent performance requirements. To pull them off, you'll need PLL solutions that give you all the performance your unique designs demand. Fujitsu, the pioneer in the PLL market, has just introduced the E, F and S Series, representing the next evolution in its expansive line of PLL devices. With Fujitsu's broad PLL offering you can make your ideas a reality.

Fujitsu's high-performance E, F and S Series PLLs deliver faster lock times, lower power consumption and improved phase noise to meet your design requirements in cellular, PCS and data communications.

	Maximum Frequency	Current Consumption	Package
E Series (single)	2.5GHz	3.5mA	16-pin SSOP
F Series (dual)	2.0GHz	6.0mA	16-pin 20-pin SSOP
S Series (masked)	300MHz	3.5mA	8-pin SSOP

What's more, Fujitsu's exclusive S Series architecture is mask programmable—dramatically simplifying your system design since no external programming is required. Reference and divide counters are pre-programmed, making it easier to turn great ideas into great wireless products.

And, Fujitsu's wireless roadmap enables you to create highly integrated monolithic solutions based on an extensive portfolio of RF products, including their PLL family of devices that fit any design.

So, if you're geared up for the right PLL parts, set your sights on Fujitsu. Call us today at 1-800-866-8608. Or visit our web site at www.fujitsumicro.com.

Advanced Cellular/PCS

Wireless Data Communication

Two-way Messaging

FUJITSU

COMPUTERS, COMMUNICATIONS, MICROELECT

INFO/CARD 19

OUR STANDARD MONOLITHIC CRYSTAL FILTERS

All 2 pole and 4 pole monolithics ship from stock on hand.

10.7 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5000	3	3.75	20	18.0	-	-	2	1.0	50	1800//+4
4	TE5010	3	3.75	30	14.0	-	-	3	2.0	60	1500//+3
6	TE5020	6	3.75	60	12.5	-	-	4	2.0	70	1500//+3
8	TE5030	6	3.75	60	10.0	90	12.5	5	2.0	80	1500//+3
2	TE5040	3	6.50	20	30.0	-	-	1	1.0	50	2700//0
4	TE5050	3	6.50	30	15.0	-	-	2	2.0	75	3100//0
6	TE5060	6	6.50	60	19.5	-	-	3	2.0	90	3100//0
8	TE5070	6	6.50	60	13.0	80	17.5	4	2.0	100	3100//0
2	TE5080	3	7.50	20	35.0	-	-	1	1.0	50	3000//0
4	TE5090	3	7.50	30	17.5	-	-	2	2.0	75	3300//0
6	TE5100	6	7.50	60	22.5	-	-	3	2.0	90	3300//0
8	TE5110	6	7.50	60	15.0	80	20.0	3	2.0	100	3300//0
2	TE5120	3	15.0	20	70.0	-	-	1	1.0	35	5000//-1
4	TE5130	3	15.0	30	35.0	-	-	2	2.0	60	5000//-1
6	TE5140	6	15.0	60	45.0	-	-	2	2.0	90	5000//-1
8	TE5150	6	15.0	60	30.0	80	40.0	3	2.0	100	5000//-1

21.4 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5180	3	3.75	15	12.5	-	-	2	1.0	50	850//+6
4	TE5190	3	3.75	30	12.5	-	-	3	2.0	70	850//+5
6	TE5200	6	3.75	60	12.5	-	-	4	2.0	90	850//+5
8	TE5210	6	3.75	60	10.0	80	12.5	5	2.0	100	850//+5
2	TE5220	3	6.50	15	20.0	-	-	2	1.0	50	1300//+2
4	TE5230	3	6.50	30	22.5	-	-	3	2.0	70	1400//0
6	TE5240	6	6.50	60	22.5	-	-	4	2.0	90	1400//0
8	TE5250	6	6.50	60	17.5	80	22.5	4	2.0	100	1400//0
2	TE5260	3	7.50	15	25.0	-	-	2	1.0	50	1500//0
4	TE5270	3	7.50	30	25.0	-	-	3	2.0	70	1600//0
6	TE5280	6	7.50	60	25.0	-	-	4	2.0	90	1600//0
8	TE5290	6	7.50	60	20.0	80	25.0	4	2.0	100	1600//0
2	TE5300	3	15.0	15	50.0	-	-	2	1.0	45	3000//0
4	TE5310	3	15.0	30	45.0	-	-	3	2.0	60	3000//-1
6	TE5320	6	15.0	60	45.0	-	-	3	2.0	90	3000//-1
8	TE5330	6	15.0	60	33.0	80	45.0	4	2.0	100	3000//-1

45.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE9420	3-OT	3	3.75	18	16.0	3	1	40	2000//-1.0
4	TE9310	3-OT	3	3.75	30	12.5	3	1	70	2000//-1.0
2	TE7420	3-OT	3	7.50	18	28.0	2	1	40	3000//-1.0
4	TE7430	3-OT	3	7.50	40	30.0	3	1	70	3000//-1.0
2	TE7440	3-OT	3	15.0	15	47.0	2	1	40	8000//-1.5
4	TE7450	3-OT	3	15.0	30	50.0	3	1	70	8000//-1.5
2	TE7730	FUND	3	15.0	15	50.0	2	1	40	1100//+1.5
4	TE7740	FUND	3	15.0	40	60.0	3	1	70	800//+1.0

70.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10400	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10410	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10420	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10430	3-OT	3	10	35	40	80	-910	3	1	2500//-1

90.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10440	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10450	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10460	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10470	3-OT	3	10	35	40	80	-910	3	1	2500//-1
4	TE10480	3-OT	3	15	30	50	80	-910	3	1	4000//-1

European contacts:

France or Benelux
(Tel) (33)25.76.45.00
(Fax) (33)25.80.34.57

United Kingdom
(Tel) (44)1.734.258.040
(Fax) (44)1.734.258.050

Germany
(Tel) (49)89.51.640
(Fax) (49)89.51.64.194

Nordic
(Tel) 46)8.756.70.40
(Fax) (46)8.756.70.44

Italy
(Tel) (39)2.761.101.68
(Fax) (39)2.738.54.62

All Others:
(Tel) (33)25.76.45.00
(Fax) (33)25.80.34.57

VISA AND MASTERCARD ACCEPTED

MONOLITHIC CRYSTAL FILTER PROTOTYPING KITS ARE STILL AVAILABLE

CONSULT TEMEX FOR ALL YOUR FREQUENCY CONTROL PRODUCTS

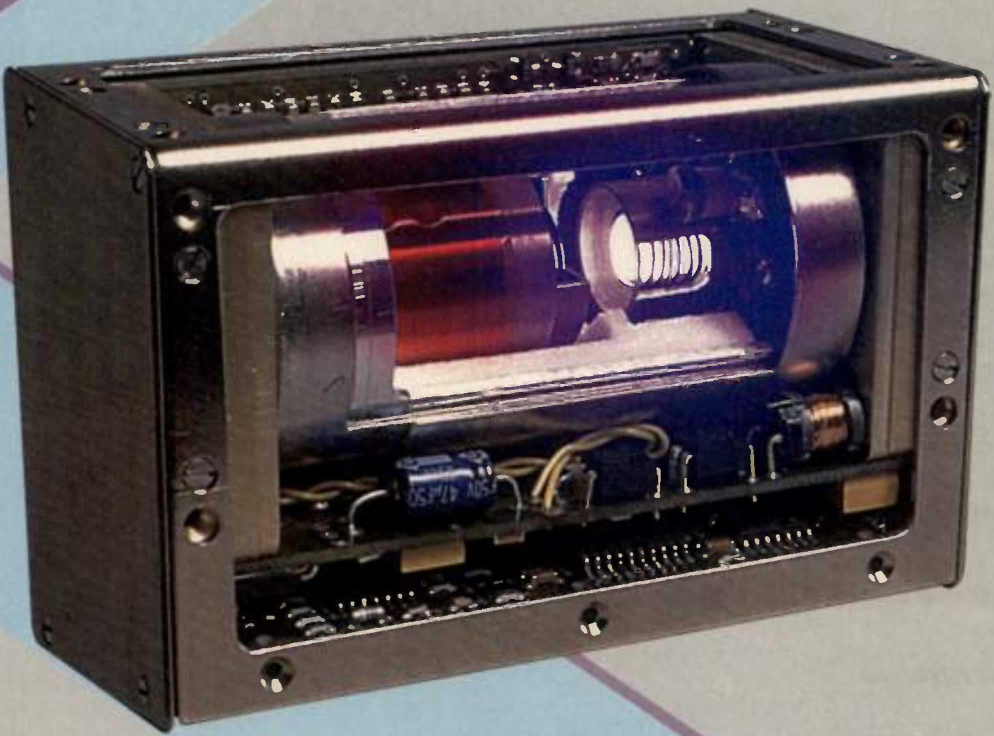
TEMEX

IN THE UNITED STATES CONTACT: **TEMEX ELECTRONICS, INC.**
3030 W. DEER VALLEY RD. PHOENIX, AZ USA 85027
(602) 780-1995 FAX (602) 780-2431

NEW FROM OUR FACILITY IN
NEUCHATEL, SWITZERLAND.

TEMEX

RUBIDIUM ATOMIC CLOCKS



FEATURING:

- LOW TEMPERATURE SENSITIVITY
- LOW PHASE NOISE
- EXCELLENT SHORT & LONG TERM STABILITY
- LOW POWER CONSUMPTION
- FAST WARM-UP
- SMALL VOLUME
- 5 YEAR Rb LAMP LIFE EXPECTANCY
- PLUG-COMPATIBLE WITH AN INDUSTRY STANDARD
- RS 232 INTERFACE FOR CENTER FREQUENCY ADJUSTMENT AND MONITORING OF THE WORKING PARAMETERS

INFO/CARD 22

RF letters

Letters should be addressed to Editor, RF Design, 5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111. Letters published may be edited for length or clarity.

Editor,

I am designing a narrowband FM receiver in the 930 MHz range for an interactive TV program guide in the United States. One of the topics I have been frustrated trying to learn about is co-channel rejection (sometimes termed capture ratio). Of all the IC vendors I have contacted (Philips, Harris, Anadigics, RF Micro Devices, Motorola and others), only GEC Plessey even mentions this particular parameter. This parameter is important for wide-area paging, at least for nationwide paging.

Nationwide paging carriers in the United States divide the country into 5–100 regions, all on the same frequency. A region may have 100 transmitters, all of which operate in a simulcast mode and deliver the same datastream. Adjacent regions often overlap, and even if they carry the same datastream, there is no synchronization between regions. So an area of "simulcrash" is formed. The only way for a receiver to function in such an area is to have a good capture ratio, on the order of 1 dB. Motorola claims such performance. Nobody I have talked to has been able to explain how to achieve such a capture ratio figure. I know that demodulator linearity and IF strip AM rejection is important, but I don't know much more. Most integrated solutions I have analyzed have capture ratios of 5–7 dB, far from ideal!

I have studied theses on receiving the weaker of two co-channel signals, but these tend to lead to expensive, esoteric designs, and I am trying to design a consumer electronics product. Can you suggest where I might find information on what is required in terms of demodulator design, etc. to achieve such performance? I know it's not uncommon for broadcast FM stereo radio receivers to achieve around 1 dB capture ratio, but these are not narrow- band devices, and I think the techniques are somewhat different.

Klaus Renner, VideoGuide, 209 Burlington Road, Bedford, MA 01730, Tel. 617-276-8811; Fax 617-276-8878; E-mail klaus@vgi.com

Readers, please contact Mr. Renner directly if you have information.

Introducing A New Generation Of Low Cost, Easy-To-Use Digital Frequency Synthesizers.

Now you don't have to sacrifice price and power for the fine frequency resolution and phase control associated with DDS solutions. Analog Devices' AD9830, AD9831 and AD9850 are leading a revolution for digital frequency synthesizers that will replace your analog alternatives.

PARAMETER	AD9850	AD9830	AD9831
Clock Speed	125 MHz	50 MHz	20 MHz
Power Consumption	380 mW (typ)	250 mW (typ)	75 mW (typ)
Power Supply	5 V or 3.3 V	5 V	5 V or 3.3 V
Price*	$9.95	$8.75	$5.51
Package	28 SSOP	48 TQFP	48 TQFP
Faxcodes	1990	1993	1994

The Best Of PLL And DDS Combined
With the user friendliness of PLL and the precise digital control of DDS, you can now design-in frequency synthesizers that have no downside. And since the AD9850 (at max clock rate) dissipates only 155 mW on a 3.3 V supply, it enables use in portable applications, which are off limits to power-hungry discretes.

Integrated DAC For Easy Use
All DDS family members come with an integrated DAC on-chip, eliminating nightmarish learning curves or the need for an analog circuit genius to select and interface other DAC options. You're saving yourself a lot of headaches, and you're using about 1/5 the board space when compared to discrete solutions. This optimized CMOS DAC core is also singularly responsible for dynamic performance that provides a wideband SFDR greater than 50 dB at 40 MHz A_{OUT}.

So for consumer electronics prices, you can receive a tiny TQFP or SSOP package that marks a new age in digital frequency synthesizers with breakthrough advancements in virtually all specification categories including: level of integration, power dissipation, size, speed and dynamic performance.

For AD9830, AD9831 or AD9850 samples, data sheets and evaluation boards, call the appropriate numbers below.

For samples and technical information call 1-800-ANALOGD (262-5643).† For data sheets dial AnalogFax™ at 1-800-446-6212, or visit us on the World Wide Web.

http://www.analog.com

ANALOG DEVICES
Analog. Digital. Solutions.

Analog Devices, Inc., One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106.
Distribution, offices and application support available worldwide.

* USD 10,000s, recommended resale, FOB U.S.A.

† Outside U.S., please call 617-461-3392.

RF calendar

August 19–21 **Wireless Communications Conference**—*Boulder, CO.* Information: Dr. Roger Marks, National Institute of Standards and Technology, 325 Broadway, MC 813.06, Boulder, CO 80303. Tel. 303-497-3037; Fax 303-497-7828; E-mail r.b.marks @ieee.org.

19–23 **IEEE International Symposium on Electromagnetic Compatibility**—*Santa Clara, CA.* Information: Gherry Pettit, Intel. Tel. 503-696-2994; Fax 503-640-6411.

September 8–12 **Electrical Overstress and Electrostatic Discharge Symposium**—*Orlando, FL.* Information: ESD Association, 7902 Turin Road, Suite 4, Rome, NY 13440-2069. Tel. 315-339-6937; Fax 315-339-6793; Web site http://www.eosesd.org.

16–18 **Connector and Interconnection Symposium and Trade Show**—*Boston.* Information: Electronic Industries Association Components Group, 2500 Wilson Blvd., Arlington, VA 22201-3834. Tel. 703-907-7536; Fax 703-907-7501; Web site: http://www.eia.org.

16–20 **Accelerated Reliability Technology Symposium**—*Denver.* Information: Hobbs Engineering, 10218 Osceola Court, Westminster, CO 80030. Tel. 303-465-5988; Fax 303-469-4353; E-mail learn@hobbsengr.com.

17–20 **Electromagnetic Compatibility (EMC '96 Roma)**—*Rome.* Information: Prof. Mauro Feliziani, Department of Electrical Engineering, Univ. of Rome "La Sapienza," Via Eudossiana 18, 00184 Rome, Italy. Tel. +39 6 44585.809/ 44585.810; Fax +39 6 4883235/4825380; E-mail emc96rom@elettrica.ing.uniroma1.it.

19–20 **Electromagnetic Compatibility: Planning for Compliance in the U.S., Europe and Japan**—*Phoenix.* Information: Seminars Department, Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096. Tel. 847-272-8800 ext. 43481; Fax 847-509-6235; E-mail seminar@ul.com.

24–26 **Electrical Manufacturing & Coil Winding EMCW '96**—*Chicago.* Information: Electrical Manufacturing & Coil Winding '96, Dept. 77-5053, Chicago, IL 60678-5053. Tel. 708-260-9700 or 800-323-5155; Fax 708-260-0395.

25–26 **Chesapeake Electronics Show**—*Chantilly, VA.* Information: Bonnie Lasky, MACC, P.O. Box 513, Colmar, PA 18915. Tel. 215-822-6319; Fax 215-822-3332.

29–Oct. 2 **Wireless Workshop**—*Sedona, AZ.* Information: 100 S. Roosevelt Ave., Chandler, AZ 85226. Tel. 602-961-1382; Fax 602-961-4533.

October 1–4 **Eighth Annual Digital Audio and Video Workshop**—*Philadelphia.* Information: Lisa Fasold, Consumer Electronics Manufacturers Association, 2500 Wilson Blvd., Arlington, VA 22201-3834. Tel. 703-907-7669; Fax 703-907-7690; E-mail lfasold@eia.org.

2–3 **NEPCON Exhibition and Conference**—*San Antonio.* Information: Customer service, Tel. 800-467-5656; Web site http://nepcon.reedexpo.com.

7–10 **Signal Processing Applications and Technology**—*Boston.* Information: Megan Forrester c/o Miller Freeman, 600 Harrison St., San Francisco, CA 94107. Tel. 415-356-3391; Fax 415-905-2220; E-mail dsp@mfi.com.

7–11 **Wireless Technology '96**—*Providence.* Information: Dawn Averyt. Tel. 407-878-8200; Fax 407-879-7388; E-mail Expo96@aol.com.

8–10 **Microwaves & RF Conference and Exhibition**—*London.* Information: Beverley Lucan, Nexus Information Technology, Nexus House, Swanley, Kent, BR8 8HY, United Kingdom. Tel. +44-(0)1322-660070; Fax +44-(0)1322-661257.

21–23 ***RF Design* Seminar Series**—*Wakefield, MA.* Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

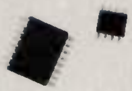
22–24 **Wescon '96 Technical Conference**—*Anaheim, CA.* Information: Wescon, 8110 Airport Blvd., Los Angeles, CA 90045. Tel. 800-877-2668 or 310-215-3976 ext. 251; Fax 310-641-5117; E-mail m.potthoff@ieee.org; Web site http://www.wescon.com.

29–30 **Radio Solutions '96**—*Birmingham, UK.* Information: LPRA Secretariat, Walker Mitchell Ltd., Brearley Hall, Luddenden Foot, Halifax HX2 6HS, United Kingdom. Tel. and fax +44 (0) 1422 88 69 50.

29–31 **Signal Processing Applications and Technology**—*Santa Clara, CA.* Information: DSP Associates, 49 River St., Waltham, MA 02154. Tel. 617-891-6000; Fax 617-899-4449; E-mail icspat@dspnet.com.

November 6–8 **Plastics in Portable & Wireless Electronics**—*Phoenix.* Information: Judy Wales, Donnelly. Tel. 520-321-7680; Fax 520-322-5635; E-mail judy@donnelly.ppp.theriver.com.

18–22 **IEEE Global Telecommunications Conference**—*London.* Information: Vikki Pollard, Globecom, RT 10/5a, BT Laboratories, Martlesham Heath, Ipswich, Suffolk, IP5 7RE, United Kingdom. Tel. +44 1473 644799; Fax +44 1473 647488; E-mail pollarv@btlip10.bt.co.uk.



THAT'S SUCCESS YOU'RE SQUINTING AT.

Low profile, small size, surface mount package with big performance and cost advantages.

It's virtually impossible to find a better way to develop solutions for wireless standards than with M/A-COM power splitters and combiners. And there's no better place to get exactly the splitters/combiners you need than at Richardson.

- **Smallest** in their class to maximize PCB space for all applications.
- Excellent performance and superior **repeatability** versus conventional designs.
- Industry **standard packaging** for automated insertion-and-assembly.
- **Low cost** and a technology that offers continuous cost performance and size enhancements.

From infrastructure to portables, these devices are fully operational and require no additional external components. So for smaller more affordable solutions, take a look at the M/A-COM product family of splitters/combiners and other passive devices available through Richardson.

GPS hand-held receivers

Cellular phones and pagers

Cellular base stations

Call Richardson for in-depth inventory support. Their team of dedicated applications engineers has over 200 years of combined RF and DC experience. That's why they can handle all your needs from RF design support to same day shipments, custom stocking programs, special testing, selecting and matching. Call today for samples and data sheets. When you do, ask about M/A-COM's other passive components as well.

	Frequency (dB) (MHz)	Insertion Loss (dB) Typ.	Isolation (dB) Typ.	VSWR Typ.	Amplitude Balance (dB) Typ.	Phase Balance (°) Typ.	Part No.
2-Channel							
	824 - 960	0.5	23	1.2:1	0.05	0.5	DS52-0001
	1510 - 1660	0.4	20	1.3:1	0.05	1	DS52-0004
	1700 - 1900	0.3	20	1.3:1	0.05	2	DS52-0005
	1850 - 1990	0.5	21	1.2:1	0.05	1	DS52-0002
	2200 - 2500	0.3	20	1.3:1	0.05	3	DS52-0003
4-Channel							
	824 - 960	1	23	1.2:1	0.30	2	DS54-0001
	1200 - 1660	1	23	1.2:1	0.30	2	DS54-0003
	1700 - 2000	1	23	1.4:1	0.30	3	DS54-0002
New	2200 - 2500	1	21	1.4:1	0.20	2	DS54-0004
6-Channel							
	824 - 960	1.3	25	1.4:1	0.30	6	DS56-0001

Richardson Electronics, Ltd.

ISO9002 Registered

(800) RF-POWER U.S./Canada

More than 33 locations in the U.S. to serve you - U.S. and Canada Toll Free: (800) RF-POWER or (800) 737-6937; Internet: http://www.rell.com, U.S. Corporate Headquarters: LaFox, IL (708) 208-2200, Fax (708) 208-2550.

M/A-COM
an AMP company

INFO/CARD 18

RF courses

Training Program for Cellular, PCS Staff—Home-study course. Information: Virginia Polytechnic Institute and State University, Mobile & Portable Radio Research Group, 840 University City Blvd., Pointe West Commons, Suite 1, Blacksburg, VA 24061-0350. Tel. 540-231-2970; Fax 540-231-2968.

Communications Tech Training—1996 schedule for Orland Park, IL, Sept. 3–5, Oct. 8–10, Nov. 5–7, Dec 3–5, Information: Andrew Corp., Dept. 355, P.O. Box 9000, San Fernando, CA 91341-9978. Tel. 800-255-1479 ext. 117.

George Washington University—Washington, DC. *Wireless Infrastructure Network Engineering for Cellular, PCS, LE, and WPBX*—Oct. 21–25. Information: George Washington University, Continuing Engineering Education, Academic Center, Room T-308, 801 22nd St. N.W., Washington, DC 20052. Tel. 202-994-6106 or 800-424-9773; Fax 202-872-0645; E-mail ceepinfo@ceep.vpaa.gwu.edu.

1996 CEI-Europe in Cambridge, United Kingdom
Wireless Digital Communications: Mobile, Cellular, Personal, Voice and Data Networks—Sept. 30–Oct. 4; *Applied RF Techniques: Linear Circuits*—Sept. 30–Oct. 4; *Adaptive Synchronous Receiver Structures for Mobile Communications*—Sept. 30–Oct. 4.
in Baveno, Italy—
Mobile and Wireless Personal Communications Networks —Oct. 14–18; *Modern Digital Modulation Techniques*—Oct. 14–18; *Modeling and Simulation of Communication Systems*—Oct. 15–18; *Speech and Channel Coding for Mobile Communication*—Oct. 21–23; *Digital Cellular and PCS Communications: The Radio Interface*—Oct. 21–25; *Spread-Spectrum and CDMA*—Oct. 21–25.
in Barcelona, Spain—
Mobile Cellular and PCS Telecommunications Systems—Nov. 11–13; *RF Circuit Components*—Nov. 18–21; *Receivers and Transmitters*—Nov. 18–22; *Advanced Digital Receivers for Wireless Communications*—Nov. 18–21; *Cellular and Personal Communications Infrastructure*—Nov. 20–22. Information: CEI-Europe, P.O. Box 910, S-612 25 Finspong, Sweden. Tel. 46 122 175 70; Fax 46 122 143 47; E-mail cei.europe@one.se.

DSP Without Tears—Aug. 26–28, Washington, DC; Sept. 30–Oct. 2, San Jose, CA. Information: Z Domain Technologies, 325 Pine Isle Court, Alpharetta, GA 30302. Tel. 800-967-5034 or 770-587-4812; Fax 770-518-8368; E-mail dsp@mindspring.com.

Celwave University—Marlboro, NJ. Modules offered include: *Antenna Basics, Advanced Theory, Towertop Amplifiers, Bidirectional Amplifiers, Filters* and *Combiners*. Information: Gail Magid, Celwave, 2 Ryan Road, Marlboro, NJ 07746-1899. Tel. Sales Engineering Dept. 800-235-9283.

Georgia Tech Continuing Education
Near-field Antenna Measurements and Microwave Holography—Sept. 10–13, Boulder, CO; *Wireless Communication*—Sept. 24–27, Atlanta, GA. Information: Dept. of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel. 404-894-2547; E-mail conted@gatech.edu; Web site http://www.conted.gatech.edu.

Johns Hopkins University Whiting School of Engineering
—courses in Washington, DC
Modern Terrestrial Radio Systems Engineering—Sept. 9–12; *Cellular and Personal Communications Services (PCS): Systems Engineering and Perspective with Emphasis on CDMA Technology*—Sept. 16–19; *Wireless and Personal Communications Systems*—Oct. 7–9; *Wireless Digital Communications Systems: Specification, Test and Evaluation*—Oct. 21–23; *The Telecommunications Revolution and its Impact on Organizational Planning*—Oct. 28–30. Information: OEI 14515 Barkwood Drive, Rockville, MD 20853. Fax 301-871-4942; E-mail info.oei@apl.jhu.edu.

GSM and DCS-1800 C/I Testing

The GSM and DCS-1800 specifications require testing of receivers under multipath fading conditions. To comply with the specifications, there are several important performance issues that a multipath fading emulator must meet:

1. Twelve(12)-tap configurations. GSM Rec. 05.05 calls for various tests under multipath fading. To emulate different terrain environments, it is recommended that full 12-tap configurations are used for higher confidence and reduced test time.

For the multipath emulation on an interfering signal, a reduced configuration of 6 taps is used. For example, to perform adjacent channel interference tests, the fading emulator must provide two different channels with 6 taps on each channel.

Noise Com's MP2600-12 is well suited for this test scenario as it provides 12 taps on one channel, and by a single click on the mouse, the configuration is easily changed to 2-channel, 6-tap configurations internally without any external hardware modifications.

2. Greater than 3 hours of non-repetitive random fading. GSM 11.20 (base station test standard) specifies 10,200 seconds (~3 hours) of continuous test time under fading conditions. The Phase II specification for mobile station testing (GSM 11.10-1) calls for a minimum of about 3,300 seconds of test time. Therefore, during the entire test period, the fading statistics should not be repeated in order to provide true randomness. The MP2600-12 exceeds the above specifications by providing more than twenty-four (24) hours of non-repetitive fading.

3. Adjacent channel interference testing with C/I of -41 dB at 400 kHz offset. GSM 11.10 and 11.20 call for receiver testing with a very high level of interference from the adjacent channel. This exceeds the dynamic range of most fading emulators because the faded signal itself already has severe variations in the power level. The MP2600-12 is specially configured to accommodate the C/I testing by extending the dynamic range of the power level and also eliminating the noise floor problems of the interfering channel.

4. 20 MHz bandwidth for frequency hopping. Phase I of DCS-1800 (GSM 11.10 - DCS) requires wider than 20 MHz communications bandwidth for thorough testing. To achieve the specified frame erasure rate (FER) under the condition of co-channel interference with frequency hopping, an ideal frequency hopping is assumed. However, the combination of TU1.5 propagation conditions and frequency hopping with a bandwidth of 5 MHz (as required by the standard) results in a loss compared to ideal frequency hopping. This is due to the correlation of the FER among consecutive bursts. The preferred solution to eliminate the correlation effects at this low vehicle speed of 1.5 km/hr is to increase the bandwidth to 20 MHz. This allows sufficient decorrelation of consecutive bursts to perform proper testing.

The MP2600-12 provides 20 MHz of RF bandwidth that allows thorough testing as it was originally intended: co-channel interference with frequency hopping under slow vehicle speeds.

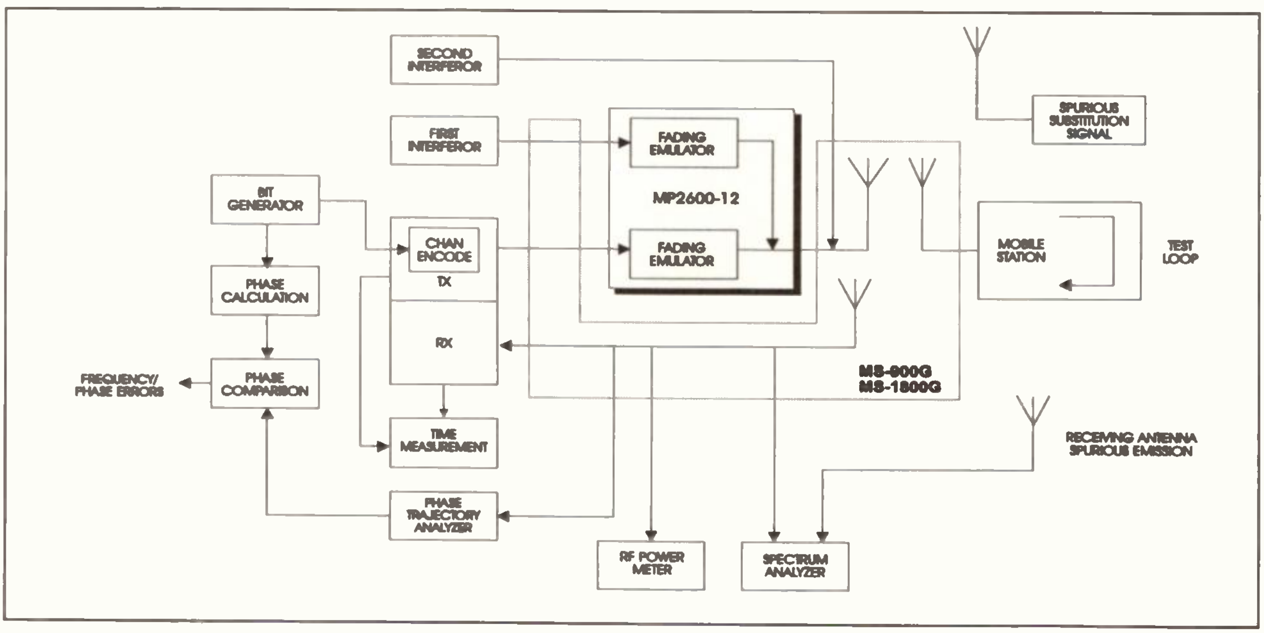


Figure 1. C/I test configuration with MP2600-12.

NOISE/COM
A WIRELESS TELECOM GROUP COMPANY

Wideband Multipath Fading Emulator (MP2600-12)

Multipath fading emulator for GSM and DCS-1800 C/I Testing

The MP2600-12 emulates wireless communication channels with up to 12 different reflected signal paths for wideband applications. For testing GSM and DCS-1800 receivers, the instrument is an ideal partner for providing realistic channel environments.

The instrument has pre-stored in its memory all the GSM and DCS-1800 specified test parameters. It also provides programmable output power, delay, attenuation, frequency shift (Doppler), and a choice of Rayleigh, Rician, log-normal, Nakagami, and Suzuki fading statistics for each path.

The MP2600-12 includes a built-in 486DX/33 computer and LCD display. A Windows-based graphical user interface simplifies setup and operation.

Ordering Information

Model Number	Frequency Range	Application
MP2600-12	300-2500 MHz	GSM, DCS-1800, PCS-1900

Options:

- Synthesized local oscillators
- Dual duplex interface
- 26 MHz RF bandwidth
- I/Q interface (DC to 13 MHz)
- High-power attenuator
- Lower or higher frequency ranges

Your global partner for wireless and communications testing.

NOISE/COM

A WIRELESS TELECOM GROUP COMPANY

E. 49 Midland Avenue
Paramus, New Jersey 07652
Tel: (201) 261-8797
Fax: (201) 261-8339
E-mail: noisecom@haven.ios.com

Policies set to change African telecommunications

The African Regional Telecommunications Conference (ARTC), convened by the International Telecommunications Union, resolved to continue to improve Africa's telecommunications and information infrastructure. In a five-day conference, leaders of the ARTC adopted policies and strategies that would attempt to shift government responsibility away from ownership and management of public companies to a more regulatory and legal role. Other policies adopted would restructure the telecommunications network operators as autonomous corporations, involve the private sector in the management and implementation of national telecommunications, and introduce competition in a stable, regulated business.

Survey reports use trends for cellular in five nations

Motorola commissioned the Gallup Organization to conduct a survey examining cellular phone use in Canada, Great Britain, the United States, Hong Kong and Mexico. Hong Kong tops the list in daily use; 93 percent of cellular owners report using their cellular phone everyday. The lowest daily use was reported by Mexico (49%) and the United States (44%). Cellular phones appear to be more all-purpose communications tools in the United States than elsewhere. That is, U.S. cellular owners report using their telephones almost equally for business and personal reasons. In four out of the five countries surveyed, the top reason for using a cellular phones was to say that the user would be late. A higher percentage of owners in Mexico than in the other countries reported that a cellular phone allowed them to leave work on time because they can make calls on the way home.

Partnership forms American Industrial Microwave

A partnership between Manitou Systems of Danbury, CT, and German-based Muegg Electronics has resulted in the formation of American Industrial Microwave. The new company will expand the current line of products from Manitou by bringing German-developed microwave power supplies and components to the U.S. market. American Microwave Products will develop new products in the Danbury facility, as well as provide sales and service for the German-manufactured products.

Gorca group expands, acquires Fountain Group

The Gorca Group, headquartered in Cherry Hill, NJ, has acquired The Fountain Group, a consulting and engineering firm located in Washington, DC. The acquired company will be renamed Fountain Integrated Systems and will focus its initial marketing efforts on providing low-cost mobile communications and fleet asset management systems for trucking companies. Fountain Integrated Systems, which will be based in Cherry Hill, plans to open facilities in Washington, DC, later this year.

Contracts:

NASA awards contract—A Small Business Innovative Research (SBIR) contract for $600,000 was awarded to Sicom by NASA. The contract is to help Sicom develop a high-speed digital data modem for two-way satellite communications. The design, fabrication and testing of two high-speed digital wideband modems will meet the needs of satellite and terrestrial network operators by providing integrated data, voice and video with bandwidth up to 155 Mbps. Projected uses for the modems will be in telecommunications, commercial TV, video conferencing and data networks.

Digital TV Agreement—ComStream and Matsushita Electric have agreed to develop and produce TV set-top products to support the anticipated demand for digital TV. The set-top box acts as receiver and decoder of digital television satellite, cable and multichannel multipoint distribution system

Business Briefs

Proxim and Data General Enter Alliance—Proxim and Data General have formed an alliance in which Data General will integrate Proxim's RangeLAN2 as its 2.4 GHz wireless LAN technology of choice.

Motorola and Teleflex Alliance—Motorola's Oncore GPS technology and Teleflex's electronics packaging capabilities have combined to manufcture and market a GPS receiver and antenna integrated into a single package. The new product, for use in harsh environments, will output a serial data stream and a highly accurate one-pulse-per-second signal used in precision time and frequency devices in telecommunications, computer networking, and other timing applications. The weatherproof housing eliminates the need for expensive coaxial cable, and RF signal loss problems are eliminated.

Surge Components Opens Test Lab—A new, in-house test laboratory has been opened at the Surge facility in Deer Park, NY. The fully equipped and QA certified lab for the testing of Surge's line of discrete components brings most of Surge's testing needs to its own facility from off-shore.

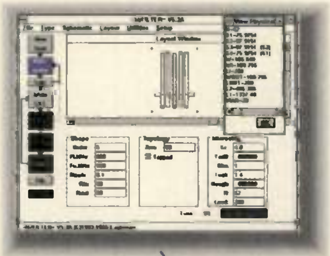
Ortel to Provide Countermeasure Photodiode Receivers—Sanders, a Lockheed Martin company, has selected Ortel to provide linear fiberoptic technology for a joint U.S. Navy and Air Force Integrated Defensive Electronic Countermeasures (IDECM) system. Ortel will provide Sanders with photodiode receivers for the wide-frequency fiberoptic towed decoy portion of the IDECM system. As many as 1,000 military aircraft will be fitted with this new self-protection system.

Based in Alhambra, CA, Ortel designs, manufactures and sells a broad range of RF signal transmission products worldwide for the broadband and wireless sectors of the communications industry as well as select government and defense applications.

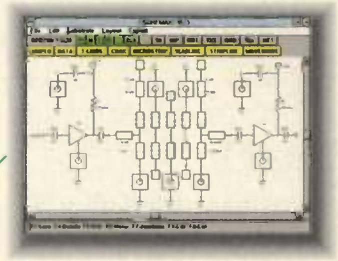
Marconi Relocates to Fort Worth—Marconi Instruments relocated from Allendale, NJ, to the Alliance Development complex in Fort Worth, TX. The new facility is the headquarters for both Marconi Instruments, Inc. and for the newly formed Americas Region of Marconi Instruments Limited. The facility houses customer service, administration, sales and marketing and senior management.

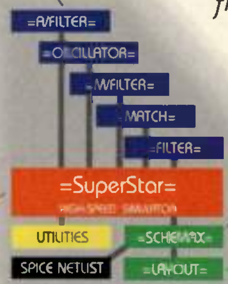
DESIGN FROM START-TO-ART

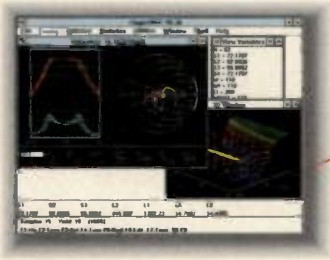
1 GENESYS synthesis modules make it easy to create initial designs for L-C filters, matching networks, active filters, oscillators, printed and machined filters, amplifiers and group delay equalizers. The many design alternatives and quick evaluation of each help you save time and achieve higher performance.



2 Schematics make it easy to enter your own designs, modify synthesis created designs and merge subcircuits. Schematics and simulation are integrated for back annotation. The GENESYS schematic module also writes Touchstone and Spice files.







3 =SuperStar= Professional redefines the circuit simulator standard. Step up to real-time tuning, statistical analysis, unrestricted global noise analysis, adaptive optimization, accurate models, unparalleled execution speed and the industry's easiest to use interface. Non-linear and time domain analysis is supported through the Spice interface.

NEW!

4 The new layout module creates artwork on your plotter or printer and in DXF (AutoCad) and optimized Gerber file formats. Discontinuity and transmission line dimensioning, coplanar ground pours, multilayers, arbitrary polygons and user footprint libraries make RF and microwave layout easier than ever before.

EAGLEWARE
11th Anniversary

Our first program shipped in 1985. Today, with thousands of users worldwide, Eagleware is a recognized leader in RF and microwave design software for IBM and compatible PCs. Here are a few reasons why we feel GENESYS provides unequaled value:

* Start-to-art solution including synthesis
* One easy to learn interface for all programs
* Industry's fastest execution means less waiting
* Accuracy verified with in-house lab
* Reads industry standard S-parameter files
* Free technical support with no annual fees
* Low cost
* 30 day money back satisfaction guarantee

Eagleware products run on standard IBM and compatible PCs under DOS, Windows 3.1, Windows NT and Windows 95. Windows versions are 32-bit for even faster execution.

GENESYS
VERSION 5.4

=SuperStar= Professional simulator	$999
Simulator with schematic entry and layout	$1990
Complete GENESYS package with synthesis	$5990
Layout upgrade for current customers	$699

(Upgrade discounts available for a limited time)

日本のお問い合わせ先
テクダイヤ株式会社
170 東京都豊島区東池袋3-1-1
TEL 03-3988-1731 FAX 03-3988-1706

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

EAGLEWARE

Eagleware Corporation ★ 1750 Mountain Glen ★ Stone Mtn, GA 30087 ★ USA
http://www.eagleware.com ★ eagleware@eagleware.com
TEL (770) 939-0156 ★ FAX (770) 939-0157

INFO/CARD 16

broadcast transmissions. The agreement combines Com- Stream's ability to design and produce video transmission systems with Matsushita's high-volume manufacturing capabilities. Manufacturing will begin in Matsushita's Wales facility this year and will be marketed under the Panasonic brand name.

Additionally, ComStream has been selected by Thomson Consumer Electronics as its exclusive supplier for front-end technologies for Thomson's Tele-TV systems' multichannel multipoint distribution system, designed to deliver as many as 100 television channels to an estimated 3 million homes beginning in late 1996.

Andrew to supply antenna and transmission line for high-definition television (HDTV)—Capitol Broadcasting Company has selected Andrew to supply WRAL in Raleigh, NC, with a special version of the company's UHF-TV transmit antenna and transmission line. The new digital transmission system will provide viewers with high-definition picture quality with more than twice the resolution of the current analog standards. Cinematic-quality pictures and stereo sound with better frequency response than broadcast FM will be delivered over the air to home receivers.

Amtech expands Houston electronic toll and traffic management (ETTM)—Amtech has received a $3.9 million contract for work on phases III and IV of the Greater Houston traffic management system. Amtech will provide additional equipment for Houston's high-tech system, which uses automatic vehicle identification (AVI) technology for traffic management. Reader stations located on toll roads and freeways in the metropolitan area read Harris County toll road authority electronic EZ tags supplied by Amtech, as well as compatible out-of-area Amtech tags, compatible American Trucking Association (ATA) tags for equipment and cargo tracking and traffic management systems tags issued to drivers who commute during peak travel periods. Vehicles equipped with ETTM tags relay travel-flow and travel-time information to traffic engineers, transportation officials and emergency-related agencies. Data gathered are transmitted to Houston TranStar, the traffic-control center for Houston and Harris County. The information is used to manage traffic flow and to respond more quickly to traffic incidents.

RF research rising on tide of commercial activity

By Andy Kellett
Contributing Editor

Market opportunities are abundant in wireless technology, and companies are looking for technical talent in both in-house labs and in academia's labs to take advantage of those opportunities.

Ten years ago "wireless" research was concentrated in government microwave programs. Research into devices and systems below a few GHz was dormant. Today, the spectrum below a few GHz is the domain of hundreds of millions of dollars worth of research. Most of that money is coming from private companies.

Research areas

Where is radio research active? At the semiconductor device level, research is still primarily a commercial research endeavor because semiconductor manufacturing equipment is expensive. But there are a few universities with modern semiconductor research facilities (UCLA and UC Berkeley, specifically). Although semiconductor research is focused mostly on reducing geometries for digital circuits and on improving packaging technologies, advances in these areas eventually are felt in the RF arena. At the system level, RF research begins to spread out more. Both industry and academic labs are working to use new semiconductor devices in new system architectures—for instance, "software receivers" that use digital signal processors (DSPs) to perform many of a radio's traditionally analog functions.

Propagation studies are vital to every wireless service provider. Each one must determine how well its signal will reach its customers. Propagation studies in their own backyard is becoming a research niche that some universities are beginning to fill. More general propagation studies also are the focus of research. A lot of research is going on to determine how various modulation methods are affected by propagation. (There is a particularly large amount of research into the robustness of CDMA in real-world propagation conditions.)

Mobile computing probably is the most active area of RF system research. Sixty-three wireless computing projects, both commercial and academic, are listed on the University of Washington's Mobile and Wireless Computing index on the world wide web. Several vertical markets already use wireless data transmission—point-of-sale terminals, package tracking and inventory control—but dollars also are being poured into wireless computing in hopes that a "killer application" will emerge to bring wireless computing to a broad market. Many labs are working to help wireless computing reach that broad market.

"To make [the emergence of a broad mobile computing market] more likely, WINLAB is working to bridge the technology gaps between conventional computer communications and wireless communications," says Dr. David Goodman, director of the Wireless Information Network Laboratory (or WINLAB) at Rutgers. Several commercial and academic researchers are working on reducing power consumption in mobile computing devices, designing network architectures that are more tolerant to the noise and distortion in wireless channels, predicting system behavior and measuring system performance.

Industry in academia's labs

Most of the new research endeavors at universities are heavily sponsored by industry. WINLAB was formed in 1989 with money from the State of New Jersey. It quickly attracted financial support from seven companies and has steadily been adding sponsors since, says WINLAB's Goodman. The Mobile and Portable Radio Research Group (MPRG) at Virginia Tech has 16 affiliates, and the analog semiconductor device groups at UCLA and UC Berkeley are supported by several semiconductor companies. Other programs have similar support.

What does a dollar spent on research at an academic lab get a company that it doesn't get it at the company's own in-house lab? "Cross-industry leverage," says Arnie Moore, director of wireless communications at Southwestern Bell Technology Resources, Moore says that several companies supporting research at a university lab can each save money if they all can use the university research results.

MPRG's director, Ted Rappaport, Ph.D. says companies fund research because they have both a shortage of manpower and a need to help shape the engineers they will be hiring. "Also, I think it's happening because companies are finding that academics, in particular students, are extremely motivated, and it makes good business sense," says Rappaport, "I'd say if you go to a highly motivated, highly driven [university] research lab, you can get three to five times the output per dollar, and maybe even more, compared to industry."

Rappaport admits that to get wireless research money from industry, researchers have to be aware of eventual end-uses, and that they may give up some research in pure, fundamental areas. "But I believe the academics and industry sponsors can strike a nice balance so that the faculty and students get the intellectual stimulation that they want, and the company receives students that are sensitive to the needs of industry," says Rappaport.

Dr. Lance Glasser, director of the Electronic Technology Office at the Defense Advanced Research Project Agency (DARPA), has spent time as a researcher in both industry and academia before joining DARPA in 1988. Glasser points out that, "If I look back a decade, there was very little RF work—long or short term—being done in academia, so in absolute terms, I think the amount of long-term work has gone up." RF

Andy Kellett can be contacted via E-mail at akellett@stsidebars.com

A novel GPS avionics slot antenna

By Chien H. Ho, Paul K. Shumaker, Keith B. Smith, Juhn W. Wang and Hua Y. Wang
Garmin Communication & Navigation

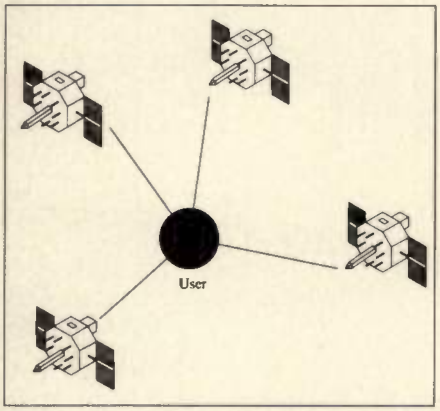


Figure 1. A good satellite geometry with a low GDOP number.

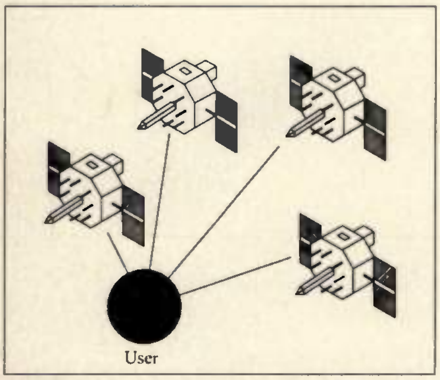


Figure 2. A poor satellite geometry with a high GDOP number.

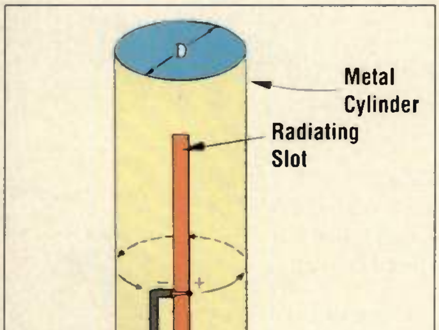


Figure 3. Physical configuration of the conventional slotted-cylinder antenna.

The satellite communications networks evolution has advanced from design and development to actual working systems within the last decade. The construction of the NAVSTAR Global Positioning System (GPS) is one of the largest accomplishments in satellite communications. It provides accurate position information in three dimensions, the velocity of the GPS receiver and precise time signals traceable to coordinated universal time. GPS service is available continuously worldwide, and it can be used in any weather. No user fees are charged, nor are any anticipated. As a result, international civilian use of GPS receivers continues to grow.

A position can be calculated in three dimensions when the exact distance or *range* from three satellites is known. The range between a satellite and a user is calculated by using the propagation delay of the signal coming from the satellite. This *time-of-arrival* (TOA) *ranging system* differs from earlier satellite navigation systems, such as *transit*, which used doppler shift as the measuring domain. Based on the TOA theory, two important factors can limit the potential accuracy of a GPS receiver's position solutions. The first is the measurement error in pseudorange (PR), and the second is the satellite-to-user geometry.

The PR measurement is the raw range measurement before correcting for clock bias. The error in the receiver's PR measurement is called *user-equivalent range error* (UERE). The UERE is affected by the quality of the received satellite signals, and it varies among satellites and times. The UERE also varies among different user receivers.

The second accuracy-limiting factor of satellite-to-user geometry is called *geometric dilution of precision* (GDOP). GDOP is a geometric quantity that describes the relative positions of the user and selected satellites. The GDOP value, an amplification factor, multiplies the UEREs and increases the receiver's position, velocity and time (PVT) solution errors. High values of GDOP cause small range-measurement errors to become large position errors. The receiver must select satellites with low GDOP to improve the potential accuracy of the receiver's PVT calculations and to limit the amplification of UERE. Good GDOP has low numbers and indicates that the satellites exhibit good geometry relative to the user. The lowest GDOP number occurs when the selected satellites are spaced widely in the sky above the GPS receiver. Figure 1 shows a good satellite geometry with a low GDOP number. Poor GDOP, as shown in Figure 2, occurs when the selected satellites are close together or when they form a row or circle. It is possible to have such poor GDOP numbers (high numbers) that the receiver is unable to process a solution. The best possible satellite geometry for PVT solution requires one satellite to be directly overhead and three others equally spaced around the horizon. For this reason, the commercial GPS user equipment for aircraft networks requires an antenna that can provide a right-hand circular polarization and a uniform pattern coverage over nearly the entire upper hemisphere.

The uniform amplitude response over a wide coverage region allows the receiver to maintain signal-lock to satellites with a useful signal-to-noise ratio. Because a high-speed aircraft constantly changes its *look angle* to satellites, the wide beamwidth coverage allows the receiver to track as many visible satellites as possible and to maintain the system's proper GDOP. An airborne terminal in a satellite-to-air communications link should have a mechanical configuration with no appreciable drag and that requires no elaborate structural modification to the aircraft. Slot antennas fit high-dynamic aircraft applications where low-profile or flush installations are required.

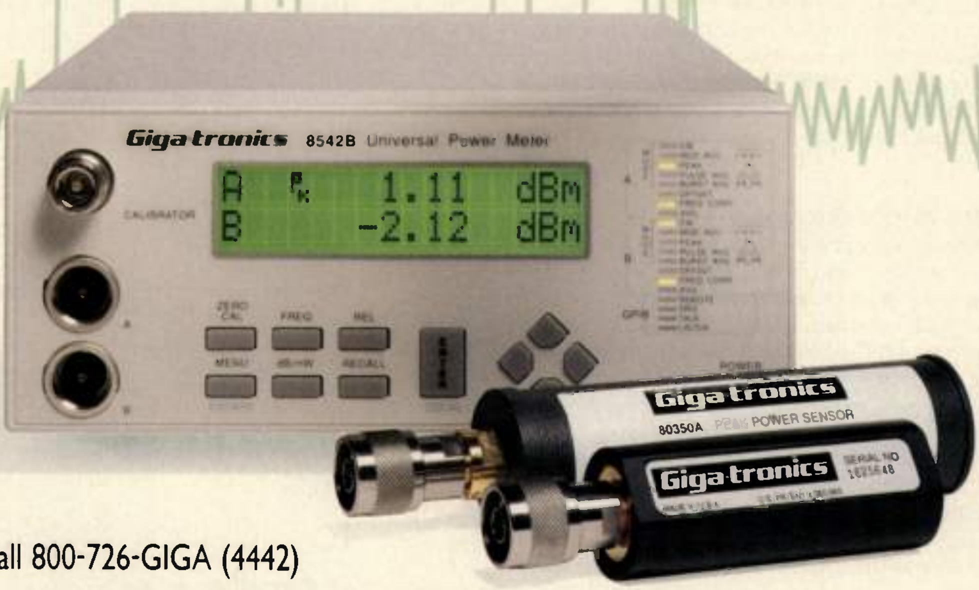
The slotted cylinder antenna first was introduced by Andrew Alford [1] in 1946. The physical structure of the slotted-cylinder antenna proposed in [1] consists of a piece of slotted sheet metal bent into a cylinder. Alford described this type of vertical slotted cylinder as a resonant transmission line with a sufficient number of shunt loops. Figure 3 shows the physical configuration of the conventional slotted-cylinder antenna. As shown in Figure 3, the antenna is

The Giga-tronics 8540B is the World's Best Power Meter for Communications Testing.

But Don't Take Our Word for It.

"Power meters generally fare well when characterizing simple continuous wave (CW) or pulsed RF/microwave signals. But modern communications signals, with digital information on phase–, frequency–, and amplitude–modulated carriers, pose problems for most power meters. The exception is the 8540B from Giga-tronics. The latest version of this high-speed measurement tool performs true average power measurements even on multitone signals with digital modulation."

Microwaves & RF
June 1995



Call 800-726-GIGA (4442)
or fax 510-328-4700 for more information 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

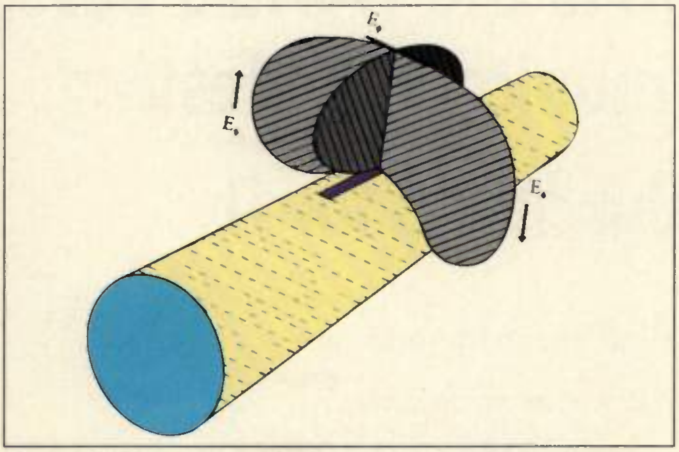


Figure 4. Radiation pattern of the conventional- slotted cylinder antenna.

formed by bending a piece of slotted sheet metal into a cylinder. Because of the sufficiently low impedance of the circumference path around the cylinder [2], most of the current flows in horizontal loops around the cylinder. The antenna radiates a horizontally polarized field with a nearly circular pattern in the horizontal plane. Figure 4 shows the radiation pattern of the slotted-cylinder antenna. At the cardinal points on the horizon, only the horizontally-polarized signal for the antenna is present. This type of vertical-slot antenna is suitable for broadcasting a horizontally-polarized wave with an omnidirectional or circular pattern in the horizontal plane.

To make a low-cost, lightweight and small-sized antenna for commercial GPS aircraft applications, a printed cylindrical-slot antenna was developed using microstrip baluns. The design technique employs four $^1/_2$-turn cylindrical slots etched in the ground plane of four 90° differential-fed microstrip lines. The phase quadrature among the microstrip feed lines excites a circularly-polarized wave. Experimental results show that the proposed cylindrical-slot antenna has a fairly good circular polarization, radiation pattern and front-to-back ratio and a wide beamwidth.

Quarterwave cylindrical slot antenna

The radiation properties of microstrip-fed slot antennas first were reported by Yashimura [3] in 1972. He measured the input impedances and radiation patterns for various geometries of microstrip-fed slot antennas. The physical structures of these slot antennas are fabricated by simple and conventional photoetching techniques and are considered suitable in microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC) transceivers. They also have the advantages of being able to produce bidirectional and unidirectional radiation patterns and of requiring simple feeding and matching techniques. Figure 5 shows the physical structure of the microstrip-fed slot antenna. The longer sides of the slot radiator are perpendicular to the microstrip feed line.

The microstrip conductor crosses the radiating slot and is short-circuited through the dielectric substrate. The slot radiator can be excited either from its center or at a distance from its center. The center-fed slot antenna requires a matching circuit to match the input impedance of the radiating slot to the 50 Ω microstrip feed line. Using the offset-fed slot configuration allows you to choose the position of microstrip feed line to provide an input match to the characteristic impedance of the line. The radiation resistance of the microstrip-fed slot antenna at an arbitrary offset position has been evaluated by Nakaoka et al and is given by [4] as the following:

$$R=\frac{\left[45\pi^2\int_{-\frac{L}{2D}}^{\frac{L}{2D}}\frac{1}{2\pi}\int_{-\infty}^{\infty}g(p)\frac{e^{-jpx}}{e^{(|ph|)}}dp\left(\cos\left(\frac{\pi}{L}(x+D)\right)dx\right)\right]^2}{\left(\frac{L}{\lambda_o}\right)^2\left(1-0.374\left(\frac{L}{\lambda_o}\right)^2+0.13\left(\frac{L}{\lambda_o}\right)^4\right)} \tag{1}$$

$$g(p)=\frac{\sin\left(\frac{pw_m}{2}\right)}{\frac{Pw_m}{2}}-\frac{\sin^2\left(\frac{pw_m}{4}\right)}{\left(\frac{Pw_m}{4}\right)^2}\frac{\sin\left(\frac{Pw_m}{2}\right)}{\frac{pw_m}{2}}-\frac{\sin^2\left(\frac{Pw_m}{4}\right)}{\left(\frac{Pw_m}{4}\right)^2} \tag{2}$$

where:

- L = length of the slot
- D = distance between the center of the slot of width W_s << l0 and the center of the strip conductor of width W_m
- p = Fourier transform variable
- R = measured on the microstrip plane

A number of authors [5,6] have thoroughly investigated impedance properties of slotline. The characteristics of slots on low-dielectric constant substrates, where slotlines have applications as antennas, were reported by Janaswamy and Schaubert [7] in 1986. Figure 6 shows the physical geometry of a wide slotline on a low-permittivity substrate. The empirical formulas for the normalized slot wavelength λ'/λ_o and slot characteristic impedance Z_o are given as follows according to [7]:

$$0.006\le\frac{d}{\lambda_o}\le 0.060 \tag{3}$$

$$2.22\le\varepsilon_r\le 3.8 \tag{4}$$

$$0.075\le\frac{w}{\lambda_o}\le 1.0 \tag{5}$$

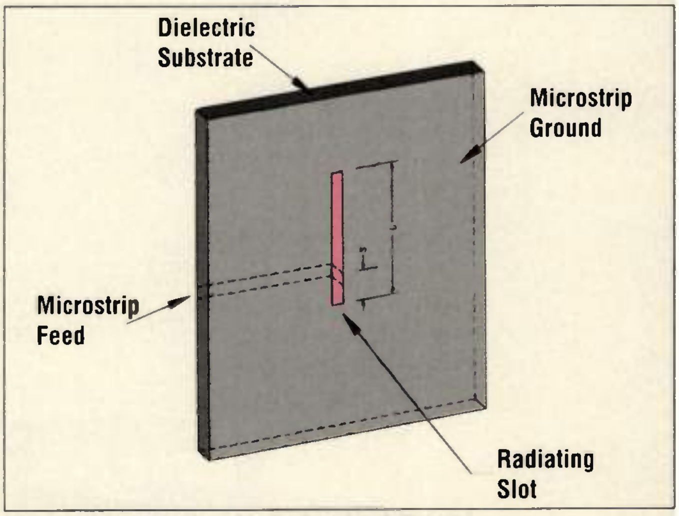


Figure 5. Microstrip line with displaced radiating slot.

European Correspondent.

DECT has arrived and Europe's going cordless. It's a huge market and you can write yourself a great profit story...if you have the right correspondent.

And here it is: ITT's new 400 mW, 28 dB power gain RFIC power amplifier for DECT.

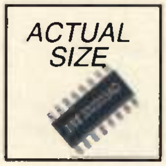
It requires only a single 3.6 volt battery, yet this 1880 -1900 MHz amplifier tolerates any mismatch in pulsed or CW operation. And, it produces an RF output signal strong enough to overcome filter and switch losses in the T/R path.

Like any good correspondent, it keeps a low profile. Its small 16-pin narrow body SOIC plastic package can fit into any design. It offers 50Ω input/output impedance. And it's tough and stable enough to handle any assignment.

It will make the most of your communications. With constant input VSWR in either the on or off state, it provides a constant load for your drive signal.

Don't risk getting written off in this competitive new market.

Call us at 540-563-3949 or fax us at 540-563-8616 for more information on this important new ITT correspondent.



ITT GTC
7670 ENON DRIVE
ROANOKE, VA 24019

ITT GTC

INFO/CARD 37

$$\frac{\lambda'}{\lambda_o} = 1.194 - 0.24\ln\varepsilon_r - \frac{0.621\varepsilon_r^{0.835}\left(\frac{w}{\lambda_o}\right)^{0.48}}{1.344+\frac{w}{d}} - 0.0617\left[1.91-\frac{\varepsilon_r+2}{\varepsilon_r}\right]\ln\left(\frac{d}{\lambda_o}\right) \tag{6}$$

$$Z_o = 133 + 10.34(\varepsilon_r - 1.8)^2 + 2.87\left[2.96+(\varepsilon_r-1.582)^2\right] \bullet \left[\left(\frac{w}{d}+2.32\varepsilon_r-0.56\right)\left((32.5-6.67\varepsilon_r)\left(100\frac{d}{\lambda_0}\right)^2-1\right)\right]^{\frac{1}{2}} - \left(684.45\frac{d}{\lambda_0}\right)(\varepsilon_r+1.35)^2 + 13.23\left[(\varepsilon_r-1.772)\frac{w}{\lambda_0}\right]^2 \tag{7}$$

Figure 7 shows the printed quarter-wavelength cylindrical slot antenna using microstrip baluns. Each of the slot radiators in Figure 7 is etched in the ground plane of the microstrip feedlines. The microstrip feedline crosses the slot radiator at a right angle and extends about $^1/_4$-wavelength beyond the slot. Unlike the slotted-cylinder antenna proposed in [1], each of the four vertical slots in Figure 7 is rolled by $^1/_2$-turn around the cylindrical laminate. This resonant quadrifilar structure [8] provides the right-hand circular polarization and increases the radiation coverage in the horizontal plane. At the feedpoint, the center conductor of the microstrip line extends about $^1/_4$-wavelength beyond the slot with an open circuit. This transition causes balanced currents to flow on both sides of the radiating slot and has less effect on the impedance transformation. Therefore, the input impedance of each slot radiator can be matched to a 50 Ω microstrip feed line by a minor adjustment of the length ratio between two short-circuited ends.

The 90° phase relationship between the four radiating slots can be achieved by using a microstrip feeding network. The choice of the feeding network can be either hybrid types, such as the branch line or ratrace coupler, or T-splitters of either matched or unmatched form. Feeds using hybrid couplers and matched T-splitters incorporate a fourth port with an absorbing load. Though these three types of feeding networks have good isolation between the output ports, using the add-on component reduces the basic simplicity of the printed construction. To reduce the complexity of fabrication and assembly, you should use an on-isolating in-line power splitter with an excess quarter-wavelength line in one output arm to generate the required 90° phase differentials between the radiating slots. The approximate design requires:

$$\frac{1}{Z_{in}} = \frac{1}{Z_{slot1}} + \frac{1}{Z_{slot2}} \tag{8}$$

where Z_{in}, Z_{slot1}, and Z_{slot2} are the input impedance and slot output impedances, respectively.

Figures 8 and 9 show the measured frequency responses of return loss and the input impedance for a microstrip-fed cylindrical slot antenna. As shown in Figure 9, the antenna is resonant at 1.5754 GHz with an input impedance of 50.07 – j1.3 Ω. The return loss at the center frequency is greater than 30 dB, as shown in Figure 8. The bandwidth with 10 dB return loss is about 1.5% of the center frequency. The input impedance and return loss were measured at the input terminal of the microstrip feeding network by using an HP8719A vector network analyzer.

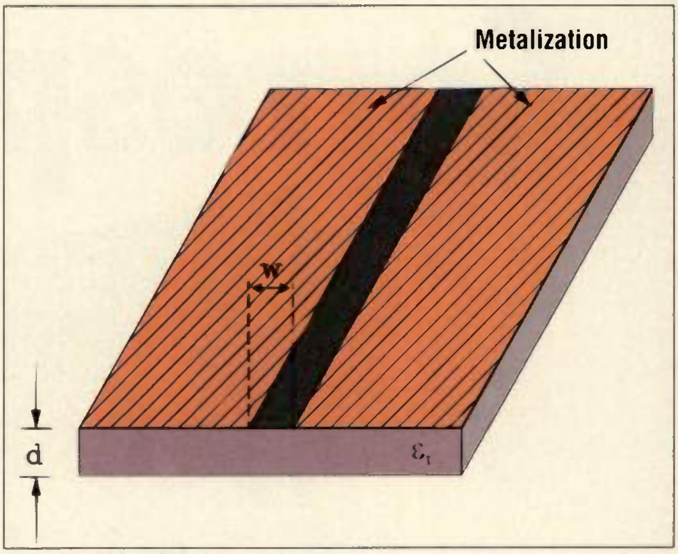


Figure 6. Physical diagram of slotline.

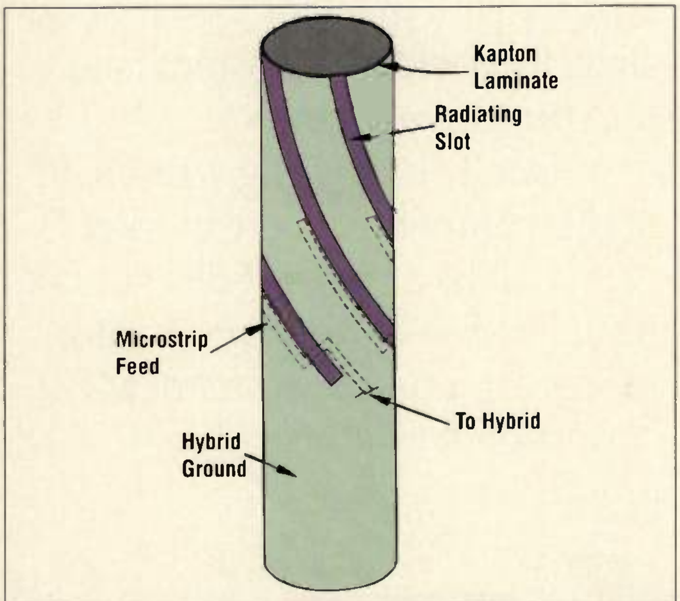


Figure 7. Physical configuration of the quarter-wavelength cylindrical-slot antenna.

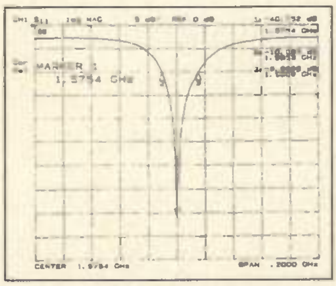


Figure 8. Measured frequency response of return loss for a $^1/_4$-wavelength cylindrical-slot antenna.

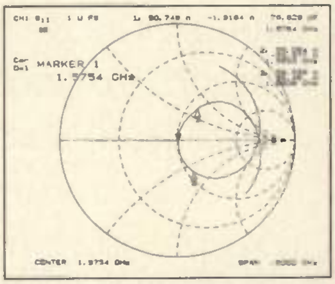


Figure 9. Measured frequency response of input impedance for a $^1/_4$-wavelength cylindrical-slot antenna.

Is this what BIPOLAR TECHNOLOGY has finally come DOWN TO?

12 GHz f_T Bipolars: one third the size of a SOT-23!

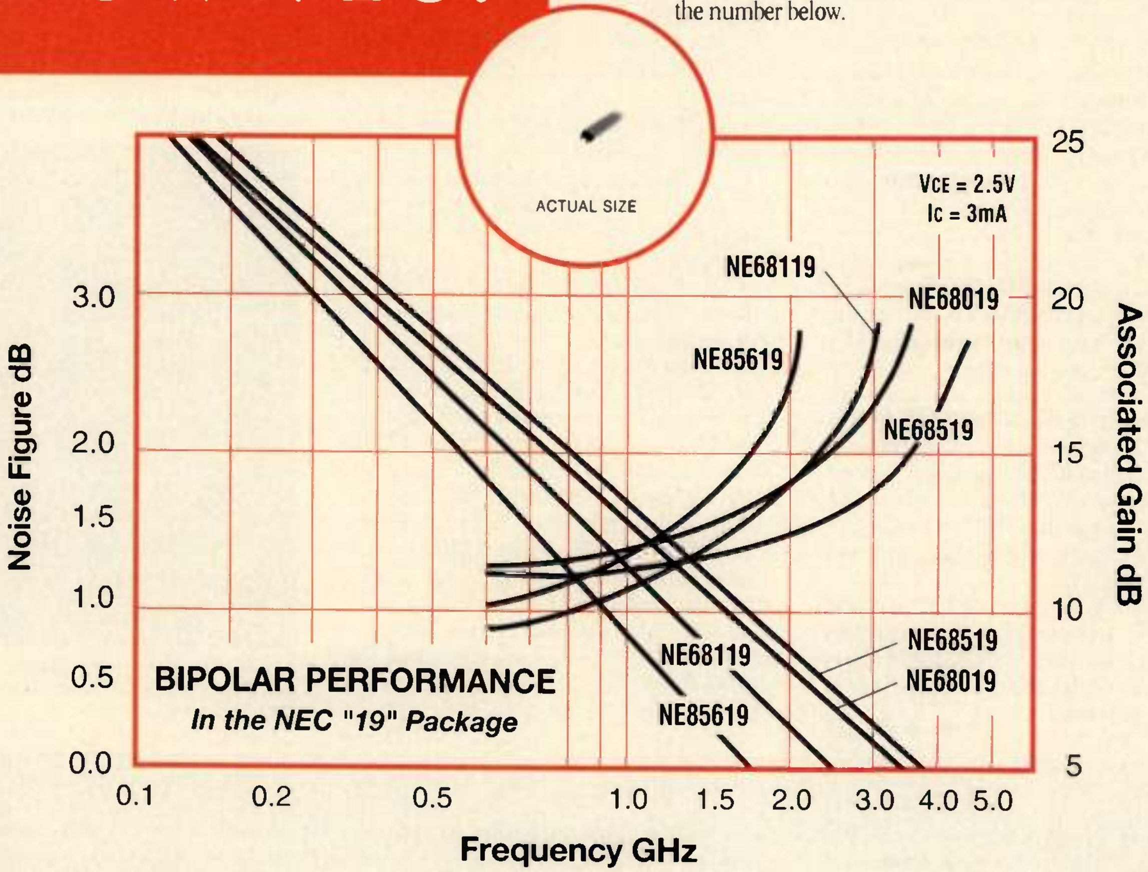
Need performance, but short on real estate?

Our new bipolars from NEC deliver up to 9 dB Gain and 1.5 dB Noise Figure at 1.9 GHz — in an ultra-super mini mold "19" package that's just 1.6 X 0.8 mm!

These bipolars operate below 3V and at low current to reduce battery size and increase battery life for your wireless applications.

Want the performance, but not quite ready for the miniature package? They're also available in traditional SOT-23, 323, and 143 style packages — and a new high performance 4 pin "18" package that delivers MAG of 13.0 dB at 1 V, 1 mA, 900 MHz.

They're available now, on tape and reel, and priced to meet your needs. For Data Sheets and a copy of *Automated Assembly of Miniature Parts*, call your nearest CEL Sales Office or circle the number below.



**Need Product Information Fast?*
Use CEL's 24 Hour Fax Sytem!

CEL/Fax 800-390-3232

NEC Bipolars are available in these packages (shown approx. 2X size)

NEC "19" Pkg	NEC "18" Pkg	NEC "30" Pkg	NEC "33" Pkg	NEC "39" Pkg
Ultra Super Mini Mold	4 Pin Super Mini Mold	SOT-323 Style	SOT-23 Style	SOT-143 Style

CEL California Eastern Laboratories **NEC**

CEL Headquarters 4590 Patrick Henry Drive, Santa Clara, CA 95054-1817; (408) 988-3500 FAX (408) 988-0279 http//www.cel.com
Sales Offices Santa Clara, (408) 988-7846 Los Angeles, CA (310) 645-0985 San Diego, CA (619) 450-4395 Bellevue, WA (206) 644-3307 Richardson, TX (214) 437-5487 Olathe, KS (913) 780-1380 Woodridge, IL (708) 241-3040 Timonium, MD (410) 453-6600 Middleton, MA (508) 762-7400 Hackensack, NJ (201) 487-1155 Snellville, GA (770) 978-4443 Altamonte Springs, FL (407) 774-7682

INFO/CARD 65

Figure 10 shows the radiation pattern of the printed quarter-wavelength cylindrical slot antenna. As shown in Figure 10, the half-power beamwidth is more than 120°, and the front-back ratio is more than 20 dB. These figures offer fairly good rejection of multipath signals reflected from the ground. The radiation pattern was measured with an HP8719A vector network analyzer with a calibrated, right-hand circularly-polarized, helical antenna.

Field tests for verifying the quarter-wavelength cylindrical slot antenna were conducted with GPS receivers. Figure 11 shows the field test results of a quarter-wavelength cylindrical slot antenna with a GPS90 avionics receiver. The test was performed using a satellite geometry with a position dilution of precision (PDOP) of 69 feet. The receiver bar graph shows that satellites 1, 15, 20, 21 and 25, located within the axis angle of $\theta = 45°$ have calibrated signal scales of 9, 9, 8, 8 and 9, which correspond to the receiver phase noise of 51 dB, 51 dB, 49 dB, 49 dB, and 51 dB, respectively. Satellites 5, 14 and 22, located outside the axis angle of $\theta = 45°$, have calibrated signal scales of 6, 7 and 8, which correspond to the receiver phase noise of 45 dB, 47 dB and 49 dB, respectively According to the test results, the radiation pattern coverage of the quarter-wavelength cylindrical-slot antenna allows the GPS receiver to track satellites at extremely low elevation angles.

In addition to the electrical characteristics, the $^1/_4$-wavelength cylindrical slot antenna has favorable mechanical characteristics. Its cylindrical dimensions are about $^1/_2$" in diameter by 1-$^1/_2$" long. The weight, including the supporting base and radome, is about 1 ounce.

Conclusion

The experimental results of the new microstrip-fed cylindrical slot antenna illustrate fairly good input impedance-matching and front-to-back ratio, and a nearly hemispherical radiation pattern coverage. With its advantages of lowcost, light weight, compact size and ease of fabrication and assembly, the new printed cylindrical-slot antenna is suitable for commercial GPS aircraft applications .

RF

References

1. A. Alford, "Long Slot Antennas," *Proc. Natl. Electronics Conference*, pp. 143, 1946.
2. J. D. Kraus, *Antennas*, New York, McGraw-Hill, pp. 642–644, 1988.
3. Y. Yashimura, "A Microstrip Slot Antenna," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 760–762, November 1972.
4. K. Nakaoka, K. Itoh and T. Matsumoto, "Microstrip Line Array Antenna and Its Application," *Int. Symp. on Antennas and Propagation*, 1978, pp. 61–64.
5. J. B. Knorr and K. Kuchler, "Analysis of Coupled Slots and Coplanar Strips on Dielectric Substrate," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 541–548, July 1975.
6. E. A. Mariani et al, "Slotline Characteristics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-17, pp. 1091–1096, December 1969.
7. R. Janaswamy and D. H. Schaubert, "Characteristic Impedance of a Wide Slotline on Low-permittivity Substrates," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-34, pp. 900–902, August 1986.
8. C. C. Kilgus, "Resonant Quadrifilar Helix Design," *Microwave Journal*, pp. 49–54, December 1970.

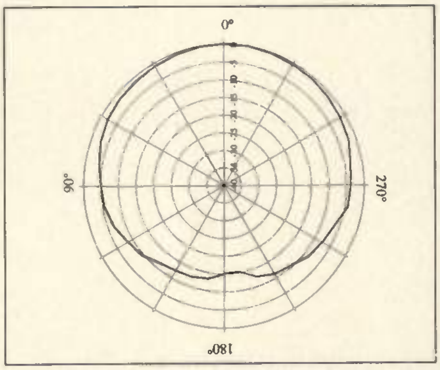


Figure 10. Measured radiation pattern of a quarter-wavelength cylindrical-slot antenna.

Figure 11. Field test results of a quarter-wavelength cylindrical-slot antenna with a GPS90 avionics receiver.

About the Authors

Chien H. Ho received a B.S. in 1985 and an M.S. in 1987 from the Electrical Engineering Department of National Taiwan University, Taipei, Taiwan. He received a Ph.D. in 1993 from Texas A&M University, College Station, TX. He is a development engineer for Garmin International, Olathe, KS. His research interests include uniplanar MIC components, low-noise receivers and microstrip antennas.

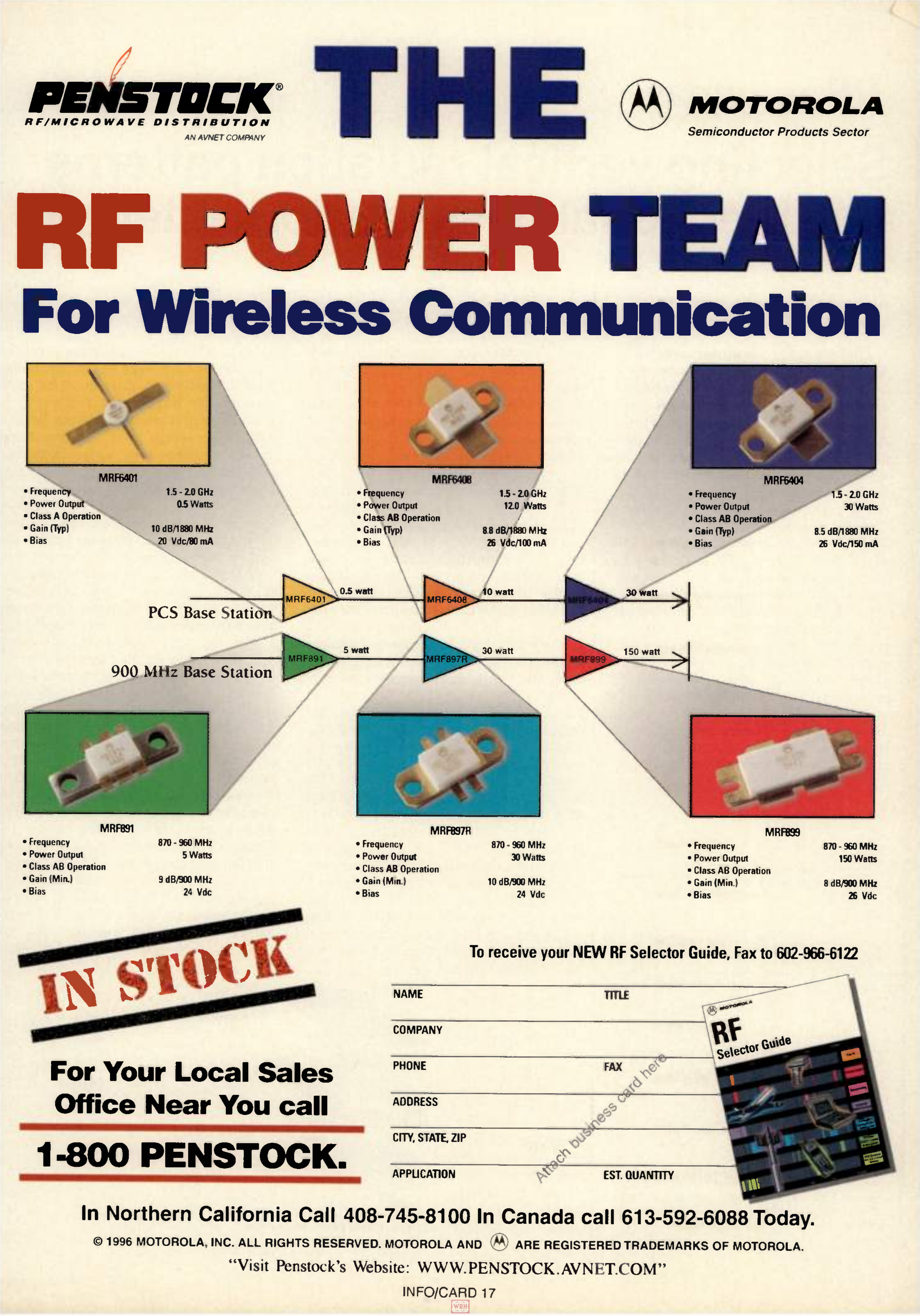
Paul K. Shumaker (member IEEE) received a B.S.E.E. in 1967 and an M.S.E.E. in 1968 from the University of Missouri at Columbia. He is with Garmin International, Olathe, KS where he has designed GPS antennas and receivers.

Keith B. Smith received an electronics technician diploma from DeVry in 1984. He worked as a lead technician at Bendix King on transponders for three-and-a-half years, then as a RF engineering technician at Aviation Systems on conventional and doppler VOR systems for three years. He is a senior engineering technician at Garmin international, Olathe, KS, working mostly with the research and development of GPS receivers and antenna systems.

Juhn W. Wang received a B.S.E.E. from Tankang University, Taipei, Taiwan, in 1993, and an M.S.E.E. from Polytechnic University, New York. He is a project engineer for Garmin International, Hsin Tien, Taiwan.

Hua Y. Wang received a diploma in electrical engineering from National Taipei Institute of Technology, Taipei, Taiwan, in 1991, and an M.S. in telecommunication from National Chiao Tung University, Hsin Tsu, Taiwan, in 1995. He is an electronics engineer for Garmin International, Hsin Tien, Taiwan.

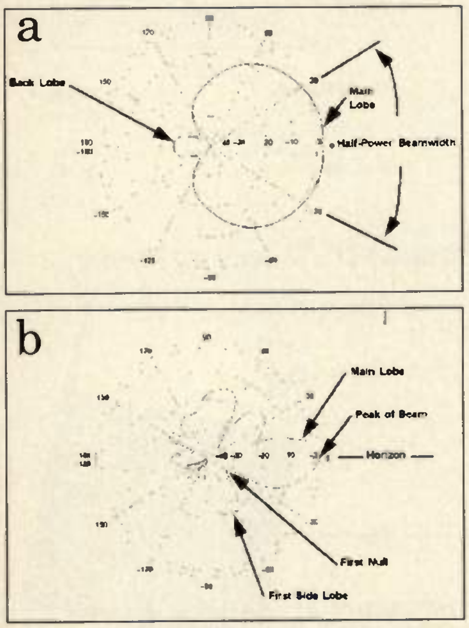
The authors can be reached at Garmin International, 1200 E. 151st St., Olathe, KS 66062 or via voice mail 913-397-8200.


PENSTOCK®
RF/MICROWAVE DISTRIBUTION
AN AVNET COMPANY
THE
MOTOROLA
Semiconductor Products Sector
RF POWER TEAM
For Wireless Communication
MRF6401
• Frequency 1.5 - 2.0 GHz
• Power Output 0.5 Watts
• Class A Operation
• Gain (Typ) 10 dB/1880 MHz
• Bias 20 Vdc/80 mA
MRF6408
• Frequency 1.5 - 2.0 GHz
• Power Output 12.0 Watts
• Class AB Operation
• Gain (Typ) 8.8 dB/1880 MHz
• Bias 26 Vdc/100 mA
MRF6404
• Frequency 1.5 - 2.0 GHz
• Power Output 30 Watts
• Class AB Operation
• Gain (Typ) 8.5 dB/1880 MHz
• Bias 26 Vdc/150 mA
PCS Base Station
MRF6401
0.5 watt
MRF6408
10 watt
MRF6404
30 watt
900 MHz Base Station
MRF891
5 watt
MRF897R
30 watt
MRF899
150 watt
MRF891
• Frequency 870 - 960 MHz
• Power Output 5 Watts
• Class AB Operation
• Gain (Min.) 9 dB/900 MHz
• Bias 24 Vdc
MRF897R
• Frequency 870 - 960 MHz
• Power Output 30 Watts
• Class AB Operation
• Gain (Min.) 10 dB/900 MHz
• Bias 24 Vdc
MRF899
• Frequency 870 - 960 MHz
• Power Output 150 Watts
• Class AB Operation
• Gain (Min.) 8 dB/900 MHz
• Bias 26 Vdc
IN STOCK
To receive your NEW RF Selector Guide, Fax to 602-966-6122
NAME
TITLE
COMPANY
PHONE
FAX
ADDRESS
CITY, STATE, ZIP
APPLICATION
EST. QUANTITY
Attach business card here
MOTOROLA
RF
Selector Guide
For Your Local Sales
Office Near You call
1-800 PENSTOCK.
In Northern California Call 408-745-8100 In Canada call 613-592-6088 Today.
© 1996 MOTOROLA, INC. ALL RIGHTS RESERVED. MOTOROLA AND ARE REGISTERED TRADEMARKS OF MOTOROLA.
"Visit Penstock's Website: WWW.PENSTOCK.AVNET.COM"
INFO/CARD 17

Selecting vertical radiation patterns for directional base-station antennas

By Charles M. DiFronzo
Huber+Suhner

The effect of physically or electrically tilting the vertical radiation pattern of a vertically polarized, planar, directional base-station antenna downward from the horizon (a 0° elevation angle) to some elevation angle below will alter the performance of a personal communications system (PCS) site. Base-station antenna pattern specifications will vary in a PCS cell site depending on the installation environment. Physical characteristics, such as topography and tower height, invariably differ for each base-station site. These variables make it nearly impossible to predict the radiation characteristics of the vertical and horizontal patterns, although one can estimate the propagation results based on a knowledge of antenna and communications theory. Antenna height from ground, physical structures (natural, man-made or both), and the vertical pattern shape have a large effect on the downtilt angle to be selected for a base-station antenna system. These characteristics must be selected to minimize co-channel interference between adjacent cell sites and to minimize reflections and multipath depolarization caused by objects in and about the direction of the major lobe of antenna radiation for a sectorized planar antenna array.



Figures 1 a,b. Principle plane radiation patterns of directional antennas. (a) Horizontal. (b) Vertical.

The beamwidth vs. gain relationship for antennas — A planar directional antenna has two distinct principal-plane radiation patterns that fully describe the effective power transmitted and received by the device. These planes are the horizontal and vertical radiation components with respect to earth. Figures 1a and 1b depict typical principal-plane patterns for planar-patch antennas and terms associated with these radiation characteristics. Both horizontal and vertical radiation pattern components are controlled by the geometry of the antenna elements. The area of the antenna elements' radiating aperture dictates the beam shape or resulting coverage. This in turn dictates the directivity or gain of a directional planar antenna array. The beamwidth of an antenna pattern is defined by the 3 dB or half-power point from the peak of the main beam. The field intensity at the half-power beam points is equal to 0.707 times the maximum field intensity of the antenna pattern. A directional antenna for a base station is specified and designed by its gain (expressed in dBi or dBd) and 3 dB beamwidth in the direction of the main energy induced. In general, the wider the beamwidth of an antenna pattern, the lower the gain and the less the control of directivity. Designing these types of antennas merely by maximizing the gain does not provide the best coverage reliability. Some form of pattern-shaping must be used in both the horizontal and vertical planes to optimize the antenna for the required coverage area. Pattern-shape design also reduces sector-to-sector antenna and site-to-site signal overlap, which causes co-channel interference.

The horizontal radiation pattern — The horizontal principle-plane pattern for a directional antenna for PCS base-station applications is ideal for a sectorized approach. Planar patch technology (Figure 2) provides horizontal beamwidths of 60° or 85°, depending on groundplane width. A sectorized base station approach enables a site to become omnidirectional in the horizontal direction. Directional antennas allow for interference reduction caused by overlapping coverage occurring from antennas within a base station, as well as from other base stations. This allows the site to cover an area with a distinct radius of field strength and minimal co-channel interference from sector to sector and from site to site. The horizontal beamwidth of an antenna is chosen by the system designers. The number of sectors dictates the horizontal beamwidths required. Typically a three- or four-sector approach is used in PCS base-station sites. Directional antennas with 85° and 60° horizontal beamwidths are installed in three-and four-sector sites, respectively.

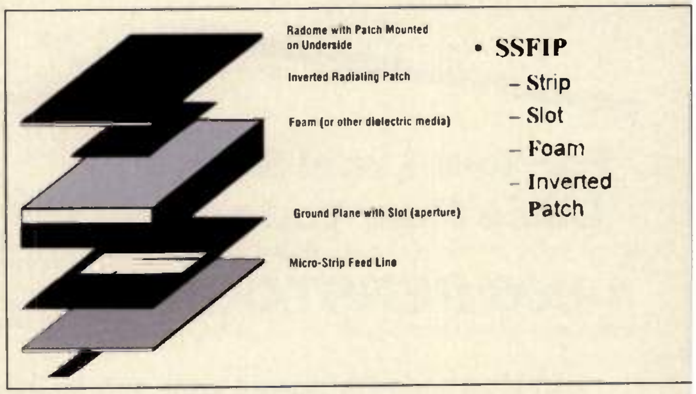
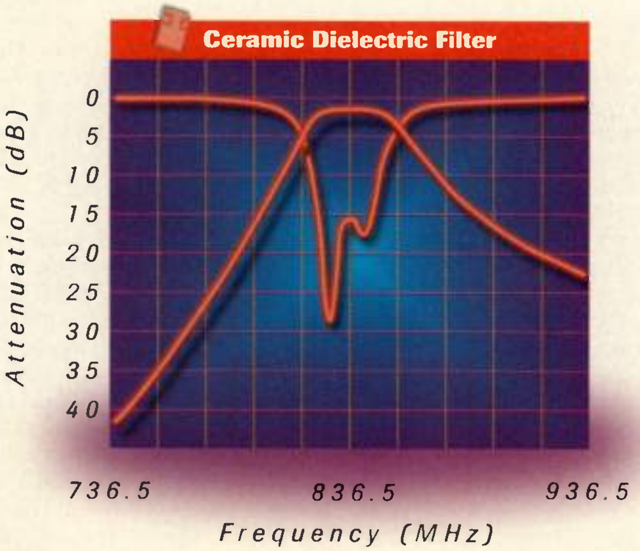
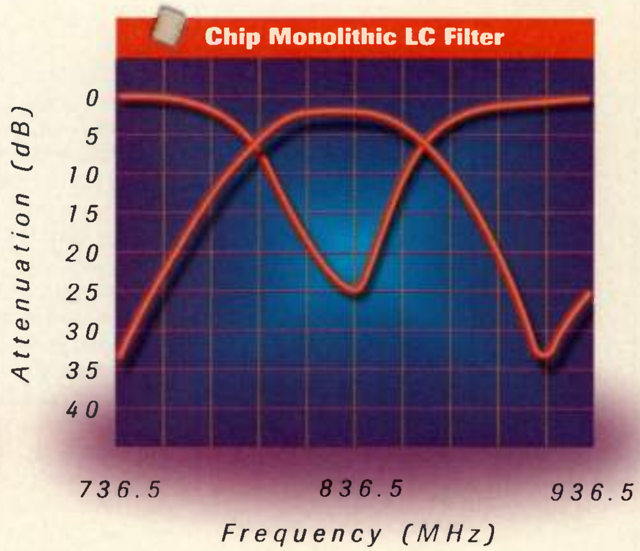
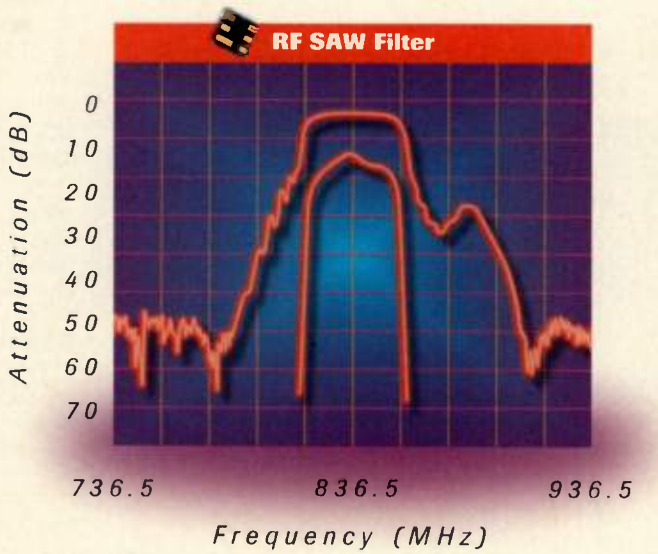


Figure 2. Planar patch technology.

Downsizing a microwave filter is one thing, upsizing its performance is something else.







At Murata, what goes down often goes up, too. Way up. Which is nice to know when your wireless product design requires sub-miniaturized, surface mount packages that also offer great performance.

Moreover, as the analyzer screens show, we offer the breadth of choices you need to meet design needs and budget considerations. From our Ceramic Dielectric Monoblock Filters, with their high temperature and mechanical stability, low insertion loss and excellent out-of-band rejection; to Chip Monolithic LC Filters, whose small size, light weight and cost-effectiveness make them ideal for hand-held communications; to RF SAW Filters with very low loss, excellent waveform symmetry and high selectivity.

It's what you would expect from the industry pioneer in miniaturizing microwave products. For free technical manuals or more information, call us at **1-800-831-9172, ext. 575.**

muRata®

Innovator in Electronics

The horizontal pattern shape can be altered by tilting the antenna vertically. The directivity can be displaced in the horizontal direction by tilting a directional antenna downward. The free-space radiation characteristics of the antenna will be altered to some degree in an actual base-station installation. The antenna height, degree of downtilt and the environment surrounding the sectorized base station antenna will dictate the actual performance of the PCS site.

The vertical radiation pattern — Adding patch elements in the vertical plane enables the design of phased planar-patch arrays having various vertical beamwidths and gains. Because of this, planar-patch technology is well-suited to addressing the design needs of PCS site planners. Vertical pattern-shaping is key in providing sectorized coverage to a distinct area and the concentrated signal strength required by site and system designers. A general rule of thumb in selecting base-station antennas by the means of beamwidth is that the smaller the beamwidth, the more distinctly the field intensity will be concentrated to the main lobe. The series addition of like-phased patched elements increases gain and reduces beamwidth in the plane of the element addition. Continuous stacking of elements does not result in unlimited gain and narrowing in beamwidth. When designing these types of antennas, physical size and manufacturing methods also limit the gain and beamwidths that can be achieved. Typical gains and beamwidths that result from spacing planar patch elements a half-wavelength apart in the vertical direction can be seen in Figure 3. The values in Figure 3 represent planar patch antenna arrays having one-to-12 half-wavelength elements spaced vertically by a half-wavelength center-to-center at 1,850 MHz. The larger the constant spacing from element-to-element, the narrower the vertical patterns. The opposite is true for tighter constant spacing of like-phased elements. As the patch elements approach one another, pattern symmetry and bandwidth are effected by mutual coupling of patches and feed-circuit geometry.

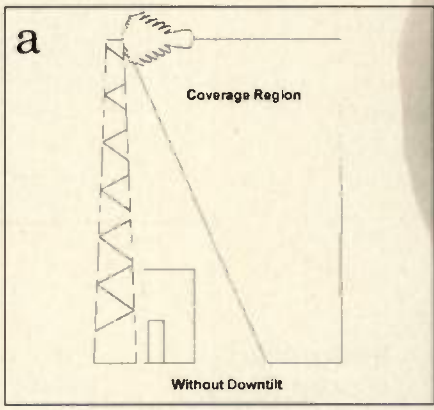
The vertical pattern of a directional antenna can be physically or electrically tilted downward or upward from a horizon reference point. Downtilting of a sectorized antenna is common in a PCS site environment. Mechanical tilting of a directional antenna is done by physically manipulating the antenna downward a set elevation angle in the vertical plane (Figure 4). In most cases, the antenna bracket allows the installer to make the adjustment. Electrical tilting of a vertical antenna pattern also is a means of directing coverage in a desired location. Electrical manipulation of the radiation is performed by feeding the arrayed antenna elements with different phases that steer the main lobe of radiation in the desired direction. As stated previously, the angle of tilt required for a site depends on antenna height, coverage distance desired, location of adjacent sites and the site location itself.

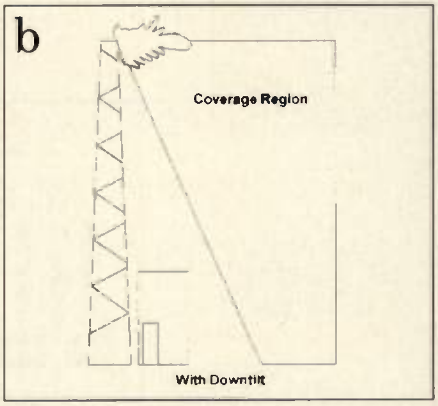
Downtilting results

Tilting an antenna downward effects the radiation patterns based on antenna height and the base-station environment. Both means of downtilting are ac-

NUMBER OF STACKED VERTICAL PLANAR PATCH ELEMENTS IN ARRAY	HORIZONTAL 3 dB BANDWIDTH (°)	VERTICAL 3 dB BANDWIDTH (°)	GAIN (dBi)
1	85	85	7.5
2	85	42	10.5
3	85	32	11.8
4	85	26	12.8
5	85	20	13.6
6	85	16	14.4
7	85	14	14.9
8	85	13	15.5
9	85	11	15.9
10	85	10	16.4
11	85	9	17.0
12	85	8	17.2

Figure 3. Typical beamwidth and gain of 1/2-wavelength spaced planar patch elements arrayed in the vertical axis



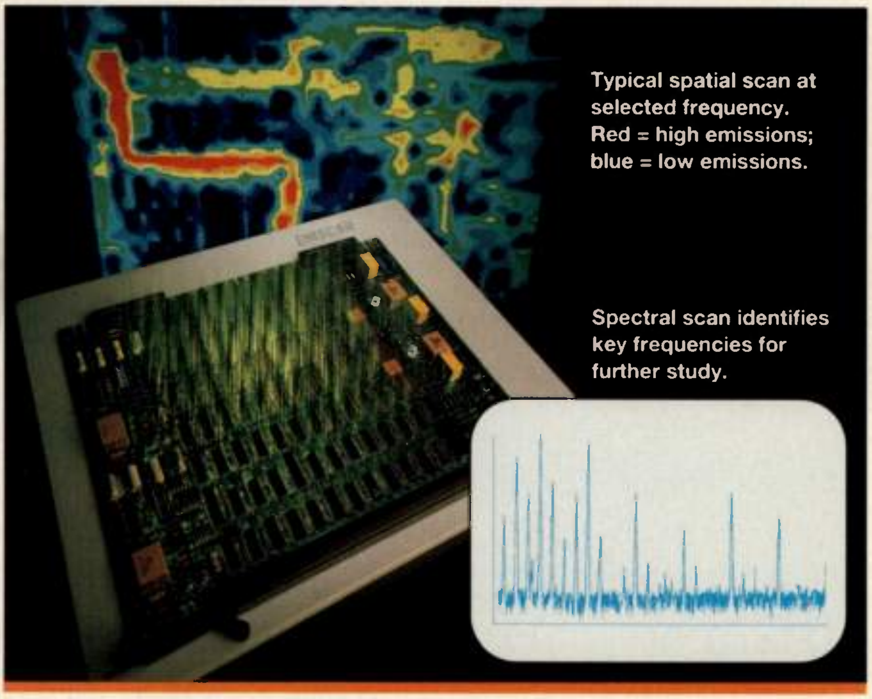


Figures 4 a and b. Downtilt of directional base station antennas. (a) Without downtilt. (b) With downtilt.

ceptable, but the system planners must be aware that each method has pros and cons associated with it.

Physical or mechanical tilt of an antenna is accomplished with a variable-angle mounting bracket. Mounting brackets commonly used in cellular base stations and PCS site applications are virtually the same, except for the size. The brackets allow various downtilt options to be used when optimizing coverage of a wireless communications system. Typically, a protractor device or graduated angle increments provided on the antenna bracket are used to physically locate the tilt required, and this is set upon installation. When mechanical tilt is used, the radiation pattern is displaced by the angle chosen by the site planner or designer.

On the positive side, mechanical downtilting of antennas allows each one to be tweaked individually in the field for maximum performance. The ability to change downtilt easily can can make it less expensive to fix coverage problems if terrain and physical structures change over time. On the negative side, mechanical downtilting of an antenna results in the side lobe level closer to the base sta-



Catch rf emissions problems at board level, where compliance fixes are least costly.

Now you can quickly get a color image of the electromagnetic performance of your printed-circuit board or subassembly *before* final compliance testing. Spatial and spectral displays generated by the EMSCAN PCB emissions scanner show you which frequencies and which areas of the board under test are guilty. These scans are stored for later comparison after design alterations, to check whether offending emissions are now down to acceptable levels.

Just plug your receiver or spectrum analyzer, and your computer with IEEE-488 interface, into the EMSCAN scanner, and a matrix of 1280 H-field probes maps the area of your test board (up to 9" x 12") for high, medium, and low-emissions spots within the 10 MHz-1.5 GHz frequency range. Or you can see a spectral display showing the overall condition of the board across the spectrum. You may then choose a frequency of particular interest for intensive spatial examination.

After the development stage, you can use EMSCAN as a quality-control tool, checking completed boards against a "good" scan before they go into assembly. This is the point where production compliance becomes virtually assured.

The software operates under "Windows" to make early diagnosis easy, even for those who are new to compliance testing. It can run on several PCs (486 or higher), and is readily ported to other environments for analysis.

You should learn all about this qualitative and quantitative measure of emissions for use during product development—where design corrections are least costly. To start, call toll-free (1-800-933-8181) to speak with an applications engineer and arrange to see a demonstration in your office or plant.

www.ar-amps.com

ar® AMPLIFIER RESEARCH

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

For engineering assistance, sales, and service throughout Europe, call
EMV • Munich, 89-614-1710 • London, 908-566-556 • Paris, 1-64-61-63-29

16084

ar is where you are.

AUSTRALIA, NEW ZEALAND
R.F.I. Industries Pty. Ltd.
Ph: 3-9762-6733 • Fax: 9762-8501

BELGIUM, NETHERLANDS, LUXEMBOURG • Koning en Hartman B.V.
Ph: 15-2-609-906 • Fax: 15-2-619-194

BRAZIL • IME LTDA
Ph: 11-871-2164 • Fax: 62-6981

CANADA • Instrument Systems EMC
Ph: 613-729-0614 • Fax: 729-9067

CHINA & HONG KONG • Corad Technology Ltd. • Ph: 852-27930330 • Fax: 27930606

DENMARK • Stantronic Instruments
Ph: 75-643366 • Fax: 644080

ENGLAND (UK) • EMV Limited
Ph: 908-566556 • Fax: 560062

FINLAND • Euroshield OY
Ph: 38-8383300 • Fax: 8651233

FRANCE • EMV S.A.R.L.
Ph: 1-64-61-63-29 • Fax: 61-64-51

GERMANY • EMV GmbH
Ph: 89-614-1710 • Fax: 612-8593

GREECE • Axel Representations Ltd.
Ph: 301-7236753 • Fax: 7241361

INDIA • Complus Systems Pvt. Ltd.
Ph: 80-3430102 • Fax: 80-2251468, attn: IC FAX 849

ISRAEL • Telsys, Ltd.
Ph: 972-3-6492001 • Fax: 6497407

ITALY • TESEO S.p.A.
Ph: 11-7396515 • Fax: 7381420

JAPAN • Nippon Automatic Control Co.
Ph: (0)3-5434-1600 • Fax: 5434-1630

MEXICO • Unitronica S.A. de C.V.
Ph: 5-2953673 • Fax: 2953298

NORWAY • Teleinstrument A/S
Ph: 6383 5700 • Fax: 6383 5710

SINGAPORE, INDONESIA, THAILAND, PHILIPPINES, MALAYSIA
Precision Technologies PTE, Ltd.
Ph: 2734573 (5 line) • Fax: 2738898

SOUTH AFRICA • S.A. Electro-Medical
Ph: 12-804-1620 • Fax: 804-2009

SOUTH KOREA • Kwang Wha Trading
Ph: 2-679-3996/7 • Fax: 679-3998

SWEDEN • CE-BIT Elektronic AB
Ph: 8-7357550 • Fax: 8735-6165

SWITZERLAND • Isatel Electronic AG
Ph: ++41 41 748 60 10 • Fax: 748 50 55

TAIWAN • Evergo Electronics
Ph: 886-2-7150283 • Fax: 7122466

TURKEY • Erkman Elektronik Aletler
Ph: 212-2441546/2937651 • Fax: 2497037

*Add international access and country codes as needed.

ar® AMPLIFIER RESEARCH®

160 School House Road,
Souderton, PA 18964-9990 USA
Phone 215-723-8181 • Fax 215-723-5688
www.ar-amps.com

16461P

tion changing as you increase the tilt-angle of the antenna. This method also causes deformation of the horizontal pattern at the peak of the beam.

The first side lobe off the main beam usually is observed to be –15 to –20 dB below the peak of energy associated with the vertical radiation characteristics of a directional antenna. The null, or lack of signal created by the antenna array in the vertical pattern, is fundamental in antenna theory. This null is found between the main lobe and the first side lobe (Figure 1). By physically downtilting the antenna in various increments, one will observe that the signal level of the first null changes as downtilt increases. The increased tilt will alter the level of signal that exists close to the base station, leaving holes in coverage near the site. Depending on the site installation, PCS operators and system planners will then have to place microcell antennas in this area for increased site coverage, thus increasing infrastructure cost to the PCS provider. Also, tilt angles greater than 15° drastically change the horizontal radiation patterns of a directional-site antenna. A notch in the pattern will be present at the peak of the main lobe in the horizontal plane. This condition could only occur with antennas placed more than 350 feet above ground level.

Electrically tilting antenna patterns is another method used to steer desired coverage to certain locations. This type of tilting, caused by phase-tapering the antenna elements, prevents the shape of the main lobe of radiation from being deformed at the coverage border. These antennas can be mounted flush to a surface, making the antenna blend into the background. Two types of installations that can use electronic downtilting include antennas mounted on walls and on the sides of buildings. Just as with mechanical tilting, some positive and negative aspects will be encountered when electronic tilting takes place. As stated previously, a site antenna mounted to a building facade with a designed electrical downtilt will operate as designed and will allow the antenna to be camouflaged or hidden. From the zoning and real estate acquisition standpoints, this is a plus. The drawback to electrical downtilting is that any changes in site optimization and terrain or environmental variation are extremely difficult to overcome without replacing antennas with others that have different electrically-phased downtilt. Also, electronically downtilting radiation patterns has an effect on the maximum efficiency or gain that can be achieved. The greater the angle of downtilt designed into the circuitry of an antenna, the greater the reduction of gain as compared to a mechanically-downtilted antenna with the same array factors.

Antenna height and downtilt

The actual height at which a site antenna is located will have an effect on the required vertical downtilt. Most early-stage cell-site design and planning is done with the assumption of a flat terrain. The choice of directional antenna specifications, such as gain or horizontal and vertical 3 dB beamwidths, will depend on the type of site. These site types can be segmented into

MATRIX SYSTEMS SWITCHING

DC TO WIRELESS

Since 1969, Matrix Systems has been designing and manufacturing a wide range of reed relay and solid state switching modules, matrices and complete systems. These high performance products are built to rigid specifications for defense contractors, government agencies, the TV industry, ATE and telecom companies. Matrix Systems has supplied thousands of unique switching systems, with computer interfaces, control panels status indicators and power supplies.

WE SPECIALIZE IN SPECIAL SYSTEMS

All available with RS-232/IEEE-488/keypad control

- Solid-state R.F. matrices
- Fast risetime matrices
- Combine/splitter matrices
- 50 Watt coaxial matrices
- Solid-state UHF matrices
- DC-1GHz scanners
- 2000 volt multiplexers
- UHF pin diode matrices
- Low leakage triaxial matrices

STANDARD SYSTEMS

All available with RS-232/IEEE-488/keypad control

- Low noise R.F. switching systems
- I.F. matrices
- High power matrices
- NTSC/PAL Video matrices
- Audio pair matrices
- RGB systems
- Video distribution matrices
- Programmable Attenuators

RELAY MODULES

Relay modules to configure systems and matrices with RS-232/IEEE-488/keypad interfaces standard.

- Coaxial
- Twinaxial
- Triaxial
- Audio
- Kelvin
- Transducers
- Solid-state
- Hard contacts

So whether you are switching DC to wireless, or anything in between, switch to Matrix Systems for experience, quality and performance.

Call us today at **(818) 222-2301**
or FAX us at **(818) 222-2304** for our latest catalog.

MATRIX
SYSTEMS CORPORATION
5177 N. Douglas Fir Road
Calabasas, CA 91302

INFO/CARD 23

three general categories: urban, suburban and rural. Most PCS base-station applications will require towers, monopoles and building-mounted installations with maximum heights around 250–300 feet. The desired cell coverage initially required in the PCS infrastructure will vary. Maximum distances of signal strength for a site will be approximately two to three miles in diameter for omnidirectional cells. Actual site-antenna performance depends on the effective height of the antenna. Differences in height change the signal level reception concurrent with the terrain contour and the locations of mobile handsets within the coverage area.

The vertical downtilt of a directional antenna in a PCS site will be dictated by the site location itself and by its physical surroundings. Antenna height, coverage distance and proximity coverage close to the site are taken into account when selecting tilt angles. The greater the height of a base-station tower or building, the greater the effective gain realized by the site antenna, thus producing greater distance coverage. The doubling of antenna height in flat-terrain propagation studies yields an increase in gain of 6 dB. The increased height will also require greater downtilt angles and the probability of distortion to both principal-plane patterns. This could take place because of co-channel interference generated by adjacent sites. As was stated previously, most antenna heights for PCS installations will not exceed 300 feet. PCS installations less than 300 feet high will require downtilt angles of no more than 0° to –5° for maximum site performance.

The real world can be cruel to both the site and planner. Topographical and man-made objects challenge system designers. Mountains, trees (with and without foliage), water, buildings, signs and existing towers are just some of the obstacles that are encountered in developing a wireless communications infrastructure. Reflections and diffraction of the radiated energy of an antenna occur when these phenomena are added to the transmission equation. (See Figure 5.) If located close to the base station, these structures will generate depolarization of the transmitted or received wave and will cause multipath effects. In the polarized sense of the antenna (usually vertically polarized antennas are used), the wider the beamwidth of an antenna pattern, the larger the chance for multipath or reflections. Predicting this phenomenon is difficult because a real reflection is not completely known until site testing is performed with actual site antennas on a building or tower.

Vertical beamwidths can be varied with the addition or subtraction of planar-patch antennas arrayed in the vertical plane. This control over the half-power beamwidth allows PCS system designers to choose directional arrayed antennas having characteristics that fit into variable site plans that change with topographical and zoning conditions. To concentrate the base-station energy over a greater transmitting area, a high-gain antenna usually is chosen for a highway or rural site plan. The high gain will yield a more directive antenna pattern in the vertical plane, resulting in a narrow main lobe of energy.

A wide vertical beam is associated with antennas having low-to-medium-type gains, usually from 7 to 15 dBi. These types of antennas are used primarily in suburban or urban environments where shorter distances of transmission are required and wider areas of concentrated energy are needed from the vertical radiation pattern of the site antenna. For PCS, multipath can be used to advantage in an urban environment. Dual-polarized (or circularly polarized) antennas can be used to receive the multipath signals that proliferate there.

Antennas with extremely narrow vertical beamwidths yield high gain. In rural and suburban sites, energy must be concentrated in a distinct direction and into a certain region of coverage. Directional antennas with gains of 15 to 18 dBi generally are preferred by system designers.

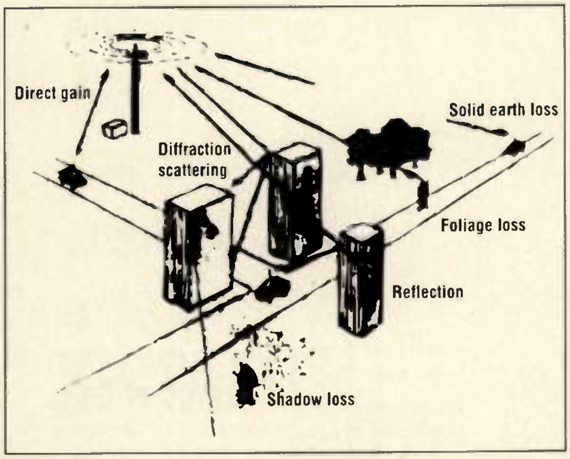


Figure 5. A real world wireless communications environment.

Conclusion

One easily can state that the design and optimization of PCS base stations is difficult. Directional antennas chosen for a site can be manipulated and designed to maximize coverage and to minimize co-channel interference. System designers use powerful propagation software to predict the performance of antennas selected for a site. Modeling and testing only can provide data that are not supported by real-life problems encountered when the base station is operational. Field optimization is required to achieve the best performance at a site. Each base station type or location provides unique propagation and transmission. Mechanical or electrical downtilting of an antenna can be predicted when certain characteristics are shown prior to actual operation, but terrain changes and physical anomalies may be encountered after installation.

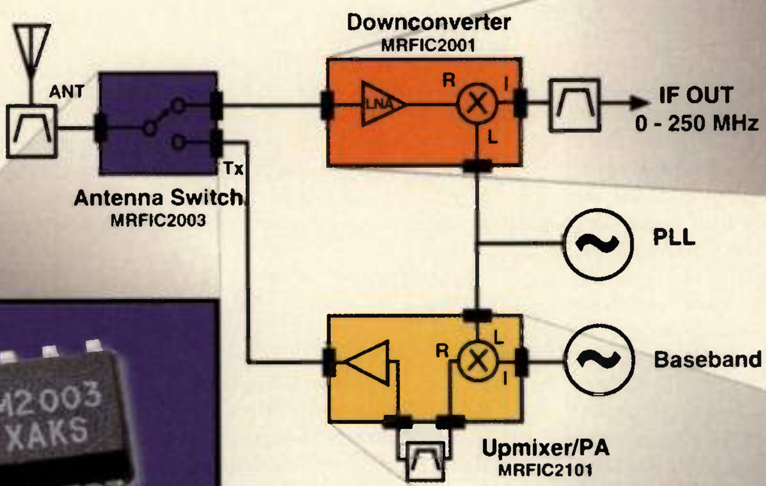
The fact remains that direct path, flat-terrain transmission rarely is realized in a wireless communications system. Downtilting of antennas mitigates reflections that can be caused by certain topographical and man-made structures when antennas are placed high above ground (around 350 feet) and when narrow beamwidths are required. PCS base station locations and antenna mounting heights generally will be low in comparison to cellular base station standards. This fact provides site planners with the task of designing directional-site antennas with narrow vertical beamwidths and small downtilt angles. Both real estate value and directional antenna performance in PCS base-station applications have one thing in common: location, location, location. Every site has unique operational requirements and must be designed individually. **RF**

About the author

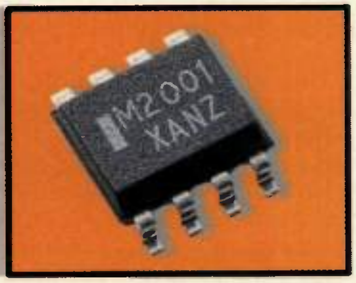
Charles M. DiFranzo is a regional sales engineer in the radio transmission products business group of Huber+Suhner. The planar patch technology featured in Figure 2 is a patented strip-slot-foam-inverted patch (SSFIP) that was designed by Huber+Suhner.

What Other Manufacturer or Distributor Has the RF Leadership of Penstock and Motorola?

In Stock for Immediate Delivery

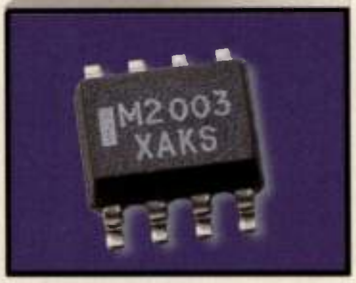


A Typical **900 MHz ISM** Block Diagram



MRFIC2001 Down Converter LNA/Mixer (SO-8)

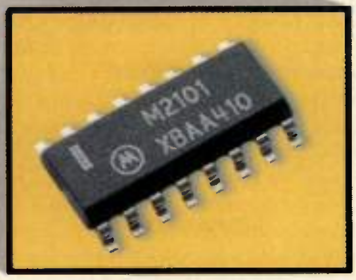
- Frequency 500 to 1000 MHz
- Supply Voltage 2.7 to 5.0 Vdc
- Supply Current (On Mode) 4.7 mA (typ)
- Conversion Gain 23 dB (typ)
- Single Sideband Noise Figure 5.5 dB (typ)
- P out; 1 dB Gain Compression -10 dBm (typ)



MRFIC2003 GaAs Antenna Switch (SO-8)

- Frequency 100 to 1000 MHz
- Supply Voltage 2.8 to 6.0 Vdc
- Supply Current <10 mA (typ)
- Recommended Input Power 17 dBm
- Insertion Loss (RF1 to RF2)/ (RF1 to RF3) 0.8/0.5 dB (typ)
- Isolation (RF1 to RF2)/(RF1 to RF3) 23/20 dB (typ)

Call 1-800 PENSTOCK for FREE SAMPLES



MRFIC2101 Tx-Mixer/Exciter (SO-16)

- Frequency 900 MHz
- Supply Voltage 5.0 Vdc
- High Linearity IP^3o = 23 dBm (typ)
- Low LO. Drive Required = -15 dBm (typ)
- Power Down Supply Current = 2.0 µA (typ)
- Externally Adjustable Exciter Bias Current

To receive your NEW RF Selector Guide, Fax to 602-966-6122

AME	TITLE
OMPANY	
HONE	FAX
DDRESS	
ITY, STATE, ZIP	
PPLICATION	EST. QUANTITY

Attach business card here

Visit Penstock's Website: WWW.PENSTOCK.AVNET.COM"

PENSTOCK®
RF/MICROWAVE DISTRIBUTION
AN AVNET COMPANY

1-800 PENSTOCK.

In Northern California Call 408-745-8100

In Canada call 613-592-6088 Today.

MOTOROLA
Semiconductor Products Sector

INFO/CARD 36

Log-periodic antenna as a standard gain antenna

By John R. Tighe and Sharon Bradley, Synthesizers Ltd. and Joe Granados, New Mexico State University

The classic problem confronting HF, VHF and UHF antenna designers is the need for a standard-gain antenna, particularly one with reasonable size and weight. Narrow horizontal and vertical beamwidths, as well as flat, broad bandwidths, are preferred characteristics on any antenna test range. The ability to calibrate the standard rapidly, easily and repeatedly on the range, at any frequency and with a high degree of certainty, are additional desirable characteristics. Dipoles and monopoles above a large ground plane often are used as the standards (i.e., references) in the HF, VHF and UHF bands [1], and the standard-gain horn may be used where real estate is plentiful. The dipole, however, is a reference only at its tuned frequency. It suffers from multipath errors [2] unless it is used in a true free-space environment—which is not the case for an outdoor range. The vertical monopole is a viable reference at a single frequency (unless it is tunable), and it is large (30 to 60 foot ground planes). Either antenna is calibrated under the assumption that it meets theoretical values. In either case, measuring the antenna under test (AUT) over a broad frequency range requires a multiplicity of standard-gain dipoles, monopoles, a collection of large horn antennas or a combination. The log-periodic antenna, although used as a source, normally is not used as a reference antenna (standard gain), partially because it is easily damaged (changed). Additionally, its gain is published as relative to a dipole or is based on scaling, and the gain generally is published only for a few frequencies. By using two or more identical log-periodic antennas and the classic Friis formula [3], one can establish a valid and repeatable reference antenna in the field without resorting to comparisons to dipoles, monopoles or horns. This performance can be achieved at a multiplicity of frequencies without demounting the reference antenna or the AUT.

The log-periodic antenna, although large, is smaller and weighs less than a horn antenna. It has an equivalent beamwidth, a broader bandwidth and a relatively flat gain-vs.-frequency response. Stainless-steel versions are repairable, and they maintain their dimensions as well as the standard-gain horn does. All of these attributes are advantages. What remains is to establish the gain (on the range) accurately and at all the frequencies of interest. For the standard-gain horn, the classic method of establishing the gain is to use the Friis formula and to apply it to two—and preferably three or more—identically-made horn antennas in a free-space environment (anechoic chamber). A standard-gain horn then is sent to the outdoor range for mounting adjacent to or facing toward the rear of the AUT. The AUT then is compared to these standards, which are periodically returned for calibration. Applying the same technique daily to log-periodic antennas on the range is equally applicable, and it can, with the aid of a computer for data acquisition, achieve highly repeatable results.

The use of the Friis formula for establishing an antenna's gain is well-documented. One of the best examples is cited in reference [3] and originally was described in reference [10]:

$$Ps(\max) = \frac{Ps(Gs)}{4\pi} \tag{1}$$

where:

Gs	= effective gain of the source antenna
Ps	= power delivered to the source antenna
π	= 3.1415
Ps(max)	= max power transmitted per unit solid angle

$$Pr = \frac{Ps(Gs)Ar}{4\pi R^2} \tag{2}$$

where:

Pr	= power delivered to the reference antenna
Ar	= area of the reference antenna = $(Gr \bullet \lambda^2)/4\pi$
R	= range length
Gr	= effective gain of the reference antenna
λ	= free space wavelength

Note that the antenna losses are combined in Gs and Gr, i.e., the effective gain is what is measured, not the directivity (lossless gain). Combining (1) and (2) gives:

$$Pr = \frac{Ps(Gs)Gr(\lambda^2)}{(4\pi R)^2} \tag{3}$$

$$Gs(Gr) = \left(\frac{Pr}{Ps}\right)\left(\frac{4\pi R}{\lambda}\right)^2 \tag{4}$$

The Friis formula assumes that Gs = Gr = G (i.e., the antennas are identical). Hence;

$$G = \left(\frac{4\pi R}{\lambda}\right)\sqrt{\left(\frac{Pr}{Ps}\right)} \tag{5}$$

$$G(dBs) = 10\log(g) = 10\log\left[\left(\frac{4\pi R}{\lambda}\right) + \frac{1}{2}10\log\left(\frac{Pr}{Ps}\right)\right] \tag{6}$$

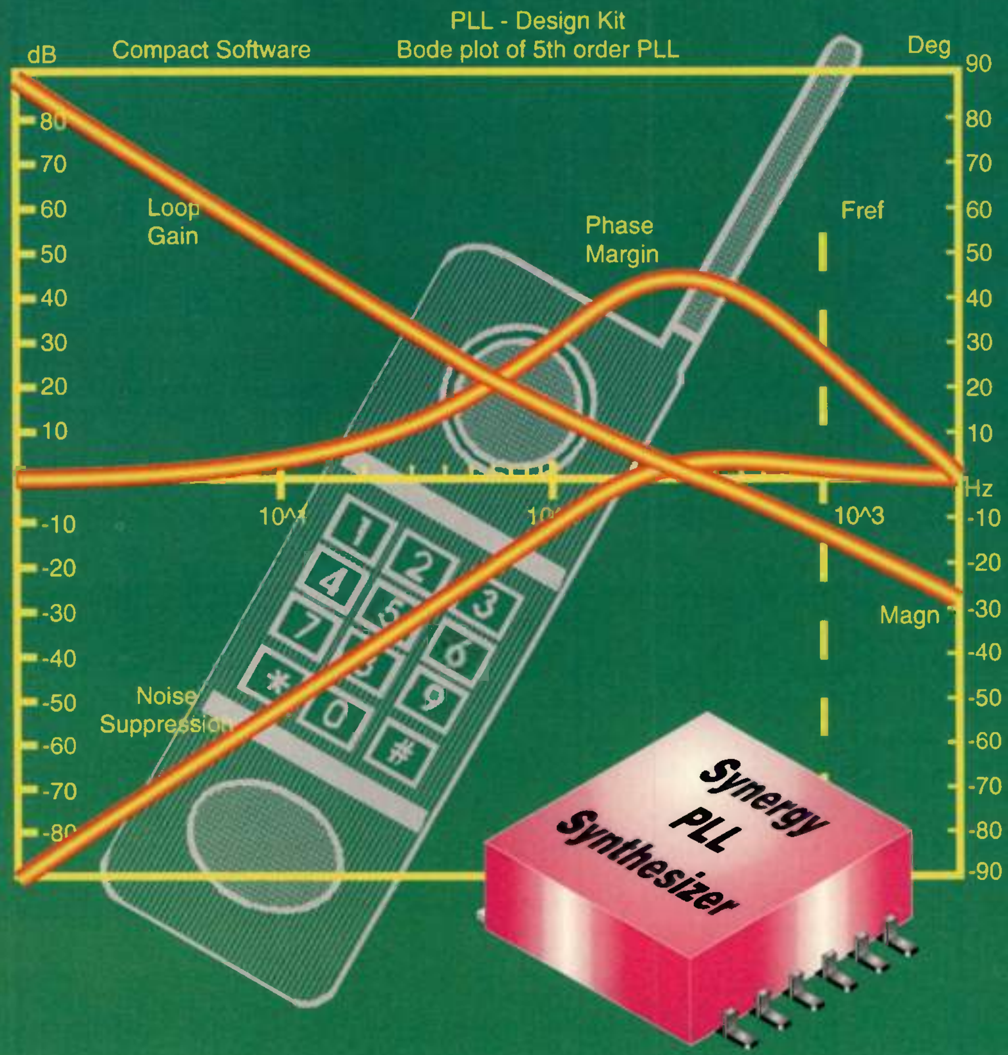
The second term contains S21 [S21 = 10 Log(Pr/Ps)], which is the familiar S-parameter for transmission loss. S21 is readily measured at these frequencies by vector network analyzers with suitable correction for the connecting cable losses. The space-loss term is computed for the measured range length, R.

The modern vector network analyzer step-sweeps the frequency band, which typically results in a large number of data points that are repeatable, because the frequency source is synthesized from a stable source [4]. The technique also lends itself to the time-domain method of reducing errors caused by multipathing [5].

The technique described here is not unique. It is applied routinely in antenna laboratories at microwave frequencies. With the aid of the modern network analyzer, the computer and statistical techniques, these laboratories measure small-aperture,

INTEGRATED PLL

SYNTHESIZERS



Synergy's new series of Integrated Frequency Synthesizers consists of our low noise miniature voltage controlled oscillator and an integrated circuit PLL device. Housed in an all ceramic, moisture-proof, 0.6" x 0.53" x 0.3", surface mount leaded package, these new low-cost synthesizers are most suitable for portable and base station applications in the UHF and Cellular bands. With only +5 volts bias, this device delivers an output power of 0 dBm and typical phase noise of -105 dBc/Hz @ 10kHz offset and 15 msec settling time with 30 kHz step size.

For further literature or for assistance with your specific synthesizer and other processing requirements, contact the Sales and Applications Engineers at Synergy.

SYNERGY®
MICROWAVE CORPORATION

201 McLean Boulevard, Paterson, NJ 07504

TEL: (201) 881-8800 • FAX: (201) 881-8361

INFO/CARD 47

standard-gain antennas. Outdoors, and in the HF, VHF and UHF ranges, the method presented here is the same. In both cases, suitable care must be exercised to ensure that the physical (multipath) environment is controlled or compensated for.

Technique

The first step in the technique is to use a vector network analyzer to characterize the cable losses vs. frequency from the analyzer to the source antenna input and the losses from the reference antenna's output back to the analyzer. Additionally, corrections can be made for the source and reference antenna losses caused by mismatch. As many as 12 terms of error correction can be applied, depending only on the analyzer used and the degree of error correction desired [6]. Because the antenna cable runs can be longer than 100 feet and because calibrating every day is not as feasible outdoors as it is in the lab, these results are stored on disk and checked periodically. Outdoors, depending on the weather, it may prove advisable to correct for temperature. Even mild climates have 30° day-to-day temperature differentials. Such differentials represent significant cable loss changes for long runs.

Next, the cables are reconnected to the antennas, and the antennas are aligned. The cable correction data is recalled from the disks and stored in the analyzer. Now the measured source antenna to reference antenna S21 is corrected by the analyzer for the cable losses, and the results are the transmission gain (including internal losses) of the antennas vs. frequency, i.e., S21 = 10Log(Pr/Ps) in (6).

Finally, the corrected S21 is extracted from the analyzer by the computer and inserted into equation (6) along with the range length R. The gain then is calculated as a function of frequency and can be plotted or tabulated as required. Additionally, the results can be retained (stored to disk) for statistical comparisons of the gains as a function of variety of characteristics, such as different but identically made antennas, time and weather, or for monitoring the repeatability of the range.

Modern network analyzers typically can provide as many as 1,601 frequency data points over the band of interest. By applying time-domain techniques, one also can correct for multipathing limited only by the antenna and cable systems dispersion, the range length and the multipath length [7]. Proper far-field separation and antenna heights above ground still are necessary [8]. The advantage in using this technique is that the effects of raising and lowering the antennas, or changing the separation (i.e., surveying the quiet zone), are observable in almost real time. Multipath, for example, is seen in the frequency domain as a periodic variation of the gain vs. frequency (ripple). If the environment is simple (uncluttered), as is usually the case for well-constructed elevated or ground-reflection ranges [9], then the period is singular and depends on the distance to the ground, and it can be accounted for or erased (time domain). Time-domain techniques are well-documented [5,7].

Results

Figure 1 is a plot of the results of a test using the Friis formula (5), performed on a pair of identical, vertically polarized, log-periodic antennas. Not shown but readily available are the tabulated results from the same computer-driven program that lists the computed space loss, the range and the computed gain. This range had a height of 40 feet but it was cluttered. The ground-path frequency difference is noted in Figure 1.

The frequency band shown in Figure 1 is from 50 to 550 MHz with 801 data points (frequency points) taken. Only 50 of those are shown (every 10 MHz), although all 801 are stored on disk for future use. For comparison, the manufacturer of these antennas could provide data only at three frequency points in the same band. The manufacturer's results for these antennas are shown in Figure 1. At each of these three frequencies, the manufacturer provided data based on two techniques, the *scaled to* and the *reference to a dipole* methods, which produced results that differ by as much as 2 dB.

The test methods for these techniques was not given. For the scaled-to method, the gain may possibly be determined by comparison of the scaled-to antenna (usually scaled to a higher-frequency equivalent design antenna) to another antenna, possibly a standard-gain horn. The manufacturer also did not specify the measurement environment (anechoic chamber, outdoor range or lab). As a consequence, the certainty of the data is not known. The manufacturer also provided results based upon referencing these antennas to dipoles. Those values also are noted in Figure 1. As previously pointed out, the usefulness of comparing antennas to dipoles at these frequencies in environments that cannot be made to behave like free space is extremely limited. A better method would have been to provide comparisons to monopoles above a large ground plane. But even that method has limitations [1] and certainly cannot be used for comparisons with horizontal polarizations.

Of the data shown, which is the real gain? The first questions that should be

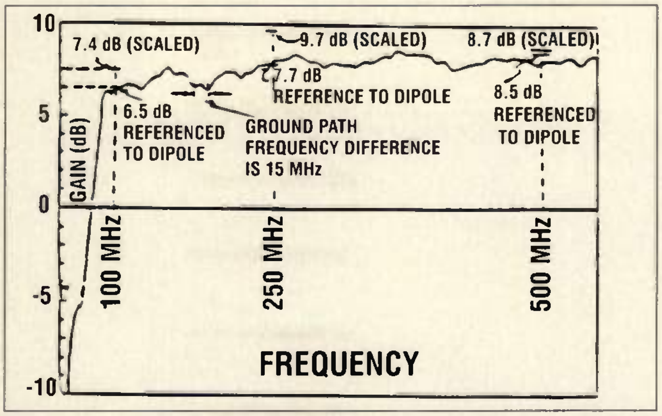


Figure 1. Log periodic antenna, gain vs. frequency, two identical antenna method, comparison to dipole and scaling.

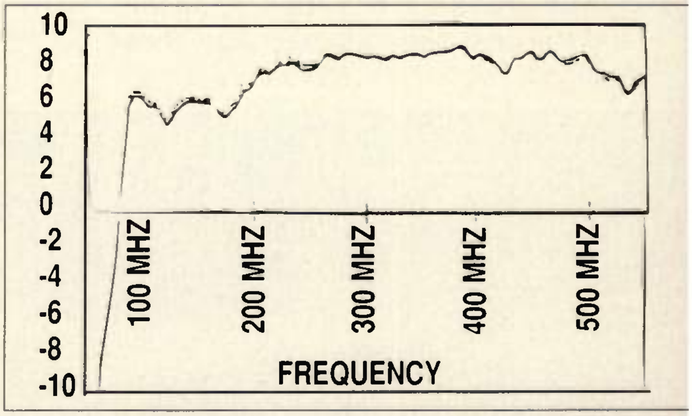


Figure 2. Log-periodic antenna, gain vs. frequency, two identical antenna method, same environment and same antenna pair.

SPANNING THE DECADES

HIGH POWER DIRECTIONAL COUPLERS

OUTSTANDING PERFORMANCE

100% HIGH POWER BURN-IN

HIGH AVERAGE POWER RATINGS

OVER 1500 MODELS AVAILABLE

FREQ. RANGE 0.01-2000 MHz

HIGH POWER COMPONENTS

SINCE 1965

PERFORMANCE SPECIFICATIONS

MODEL NO.	FREQUENCY MHz	COUPLING dB	DIRECTIVITY dB	POWER WATTS
C2630	0.01-1000	40	20	100
C1460	0.01-250	50	20	2Kw
C3271	80-1000	50	20	1.5Kw
C2717	1-30	70	35	100Kw
C2868	30-100	60	20	50Kw

WERLATONE BROADBAND DIRECTIONAL COUPLERS OFFER NO COMPROMISE

HIGH POWER MULTI-OCTAVE PERFORMANCE

Call us today for product information and your application needs.

WERLATONE
DECADES AHEAD

WERLATONE INC.
P.O. Box 47, Brewster, New York 10509
Telephone: (914) 279-6187
FAX: (914) 279-7404

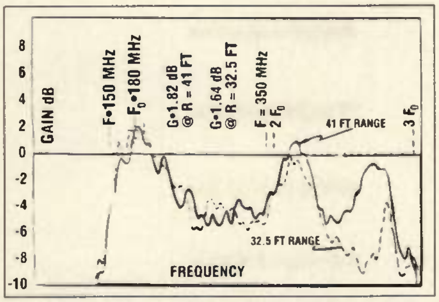


Figure 3. Standard dipole. Range = 32.5 and 41 ft.

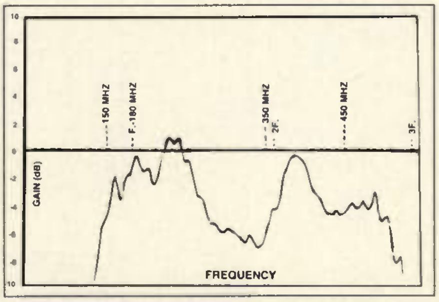


Figure 4. Dipole antenna. Elevation angle = 6°.

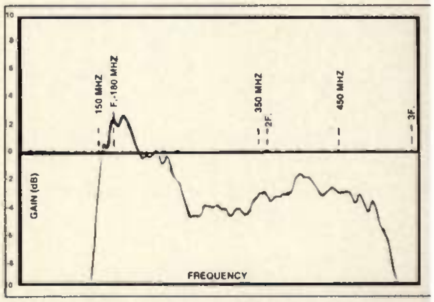


Figure 5. Dipole antenna. Elevation angle = 18°.

asked are: Can we make a series of identical antennas and get identical results? Can we get the same results in the same environment for the same antenna pair? Figure 2 answers the latter question. These data were acquired using the same techniques as described for Figure 1 and used a program that was expanded to include some statistical comparisons. Also, the measurements were made on a different range (height = 9 ft.). The solid line represents the data taken on the day denoted, whereas the dotted line represents the average gain for 24 measurements on 24 days and on the same range for each day in a 6-month period. Figure 1 represents the same antenna pair but with measurements made on a different range more than one year earlier.

Repeatability is excellent on the same range (Figure 2) but not on different ranges. (Compare Figure 1 with Figure 2.) The first range (Figure 1) was deeper (height = 40 ft.) and cleaner, and gave the smoothest results vs. frequency. As the data indicate, the second range (9 ft.) was more cluttered. Real estate limitations prohibited construction of a proper ground reflection range [9]. Nevertheless, this measurement technique was invaluable in the construction and the location of diffraction fences. These results suggest the answer to the question of being able to produce identical antennas. The manufacturer of the antennas should provide similarly swept gain data, at least at one aspect angle (0° azimuth and 0° elevation), along with the normal typical pattern data for all antennas delivered. The manufacturer also should supply a description of the test range and the methods used. Although this information may not completely answer the question concerning which is the *true gain*, it would answer the "identical antenna" question. If the manufacturer does not supply the necessary information, the user can achieve the certainty required by the methods proposed here. This technique for establishing a standard gain is easily applied in the HF, VHF and UHF bands using log-periodic antennas and can provide heretofore unavailable data.

The same basic technique is readily extended to an unknown antenna simply by connecting the reference antenna's cable to the unknown antenna and by using a similar computational technique. This is the comparison method [3,10]. From (4):

$$Gu = \left(\frac{1}{Gs}\right)\left(\frac{4\pi R}{\lambda}\right)^2 \frac{Pu}{Ps} \qquad (7)$$

$$Gu(dB) = 2\left(10\log\left(\frac{4\pi R}{\lambda}\right)\right) - 10\log(Gs) + 10\log\left(\frac{Pu}{Ps}\right) \qquad (8)$$

$$= 2(\text{space loss}) - \text{gain of the source} + S_{21}$$

where:

Gu = gain of the unknown antenna
Pu = power delivered to the unknown antenna

The only unknown in this measurement is the new S21. Everything else is known, including the range, which also is measurable. Corrections for losses caused by mismatch and other errors are not included in the comparison method, but are corrected for in the measurement of S21 and the previously measured source (or reference) antenna gain. It is not necessary to use the reference antenna's cable as noted above. A separate AUT cable can be calibrated and used.

Known antenna examples

If we use this technique to measure the gain of a dipole antenna on an outside range, will we measure the theoretical 2.2 dB—or even 2.0 dB, assuming some losses? Or, will we see the gain vary dramatically as a function of range position changes? The position sensitivity should be larger than it would be for a log-periodic antenna, because the dipole has a 180° beamwidth. The solid curve in Figure 3 is a measurement of a dipole mounted on a tripod in the same range position as the reference log-periodic antenna (40 feet above a clean ground and 10 feet above the edge of the test building). The dipole was set to frequency (170 MHz) and verified to be on frequency by measuring the return loss null. The solid curve and dotted curve differ in the length of the range only. The apparent peak is at 180 MHz (solid curve) and at 195 MHz (dotted curve) and the ripple in the dotted curve clearly indicates that multipathing apparently is affecting the results. The dipole was oriented in the horizontal plane for Figure 3, and because the earth is an excellent reflector for horizontal polarizations multipathing was the prime suspect. Rotating the dipoles to the vertical position (the dipoles' null pointed down) and sweeping the same frequency range (data not shown), in addition to changing height and range length, confirmed that the ripple was caused by multipath.

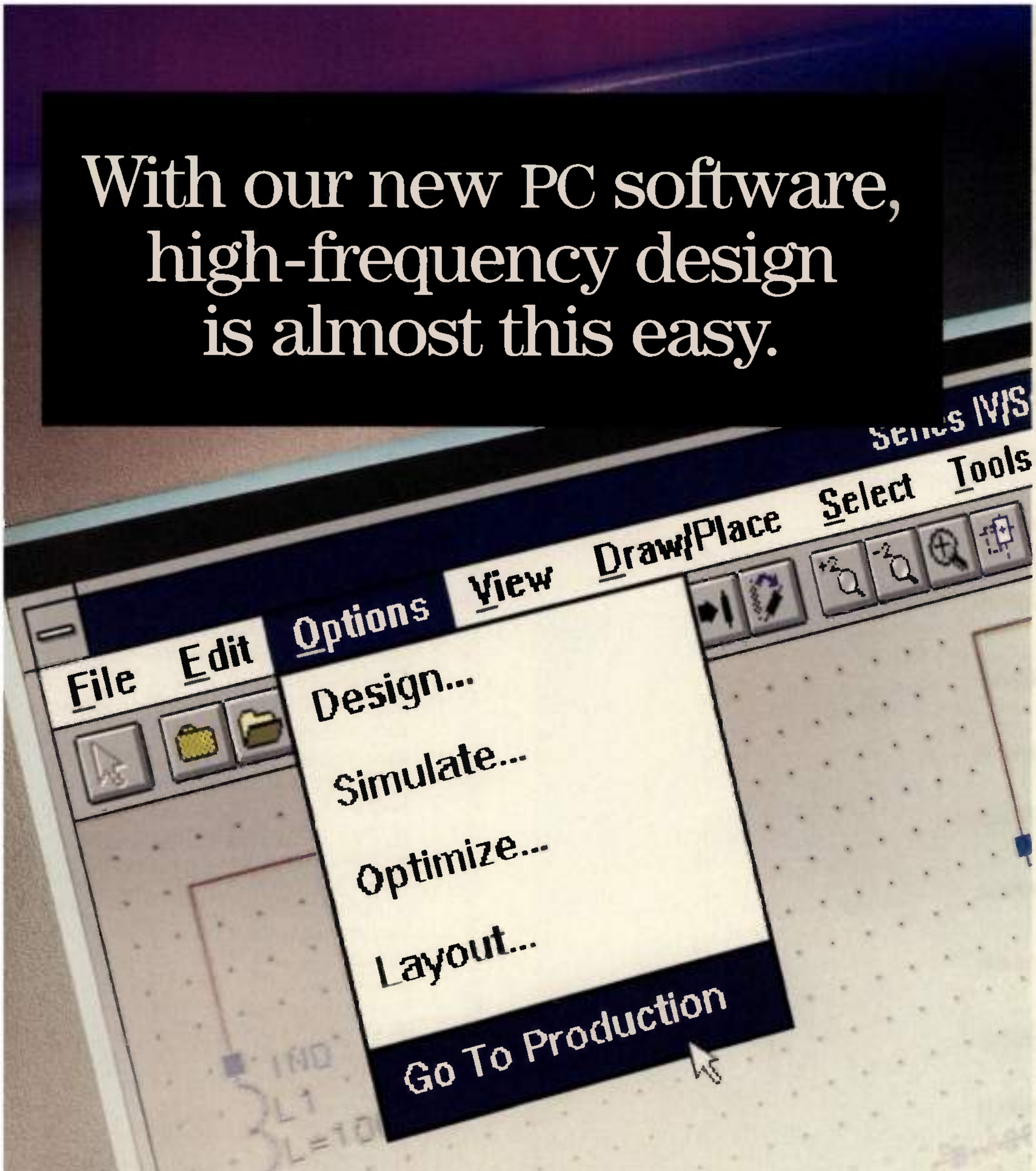
Let's assume that the manufacturer's data for the log-periodic antennas (see Figure 1), which was specified as based on comparison to a dipole, were acquired on a similar outdoor range. Then uncertainties in using the dipole as a gain standard are evident from the results shown in Figure 3.

Figures 4 and 5 are measurements on the same dipole antenna mounted 5 feet above a mockup, which was configured with dimensions that represent the belly of a military aircraft. Swept gain data are presented at two elevation angles, 6° and 18°. Certainly the data show that the dipole cannot be used as a standard gain in this environment by arbitrarily assuming its gain to be 2.2 dB. Clearly, a narrower beam antenna, such as the log-periodic, is required. It should be mounted such that the range-path environments are the same for the source-to-reference path and the source-to-AUT path.

Unknown antenna

The Friis formula and the techniques described here can be applied to any

With our new PC software, high-frequency design is almost this easy.



Introducing HP EEsof Series IV/PC: Total integration from a single software package.

Okay, so you can't get your high-frequency designs all the way to production just by pointing and clicking. But thanks to HP EEsof Series IV/PC, designing for manufacturability is almost that simple.

You see, HP EEsof Series IV/PC is a truly integrated high-frequency circuit design solution, bringing schematic capture, simulation, analysis and layout together in a single software package. That means you can now simulate and tune your designs directly from layout. And you only have to learn one tool.

HP EEsof also features the world's largest parts libraries — over 90,000 models in all. So you not only get the highest performance simulators money can buy, you get the accurate models you need.

In fact, the Discrete Value Optimizer lets you fully analyze your designs with actual, not theoretical, parts. Making product development time shorter than ever.

For more information on Series IV/PC, or the other innovative solutions HP EEsof is bringing to high-frequency design, call **1-800-452-4844, Ext. 1396*** or your local sales representative today for a free brochure.

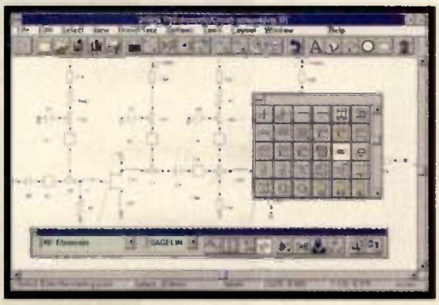
Taking your designs from concept to production has never been easier.

There is a better way.

*In Canada, call 1-800-276-8661, Dept. 255.

http://www.hp.com/go/info/sivpc

HP EEsof Series IV/PC lets you solve real world problems using real world parts.



INFO/CARD 52

two identical antennas including low-gain types, fixed probes, and cellular phone antennas. The most difficult aspect of measuring these antennas is to be able to make the measurement of Ps and Pr without the measuring equipment becoming part of the antennas environment. A more straightforward example will be given next.

Figure 6 is an example of using the identical log-periodic antennas as the standard gain and of measuring an unknown antenna on an equivalent range path. The source antenna and the reference antenna are identical. The first step is to point the source antenna at the reference antenna along the source-to-reference antenna path to establish gain. This gain datum is stored in a reference antenna file which usually includes the data for many calibration runs as well as the average gain. Figure 2 was a typical example. The source then is rotated to point at the AUT along an identical path. Corrections for cable losses and mismatch losses as previously discussed also are applied.

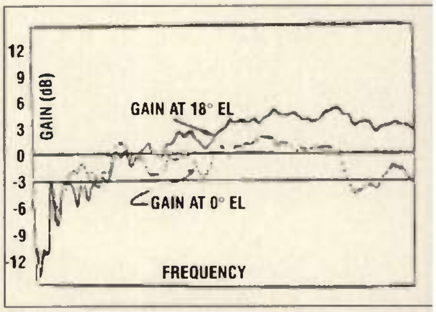


Figure 6. Gain vs. frequency for four closely-spaced, phase-arrayed, vertically polarized antennas. Elevation angle = 18°.

Figure 6 is a typical measurement of four closely spaced, phased-arrayed, vertical monopoles, which are designed to provide omnidirectional coverage in the horizontal plane. The dotted line curve in Figure 6 is the gain vs. frequency for this antenna (the antenna under test) at 0° azimuth and 0° elevation. Also in this figure, the solid line represents the data at 0° azimuth and 18° elevation.

A logical extension of this single aspect (0° elevation) measurement is to acquire data automatically at each of the desired angular positions over the net angular range using computer-driven antenna positioners. Plotting the patterns either in rectilinear or polar format is the next simple step. The older technique is to use a separate receiver to acquire the AUT's signal and to plot the pattern results continuously over the angular range required. Switching to another receiver leads to additional errors caused by nonlinearities in the new receiver.

The technique used here was to use the same vector network analyzer to acquire the pattern data as that which was used to acquire the gain-vs.-frequency data. Pattern results are not the important subject of this methodology, but stability and repeatability of the results are. Figure 1 and 2 illustrate the excellent stability and repeatability achievable using these techniques.

Conclusion

Applying the Friis formula is quite often overlooked as the method of choice

Pre-Registration Deadline: OCTOBER 14

RF design

SEMINAR SERIES

Catch The New Wave of RF

October 21-23, 1996

Colonial Hilton & Resort

Wakefield, Massachusetts

Sponsored by:

RF design

Track One: Engineering Fundamentals (Instructional Level: Introductory)

T1-1

RF and Wireless Engineering Part I: Fundamental Concepts
Monday, October 21, 1996 — 8:00 a.m. - 5:00 p.m.

The first day reviews fundamental ideas and terms that are important in all RF and wireless systems. Concepts such as gain, bandwidth, noise figure, dynamic range, resonance and Q are presented. Practical components are discussed and models for them are developed. Fundamentals of electromagnetic theory are reviewed, transmission lines are discussed. The Smith chart is developed from transmission line theory and its use in RF design is introduced.

T1-2

RF and Wireless Engineering Part II: Fundamentals of Amplifier Design
Tuesday, October 22, 1996 — 8:00 a.m. - 5:00 p.m.

The second day begins by designing lumped element and distribution impedance transformation networks using the Smith chart. Next, the course presents a unique approach to impedance matching network design that facilitates the design of T-, PI- and L-networks for specified phase shift or Q. The same procedure is extended to design resistive attenuators and balanced networks. Active device models are then introduced and important concepts such as power gain, noise figure and stability are reviewed. The theory, physical meaning and measurement of S-parameters are presented, then graphical and analytical techniques for amplifier design using S-parameters are developed. The fundamentals of computer-aided analysis and optimization are then summarized.

T1-3

RF and Wireless Engineering Part III: Amplifier Design
Wednesday, October 23, 1996 — 8:00 a.m. - 5:00 p.m.

The third day uses all the theory and techniques developed during the first two days to design several representative RF amplifiers. In addition to the basic RF design, practical topics such as bias network design, out-of-band stability, decoupling network design, the effect of microstrip discontinuities and the use of RF design software are presented.

Instructors: Dr. Robert Feeney and Dr. David Hertling, Georgia Institute of Technology

These professors bring both academic substance and practical design experience to the classroom. CEUs are available from the Continuing Education department at Georgia Tech.

Track Two: Engineering Applications (Instructional Level: Intermediate)

T2-1

Practical High-Frequency Filter Design
Monday, October 21, 1996 — 8:00 a.m. - 5:00 p.m.

HF Filter Design is a detailed review of L-C, printed and machined filter design and specification. Basic terminology and principles are discussed, followed by design procedures. Element models and unloaded Q are studied. These concepts are then applied to case studies which match various filter types to real-world applications.

Some of the topics considered are elliptic filters, determining the required order, component realizability, insertion loss, coupled resonator bandpass, ceramic resonators, filter match, controlled phase filters, group-delay equalization, bandpass symmetry, the zigzag bandpass, printed filters and required tolerances. Nearly all important transfer approximations and filter topologies are reviewed.

T2-2

Oscillator Design Principles
Tuesday, October 22, 1996 — 8:00 a.m. - 5:00 p.m.

A unified approach to oscillator design is presented which describes how to create high-performance oscillators using any type of resonator and any type of active device. Oscillators are demystified and fully understood so that design is no longer based on copying or modifying existing units. A complete understanding provides for known oscillation margins and design optimization for state-of-the-art performance. Both negative-resistance and open-loop Bode response design techniques are described. Gain margin, matching, starting, limiting, output level and harmonics are discussed. The theory is then applied to several practical oscillator circuits using L-C, SAW, transmission line and quartz crystal resonators with bipolar, FET and MMIC devices. Broadband tuning VCOs, general purpose and low-noise, high-stability oscillators are covered.

Instructor: Randy Rhea, Eagleware

Randy Rhea is the Founder and President of Eagleware Corporation. His design experience includes filters, oscillators, synthesizers, transmitters, receivers, antennas, satellites and data and video systems, cable television and wireless security systems. He has held engineering positions at Boeing, Goodyear Aerospace and Scientific Atlanta and has given tutorials at RF Expo since 1987. Mr. Rhea is the author of numerous technical papers and two books; Oscillator Design and Computer Simulation and HF Filter Design and Computer Simulation.

Track Three: Advanced Applications (Instructional Level: Intermediate to Advanced)

T3-1

Digital Modulation and Spread Spectrum for Wireless Communications
Monday, October 21, 1996 — 8:00 a.m. - 5:00 p.m.

This advanced class covers the essential topic of digital communications for wireless applications. The course begins with principles and system architectures for complex I-Q, QPSK, PI/4 DQPSK, FQPSK and other modulation schemes. Standards for specific cellular and PCS systems are introduced. A theoretical analysis of spectral and power efficiency follows, including adjacent channel interference, linear/nonlinear amplification and BER performance. Advanced modulation techniques such as 16-QAM, trellis coding and multi-level FM are presented. A section on spread spectrum covers pseudo-noise sequences, correlation, direct-sequence, CDMA and slow frequency-hopping (TDMA) principles. The near-far problem and operation in mobile environments are discussed. The course assumes substantial experience in RF design.

Instructor: Dr. Kamilo Feher, UC Davis, DIGCOM, INC.

Dr. Kamilo Feher is a professor at the University of California, Davis, and Director of DIGCOM, INC. consulting group. He has authored five books on digital communications.

T3-2

RF Power Transistors and Amplifiers: Principles and Practical Applications
Tuesday, October 22, 1996 — 8:00 a.m. - 5:00 p.m.

RF power amplifier design is rarely taught in the depth provided by this course. Topics include the unique characteristics of RF power transistors compared to small-signal transistors, performance characteristics of bipolar and field-effect transistors (FETs), and the choice of devices and amplifier configurations. The principle and techniques of practical amplifier design include wideband impedance matching, frequency compensation, negative feedback and guidelines for amplifier construction. The course assumes substantial RF design experience, and knowledge of small-signal amplifier design.

Instructor: Norman Dye, Motorola

The instructor for this course is Norman Dye, engineering consultant with extensive experience in Motorola's power transistor division. Along with Heige Granberg, he recently authored the book, Radio Frequency Transistors.

Management Track (Instructional Level: Non-Technical)

SPECIAL COURSE FOR MANAGEMENT, MARKETING AND PURCHASING PERSONNEL

MT-1

Wireless Communications For Non-Engineers
Wednesday, October 23, 1996 — 8:00 a.m. - 4:00 p.m.

The morning session of this course introduces the key concepts of signals, circuits, systems and the radio spectrum. These technical concepts are presented in an intuitive, visual manner, relating them whenever possible to familiar activities of everyday life. Demonstrations and class participation will help non-technical personnel grasp these concepts, which are essential for "speaking the language" of wireless communications. The session continues with descriptions of common communications systems: AM and FM radio broadcasting, television broadcasting, cable TV and traditional two-way radio.

The afternoon session begins with a quick review of the principles covered previously, with additional notes on how radio waves travel from one point to another. Then, modern wireless communications systems are described, including remote control systems, cordless telephones, the cellular phone system and satellite systems. Finally, the newest areas of communications: Personal Communications Services (PCS), wireless local-area networks (WLAN), automatic toll collection and RF identification (RFID) tags are described.

Instructor: Gary Breed, President Noble Publishing
Former Editor of *RF Design* magazine

Gary Breed is the former Editor of *RF Design* magazine. Mr. Breed has been a tinkerer and hobbyist since the age of 9, and an enthusiastic supporter of radio communications of all kinds.

M/A-COM an AMP company

Design Seminars

Time to market. Time to volume. Shorter design cycles. Tighter performance specs. Less board space. These are the issues you wrestle with day in and day out. The M/A-COM Design Seminar Series was developed to help you get the information you need to make intelligent design decisions and informed product selection. No sales pitches, just the straight scoop on new technologies and new products. We simply bring you the experts and let them talk. Won't you join us? It's easy to register. For additional information, pick up the phone and call our registration department at 800-746-6620 or fax us a note at 617-821-9198. Wednesday, October 23, 1996, 9:00am - 1:30pm.

Complete one form per person. If more are needed, please copy. Incomplete forms cannot be processed. Must be 18 years of age for admittance. If planning to mail form, please copy and complete in order to retain details on opposite side.

RF design seminar series

1996 Registration Form

Class size is limited; register before October 14, 1996!

General Information

Please print. All sections must be completed to be processed.

Name ____________________

Title ____________________

Company ____________________

Address ____________________

City ____________________ State ______

Country ____________________ Zip ____________

Phone ____________________
(please include country/city codes)

Fax Number ____________________

Registration Selection

Register for individual sessions, or save BIG when you register for an entire seminar track. All registrants include course materials and all scheduled breaks and luncheons.

To make your selections, cross-reference the codes below with the course descriptions found on the previous page.

Monday, October 21, 1996 (Check One)
☐ **T1-1*** ☐ **T2-1*** ☐ **T3-1**

Tuesday, October 22, 1996 (Check One)
☐ **T1-2*** ☐ **T2-2*** ☐ **T3-2**

Wednesday, October 23, 1996 (Check One)
☐ **T1-3*** ☐ **MT-1**

*CEUs are available through the Georgia Institute of Technology School of Electrical Engineering for those attendees registering PRIOR to 10/14/96 ONLY. Certificates of attendance will be granted. If you will be applying for CEUs, please enter your Social Security Number here: SS# ___ ___ ___ - ___ ___ - ___ ___ ___ ___

Registration Course Fees
Registration Deadline October 14!

☐ One course/one day (as checked above)	$295
☐ Two courses/two days (as checked above)	$525
☐ Three courses/three days (as checked above)	$775

*Not all courses will be available after 10/14; call to check availability.

Method of Payment

Checks or Credit Card Payment Only (no invoices issued and no P.O.s accepted)

☐ Enclosed check for US $__________ Check #__________

☐ Am Ex ☐ Visa ☐ MC ☐ Disc. Exp. Date ___/___

Card # ____________________

Name of Card Holder ____________________

Authorized Signature ____________________

Please contact me about special barrier-free accommodations. ☐

Mail or fax completed form with payment to:
Intertec Presentations
6300 S. Syracuse Way, Suite 650 • Englewood, CO 80111
303-220-0600 or 800-288-8606 • FAX 303-773-9166

Attendee Profile

*Please circle **ONE** selection per category

PRIMARY END PRODUCT

A. Radar Systems
B. Weapons
C. Ground Support Equipment, Aircraft/Missile
D. Navigation Telemetry Systems
E. Global Positioning Systems
F. Electronic Warfare Systems
G. Communications Systems, Equipment
H. Cellular Systems Equipment
I. Consumer Electronics
J. CATV Broadcast Systems
K. Data Transmission, Computer Systems
L. Laser/Electro-Optical Systems Equipment
M. Security/Identification
N. Test and Measurement Equipment
O. Active Components (including Antennas), Devices, Subsystems
P. Passive Components
Q. Materials, Hardware
R. Industrial/Academic Laboratories, Consultants
S. Government/Military: Research, Design, Engineering & Test
T. Medical Equipment
U. Automotive/Transportation
V. Education
W. Other (please specify) ____________

PRIMARY JOB FUNCTION

A. Design and Development Engineering
B. Design and Development Engineering Management
C. Engineering Services (Evaluation, QC, Reliability, Standards, Test)
D. Engineering Services Management (Evaluation, QC, Reliability, Standards, Test)
E. General and/or Corporate Management
F. Basic Research Management
G. Basic Research Engineering
H. Manufacturing and Production Management/Supervision
I. Manufacturing and Production Engineering
J. Purchasing and Procurement
K. College/University Faculty
L. Other (please specify) ____________

MAIN AREA OF INTEREST

A. DC-200 MHz
B. 200 MHz - 500 MHz
C. 500 MHz - 1 GHz
D. 1GHz 8 GHz
E. 8 GHz - 18 GHz
F. 18 GHz - 26.5 GHz
G. 26.5 GHz - 40 GHz
H. 40 GHz+

ANNUAL VALUE OF PURCHASE YOU INFLUENCE

A. Less than $10,000
B. $10,000 to $49,999
C. $50,000 to $99,999
D. $100,000 to $299,999
E. $300,000 to $499,999
F. $500,000 or more

Cancellation Policy: Full refunds, less a 25% administrative fee, will be given if request is received in writing on or before October 14, 1996. No refunds after October 14, 1996. No refunds or credits will be issued to no-show registrants. Substitutions are welcome in lieu of cancellation.

for establishing the gain of the reference antenna on a low-frequency (HF, VHF and UHF), outdoor antenna test range. At low frequencies where horn-type standard-gain antennas are expensive, large, unwieldy and band-limited, the log-periodic can be used with excellent results. Because co-location of the reference antenna and the AUT generally is not feasible, equality of the environment for the two paths is a prime requirement. Characterization of the two paths is feasible if sufficient data can be acquired, stored and checked for repeatability. Using the Friis formula, the computer and statistical comparison of the data sets provides the tester with the tools necessary to ascertain the requisite measurement repeatability. *RF*

References

1. R.G. Fitzgerald, "Limitations on Vertically Polarized Ground Based Antennas as Gain Standards," *IEEE Trans. on Antennas and Propagation*, March 1976, pp. 284–286.
2. J.W. Boyles, "Measuring a Dipole Antenna Radiation Pattern Using Time Domain and Gating," *RF Design*, September 1985.
3. H. Krutter and S. Silver, "Microwave Antenna Theory and Design," Radiation Laboratory Series, Massachusetts Institute of Technology, Vol. 12, Chapter 15.19, p. 583, Boston Technical Publishers, 1964.
4. R.G. Fitzgerald, "Swept Frequency Antenna Gain Measurements," *IEEE trans. on Antenna Propagation*, Vol. AP-14, No 2, March 1966, pp. 284–286.
5. G.A. Burrell and A.R. Jamieson, "Antenna Radiation Pattern Measurement Using Time to Frequency Transformation Techniques," *IEEE Trans. on AP*, September 1973, pp. 702–704.
6. J. Williams, "Accuracy Enhancement Fundamentals for Vector Network Analyzers," *Microwave Journal*, March 1989.
7. R. Balaberda and S.R. Mishra, "On the Use of the HP-8510 Network Analyzer for Antenna Pattern Measurements."
8. J.M. Ralston, "RCS Measurements at VHF/UHF Frequencies."
9. L.H. Hemming, "An Elevated Ground Reflection Antenna Range," Antenna Measurement Techniques Association, Vol. 11, pp. 7-9 to 7-15.
10. H.T. Friis, "A Note on a Simple Transmission Formula," *Proc. IRE*, Vol. 34, May 1946, pp. 254–256.

About the authors

John R. Tighe received a B.A. in physics in 1959 from the University of California, Riverside. He is a consulting engineer and he owns Synthesizers Ltd. Tel. 805-524-6970.

Sharon Bradley received a B.S.E.E.T. in 1979 from Cal Poly Pomona. Tel. 909-737-7299.

Joe Granados received a B.S.E.E. in 1979 from New Mexico State University and an M.S.E.E. in 1987 from San Diego State University. He is a manager at the physical science laboratory at New Mexico State University. Tel. 505-522-9309.

A circuit simulator for microwave and wireless applications

By Ulrich L. Rohde
Compact Software

In past years, high-performance linear and non-linear circuit simulators have been offered on either big computers or high-performance work stations. Their cousins, simulators for use on personal computers (PCs), typically were a subset of the more sophisticated simulator. The PC versions were limited by the DOS operating system and its memory management. Since the introduction of Windows 95 and NT, the difference between high-performance work stations and high-performance PCs, such as Pentium-Pro-based machines, have diminished. By taking advantage of the higher performance of the new PCs and by incorporating a vast number of technologies — such as those developed from small business innovative research (SBIR) projects, developments from the microwave and millimeter wave monolithic integrated circuit (MIMIC) program and current work on the microwave and analog front end technology (MAFET) program — a simulator has been given some extraordinary capabilities.

The linear part of the simulator has lumped and distributed elements. The calculations of the distributed elements are based not on curve fits or look-up tables, but on electromagnetic principles. The big advantage is that the validity of the models goes far beyond the boundaries of look-up tables and curve fits, with only a small loss in speed. If new materials are developed with an ε that ranges from 2 to more than 200, and if the impedance range drops as low as 10 Ω, then previously published model equations would not cover this operating range. For more complicated structures, items such as microstrip transformers are offered.

For modeling active devices, not only are the conventional diodes, bipolar and various GaAs models incorporated, but also physics-based models that are direct derivatives of some SBIR projects.

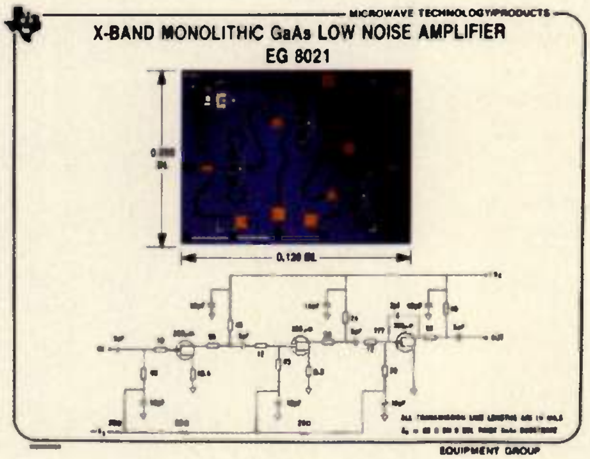


Figure 1. The x-band monolithic GaAs low noise amplifier, model EG 8021, courtesy of Tony Pavio of Texas Instruments, see [1]. This low-noise circuit was used to validate the simulator's unique modeling capability. The numbers close to the boxes refer to the electrical length and degrees of the transmission lines relative to the cut-off frequency.

The requirements of designing high-performance receiver front ends for wireless applications are not that different fromdesigning such circuits in microwave and millimeter-wave ranges. Some high-performance circuits only work well at frequencies from a few hundred megahertz to a few gigahertz. Oscillators with a low phase noise are a goodexample.

Low-noise preamplifiers are critical stages that require a simultaneous match of input and output impedances at the operating point for a low noise figure. They also require good intermodulation distortion (IMD) performance. To complicate matters even more for the users, device manufacturers frequently provide incomplete noise data.

In designing preamplifiers, even at lower frequencies, the trend is moving from bipolar transistors toward gallium-arsenide (GaAs) field-effect transistor (FETs), in part because one can fully integrate all the pieces together on one integrated circuit. The "work-around" approach to use when measured noise data are unavailable is to calculate the data from the intrinsic voltages and currents as shown in [1]. This method (with the equivalent also developed for bipolar transistors) is validated to an upper-frequency limit at which measured and predicted S-parameters still exhibit a good match. This validation does not include flicker noise contributions. The modes, however, has a provision to enter measured values for the flicker noise behavior so it can be incorporated for the simulator. This type of noise analysis, which covers frequencies from a few hundred megahertz to the millimeter range, sometimes is the only method available to conduct a feasibility study using new transistors that are not yet fully characterized. Figure 1 shows the schematic and the layout of a low-noise, GaAs FET-based, 10 GHz amplifier. Its noise and gain performance is shown in Figure 2. Specifically, this analysis capability has been necessary for the low-noise application. The intrinsic noise modes takes into

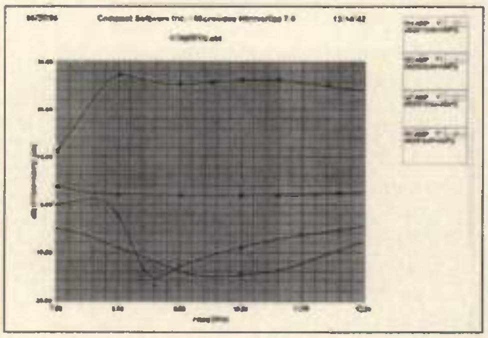


Figure 2. Measured and predicted gain of matching and noise figure of the EG 8021 low-noise amplifier shown in Figure 1.

WHEN IT COMES TO MICROMINIATURE CONNECTORS, WE STAND PRETTY TALL.

OSMT™ Interconnect System Surface Mount Coaxial Connectors

Utilized in wireless applications including cellular, PCN, GPS and personal data communications, DC-6 GHz.

Straight SMT PCB Mount Plug Receptacles

Part Number	Quantity Pricing 10 Pcs. Each
2367-5006-54	$2.50

SMA to OSMT Between Series Adapters

Part Number	Quantity Pricing 10 Pcs. Each
2381-2241-00	$55.44 Plug/Plug
2382-2241-00	$57.75 Plug/Jack

AUTHORIZED M/A-COM DISTRIBUTOR

Right Angle Jack to Jack Cable Assembly

Part Number	Cable Length[1] mm/inches	Quantity Pricing 10 Pcs. Each
PVC Flexible Cable (105°C)		
9950-1100-23	100/4	$7.00
9950-1200-23	200/8	$7.00
9950-1305-23	305/12	$7.00

[1] Consult Penstock for non-standard cable lengths. Cable length tolerance: 50-2000mm ±(2mm + 1% of cable length)

Right Angle Jack Cable Pigtail

Part Number	Cable Length[1] mm/inches	Quantity Pricing 10 Pcs. Each
PVC Flexible Cable (105°C)		
9950-2100-23	100/4	$3.50
9950-2200-23	200/8	$3.50
9950-2305-23	305/12	$3.50

[1] Consult Penstock for non-standard cable lengths. Cable length tolerance: 50-2000mm ± (2mm + 1% of cable length)

OSMT is a trademark of M/A-COM, Inc.

OSX Microminiature Snap-On Connector Series

For wireless applications including GPS, cellular, PCN, test and measurement and data communications, DC-6 GHz.

Crimp Attachment Straight Cable Plug
Non-Captured Center Contact

Part Number	Cable	Quantity Pricing 10 Pcs. Each
5831-5003-10	RG-174/U, 179/U, 187/U, 188/U, 316/U	$3.45
Crimp Attachment Right Angle Cable Plug		
5837-5003-10	RG-188/U, 316/U, RG-174/U, RG-179/U, RG-187/U	$2.35
Crimp Attachment Bulkhead Cable Jack		
5834-7388-10	RG-174/U, RG-179/U, RG-187/U, RG-188/U, RG-316/U	$5.00

Surface Mount Straight Jack Receptacle[1]

Part Number	Quantity Pricing 10 Pcs. Each	
5862-5007-13	$2.00	[1] Available in tape and reel format.
Surface Mount Rt. Angle Jack Receptacle[1]		
5864-5008-13	$7.25	[1] Available in tape and reel format.
Bulkhead Feedthrough Jack Receptacle		
5858-0000-10	$3.00	
Printed Circuit Board Straight End Launch		
5862-5018-13	$6.50	

Printed Circuit Board Straight Jack Receptacle

Part Number	Quantity Pricing 10 Pcs. Each
5862-5003-10	$1.50
Printed Circuit Board Right Angle Jack Receptacle	
5864-5001-10	$5.90

Between Series Adapters

Part Number	Description	Quantity Pricing 10 Pcs. Each
5881-2241-00	OSX Plug to SMA Plug	$52.80
5882-2241-00	OSX Jack to SMA Plug	$44.00

THESE M/A-COM PRODUCTS AND 10,000 OTHERS IN STOCK AND READY FOR IMMEDIATE DELIVERY.

PENSTOCK
Penstock is an Avnet Company

CALL 1-800-PENSTOCK
(1-800-736-7862)
In northern California, contact us at 1-408-745-8100.
And in Canada, call 1-613-592-6088.

"Visit Penstock's Website: WWW.PENSTOCK.AVNET.COM"

INFO/CARD 50

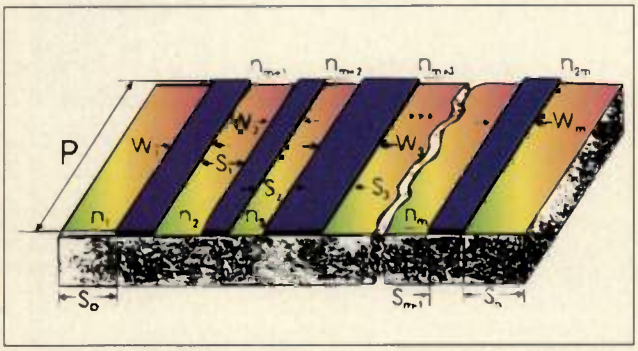


Figure 3. Multiple coupled transmission lines used for modeling coupling effects.

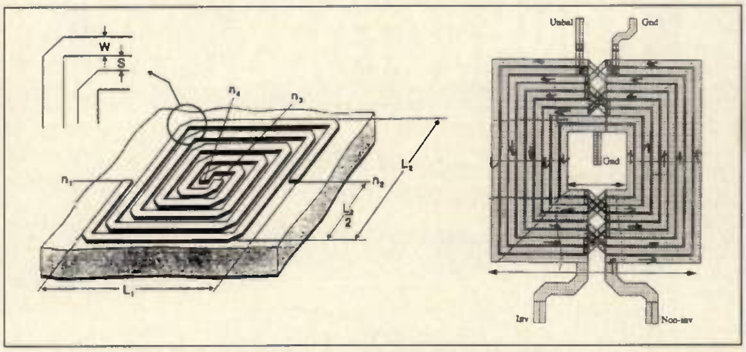


Figure 4. A 1:1 and a 4:1 microstrip-based transformer with center tap. Its calculations are done based on electromagnetic principles.

consideration the noise correlation. This feature is more accurate than other empirical and analytical models. This noise model also is applicable for bipolar transistors and is based on an enhanced model [2]. Its details are published in [3].

Because MMICs typically have high-density packaging problems, one has to look at the effect of coupling. For this purpose, a multiple coupled line element has been developed as shown in Figure 3, which can handle as many as 10 lines of arbitrary line spacing and arbitrary line widths. This model uses a proprietary, full-wave, spectral domain-based algorithm. It also can be used to design filters with many elements. An interesting spin-off is a printed transformer based on microstrip technology. It can be used for feedback amplifiers and other applications. An extension of this transformer would be a 3-port transformer such as a 4-to-1 transformer with a center tap. The simulation program uses similar electromagnetic (EM)-type models that have been extensively tested in critical frequency ranges from a few hundred megahertz to 96 GHz. Figure 4 shows both transformers.

With respect to filters, a dielectric resonator with microstrip coupling has been developed. It can be implemented as both a bandpass structure and as a bandstop structure, as seen in Figures 5 and 6. These useful structures can form the basis of a dielectric resonator oscil-

Now to 3.2 GHz clean, fast switching.

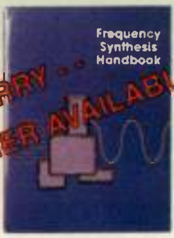
Split Personality

The Standard for Performance

For over fifteen years engineers and OEMs alike have relied on PTS frequency synthesizers for unmatched stability, speed and spectral purity. These direct analog and direct digital synthesizers meet the most challenging systems development requirements... ATE systems, satcom, wireless, medical imaging, secure communications, and more. You'll also find them in production environments, where they play a key role in quality assurance.

Our synthesizer models cover the 100 KHz to 1 GHz band with 0.1 Hz resolution. They are available with switching times from 1μsec, spurious outputs as low as -75 dBc and outstanding phase noise characteristics (SSB phase noise at 1GHz, 1 KHz offset, -110 dBc/Hz).

Free offer while supplies last



SORRY -- NO LONGER AVAILABLE

The Standard for Reliability

PTS synthesizers were designed from the outset to deliver the best reliability in the business. We adhere to conservative derating practices, keep power consumption and internal heat buildup to an absolute minimum and subject finished systems to rigorous temperature cycling and electrical testing. The result: a field-proven 25,000 hr MTBF. Since 1985 we've offered a full 2 year warranty and a flat-rate repair fee of just $350 for years 3 through 10.

It's time you had the best of both worlds. The best performance-price and the best reliability. Call today for more information and we'll also send you a free copy of the RF Design Frequency Synthesis Handbook.

Features and Options

- BCD or GPIB remote control
- DDS with phase-continuous switching
- OCXO, TCXO or external frequency standard
- Resolution to 0.1 Hz
- Digital phase rotation
- Output power to +13dBm
- Proven 25,000 hr MTBF
- 2 yr warranty
- $350 repair fee, yrs 3 - 10 ($500, Model PTS 1000)

PTS

PROGRAMMED TEST SOURCES, INC.
9 Beaver Brook Road, Littleton, MA 01460
Tel: 508 486-3008 Fax: 508 486-4495

INFO/CARD 46

lator. A typical listing of such a circuit in linear operation is shown in Table 1 (located on page 85).

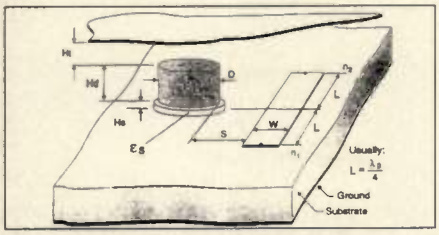


Figure 5. Dielectric resonator and microstrips coupling bandpass and bandstop structure. One transmission line.

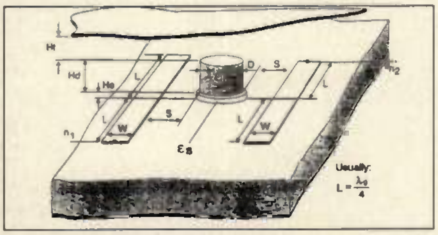


Figure 6. Dielectric resonator and microstrips coupling bandstop structure. Two transmission lines.

In moving toward non-linear operation, the balance calculation capabilities of this simulator offer an advantage. Non-linear calculation has been implemented in SPICE in the past, but this harmonic balance simulator with a dynamic range as large as 180 dB offers superior performance both in dynamic range and computation speed.

Non-linear analysis

The key prerequisite in obtaining good results of non-linear calculations is the availability of good device parameter information for non-linear models where quality counts — rather than quantity. To fully characterize a bipolar transistor or FET, it takes as long as two days to model a transistor over its validity range to cover DC to microwave, and modeling does not stop just at RF. There are several applications for the use of non-linear simulation in amplifiers. Figures of merits such as 1 dB compression point, intermodulation distortion and power-added efficiency are important. A similar topic is the non-linear calculation of mixers, and last, but not least, phase noise and output power of oscillators.

As far as non-linear models are concerned, the following are implemented.

BIP – Gummel-poon bipolar transistor model

BIP – Hetero-junction bipolar transistor (R. Anholt) model

DIOD – Non-linear diode models
- Microwave diode models
- PIN diode model
- Enhanced SPICE diode model
- Diode noise modeling

FET – GaAs MESFET and HEMT models
- Chalmers (Angelov) intrinsic model
- Curtice-ettenberg cubic intrinsic model
- Curtice quadratic intrinsic model
- IAF (Berroth) intrinsic model
- Materka-kacprzak intrinsic model

To test advanced components, you need a high quality LCR meter.

Not a high priced one.

If your current testing method isn't telling you enough about your advanced components, better get something you can be sure of: the HP 4263B LCR Meter.

You can be sure of the performance because the HP 4263B makes testing even complex components foolproof. Contact check and 0.1% accuracy with open, short and load error compensation deliver the confidence. And 11 impedance parameters and a choice of 15 HP test fixtures assure versatility.

Of course, you can be sure the HP 4263B will fit in your budget too. Because at prices as low as $4,300,* it sets a new price/performance standard. It's also the first instrument in a complete family of HP LCR meters.

Call HP DIRECT at **1-800-452-4844, Ext. 1898**. An engineer will help you determine which HP LCR meter is right for the operating frequency, impedance range, or operating test conditions you need to test.

*U.S. list price

HEWLETT® PACKARD

INFO/CARD 14

Physics-based MESFET model
Raytheon (Statz et. al.) intrinsic model
TriQuint (TOM-1 and TOM-2)
FET – MOSFET model
JFET – Junction FET model

Many users find that commercial vendors provide parameters only for some of these models. On the other hand, the simulator offers a set of parameter extraction tools to generate these model parameters in-house. The network program controls both the network analyzer and the DC-IV curve tracer. The set of data generated from this then will be used by the scout program to generate the actual model of choice.

The first and probably simplest analysis case is the evaluation of a mixer. In the analysis, the passive mixer with switching type of FETs is the most problematic. This has to do with the validity of the model and model selectors in this region. Figure 7 shows a typical GaAs FET mixer as shown in ICs for modern cellular telephones. This circuit can be analyzed both in the SPICE environment and by harmonic balance simulators. The simulator's graphic display capabilities give detailed insight in the mixer activities, as shown in Figures 8 and 9. Figure 10 shows the harmonic balance calculation of the os-cillator analysis, including the phase noise calculation for a 760 MHz voltage-controlled oscillator (VCO) for a hand-held radio. The cost of using such a computer-aided design (CAD) tool is determined by its purchase price as well as the investment of time needed to learn how best to use the tool. Thus, it is very important to have the ability for future growth in the non-linear area. Future

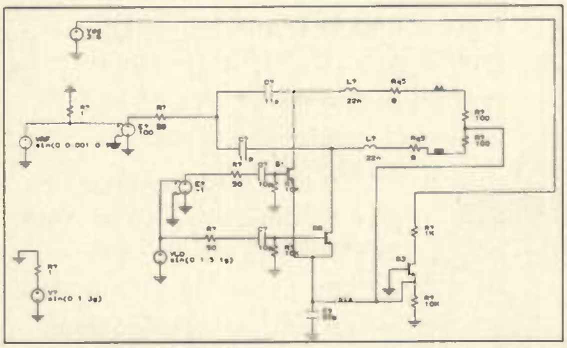


Figure 7. A GaAs FET-based shunt mixer courtesy of Wes Hayward of TriQuint.

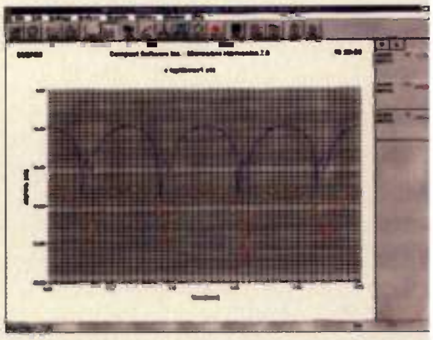


Figure 8. The output power of the mixer as a function of drive-level for a single-gate mixer.

You
Can write for *RF Design*!

You may have just the knowledge our readers need on the subjects we're featuring during the rest of 1996:

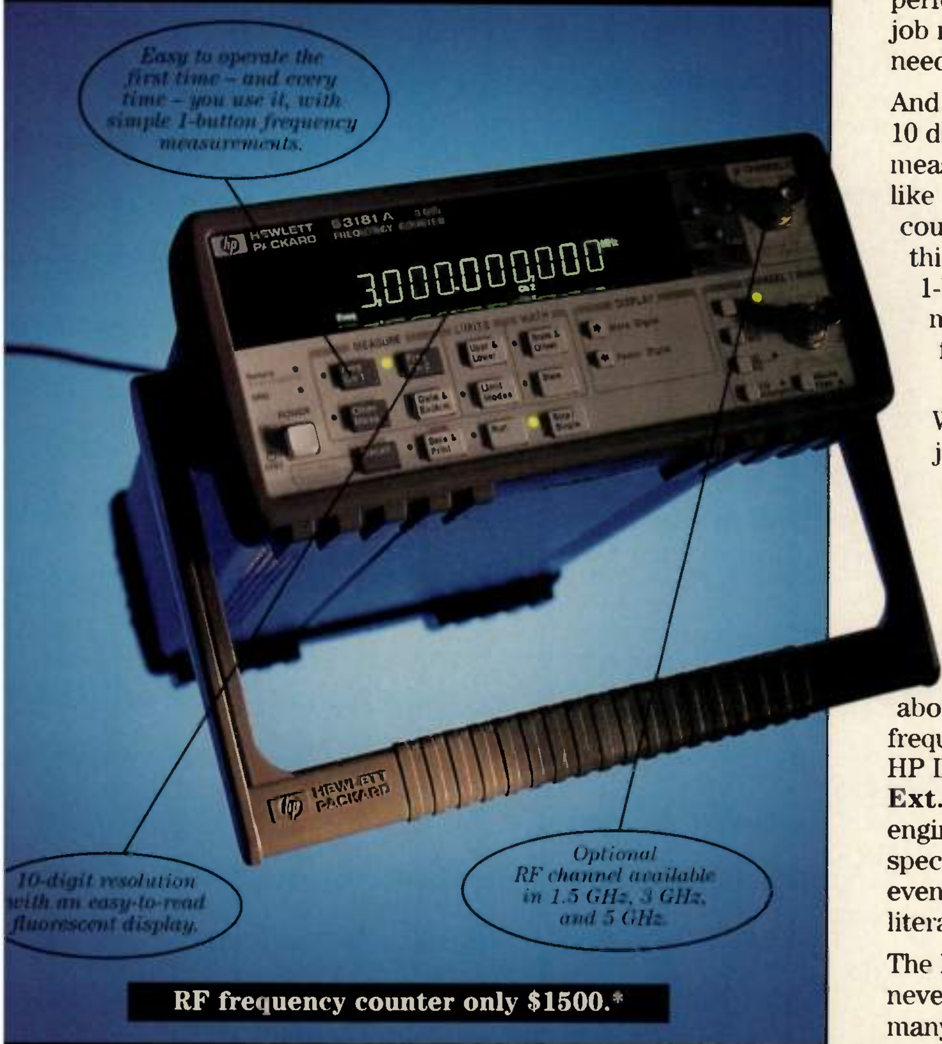
- 3 Volt designs

We also need tutorial articles on the following topics (for a new B.S.E.E. with no experience):

- Shielding fundamentals
- Digital signals

Send an outline or abstract to: Technical Editor, *RF Design*, 5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111. Fax 303-793-0454.

Ten big digits of resolution.



Four small digits of price.

When you need to make accurate frequency measurements, does it really make sense to pay for more features than you'll use?

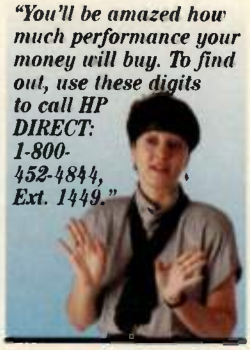
Not when there's the new HP 53181A — an affordable RF frequency counter with the performance you need to do the job right, and the ease-of-use you need to do the job fast.

And what performance! Like 10 digits of resolution and 200 measurements per second, just like our best-selling universal counter. Now imagine getting this performance with simple 1-button frequency measurements and a bright vacuum fluorescent display — a great way to increase throughput.

With the HP 53181A, you don't just get a lot of performance: at only $2300 for the 3 GHz model, you get a lot of performance for your money. And if you need different frequency coverage, there's a model at 225 MHz, 1.5 GHz, and 5 GHz.

Ready to find out more about this remarkable new frequency counter? Then call HP DIRECT at **1-800-452-4844 Ext. 1449**. You'll talk to an engineer who can give you answers, specifications, even product literature.

The HP 53181A: never have so many digits of performance been available for so few digits of price.



There is a better way.

HEWLETT® PACKARD

INFO/CARD 33

growth means that as the frequency range for wireless communication products moves higher, the non-linear simulator models is accurate enough to provide useful models with high-output powers and large signal noise performance. This capability is best shown by using such high frequencies as 39 GHz for non-linear applications. Figure 11 shows the layout of a 40 GHz push-pull oscillator that had been developed and validated using the simulator. The layout is based on the simulator's ability to analyze and optimize phase noise of any arbitrary topology of oscillators ranging from high-Q crystal oscillators to the millimeter-wave application of MMIC VCOs.

Typical wireless application

Although the design of a wireless system has many critical stages, the oscillator has a significant effect on signal quality. A good example that combines

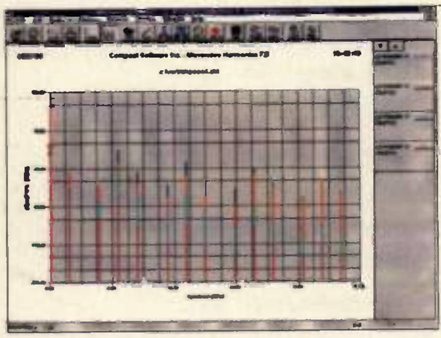


Figure 9. The power spectrum of the same single-gate mixer.

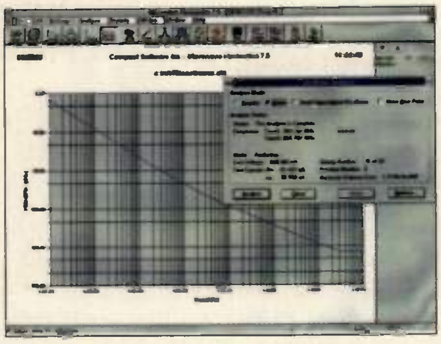


Figure 10. Harmonic balance and phase-noise calculation of the oscillator analysis (done in conjunction with Motorola).

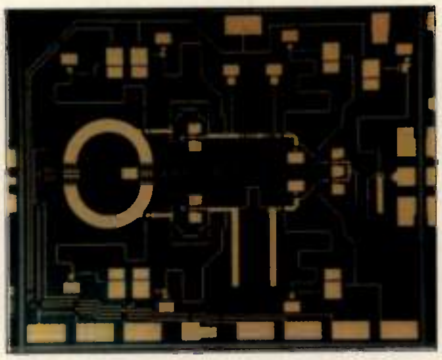
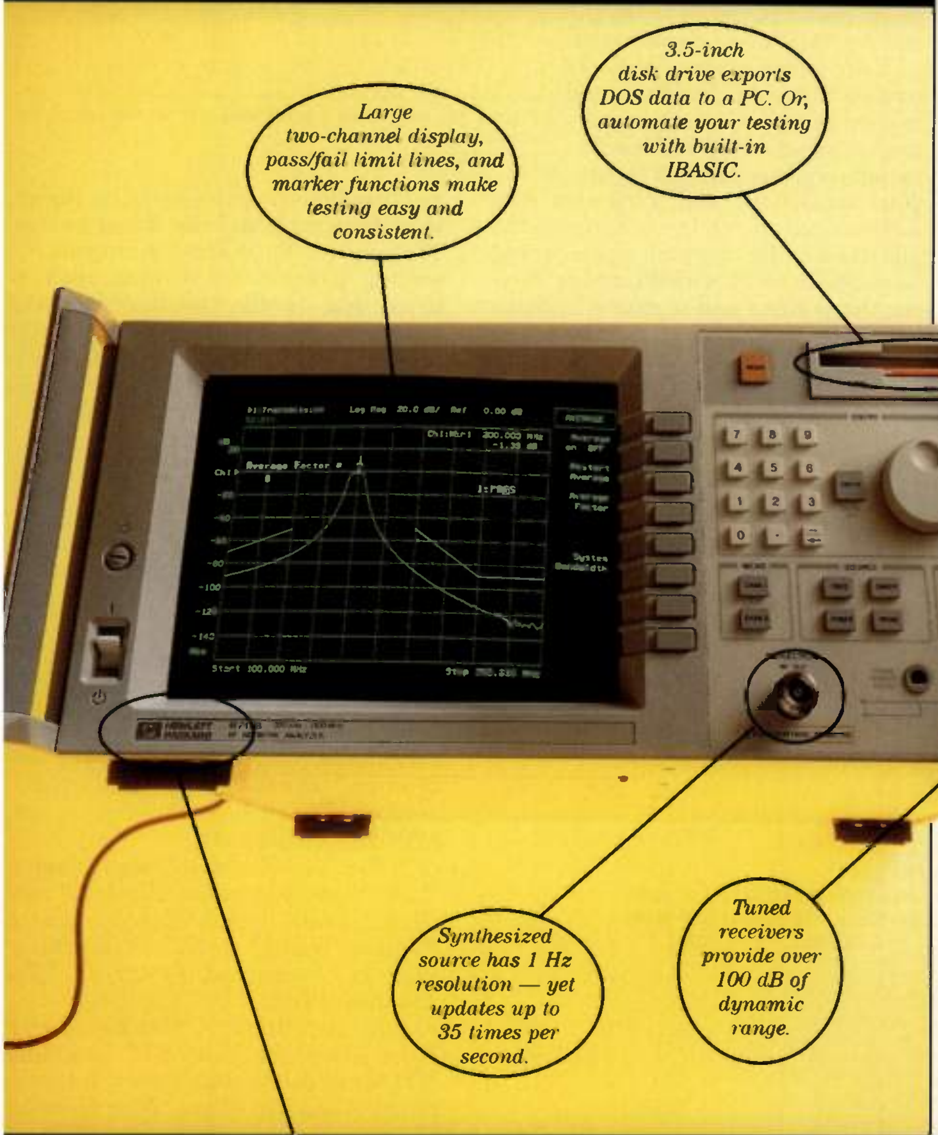


Figure 11. Layout of a push-pull 40 GHz VCO developed by General Electric under the joint MIMIC contract.

Figure 12. The picture of a ceramic resonator-based 800 MHz VCO for base stations developed with Siemens-AG, Munich, Germany.

At only $9,500,

some features on this RF network analyzer will surprise you.



If you thought you could never afford this kind of performance, think again. The HP 8711B family of network analyzers puts it well within your grasp.

Starting at just $9,500, select from four models in your choice of scalar or vector, 1.3 or 3 GHz. Each complete system has an integrated synthesized source and test set. So you can tune and test your RF communications devices faster and more economically than ever before.

To find out about all the features the HP 8711B network analyzer family has to offer, call HP DIRECT. It's the fast, easy way to get all your questions answered. With one simple call, you can get quick product specifications or any technical literature you may need to make the right decision. Or if you want one-on-one technical support, you can speak to an engineer who has firsthand experience with HP products. And, of course, if you're ready to order, we can help you do that, too.

So give us a call. You'll be surprised how affordable HP performance can be.

*In Canada, call 1-800-450-2271, Dept. 146.

But one will really amaze you.

There is a better way.

HEWLETT® PACKARD

INFO/CARD 30

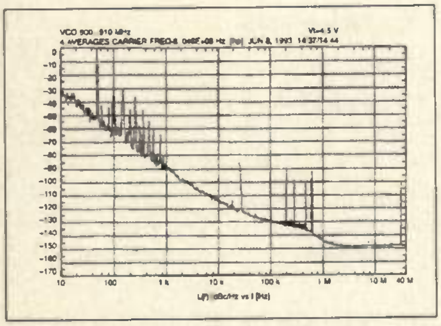


Figure 13a. The measured phase noise of the oscillator in Figure 12.

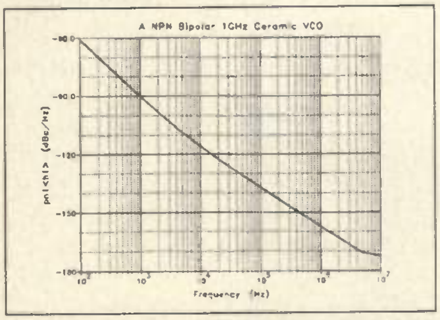


Figure 13b. The predicted phase noise of the oscillator in Figure 12.

high-frequency modeling, microwave-noise modeling and large signal performance modeling is a *ceramic resonator-based oscillator*. Figure 12 shows such an oscillator, and Figures 13a and 13b show its measured and predicted phase noise. Figure 14 is the circuit diagram. These circuits actually are quite simple. A lot of consideration in building and modeling them involves the proper selection of high-performance components, such as suitable transistors and varactors. The software has the ability to optimize the phase noise for a given topology and semiconductor. By simultaneously varying the positive and negative feedback and the DC operating point, one can obtain the best possible performance.

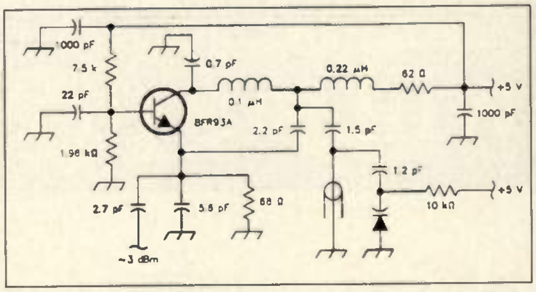


Figure 14. Simplified circuit diagram of the oscillator shown in Figure 12.

Conclusion

The PC-based simulation program, which is the result of many years of research and contribution from various research projects, can handle the needs of modern CAD tools from audio frequencies to millimeter wave, as well as linear, electromagnetic and non-linear modes. This combination makes the program extremely powerful for wireless applications that involve proximity effects (coupling, layout dependent and distributed elements) and large-signal-dependent performance of diodes and transistors, both bipolar and FETs.

RF

```
*AT41400 AT 7.5V, 30mA IN A 4 GHz DR OSCILLATOR
*SETUP FOR CB OPERATION WITH INPUT RESONATOR
*
*modeling of the transistor using the BIP model (chip only)
*
BLK
    BIP 3 2 1 A=0.990 RE=0.88 F=42GHZ T=10PS CE=5.1PF CI=0.034PF C0=0.05PF
+   RB1=4.7 RB2=6.6 RC1=5 RE1=0.2 CBC=0.085PF CCE=0.05PF LB=200PH LE=50PH
TR: 3POR 3 2 1
END
BLK
      RES       1   0       R=50
      TRL       1   2       W=2.34MM P=10MM SUB1
      DRMS      2   3       D=14.515MM HD=7MM ER=36 S=0.3X10-3 HT=8MM
   +                        W=2.34MM L=80MM SDR=2X10-3 NM=1 BSF SUB1
      TRL       3   4       W=2.34MM       P=0.392MM        SUB1
      IND       4   0       L=10UH
      IND       4   5       L-0.5NH
      IND       6   0       L=?0.64658NH?
      IND       7   0       L=10UH
      TR        6   7   5
      OSC:2POR  1   7
END
*
FREQ
    STEP 3.95GHZ 4.05GHZ 1MHZ
END
OUT
      PRI OSC S
END
OPT
      OSC
    * MS22=150GT
      rz22=-50
END
 DATA
SUB1: MS H=31MIL ER=2.3 MET1=CU 0.7MIL TAND=0.001 HU=600MIL
END
```

Table 1. The listing of a 4 GHz dielectric resonator oscillator at DRO model.

References

1. Rohde, Ulrich L., Anthony M. Pavio and Robert A. Pucel, "Accurate Noise Simulation of Microwave Amplifiers Using CAD," *Microwave Journal*, December 1988.

2. Fukui, Hatsuaki, "Design of Microwave GaAs MESFET's for Broad-Band Low-Noise Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, pp. 643-650, July 1979, "Addendum," *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-29, October 1981.

3. Hsu, Tzu-Hwa and Craig P. Snapp, "Low Noise Microwave Bipolar Transistor with Sub-Half-Micrometer Emitter Width," *IEEE Transactions Electron Devices*, vol. ED-25, pp. 723-730, June 1978.

4. Rohde, Ulrich L., "New Non-linear Noise Model for MESFETS Including MM-Wave Application," First International Workshop of the West German IEEE MTT/AP Joint Chapter on Integrated Non-linear Microwave and Millimeter-wave Circuits (INMMC '90') Digest, Oct. 3-5, 1990, Duisburg University, Duisburg, West Germany.

5. Pucel, R. A., W. Struble, R. Hallgren and U.L. Rohde, "A General Noise De-embedding Procedure for Packaged Two-Port Linear Active Devices," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 11, November 1992, pp. 2013-2024.

6. Rohde, Ulrich L. and Chao-Ren Chang, "Parameter Extraction for Large

Signal Noise Models and Simulation of Noise in Large Signal Circuits like Mixers," *Microwave Journal*, May 1993, pp. 24-28.

7. Pucel, Robert A. and Ulrich L. Rohde, "An Accurate Expression for the Noise Resistance R(n) of a Bipolar Transistor for Use with the Hawkins Noise Model," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No. 2, February 1993, pp. 35-37.

8. Rohde, Ulrich L., "Parameter Extraction for Large Signal Noise Models and Simulation of Noise in Large Signal Circuits like Mixers and Oscillators," 23rd European Microwave Conference, Madrid Spain, Sept. 6-9, 1993.

9. Rohde, Ulrich L., "All About Phase Noise in Oscillators", *QEX*, December 1993, January 1994, February 1994.

10. Rohde, Ulrich L., Chao-Ren Chang, "The Accurate Simulation of Oscillator and PLL Phase Noise in RF Sources," Wireless '94 Symposium, Santa Clara, CA.

11. Rohde, Ulrich L., "Oscillator Design for Lowest Phase Noise," RF Expo West, March 22-24, 1994, San Jose, CA.

12. Rohde, Ulrich L., "Obtain Large-Signal Models for Microwave Transistors," *Microwaves & RF*, March 1994, pp. 103-110.

13. Rohde, Ulrich L., "Oscillator Design for Lowest Phase Noise," *Microwave Engineering Europe*, May 1994.

14. Rohde, Ulrich L., Chao-Ren Chang, J. Gerber, "Design and Optimization of Low-Noise Oscillators using Non-linear CAD Tools," presented at the Frequency Control Symposium, Boston, June 1–2, 1994.

15. Rohde, Ulrich L., "Designing Low-Phase Noise Oscillators," *QEX*, Oct. 1994. pp. 3-12.

16. Rohde, Ulrich L., "A High Performance Hybrid Synthesizers", *QST*, March 1995, pp. 30-38.

17. Rohde, Ulrich L. and Chao-Ren Chang, "Analysis and Optimization of Oscillators for Low Phase Noise and Low Power Consumption," *RF Design*, March 1995, pp. 70-79.

18. Rohde, Ulrich L., "Low Noise Microwave Synthesizers, WFFD: Advances in Microwave and Millimeter-Wave Synthesizer Technology," IEEE MTT Symposium, Orlando, FL, May 19, 1995.

19. Rohde, Ulrich L., "Designing SAW and DRO Oscillators Using non-linear CAT Tools," 1995 IEEE International Frequency Control Symposium, San Francisco, May 30-June 2, 1995.

Other relevant publications

1. Daniel, T. and R. Tayrani, "DC and High Frequency Model for Hetero-junction Bipolar Transistors," accepted to 1996 IEEE GaAs IC Symposium, Orlando, FL 1996.

2. Daniel, T. and R. Tayrani, "Fast Bias Dependent Device Models for CAD of MMICs," *Microwave Journal*, February 1995.

3. Gerber, J., Anholt, R., and J. Pence, "A Self-Heating HBT Model for Harmonic Balance Simulators with Parameter Extraction", Asia-Pacific Microwave Conference, Japan, December 1994.

4. Anholt, R., J. Gerber, R. Tayrani, and J. Pence, "HBT Model Parameter Extractor for Spice and Harmonic Balance Simulators," *1994 IEEE MTT-S International Symposium Digest*, San Diego, May 1994.

5. Tayrani, R. and T. Daniel, "Fast Physics-Based Device Models for CAD of MMIC's," IEEE/David Sarnoff Conference, Princeton, April 1994.

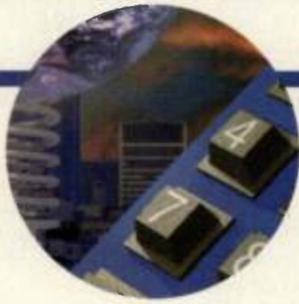
6. Tayrani, R., J.E. Gerber, T. Daniel, R. Pengelly and U.L. Rohde, "A New and Reliable Approach to Direct Parameter Extraction for MESFETs and HEMTs," European Microwave Conference, Madrid, Spain, September 1993.

7. Tayrani, R., J.E. Gerber, T. Daniel, R. Pengelly and U.L. Rohde, "Reliably Extract MESFET and HEMT Parameters,' *Microwaves and RF*, June 1993.

About the author

Ulrich L. Rohde is president and owner of Compact Software, a privately held corporation in Paterson, NJ. He is a partner of Rohde & Schwarz, Munich, West Germany, a multinational company specializing in advanced test and radio communications systems. Having studied electrical engineering and radio communications at the universities of Munich and Darmstadt, Germany, he holds a Ph.D. in electrical engineering and an Sc.D. (honorary) in radio communications. Dr. Rohde has published more than 60 scientific papers in professional journals, as well as four books.

THE MOST PROFITABLE THREE DAYS YOU'LL SPEND FOR YOUR COMPANY.



WirelessWorld Expo 96
Oct. 30 - Nov. 1 • Orlando, Florida
Orange County Convention Center

70+ Expert Speakers
300+ Exhibits
1000+ New Ideas

Welcome to the "must attend" event of the year in wireless. The fastest-growing exhibition and conference in the industry, for one of the most dynamic and challenging new industries in the world. Sponsored by the authorities you trust the most for practical, up-to-the-minute guidance on how to succeed in the competitive wireless arena.

Cellular carriers, PCS licensees and applicants, paging service providers, retailers, dealers, resellers, manufacturers, large volume end-users—anyone whose future is affected by the new age of wireless voice and data communications—will find hundreds of new ideas at the WirelessWorld '96 Exhibition & Conference.

Return this form now for your FREE Expo Pass (value $20), plus complete information on the conference, hotels, special events and more. Or for more information, call FAX-ON-DEMAND at 1-800-601-3858 or call Intertec Presentations at 1-800-288-8606.

EXPO 96 WIRELESS WORLD

Send my FREE Expo Pass (value $20), plus complete information on the conference, hotels, special events and more.

First Name ____________ Last Name ____________
Title ____________
Company ____________
Address ____________
City ____________ State/Prov. ____________
Zip ____________ Country ____________
Phone ____________ Fax ____________

❑ Check here if you have a disability that may require special services, and attach a written description.

MAIL OR FAX TO: WirelessWorld Registration • Matrix Marketing
13610 N. Scottsdale Rd., • #10-246 • Scottsdale, AZ 85254
602-443-4058 • FAX 602-443-8767

PLEASE COMPLETE THE FOLLOWING:

YOUR PRIMARY BUSINESS
Wireless System Operator
- A ❑ Cellular
- B ❑ PCS
- C ❑ Paging
- D ❑ SMR/ESMR
- E ❑ Radio Common Carrier
- F ❑ Other ____________
- G ❑ Dealer/Retailer/Sales Agent
- H ❑ Manufacturer/Manufacturer's Rep
- I ❑ Consultant/Analyst
- J ❑ End User
- K ❑ Other: ____________

YOUR TITLE
- A ❑ Owner/President/CEO/Partner
- B ❑ VP/Manager/Director
- C ❑ Engineer/Service Manager/ Supervisor/Technician
- D ❑ Purchasing Director/Manager
- E ❑ Marketing/Sales Manager
- F ❑ MIS/DP/LAN Manager
- G ❑ Other: ____________

YOUR PURCHASING ROLE
- A ❑ Make Final Decision
- B ❑ Recommend
- C ❑ No Purchasing Role

SOURCE CODE AD

ATTENTION VENDORS: For exhibiting information, call Ms. Billi Famiglietti at 301 986-7800

WirelessWorld is organized by Intertec Presentations division of Intertec Publishing, and E.J. Krause & Associates. Sponsored by:

Cellular Business   WIRELESS WORLD   Mobile Radio Technology   CELLULAR & MOBILE International   Telephony

Coaxial cables

By Jim Weir
RST Engineering

Much engineering effort is expended in transferring power from one point to another. Whether the power is measured in gigawatts (transferring Boulder Dam power to the residents of the Los Angeles basin) or picowatts (transferring cosmic signals from the feedhorn of the Aricebo deep-space radio telescope to the sensitive receiver input), the problem is fundamentally the same — move power from one point to another with as little loss as is reasonably possible.

If we look at only the RF portion of the problem, then we can limit the scope of power transfer to a reasonably small number of methods and power levels.

Background

Moving RF power around in the days before silicon generally meant piping signals around a radio chassis between vacuum tubes with ordinary hookup wire. When it came to connecting a radio to an antenna, the usual choice was parallel-wire feedline or *ladder line* (Figure 1). Amateur radio operators used to spend a lot of time drilling popsicle sticks and feeding No. 22 bare wire through the holes to make 300 Ω ladder line so they could elevate that inverted-vee antenna a little higher.

Of course, ladder line left a bit to be desired, from an RF point of view. First, to make ladder line match the intrinsic 72 Ω impedance of a dipole, the spacing between the wires should be roughly the diameter of the wire itself. Hand-drilling popsicle sticks with holes that close together and keeping the bare wires from touching during a windstorm when the ladder line was a couple of hundred feet long wasn't easy. Most operators used 300 Ω (six times wire diameter for spacing), and then wound 4:1 transformers to couple the 72 Ω antenna to the 300 Ω line.

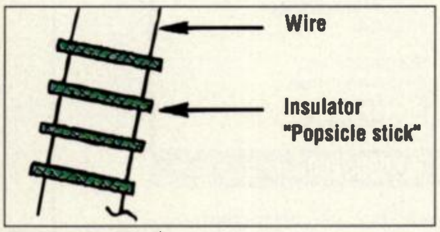


Figure 1. Ladder line.

Corrosion often resulted from the wires being exposed to the elements. Because RF energy travels on the surface of a conductor (skin effect), open-wire transmission line subject to corrosion suffers from rapidly increasing attenuation vs time.

There were also squirrels. It turned out that squirrels love to play on the ladder line. And every time a kilowatt pulse of power fried one of them, it also fried the output tube.

One day, a British engineer got the idea of enclosing the ladder lead in a metal tube to keep the squirrels out, and coaxial cable was born.

Definition

Coaxial cable (coax) is a wire inside of another hollow wire—the two wires being separated by an insulator. This is a broad definition, so let's itemize what we are *not* going to talk about. Stripline coax is a rectangular wire surrounded by another rectangular wire separated by printed circuit (pc)-board material. Multiconductor coax is several wires inside the hollow wire, with each wire separated from the others by insulation.

We are going to talk about garden-variety coax (Figure 2)—a single center conductor, surrounded by an insulator, covered by a hollow conductor. This type of coax is used to connect your TV set, to show your ham antenna and to make lab cables.

The center conductor is called . . . the *center conductor*. The insulator is usually given the name *dielectric*. The outer conductor is called the *shield*, or more commonly the *braid*. In almost all cases, the braid is covered with another layer of insulator, called the *sheath* or *jacket*, for protection from the elements.

Characteristic impedance

Straight round wire has an intrinsic inductance. For a No. 22 wire, this inductance is about 10 nH per inch. If you surround this wire with a dielectric and then another conductor (as in coax cable) there is capacitance between the two conductors. The characteristic im-

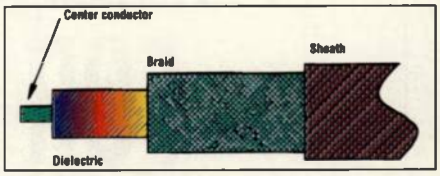


Figure 2. A coaxial cable.

pedance of the cable is the square root of the inductance of the center conductor divided by the capacitance of the center conductor to the braid, or in mathematical form:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{1}$$

Let's presume that a coax cable is made from a No. 22 wire as its center conductor, and that the capacitance of an inch of cable measures 4 pF. The square root of 10 nH divided by 4 pF equals 50, so the coax cable has a characteristic impedance of 50 Ω.

Instead of making an electrical measurement, a mechanical measurement can be used to find the characteristic impedance of the coax. If we call the outside diameter of the center conductor *d*, and if we call the inside diameter of the braid *D*, and if the insulation between them has a dielectric constant of ε, then the characteristic impedance of the cable is given by:

$$Z_0 = \left(\frac{138}{\sqrt{\varepsilon}}\right)\log_{10}\left(\frac{D}{d}\right) \tag{2}$$

Once again, to give a practical example, assume that the center conductor is still No. 22 wire with an outer diameter of 0.025″, or about 25 mils. The insulator is polyethylene with a dielectric constant of about 2.25. The braid or shell has an inner diameter of 0.15″. The numerator 138 divided by the square root of 2.25 equals 92. Log base 10 of .15 divided by .025 equals 0.77. Multiplying 92 × 0.77 equals 71.5 Ω. You could say that the coax was 70 Ω cable or 72 Ω cable, and either one would be accepted as correct.

The error most laymen make is to take a piece of coax, put an ohmmeter on it, and declare it to be no good because it measures infinity. It is going to measure infinity because the coax cable

is nothing more than a couple of wires separated by an insulator—a whole bunch of series inductors and shunt capacitors. What is important to remember is that characteristic impedance and DC resistance have little, if anything, to do with one another.

Wither impedance

So far we've mentioned the 50 and 70 Ω varieties of coax without saying why one impedance or the other is used. The fact of the matter is that there is no one best impedance for a system. If power-handling capacity is your goal, then the math shows that 30 Ω is the optimum impedance cable and system to work within. If voltage breakdown is important, the curve of voltage breakdown vs. cable impedance peaks rather broadly at about the 60 Ω point. If minimum cable loss is paramount, the curve of attenuation vs. impedance goes through a minimum at about 73 Ω, rising steeply below that value and slowly above (Figure 3).

So how did the RF world settle on 50 Ω? Remember the squirrels? When the first coax was being designed, the copper water pipes that could be bought off the shelf when assembled in air-coax form had a characteristic impedance of 50 Ω. Thus, today's modern RF impedance standard of 50 Ω was derived from the British plumbing standards of the 1930s. One might ponder this with a certain amount of irony.

Most cables today are either 50 Ω (RF communications) or 70 Ω (cable TV) impedance. Some specialized industries also use 93 Ω and 125 Ω.

Practical coax construction

There are two main categories of coax — *flexible* and *semirigid*. Flexible coax is used with a TV antenna—you can bend it around corners, thread it through walls and tie it in knots. It is *limber*. Semirigid cable can be bent once (and sometimes only with heavy tools), but bend it twice and it breaks. Flexible coax is easy to work with, but it has a slightly higher loss and more leakage of the signal from the center conductor past the shield. Semirigid is more difficult to work with, but it has slightly lower loss and almost indetectable leakage.

Flexible cable can have a center conductor made of either a solid wire or twisted strands of wire, but the most flexible coax has a stranded center conductor. The stranded center conductor generally has slightly higher loss.

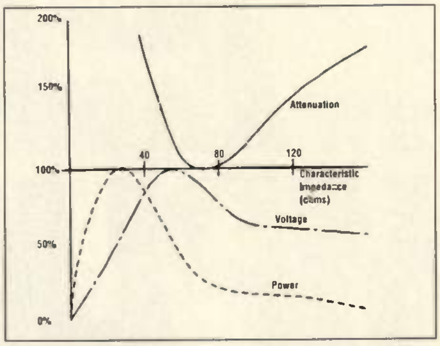


Figure 3. Cable performance goals vs. characteristic impedance.

Semirigid coax always uses a solid center conductor.

The center conductor can be either bare copper (low-cost but prone to corrosion), stranded, tinned copper (medium-cost), or silvered copper (high-cost but low-loss).

The dielectric material can be either air or plastic. Although air-line is used in some special applications and certainly has the lowest loss of any of the dielectrics, most engineers use plastics as coax insulation. Plastic is generally limited to one of two varieties—*polyethylene* for low-cost, and *Teflon* for low-loss. One way to get the good low-loss qualities of air and the mechanical strength of plastic is to foam the plastic, or inject it with air while it is still molten. This way, 95% of the dielectric can be low-loss air and 95% of the strength can be the air-filled plastic cells. Almost all semirigid coax uses solid Teflon as the dielectric.

The outer shield or braid can be a true braid of fine wire for flexible coax or solid copper pipe for semirigid. Solid copper pipe, of course, is leak-proof. However, braided flexible coax is generally given a value for the percentage of shielding. This is an optical percentage, so a coax rated as a 90% shield will have 10% of the dielectric exposed to the outside world. Of course, this amount of shielding may be fine at relatively low frequencies, but as the frequency increases, so will the amount of the signal leaked out of the coax.

There are three ways to increase the shielding percentage. One is with a finer weave of the braid—more and smaller wires woven into the braid. Another is by putting a second braid over the top—in essence braiding the braid. A third way, foil shielding, uses a thin metal aluminum foil as the braid, and a drain wire running between the foil and the dielectric to act as a contact to the foil. This method creates a 100% shield for flexible cable.

Tricks

1. The first trick is simply the slowing of an electromagnetic wave when it is forced from air into some other dielectric. For example, if a wave is forced down a coaxial cable using a dielectric with a dielectric constant E, the wave is slowed up in proportion to the reciprocal of the square root of the dielectric constant.

In particular, an electromagnetic wave has a wavelength in free air of approximately 11,805/f, where the wavelength is in inches and f is the frequency in megahertz. For example, a frequency of 125 MHz has a corresponding wavelength of 94.5 inches. However, in coaxial cable, this wavelength is reduced by a factor of the square root of 2.25 (the dielectric constant of polyethylene), and the wavelength is then shortened to about 62.9″. This reciprocal of the square root of the dielectric constant is sometimes given the name *velocity factor*, and in the case of polyethylene, it is 0.66 (a dimensionless constant).

2. The trick most of us learn to use is to make a trap for an interfering signal from a quarter-wavelength of coax. Neglecting the second-order effects of cable loss, the impedance looking into a length of coaxial cable that is open on the other end is given by:

$$Z_{in} = \frac{Z_o}{\tan(\Theta)} \qquad (3)$$

where Z_o is the characteristic impedance of the line and θ is the electrical length of the line in degrees. With a quarterwave line, the length is 90 electrical degrees, and the tangent of 90° is infinity. The impedance looking into that open-ended quarterwave line is therefore exceedingly small (a dead short) at that one exact frequency.

So, to return to our original example of 125 MHz, let's say that a receiver has an interfering signal at 132 Mhz. If a T-fitting is placed into the coax line between the antenna and the receiver, and then an open coax line stub a quarter wavelength long at 132 MHz is attached to that fitting, then the interfering signal at 132 MHz will be shorted out. But the desired 125 MHz and the signal should make it through nicely (Figure 4).

So how do we calculate this quarter-wave open stub? In air, a quarter wavelength would be (11,805/132)/4 or about

22.5 long. However, in coax, the dielectric foreshortening factor (or velocity factor) must be considered, so the quarter-wavelength would be (22.5)(0.66) or 14.9 inches long.

How about a tuning tool? Obtain a pair of wirecutters and an S-meter (or RSSI output) of the receiver, a signal generator tuned to the offending frequency piped down the line, and you are ready to tweak it onto frequency. Start a couple of megahertz low and come up. If you cut it off twice too short, it will still be too short.

One little refinement may be made. You can "fool" the coax into thinking it is longer than it really is by putting a small value trimmer capacitor across the open end of the coax. (All you are actually doing is putting a few more Ls and Cs at the end of the coax and tricking the circuit into thinking it is coax instead of lumped elements.) At any rate, you now have a tunable filter instead of the cut-and-try method above.

3. There are times when you need to split a power source into two equal parts. Say, for example, that you are testing your new oscillator design and you want to measure frequency and power simultaneously. Once again, the quarterwave coaxial cable comes to the rescue. It seems that with a 50 Ω system, and with two quarterwave 70 Ω cables connected to the power source, and a 100 Ω carbon (not wirewound or inductive construction) resistor connected across the two outputs, we have what is called a Wilkenson splitter, in which outputs are isolated from one another. You can short one output, open it, put any reactance across it you wish, and it will not affect the other output to a measurable degree. Not only that, but this phenomenon continues over almost an octave of bandwidth before the isolation and equal split begin to deteriorate. You can run your power meter and your frequency counter independently of one another and not worry about one measurement affecting the other (Figure 5).

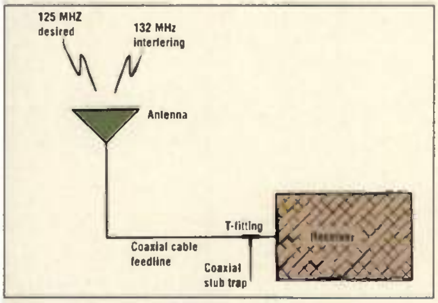


Figure 4. An example system.

Conclusion

There are many additional ways to use coaxial cable that I didn't mention: quarterwave transformers; loop baluns; hybrid transformers; emergency dog leashes; and more. However, this article has conveyed some of the most important information on the basics of coaxial cables and their uses for RF design. The minimum of mathematical formulas was intentional. Many times, simple concepts get lost behind a smokescreen of unintelligible hieroglyphics, and the student is lost. This article attempted to explain coaxial cables in a language the competent layman could understand. *RF*

References

1. *Reference Data For Radio Engineers*, Fourth Edition, H. P. Westman, Editor, International Telephone and Telegraph, 1956.

2. "Watts New From Bird," Vol. 6 Number 2 (August 1969), Bird Electronic.

3. Wilkinson, Ernest. "An N-Way Hybrid Power Divider" IRE-MTT, January 1960, pp. 116–118.

4. Weir, Jim, *The RST-802 Plastic Plane Antenna Book* 1996, RST Engineering.

About the author

Jim Weir is the founder and engineer for RST Engineering, a small California company dedicated to keeping the spirit of "kit building" alive and well in the aviation electronics field. His hobbies include flight instruction, competitive cooking, slow-pitch softball and beer-making. He can be reached at jim@rst-engr.com, but he would prefer to answer readers' technical questions on the Internet newsgroup sci.electronics.basic.

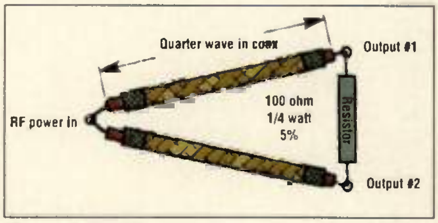


Figure 5. Trick 3.

AMPLIFIERS

- LOW NOISE
- LIMITER INPUT
- MEDIUM POWER
- CRYOGENIC OPERATION

MODEL NUMBER	OPERATING FREQUENCY (GHz)	GAIN (dB) (Min.±)	GAIN FLATNESS (±dB, Max.)	NOISE FIGURE (dB,Min.)	OUTPUT POWER AT 1 dB COMPR. (dB,Max.)	VSWR IN/OUT (Max.)	DC POWER AT +15 V (Nom.)
MODERATE TO OCTAVE BAND LOW NOISE AMPLIFIERS							
AMF-2F-002020-08-10P	0.2–2	30	1.5	0.8	+10	2.0:1	150
AMF-2F-002005-05-10P	0.25–0.5	30	0.5	0.5	+10	2.0:1	150
AMF-2F-003010-05-10P	0.3–1	30	1.5	0.5	+10	2.0:1	150
AMF-3F-005010-05-10P	0.5–1	35	1.0	0.5	+10	2.0:1	150
AMF-3F-010020-04-10P	1–2	35	1.0	0.4	+10	2.0:1	150
AMF-3F-020040-05-10P	2–4	33	1.0	0.45	+10	2.0:1	125
AMF-3F-040080-08-10P	4–8	28	1.0	0.8	+10	2.0:1	125
AMF-4F-040100-14-10P	4–10	30	1.5	1.4	+10	2.0:1	150
AMF-4F-040120-15-10P	4–12	30	1.5	1.5	+10	2.0:1	150
AMF-4F-060120-12-10P	6–12	32	1.5	1.2	+10	2.0:1	150
AMF-4F-060180-20-10P	6–18	30	1.5	2	+10	2.0:1	150
AMF-4F-080120-10-10P	8–12	32	1.0	1	+10	2.0:1	150
AMF-4F-080160-14-10P	8–16	30	1.0	1.4	+10	2.0:1	150
AMF-4F-080180-15-10P	8–18	30	1.5	1.5	+10	2.0:1	150
AMF-4F-100200-20-10P	10–20	27	1.5	2	+10	2.0:1	150
AMF-4F-120180-14-10P	12–18	30	1.0	1.4	+10	2.0:1	150
AMF-4F-180265-25-10P	18–26.5	26	2.0	2.5	+10	2.0:1	150
AMF-2F-001010-07-10P	0.1–1	30	1.0	0.7	+10	2.0:1	175
AMF-3F-001040-10-10P	0.1–4.0	35	1.5	1	+10	2.0:1	250
AMF-3F-006007-04-10P	0.6–0.7	40	0.5	0.35	+10	1.5:1	150
AMF-3F-007008-04-10P	0.7–0.8	40	0.5	0.35	+10	1.5:1	150
AMF-3F-008010-04-10P	0.8–1	40	0.5	0.35	+10	1.5:1	150
AMF-3F-012016-04-10P	1.2–1.6	40	0.5	0.35	+10	1.5:1	150
AMF-3F-015025-06-10P	1.5–2.5	35	0.8	0.6	+10	1.7:1	150
AMF-3F-022024-04-10P	2.2–2.4	40	0.5	0.35	+10	1.25/1.5	150
AMF-3F-023027-04-10P	2.3–2.7	33	0.5	0.35	+10	1.25/1.5	125
AMF-3F-027030-04-10P	2.7–3	33	0.5	0.35	+10	1.25/1.5	125
AMF-3F-030035-04-10P	3–3.5	33	0.5	0.35	+10	1.25/1.5	125
AMF-3F-034042-04-10P	3.4–4.2	33	0.5	0.4	+10	1.25/1.5	125
AMF-3F-043048-05-10P	4.3–4.8	33	0.5	0.5	+10	1.25/1.5	125
AMF-3F-044051-05-10P	4.4–5.1	32	0.5	0.5	+10	1.25/1.5	125
AMF-3F-054059-06-10P	5.4–5.9	32	0.5	0.6	+10	1.25/1.5	125
AMF-3F-058065-06-10P	5.8–6.5	32	0.5	0.6	+10	1.25/1.5	125
AMF-3F-064072-06-10P	6.4–7.2	30	0.5	0.6	+10	1.5:1	125
AMF-3F-072078-07-10P	7.25–7.75	30	0.5	0.65	+10	1.5:1	125
AMF-3F-079084-08-10P	7.9–8.4	28	0.5	0.8	+10	1.5:1	125
AMF-3F-085096-09-10P	8.5–9.6	28	0.5	0.9	+10	1.5:1	125
AMF-4F-090110-10-10P	9–11	32	0.8	1	+10	1.7:1	150
AMF-4F-100150-14-10P	10–15	30	1.0	1.4	+10	1.7:1	150
AMF-4F-109127-10-10P	10.9–12.7	30	0.5	1	+10	1.5:1	150
AMF-4F-140145-13-10P	14–14.5	30	0.5	1.3	+10	1.5:1	150
AMF-4F-144153-13-10P	14.4–15.3	30	0.5	1.3	+10	1.5:1	150
AMF-4F-170175-15-10P	17–17.5	30	0.5	1.5	+10	1.5:1	150
AMF-4F-175220-20-10P	17.5–22	27	1.5	2	+10	2.0:1	150
AMF-4F-177197-15-10P	17.7–19.7	28	1.0	1.5	+10	2.0:1	150
AMF-4F-180200-15-10P	18–20	27	1.0	1.5	+10	2.0:1	180
AMF-4F-180220-19-10P	18–22	27	1.5	1.9	+10	2.0:1	180
AMF-4F-210240-20-10P	21–24	26	1.5	2	+10	2.0:1	180

For additional information and full specification data sheets, please contact Phil Kalisiak at extension 291, or Mark Albert at extension 389.

NEW In MITEQ's AMF Product Line

MODEL NUMBER	OPERATING FREQUENCY (GHz)	GAIN (dB) (Min.±)	GAIN FLATNESS (±dB, Max.)	NOISE FIGURE (dB, Min.)	OUTPUT POWER AT 1 dB COMPR. (dB, Max.)	VSWR IN/OUT (Max.)	DC POWER AT +15 V (Nom.)
MODERATE BAND TO OCTAVE BAND MEDIUM POWER AMPLIFIERS							
AMF-4F-005010-40-33P	0.5–1	40	1.5	4	+33	2.0:1	1400
AMF-4F-005020-40-33P	0.5–2	40	2.0	4	+33	2.0:1	1400
AMF-4F-010020-40-33P	1–2	40	1.5	4	+33	2.0:1	1400
AMF-4B-020040-50-33P	2–4	32	2.0	5	+33	2.0:1	1700
AMF-7B-020080-100-33P	2–8	30	2.0	10	+33	2.0:1	3200
AMF-6B-040080-60-33P	4–8	38	2.0	6	+33	2.0:1	2200
AMF-7B-080124-70-33P	8–12.4	40	2.0	7	+33	2.0:1	2200
AMF-7B-060180-70-29P	6–18	30	2.0	7	+29	2.0/2.3	2800
AMF-7B-080180-70-30P	8–18	30	2.0	7	+30	2.0/2.3	2800
AMF-7B-120180-70-30P	12–18	30	2.0	7	+30	2.0:1	2800
AMF-7B-180265-95-23P	18–26.5	25	2.0	9.5	+23	2.0/2.3	1000
MODERATE BAND POWER AMPLIFIERS							
AMF-4B-012014-40-37P	1.2–1.4	45	1.0	4	+37	2.0:1	3000
AMF-4B-016017-40-37P	1.6–1.7	45	1.0	4	+37	2.0:1	3000
AMF-4B-037042-50-37P	3.7–4.2	40	1.0	5	+37	2.0:1	3000
AMF-5B-044050-50-37P	4.4–5	40	1.0	5	+37	2.0:1	3500
AMF-5B-049051-50-37P	4.9–5.1	40	1.0	5	+37	2.0:1	3500
AMF-5B-053059-50-37P	5.3–5.9	40	1.0	5	+37	2.0:1	3500
AMF-5B-059064-50-37P	5.9–6.4	35	1.0	5	+37	2.0:1	3500
AMF-5B-064072-60-37P	6.4–7.2	35	1.0	6	+37	2.0:1	3500
AMF-5B-071079-60-37P	7.1–7.9	30	1.0	6	+37	2.0:1	4000
AMF-5B-077085-60-37P	7.7–8.5	30	1.0	6	+37	2.0:1	4000
AMF-6B-085096-60-37P	8.5–9.6	35	1.0	6	+37	2.0:1	4500
AMF-6B-095105-70-37P	9.5–10.5	35	1.5	7	+37	2.0:1	4500
AMF-6B-107117-70-37P	10.7–11.7	30	1.5	7	+37	2.0:1	4500
AMF-6B-117127-70-37P	11.7–12.7	30	1.5	7	+37	2.0:1	4500
AMF-6B-127132-70-37P	12.7–13.2	30	1.5	7	+37	2.0:1	4500
AMF-7B-140145-80-37P	14–14.5	30	1.5	8	+37	2.0:1	4800
AMF-7B-145150-80-37P	14.5–15	30	1.5	8	+37	2.0:1	4800
AMF-7B-180240-80-24P	18–24	25	2.0	8	+24	2.0/2.3	1100
AMF-7B-275300-120-20P	27.5–30	25	1.5	12	+20	2.0/2.3	1500
LOW NOISE AMPLIFIERS FOR CRYOGENIC APPLICATIONS							
AMF-3F-017034-10K-CRYO	1.7–3.4	30	1.0	10 K	+5	2.0:1	+3V@25
AMF-3F-040060-20K-CRYO	4–6	30	1.0	20 K	+5	2.0:1	+3V@50
AMF-3F-095105-30K-CRYO	9.5–10.5	25	1.0	30 K	+5	2.0:1	+3V@75
AMF-3F-080180-75K-CRYO	8–18	18	1.0	75 K	+5	2.0:1	+3V@75
LOW NOISE AMPLIFIERS WITH LIMITER PROTECTED INPUTS							
AMF-3F-002005-07-L	0.25–0.5	40	1.0	0.7	+10	2.0:1	200
AMF-3F-005010-06-L	0.5–1	40	1.0	0.6	+10	2.0:1	200
AMF-3F-010020-05-L	1–2	38	1.0	0.5	+10	2.0:1	200
AMF-2F-020040-06-L	2–4	35	1.0	0.6	+10	2.0:1	150
AMF-3F-040080-12-L	4–8	27	1.0	1.2	+10	2.0:1	125
AMF-4F-080120-13-L	8–12	32	1.0	1.3	+10	2.0:1	125
AMF-4F-120180-20-L	12–18	30	1.0	2.0	+10	2.0:1	125
SATELLITE COMMUNICATION BAND WAVEGUIDE LNAs							
AMFW-7S-340420-30	3.4–4.2	60	0.5	30 K	+10	1.25/1.5	200
AMFW-7S-725775-50	7.25–7.75	60	0.5	50 K	+10	1.25/1.5	150
AMFW-6S-109127-65	10.95–12.75	50	1.0	65 K	+10	1.25/1.5	150

MITEQ

TEL (516) 436-7400
FAX (516) 436-7430
100 Davids Drive, Hauppauge, NY 11788

INFO/CARD 60

Estimating radiated emissions from electronic products

By Peter Vizmuller
RHR Laboratories

Because the usual strategy of testing a prototype unit followed by implementing design changes is carried out after the mechanical package has been defined, the discovery of radiated emissions can seriously delay product development. Mechanical redesign at such a late stage is costly and time-consuming. A better strategy is to anticipate radiated emissions early in the design cycle and to analyze the proposed product package as if it were an antenna.

Experienced design engineers and managers are familiar with the challenge of controlling radiated emissions, especially in products destined for the international market. Product designers typically rely on the past experience of testing and design iteration. Although experience is valuable, it does not necessarily guarantee success. The three biggest stumbling blocks to faster product development may be meeting the radiated emissions specifications; designing power amplifiers (PAs); and developing software. Other steps in product development effort, such as circuit design, circuit-board layout and system design, have become much easier because of the availability of many excellent computer simulation and optimization tools. However, because of the complexity of the physical processes involved, software for predicting radiated emissions and high-power PA stability has been slow in coming.

Increasing computing power and the availability of advanced symbolic mathematical software are making it possible to estimate radiated emissions. A two-step approach relies on obtaining the magnitude of exposed RF currents, and then using antenna theory to estimate the electric field strength at a certain distance from those currents. Design experience still is required for the first step of estimating currents exposed to free space, and computer simulation is required for the second step—reducing the complex antenna equations into usable numbers. This two-step technique for predicting radiated emissions analyzes three common radiating structures using a commercially available software program.

A certain frame of mind is required to tackle radiated emissions. We typically are not trained to think of circuit boards, connectors, wires or boxes as antennas. We do not commonly ask the question, "What is the directivity of our product?" at design review meetings. We need to expect and to anticipate radiation caused by the overall packaging, accessories and cable routing. Highly accurate prediction of radiated emissions seldom is required for two reasons. First, when you start looking at radiation, you will discover that you are more likely to be 30 dB out of specification than 3 dB out of specification, and even the most basic simulation of radiated emissions can be of great value in highlighting problem areas. Second, radiated emissions are highly variable when measured; radiation is simply a physical characteristic that usually is not repeatable. Therefore, designers typically aim for 10 to 15 dB of margin on the desired specification, and five-digit accuracy on the calculated numbers is unnecessary.

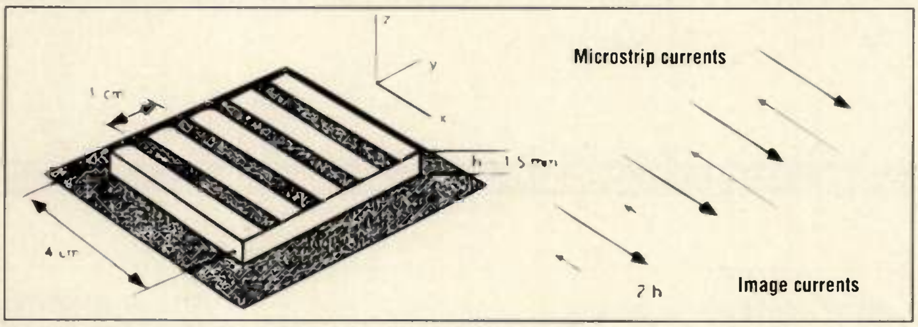


Figure 1. Every exposed circuit-board trace is a potential radiator.

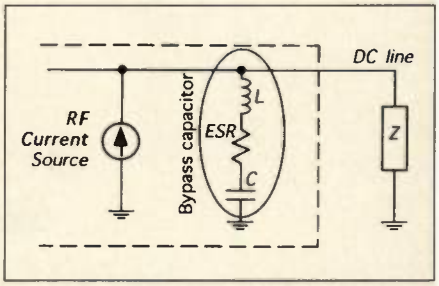


Figure 2. Bypassed external DC line. For worst-case circuit analysis, assume Z = 0, i.e., line is resonant, and bypass capacitor is ineffective.

Estimating exposed RF currents

By classifying the generation of radiating currents into four categories, the estimation of such currents is not intrinsically difficult.

1. All currents flowing on unshielded, exposed circuit boards are radiating currents. There is a common misconception that a matched microstrip line does not radiate. This is not true. Any AC current will radiate at some level if exposed to free space. Conventional circuit analysis can be used to obtain the frequencies and amplitudes of currents flowing in circuit-board traces. Another misconception is that once currents flow into ground, they can be neglected. This is not true. Ground currents will radiate, if allowed to flow on the outside surfaces of a shield. Consider ground as a low-inductance return path. If the return ground path is far from the forward signal trace, both will radiate most effectively (Figure 1).

2. RF currents are conducted to exterior wires and connectors from internal circuit boards. Conventional circuit analysis can effectively predict RF currents flowing on DC or audio leads, provided that parasitic components, such as capacitor equivalent series resistance (ESR), series inductance and inductor capacitance are modeled accurately (Figure 2).

3. Multiple-ground return pathways

ULTRA-LINEAR
50W AMPLIFIERS

20 to 512MHz *only* $1995 (1-9)

Worry free operation and a mountain of advanced features make Mini-Circuits high power LZY-1 amplifiers incredibly easy to use! Unconditionally stable, these amplifiers have their own heat sink and fan for cool operation while automatic electronic cutoff protects against overload and burnout. At 20W output, non-linearity is 0.3dB (typ) and harmonic distortion is better than -32dBc (typ). These ultra-linear LZY-1 amplifiers are very versatile too. Applications include land mobile, FM broadcast, amateur and military radio, paging, and high power testing of components. Compare this $1995 amplifier to units costing much more. You'll see why Mini-Circuits LZY-1 is the powerful choice!

LZY-1 SPECIFICATIONS:

Frequency (MHz)	20-512
Gain (dB)	
Minimum	39
Flatness Max	±1.5
Power (dBm)	
Max. Output (Typ)	+47
Min. Output (1dB Comp)	+44
Max. Input (no damage)	+10
Dynamic Range (Typ)	
NF (dB)	8.6*
IP3 (dBm)	54
VSWR Input	2.0:1
DC Power	
Volt V.	+26
Max. Current (A)	7.3**

*80-512MHz, at 20MHz 11.6dB (Typ)
**At 25W output; includes fan

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

Mini-Circuits®

US 54 INT'L 64
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www. minicircuits. com

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

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

F 217 Rev A

exist. If the ground plane under a microstrip line is continuous, the return current flowing through it will tend to reduce radiation because of the signal trace. This occurs because the two currents are of equal amplitude, they flow in opposite directions, and they are located close to each other. Return current flowing through multiple pathways has two detrimental effects on radiation. First, the signal-trace current no longer is equal in amplitude to the immediately adjacent ground current, and it will radiate. Second, large ground loops will themselves be good radiators. The problem of multiple ground pathways is easier to solve than toanalyze. Nevertheless, low-cost transverse electromagnetic (TEM) field simulators can be used to simulate transmission lines with multiple ground returns and to obtain currents on all relevant surfaces (Figure 3).

4. Radiating currents can flow on components and miscellaneous structures. Even with all connections buried on inner layers of a multilayer board, radiation can occur because of currents flowing in coils, component and IC leads, fuses, crystal cases and light-emitting diodes (LEDs). Currents can also flow on the outside braid of a coaxial cable, most likely when the electrical length of the cable is a multiple of a half-wavelength.

Digital circuits must be included in this search for radiating currents. In fact, digital circuits frequently are laid out with less regard to grounding than RF circuits. Estimation of radiating currents can benefit from a healthy dose of Murphy's law. Assume that all digital signals are perfect square waves with amplitude of their Fourier components decreasing at 6 dB per octave. Assume that all structures (especially wires) are resonant, and that ungasketed seams in metal covers allow some current to leak to the outside.

The physical arrangement of radiating currents has great influence on the efficiency of radiation. Figure 4 shows the possible current flow arrangements, their calculated E-field values and 3D radiation patterns.

RF currents flowing on exposed wires and connectors also can be measured directly by means of close-field probes, current probes, or by measuring the voltage drop across a known in-line impedance using a vector voltmeter. Those measured currents then can be used as inputs to estimate the magnitude of the far-field radiation without having to measure the equipment at a radiation site.

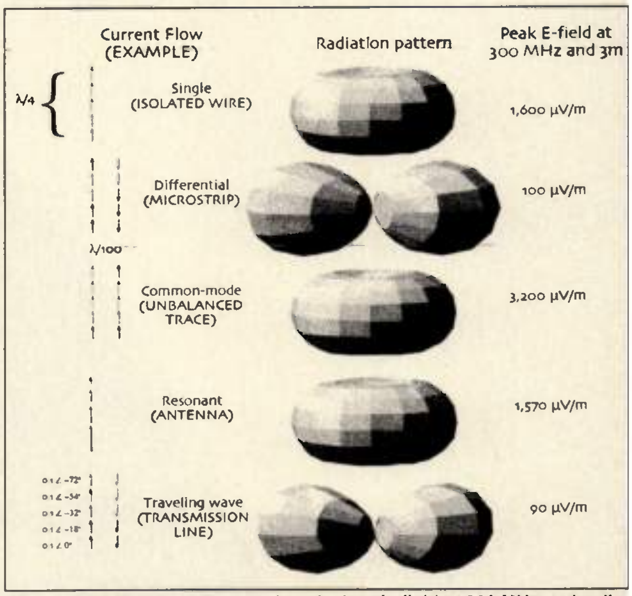


Figure 4. Radiation pattern and peak electric field at 300 MHz and a distance of 3 meters as a function of current flow pattern. The 0.1 mA current elements are 0.05λ long and 0.01λ apart. Total length = 0.25λ.

Basic antenna theory

The formula for the far-field radiation pattern of a short dipole has been known for a long time and is part of every college course on antennas [1].

$$E = \frac{30 I \beta}{r} e^{j(\omega t - \beta r)} \sin(\theta) \tag{1}$$

where:

E = electric field in V/m
I = current in amperes
β = $2\pi/\lambda$
r = distance in meters
ω = radian frequency = $2\pi f$
θ = spherical coordinate azimuth angle in radians

The composite radiation of a collection of current elements is the vector sum of all the instantaneous individual contributions. Despite the conceptual simplicity of this radiation model, the actual mathematical formulas are surprisingly complicated. The simple formula shown in equation (1) only applies in the special case of a current element of zero phase located at the origin and pointing in the z-direction. The formula for the far electric field of a short current dipole not at the origin, of any phase and orientation in space, can be obtained by expressing each current element by its three x-, y- and z-components, and by calculating the E_θ and E_φ spherical coordinate components of the electric field due to each of the x-, y- and z-components of current. The overall electric field is then the complex sum (i.e., including effects of phase angles) of all the contributions. This general dipole formula has more than a dozen terms and has been programmed into the product. The mathematical and user interface is provided by Theorist, a symbolic mathematical environment. The product is actually a Theorist Notebook, which means that all the power of Theorist can be applied to view the formulas, generate new plots, change units or include user formulas for additional calculations.

Once the electric field at a certain location is available, the power density and magnetic field are calculated as:

$$S = \frac{E^2}{2\eta} \tag{2}$$

$$H = \frac{E}{\eta} \tag{3}$$

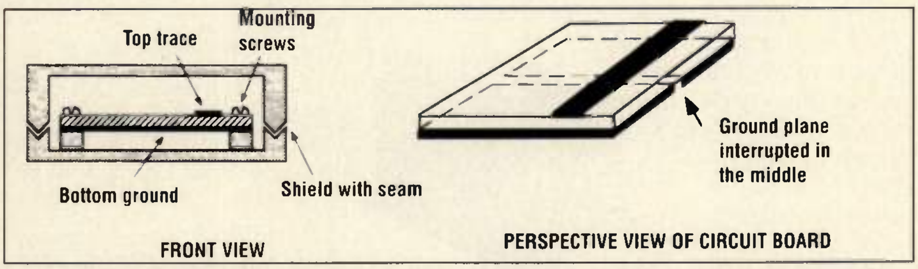


Figure 3. If the microstrip ground plane is interrupted, ground return currents are forced to flow through enclosures and along seams.

where:

- S = time-averaged power density in W/m2
- E = peak (not rms) electric field amplitude in V/m
- η = impedance of free space, 376.73Ω
- H = peak magnetic field amplitude in A/m

The product generates 3D plots of the overall E-field radiation pattern, which can be rotated in real time to find the peaks. Conventional 2D polar and rectangular plots of electric field, magnetic field and power density at the desired distance and frequency also are provided as functions of elevation and azimuth angles.

Example 1: Current carrying trace, or interconnect cable — Let's examine an isolated current element 0.1λ long at 600 MHz and determine the maximum allowed current for an electric field specification of 500μV/m at a distance of 3 meters (Figure 5). The radiation pattern is doughnut-shaped, with maximum radiation perpendicular to the current element. Peak electric field amplitude of 500 μV/m at a distance of 3 meters results from a peak current flow of 0.08 mA, or 80 μA. Now we can appreciate the difficulty of meeting the radiated specifications. Current as low as 80 μA produces measurable radiation; 80μA corresponds to about –35 dBm on a 50 Ω line.

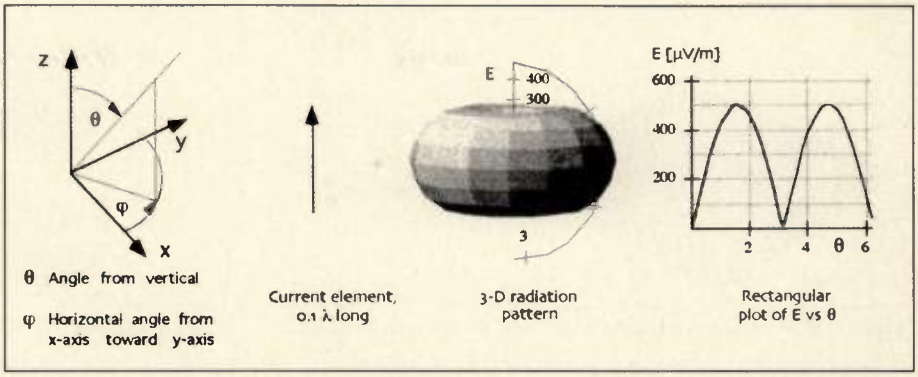
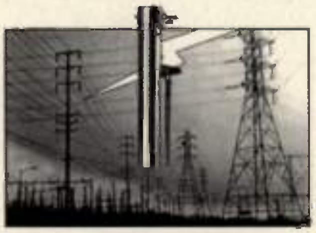


Figure 5. Peak electric field strength radiated from 0.1λ long current element flowing in the z-direction at 600 MHz and a distance of 3 meters.

Example 2: Microstrip line — A certain length L = 0.1λ of microstrip line lies along the y-axis, carries peak current of 10 mA at 300 MHz and is separated from an infinite ground plane by spacing h = 1.5 mm. As a first approximation, we will neglect the trace width and the dielectric constant of the substrate. If the ground plane is perfectly conducting and infinite in extent, we



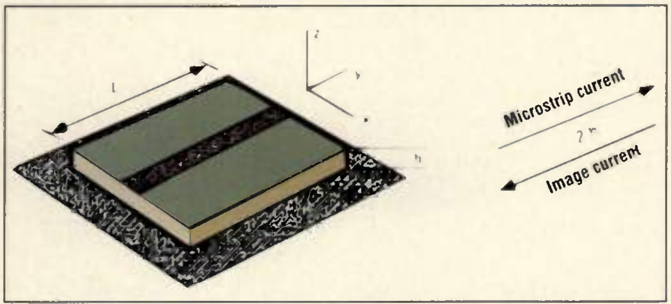


Figure 6. Microstrip trace along the y-axis, and its image representation.

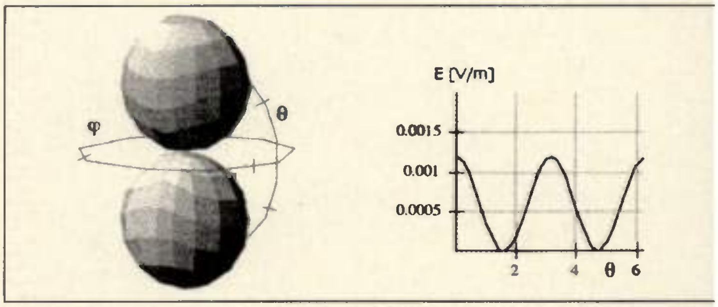


Figure 7. Radiation pattern and E-field plot for microstrip line 0.1λ long at 300 MHz.

can model the microstrip line by a current and its image, separated by 2h from each other (Figures 6 and 7). The maximum radiation occurs in the positive z-direction, perpendicular to the trace, and there is a null in the $\theta = \pi/2$ plane, i.e., the xy plane containing the microstrip line.

The electric field magnitude reaches 1.2 mV/m at its maximum, which certainly is not negligible, and in fact may violate some regulatory requirements. Thus, a microstrip line will radiate if exposed to free space. Radiation from microstrip lines will be greatly enhanced if the ground plane underneath is not continuous. Thin circuit boards will radiate less because the main and image currents flowing in opposite directions are closer to each other.

Example 3: Radiation from edge of circuit board — Four through-hole vias connecting top and bottom ground planes each carry 1 mA of ground current. The circuit-board edge is not plated, and the board will be sandwiched between top and bottom covers. The edge of the board with the four via holes is to be analyzed for potential radiation at 300 and 600 MHz (Figures 8 and 9). The calculated results are surprising. This structure is a fairly good radiator with peak radiation straight out of the board edge slot. The radiated pattern is similar to that of Figure 5. The electric field is near 400 μV/m at 300 MHz and grows with frequency to 750 μV/m at 600 MHz.

Densely placed ground holes are no guarantee against radiation, if those vias carry current near the edge of the board. Using multiple rows of vias helps to move the ground current away from the edge of the board. The two ground planes (one on top, and another on bottom of the board) then form a waveguide-beyond-cutoff structure, which further attenuates the energy reaching the open edge of the circuit board.

Conclusion

The ability to estimate radiated emissions early in the design cycle has great practical and educational value. Alternate packaging, bypassing and interconnect schemes can be evaluated at a much lower cost than measuring prototypes at a radiation site. The radiated emission modeling software shifts the design focus from measuring prototypes to accounting for exposed currents because of inadequate bypassing or poor layout practices. **RF**

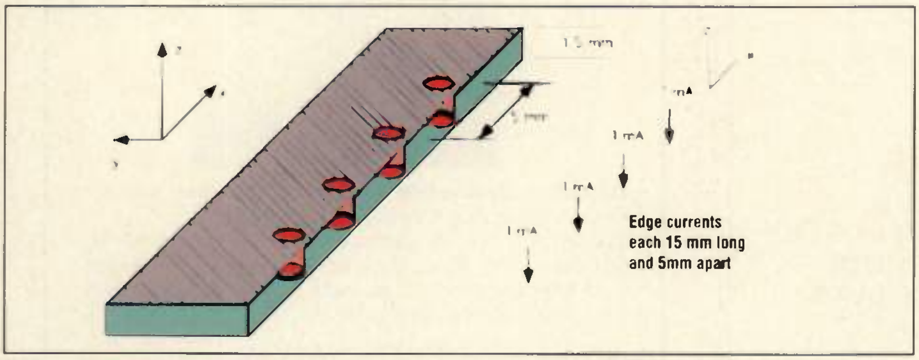


Figure 8. Row of plated-through vias at the edge of a circuit board at 600 MHz.

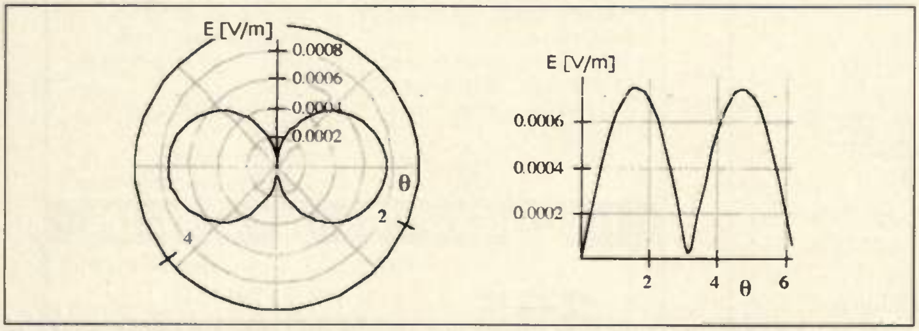


Figure 9. Polar and rectangular plots of peak electric fields in the vertical plane radiated by four ground vias at the edge of a circuit board.

Reference

1. Kraus, J. D. and K. R. Carver, *Electromagnetics*, McGraw-Hill, New York, 1973.

About the Author

Peter Vizmuller earned his M.S.E.E. from the University of Toronto in 1981. He designed high-performance RF circuits and systems as a staff engineer at Motorola. Since the publication of his reference book, *RF Design Guide: Systems, Circuits, and Equations*, he has become a consultant developing software models for designing reliable communication systems and for predicting radiated emissions. Tel. 905-884-2392. The software described in this article, "REM (radiate emissions modeling) Software," is available from RHR Laboratories, http://iypn.com/rhrlaboratories. The author can be reached at 104673.3110@compuserve.com.

ENGINEER'S NOTEBOOK

Feedback improves AGC amplifier harmonic performance

By Christopher Trask
ATG Design Services

Among the building blocks that system designers encounter, the automatic gain control (AGC) amplifier is right alongside mixers when it comes to intermodulation and harmonic generation. Both blocks are essential to the design of a radio system, be it a receiver or transmitter.

For AGC amplifiers, there are two general forms: *positive intrinsic negative* (PIN) diodes and *variable transconductance amplifiers*. The latter form has been with us for decades. The earlier vacuum tube technology focused on variable-µ pentodes such as the 6AU6 and 6BA6. In these devices, the distortion predominantly was caused by the non-linearity of the transconductance curve along the load line.

Latter-day transistor technology introduced another vehicle for distortion, this being the exponential transfer characteristics of the diode (in the case of diode mixers) and the base-emitter junction of the transistors used as either amplifiers or mixers. When used as variable transconductance amplifiers, this non-linearity is additional to the non-linear transfer characteristics of the device, and the distortion is far greater than with the earlier vacuum tube models.

By using a matched pair of transistors in a push-pull (or differential) configuration, we realize certain advantages [1]:

1. Even harmonics and even-order combination frequencies cancel at the output.
2. No fundamental frequency energy appears at the power source, thus minimizing the need for bypassing.
3. Common-mode signals, such as power supply noise, are balanced out by the output transformer.

All of these advantages depend on the assumption that both transistors are perfectly matched, and that both the input and output transformers are perfectly constructed, which is rarely the case. A remedy for real-world (i.e., less-than-perfect) implementations appears in literature pertaining to vacuum tube balanced amplifiers [2, 3]. The explanation is quite simple: Regardless of its construction, the center point of the output transformer is a summation node that has voltages relating to the imbalance of the two sides of the amplifier (in terms of odd-order content) as well as the sum of even-order signals (common-mode noise and even-order harmonics). By applying these voltages

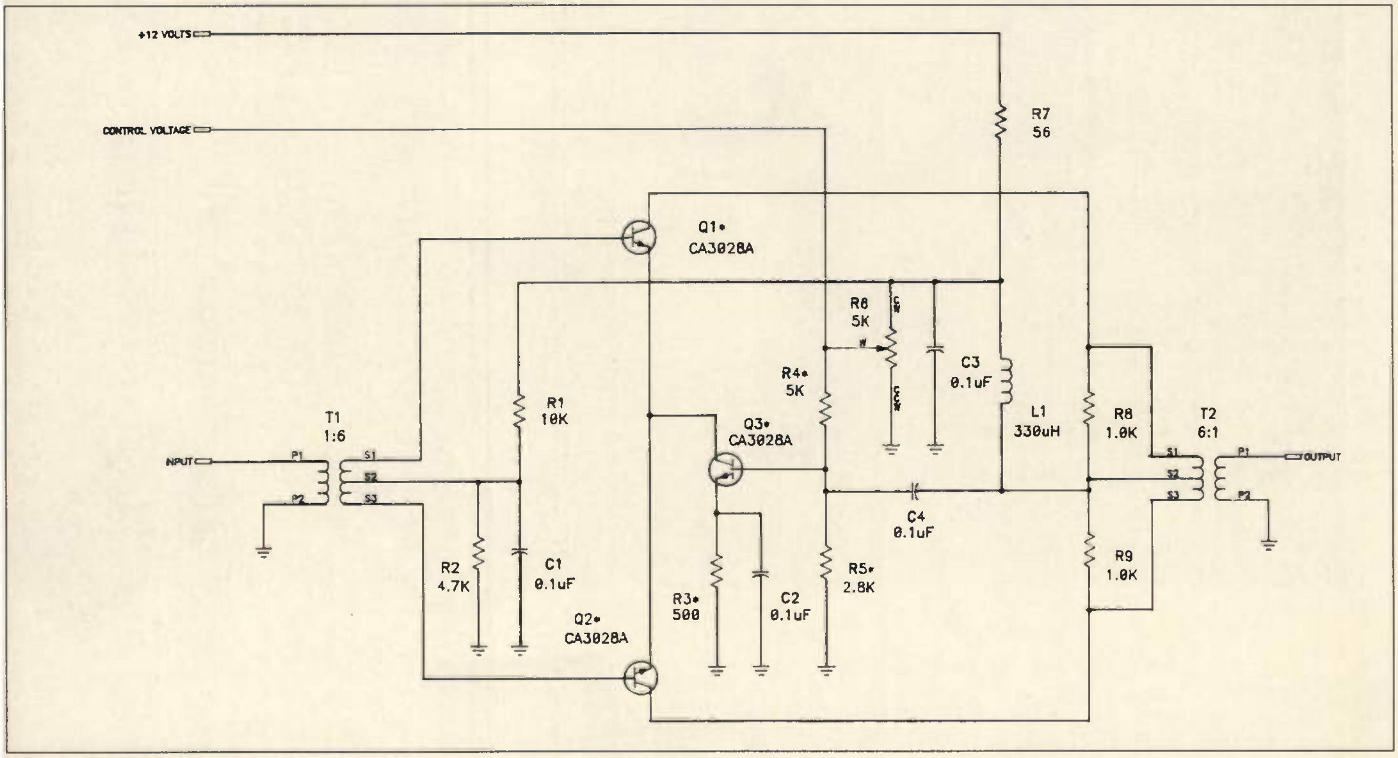


Figure 1. The CA3028A used as the test circuit.

FILTERS

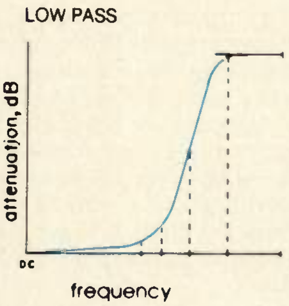
low pass, high pass, bandpass

• less than 1dB insertion loss • greater than 40dB stopband rejection • surface mount • BNC, Type N, SMA availab
• 5-section, 30dB/octave rolloff • VSWR less than 1.7(typ.) • rugged hermetically sealed pin models • constant pha
• meets MIL-STD-202 tests • over 100 off-the-shelf models • immediate delivery

Mini-Circuits RF/IF Surface Mount Designer's Guide features 48 pages of the most up-to-date and complete product and specification information about Mini-Circuits surface mount components. The RF/IF Microwave Handbook is packed with 740 pages of articles, selection guides and detailed specifications for Mini-Circuits components.

Call, write or fax for your free Surface Mount Designer's Guide and Handbook today!

dc to 3GHz from $11.45



low pass, Plug-in, dc to 155MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
•★LP-1.9	DC-1.9	3.4-4.7	4.7-200
•★LP-2.5	DC-2.5	3.8-5.0	5.0-200
★LP-5	DC-5	8-10	10-200
★LP-10.7	DC-11	19-24	24-200
★LP-21.4	DC-22	32-41	41-200
★LP-30	DC-32	47-61	61-200
★LP-50	DC-48	70-90	90-200
★LP-70	DC-60	90-117	117-300
★LP-90	DC-81	121-157	157-400
★LP-100	DC-98	146-189	189-400
★LP-150	DC-140	210-300	300-600

dc to 1200MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
★LP-200	DC-190	290-390	390-800
★LP-250	DC-225	320-400	400-1200
★LP-300	DC-270	410-550	550-1200
★LP-450	DC-400	580-750	750-1800
★LP-550	DC-520	750-920	920-2000
★LP-600	DC-680	840-1120	1120-2000
★LP-750	DC-700	1000-1300	1300-2000
★LP-800	DC-720	1080-1400	1400-2000
★LP-850	DC-780	1100-1400	1400-2000
★LP-1000	DC-900	1340-1750	1750-2000
★LP-1200	DC-1000	1620-2100	2100-2500

All models priced qty. 1-9 ($ea.), Conn. Type P = 11.45, B = 32.95, S = 34.95, N = 35.95
• Exceptions: ★LP-1.9 P = 13.95, B = 34.95, ★LP-2.5 P = 14.95, B = 35.95
On both models, add following to B price: $3.00 for N, $2.00 for S
75 ohm versions available

Surface-mount

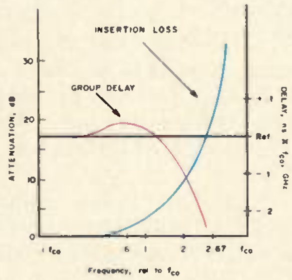
dc to 108MHz

SCLF-5	DC-5.0	8-10	10-200
SCLF-8	DC-8.0	12.5-16.5	16.5-200
SCLF-10.7	DC-11	19-24	24-200
SCLF-21.4	DC-22	32-41	41-200
SCLF-25	DC-25	36-47	47-200
SCLF-30	DC-30	47-61	61-200
SCLF-45	DC-45	70-90	90-200
SCLF-95	DC-95	146-189	189-400

dc to 1200MHz

SCLF-135	DC-135	210-300	300-600
SCLF-190	DC-190	290-390	390-800
SCLF-225	DC-225	340-440	440-1200
SCLF-380	DC-380	580-750	750-1800
SCLF-420	DC-420	750-920	920-2000
SCLF-550	DC-550	800-1050	1050-2000
SCLF-700	DC-700	1000-1300	1300-2000
SCLF-1000	DC-1000	1620-2100	2100-2500

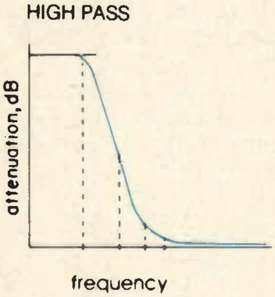
Price: SCLF 21.4–SCLF 420 $11.45 ea. SCLF-8, 10.7, 550, 700, 1000 $12.95 ea. SCLF-5 $14.95 Qty. (1-9)



Flat Time Delay, dc to 1870MHz

Model No.	Passband MHz loss < 1.2dB	Stopband MHz loss >10dB	Stopband MHz loss >20dB	VSWR Freq. Range, DC thru 0.2fco X	VSWR Freq. Range, DC thru 0.6fco X	Group Delay Variations, ns Freq. Range, DC thru fco X	2fco X	2.67fco X
★BLP-39	DC-23	78-117	117	1.3:1	2.3:1	0.70	4.0	5.00
★BLP-117	DC-65	234-312	312	1.3:1	2.4:1	0.35	1.4	1.90
★BLP-156	DC-94	312-416	416	1.3:1	1.1:1	0.30	1.1	1.50
★BLP-200	DC-120	400-534	534	1.6:1	1.9:1	0.40	1.3	1.60
★BLP-300	DC-180	600-801	801	1.25:1	2.2:1	0.20	0.6	0.80
★BLP-467	DC-280	934-1246	1246	1.25:1	2.2:1	0.15	0.4	0.55
▲BLP-933	DC-560	1866-2490	2490	1.3:1	2.2:1	0.09	0.2	0.28
▲BLP-1870	DC-850	3740-5000	5000	1.45:1	2.9:1	0.05	0.1	0.15

Price, (1-9 qty), all models: plug-in $19.95, BNC $36.95, SMA $38.95, Type N $39.95
NOTE: ▲ -933 and -1870 only with N and SMA connectors.



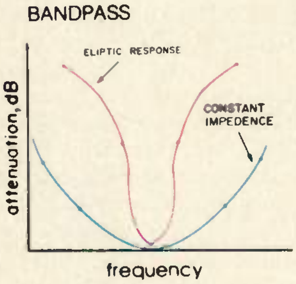
high pass, Plug-in, 13 to 1200MHz

Model No.	Stopband MHz loss > 40dB	Stopband MHz loss > 20dB	Passband, MHz loss < 1dB	VSWR Pass-band Typ.
★HP-25	DC-13	13-19	27.5-200	1.7:1
★HP-50	DC-20	20-26	41-200	1.5:1
★HP-100	DC-40	40-55	90-400	1.5:1
★HP-150	DC-70	70-95	133-600	1.8:1
★HP-175	DC-70	70-105	160-800	1.5:1
★HP-200	DC-90	90-116	185-800	1.6:1
★HP-250	DC-100	100-150	225-1200	1.3:1
★HP-300	DC-145	145-190	†290-1200	1.7:1

210 to 2200MHz

Model No.	Stopband MHz loss >40dB	Stopband MHz loss > 20dB	Passband, MHz loss < 1dB	VSWR Pass-band Typ.
★HP-400	DC-210	210-290	395-1600	1.7:1
★HP-500	DC-280	280-365	500-1600	1.9:1
★HP-600	DC-350	350-440	600-1600	2.0:1
★HP-700	DC-400	400-520	700-1800	1.6:1
★HP-800	DC-445	445-570	780-2000	2.1:1
★HP-900	DC-520	520-660	910-2100	1.8:1
★HP-1000	DC-550	550-720	1000-2200	1.9:1

Price, (1-9 qty), all models: plug-in $14.95, BNC $36.95, SMA $38.95, Type N $39.95. For ★HP-25, Add $2 ea. †Loss 1.5 dB max.



bandpass, Elliptic Response, 10.7 to 70MHz

Model No.	Center Freq. (MHz)	Passband I.L. 1.5 dB Max. (MHz)	3 dB Bandwidth Typ. (MHz)	Stopbands I.L. > 20dB at MHz	Stopbands I.L. > 35dB at MHz
★BP-10.7	10.7	9.5-11.5	8.9-12.7	7.5 & 15	0.6 & 50-1000
★BP-21.4	21.4	19.2-23.6	17.9-25.3	15.5 & 29	3.0 & 80-1000
★BP-30	30.0	27.0-33.0	25-35	22 & 40	3.2 & 99-1000
★BP-60	60.0	55.0-67.0	49.8-70.5	44 & 79	4.6 & 190-1000
★BP-70	70.0	63.0-77.0	58.0-82.0	51 & 94	6.0 & 193-1000

Price, (1-9 qty), all models: plug-in $18.95, BNC $40.95, SMA $42.95, Type N $43.95

Constant Impedance, 21.4 to 70MHz

Model No.	Center Freq. MHz	Passband MHz loss < 1dB	Stopband loss > 20dB at MHz	VSWR 1.3:1 Total Band MHz
★IF-21.4	21.4	18-25	1.3 & 150	DC-220
★IF-30	30.0	25-35	1.9 & 210	DC-330
★IF-40	42.0	35-49	2.6 & 300	DC-400
★IF-50	50.0	41-58	3.1 & 350	DC-440
★IF-60	60.0	50-70	3.8 & 400	DC-500
★IF-70	70.0	58-82	4.4 & 490	DC-550

Price, (1-9 qty), all models: plug-in $14.95, BNC $36.95, SMA $38.95, Type N $39.95

NOTE: ★**Add Prefix P, B, N, or S for Pin, BNC, N, or SMA connector requirement.**

Mini-Circuits®

US 5 INT'L 74
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www. minicircuits. com

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

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

F 200 Rev Orig

in a feedback path as an error signal, the imbalance of the amplifier can be corrected, thus enhancing the overall performance. This serves to greatly reduce even-ordered harmonics, but it has only a slight effect on odd-ordered nonlinearity products, such as intermodulation distortion.

For a test circuit, I chose the venerable CA3028A [4] because of my familiarity with this device for more than 25 years. Referring to Figure 1, the CA3028A contains the differential pair Q1-Q2, as well as the source transistor Q3. Biasing resistors R3, R4 and R5 also are part of this device. Controlling the collector current of Q1 and Q2 by way of potentiometer R6 provides for the variable gain settings. Transformers T1 and T2 are identical (but not perfectly) and consist of a primary winding of two turns and a secondary of six bifalar turns of No. 34 magnet wire in a Fair-Rite 2843-002-402 balun core [5, 6]. I chose the transformers rather than tuned matching circuits to render the amplifier suitable for wideband operation as well as to reduce the overall cost. The decoupling choke L1 is the only component added to this circuit above what normally would be required for an AGC amplifier of this configuration.

Capacitor C4 is the feedback path for the error signal. Q2 then amplifies this signal, thus providing some current loop gain. When the test is conducted, this capacitor is disconnected at the T2 end and is connected to ground for the purpose of measuring the "without feedback" performance.

Table 1 is a tabulation of the test data taken for this amplifier with –18 dBm of input power at 8.00 MHz. The first column is the applied control voltage measured at the wiper of potentiometer R6. The column labeled P1 is the signal output power, and the columns P2, P3, etc. are the output powers of the respective harmonics. Note that the power of the even-ordered harmonics P2 and P4 is significantly reduced when the feedback is applied, while the signal and the odd-ordered harmonics P3 and P5 are negligibly affected, as we would expect from the earlier discussion.

AGC AMPLIFIER TEST DATA

Differential AGC Amplifier
Transistors: Harris CA3028A Array
Vcc = 12.0 V
25 April 1996

Frequency: 8.00 MHz
Input Power: –18.0 dBm

Control	Without Feedback					With Feedback				
Voltage	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
12.000	10	–54	–8	–62	–20	10	–54	–8	<–64	–20
8.634	8	–34	–7	–60	–19	8	–56	–7	–59	–19
7.524	6	–32	–8	–60	–19	6	–58	–8	–61	–19
6.653	4	–32	–10	–55	–20	4	–59	–10	–61	–20
5.768	2	–32	–12	–51	–21	2	–60	–12	–62	–21
5.061	0	–32	–13	–49	–23	0	–61	–13	<–63	–23
4.519	–2	–32	–15	–48	–24	–2	–62	–15	<–63	–24
4.077	–4	–33	–18	–47	–26	–4	–62	–18	<–63	–26
3.809	–6	–33	–19	–47	–28	–6	–62	–19	<–63	–28
3.550	–8	–34	–21	–48	–30	–8	<–63	–21	<–63	–30
3.272	–10	–36	–23	–48	–31	–10	<–63	–23	<–63	–31
3.050	–12	–37	–25	–49	–33	–12	<–63	–25	<–63	–33
2.873	–14	–38	–28	–50	–35	–14	<–63	–28	<–63	–35
2.727	–16	–39	–29	–52	–37	–16	<–63	–29	<–63	–37
2.649	–18	–40	–30	–53	–38	–18	<–63	–30	<–63	–38
2.540	–20	–42	–33	–54	–40	–20	<–63	–33	<–63	–40
2.452	–22	–43	–35	–56	–42	–22	<–63	–35	<–63	–42
2.367	–24	–46	–37	–58	–44	–24	<–63	–37	<–63	–44
2.303	–26	–48	–39	–59	–46	–26	<–63	–39	<–63	–46
2.234	–28	–50	–41	–60	–49	–28	<–63	–41	<–63	–49
2.199	–30	–52	–42	–61	–50	–30	<–63	–42	<–63	–50

Conclusion

The performance of a variable-transconductance AGC amplifier can be greatly improved with little increase in circuit complexity or cost. By reducing the generation of second harmonic energy in transmitter and signal source systems, the difficulty and complexity of removing these unwanted signals with subsequent filtering is avoided. We also reduce costs and improve system performance. *RF*

References

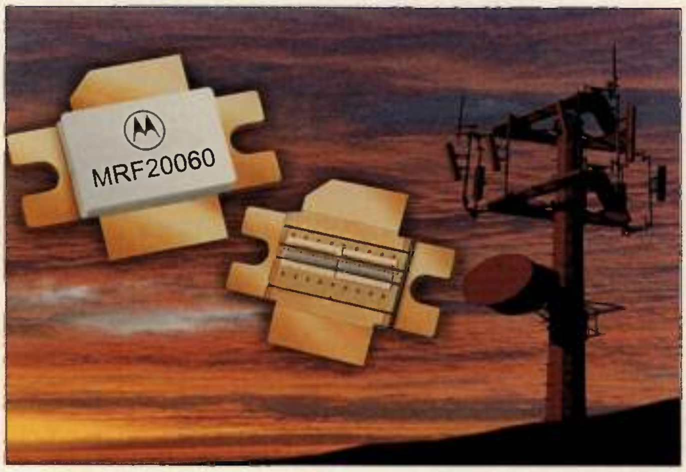
1. Terman, F.E., *Radio Engineers' Handbook*, McGraw-Hill, 1943, Section 5-8.
2. "Balanced Output Amplifiers of Highly Stable and Accurate Balance," E.M.I. Laboratories, *Electronic Engineering*, June 1946, p. 189.
3. Birt, D.R., "Self-Balancing Push-Pull Circuits," *Wireless World*, May 1960, pp. 223–227 and June 1960, pp. 283–285.
4. Kleinman, H.M., "Application of the RCA-CA3028A and CA3028B Integrated-Circuit RF Amplifiers in the HF and VHF Ranges," RCA Application Note ICAN-5337.
5. Ruthroff, C.L., "Some Broad-Band Transformers," *Proc. IRE*, August 1959, pp. 1337–1342.
6. "Use of Ferrites in Broadband Transformers," Fair-Rite Products Catalog, 12th ed., Fair-Rite Products Corp.

About the author

Chris Trask is an independent designer of analog, RF and microwave circuitry, and is the author of ALMOND, which is PC-compatible RF design software. He received B.S.E.E. and M.S.E.E. degrees from Pennsylvania State University in 1973 and 1979, respectively, taking time in between to fly C-130 transports for the U.S. Air Force. He may be reached at P.O. Box 25240, Tempe, AZ 85285-5240 or via E-mail at ctrask@primenet.com

RF sub-micron bipolar transistor for PCS CDMA base stations

Motorola's MRF20060 RF sub-micron linear bipolar transistor is designed for use in personal communications system (PCS) code-division multiple access (CDMA) base station equipment at frequencies from 1.8 to 2.0 GHz. The RF power broadband NPN bipolar device operates at an output power of 60 watts with a power gain of 9 dB (minimum), an efficiency of 33% (minimum) and an intermodulation distortion of –30 dBc (maximum), and it offers guaranteed two-tone performance at 2.0 GHz, 26 V. The MRF20060 represents the first product to ship from COM1, a new advanced communications fabrication facility. The transistor is priced at $200.26 in low volumes.
Motorola Semiconductor
INFO/CARD #153



Multilayer chip inductor

The LL1005, a new series of multilayer chip inductors from Toko America, has a 0402 footprint (1.0mm × 0.5mm) and a profile of 0.5mm. These inductors are ideal for handheld wireless communications equipment, in particular 1.9 GHz PCS devices that require ever shrinking form factors. The LL1005 series is available in

17 inductance values ranging from 1.0 to 27 nH. They feature a laminated ceramic material allowing self-resonant frequencies over 6 GHz, initial tolerances of 10% and 20% at an operating temperature between –40°C to 100°C. They have typical Qs of more than 80 at 1.9 GHz. The LL1005 series is packaged on tape and reel in 10,000-piece quantities.
Toko America
INFO/CARD #154

Surface-mount miniature TCXO

The ES6200 is a series of sinewave surface-mount

temperature-controlled crystal oscillators (TCXOs) that can maintain a frequency stability of ±1.0 ppm from –10°C to 60°C. The high degree of frequency stability is ideal for advanced communications applications that include wireless, global positioning system (GPS), pagers, RF, microwave and Personal Computer Memory Card International Association (PCMCIA) cards. Ecliptek's ES6200 series features a low-profile package (3.9 mm) that offers a practical solution to volume requirements with size constraints. Options include 3V or 5V versions and stability from ±1.0 to ±3.0 ppm.
Ecliptek
INFO/CARD #155

Digital IC test system

HP's 660 MHz compact model is the fastest digital IC production test system currently available for testing emerging new devices used in Rambus and telecommunications applications. The 660 MHz model features the highest throughput and accuracy available with a 20% smaller footprint than typical automated test equipment (ATE) systems. The model provides accuracy of ±50ps and up to 256 I/O channels. The model comes with the HP SmarTest pro-

duction test environment that allows push-button transformation of single device tests into a high-throughput test program. Price varies according to configuration but is approximately $8,650 per pin.
Hewlett-Packard
INFO/CARD #156

Electrically connect circuit boards

T-Tech's through-hole dispensing module allows engineers the opportunity to make double-sided prototype circuit boards without the need for caustic chemicals or plating tanks. The module

uses a copper-filled material called Quick Connect to give users the ability to electrically connect the top and bottom layers of prototype circuit boards. The material is dispensed into the holes drilled by Quick Circuit. It is then oven cured, achieving conductivity through holes or vias. The module can be combined with Quick Circuit models 7000 or 5000, and is retrofittable for most existing Quick Circuit systems. The theoretical resistance is 0.05 Ω per square, and median resistance for many boards is better than 0.05 Ω per hole.
T-Tech
INFO/CARD #157

DISCRETE COMPONENTS

3–50 pF trimmers offer three height options

The CTZ3 series from AVX provides designers of wireless communications systems with several new options in variable capacitors. The CTZ3 series surface-mount chip trimmers measure 4.5 × 3.2 mm with three profile height options (1.8, 1.5 and 0.6 mm). They are available in capacitance values ranging from 3 to 50 pF and feature a high stability version with a ±1% setting drift. Typical pricing ranges from 39 to 45 cents in 1,000-piece quantities.
AVX
INFO/CARD #158

Crystal fits small spaces thanks to 3.5 mm profile

The HC49/S low profile AT cut quartz crystal from Bomar is less than 1/3 the height of the standard HC49/U. Ideally suited for applications where space is a problem, the HC49/S is available in frequencies from 2.5 to 60 MHz. Equivalent resistance values range from 40 to 300 Ω depending upon frequency. The 3.5 mm high crystals are available on tape or reel in either through-hole or surface-mount configurations.
Bomar Crystal
INFO/CARD #159

Crystals boast reliability despite shock, vibration

M-Tron's PT series crystals are designed to operate reliably and hold fast despite severe shock and vibration in the operating environment. The crystals feature a frequency range from 3.58 to 60,000 MHz. Board height is 0.197 ± 0.008 inches with a length of 0.452 ± 0.0016 inches.
M-Tron Industries
INFO/CARD #160

Ceramic trimmer caps suit surface or vertical mount

Voltronics' RF ceramic trimmer capacitors, ranging from 2.0 to 40 pF maximum, are available as 0.35″ round or square trimmers and in surface- or vertical-mount styles. Tuning is more than 180° linear. They are priced at 37 cents in 10,000-piece quantities.
Voltronics
INFO/CARD #161

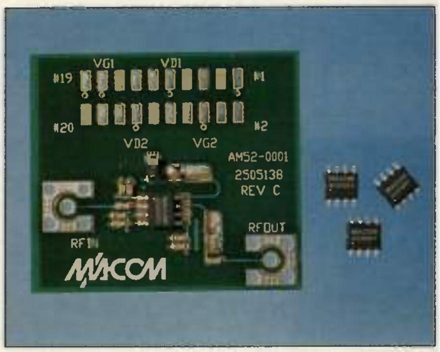
Non-magnetic variable caps for magnetic resonance

The TTNRP variable-capacitors, available from Polyflon, features a virgin PTFE dielectric. These components are non-magnetic, which makes them ideal for applications involving magnetic resonance imaging coils. The TTNRP series features 10 compact designs, each with a diameter of 0.275″ (7.0 mm), a tuning range of 0.8–8 pF on the smallest model to 5–50 pF on the largest. Each capacitor has a 2 kV peak test voltage and a 1 kV peak working voltage.
Polyflon
INFO/CARD #162

AMPLIFIERS

Integrated power amp chips serve cellular subscriber

The AM52-0001 and AM52-0002 from M/A-COM are new microwave and monolithic integrated circuit (MMIC) integrated power amplifier (IPA) chips that meet the design, economics, size and power consumption challenges posed by advanced mobile phone system (AMPS) and global system for mobile communications (GSM) subscriber sets. The chips are designed to replace amplifiers in older discrete or hybrid configurations. The AM52-0001, designed for use in AMPS and cellular digital packet data (CDPD) subscriber



sets, delivers a large signal gain of 24 dB and saturated power output of 1.2 W from 800 to 960 MHz with a DC supply voltage of 4.8 VDC. The AM52-0002, designed for use in GSM subscriber sets, delivers a large signal gain of 25 dB and saturated power outputs from 880 to 915 MHz of 3.5 W with a supply voltage of 5.8 VDC and 2.8 W with a supply voltage of 4.8 VDC.
M/A COM
INFO/CARD #163

Two-stage power amplifier covers dual-mode cellular

The TQ9143 high-efficiency, 1.4 W power amplifier IC is designed for use in dual-mode time-division multiple access (TDMA) or advanced mobile phone system (AMPS) RF transmitters. It operates over the 824 to 849 MHz frequency range. The TriQuint device has two stages of amplification and integrates most of the RF matching on-chip. The input is matched to 50 Ω and the output is matched with a simple network so external components are minimized. In AMPS mode, the TQ9143 provides output power of 31.5 dBm (1.4 W) at a typical power efficiency of 65%. In TDMA mode, the output power is 30 dBm with typical power efficiency of 40%. The TQ9143 is priced at $4.50 in quantities of 100,000.
TriQuint Semiconductor
INFO/CARD #164

Low-noise amplifiers span 1–2.5 GHz with 32 dB gain

Wessex Electronics' models SAO-03001 and SAN-02001 have been designed to meet personal communications network (PCN), personal communications system (PCS) and industrial, scientific and medical bands (ISM) requirements. These small signal, low noise amplifiers (LNAs) are available as connectorized modules with surface mount attachable (SMA) connectors. SAO-03001 can be supplied optimized to cover the 1.7 to 1.99 GHz range, or with marginal specification degrading can cover the 1.0 to 2.5 GHz range. The amplifier has a gain of 32 dB with a typical gain variation against frequency of ±1 dB. The amplifier input/output match is 2.5:1 with a noise figure of 1.5 dB. SAN-02001 spans the 1.71 to 1.785 GHz

Product focus: CAD for circuits

Circuit-board plotter makes high-precision prototypes

The Protomat 95S circuit-board plotter from LPKF CAD CAM Systems is designed to fabricate printed circuit-board prototypes with high levels of precision in fine-pitch technology. Fully automated, the unit features improved accuracy and quality, while reducing prototype development time. Because the Z-axis reference

uses an air-bearing foot, that never touches the printed circuit board (PCB) material, even soft substrates such as Teflon can be processed at higher levels of accuracy.

LPKF CAD CAM Systems
INFO/CARD #174

Circuit design software includes office tools

Compact Software's Serenade version 7.0 CAD/CAM software for designing RF and microwave circuits is written for Windows NT. The software includes schematic and simulator features such as: built-in hierarchical project management with locator display; simultaneous, multiple schematic edit and display capabilities; customizable property dialogs for tailoring information entry, customizable tool bars; coplanar waveguide, microstrip, coaxial and discrete RF component models; enhanced metal semiconductor field effect transistor (MESFET), high-electron mobility transistor and hetero-junction bipolar transistor models; and electronic Smith chart design for graphical design of matching networks for amplifiers and oscillators. The software merges electrical design and physical design tools with office productivity tools for a comprehensive design capability.

Compact Software
INFO/CARD #175

Measurement and analysis software

Anritsu Wiltron, a provider of high-performance test and measurement systems, and Optotek Limited, a supplier of RF and microwave computer aided engineering (CAE)/CAD software have joined forces to offer MMICAD for Windows. The package directly interfaces with Anritsu Wiltron vector network analyzers to measure S-parameters in circuit analysis. The software features a gain compression module that integrates with MMICAD, and has the ability to measure continuous wave. The system features a built-in interface for setting desired test conditions.

Anritsu Wiltron
INFO/CARD #176

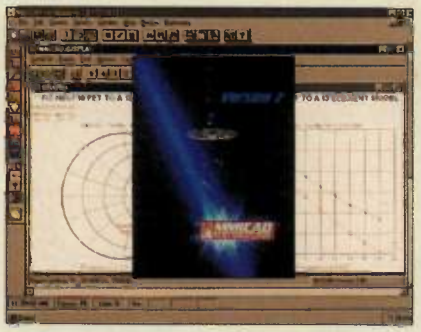
Software sweeps HF design for frequency, input power

Webb Laboratories' SysCad for Windows is an integrated environment for the design of high-frequency receivers and receive and transmit systems. With SysCad, the designer can incorporate amplifiers, multipliers, data blocks, and lumped and distributed elements in single designs. Designs can be swept in both frequency and input power level, with 2D and 3D graphical outputs available in a host of formats. SysCad utilizes the UniSpur spurious analysis engine for exact determination of spurious problem frequencies in transmit and receive systems of one-, two- or three-frequency conversions.

Webb Laboratories
INFO/CARD #177

Linear simulation software imports, exports SPICE

MMICAD version 2 is a Windows-based RF and microwave linear simulation software for the PC. The simulation library includes coplanar waveguide, microstrip, suspended substrate, stripline, ideal elements, RF elements and noise elements models. Expanded design aids cover



capacitor, matching circuit, transmission element, resonator and filter designs. After layout has been optimized, the software can simulate the effect of changes on circuit performance. Import and export capability allows SPICE users to import circuit files. After simulation, the circuit can be exported back to SPICE format.

Optotek Limited
INFO/CARD #178

range. The amplifier has a gain of 13 dB with a typical gain variation against frequency and temperature of ±0.5 dB. The amplifier has a third-order intercept figure of –130 dBm.
Wessex Electronics
INFO/CARD #165

High-power pulse amplifier generates gaussian shaping

A high-power pulse amplifier utilizes the latest digital technologies to generate the required gaussian pulse shaping necessary for TACAN applications. Model CPHC968129-3000 from Comtech operates over the 960 to 1,215 MHz frequency band with adjustable output power from 150 W to 3 kW peak. The amplifier is fully protected and has a soft failure feature. Prime power required is 115/220 VAC single phase, 50/60 Hz.
Comtech Microwave Products
INFO/CARD #166

TEST EQUIPMENT

Cellular modem test system offers network emulation

The GT-Cellular Lite automatic cellular modem test system is a cost-effective, easy-to-use solution for testing cellular modems and other cellular data communications devices. The system from Telecom Analysis Systems (TAS) emulates an end-to-end cellular-to-public switched telephone network (PSTN) communications link and provides performance tests for cellular modems. Standard system components include a wireless communications analyzer, a telephone network emulator, a dual terminal emulator and software. Prices start at $30,000.
TAS
INFO/CARD #167

Test measurement antenna has dual polarized horn

Model DP240 dual polarized horn by Flann Microwave is a multi-active, coaxially fed, quadridged horn offering a high performance over the 2 to 18 GHz frequency band. The DP240 features a 25 dB isolation with low phase and amplitude imbalance between ports. The horn maintains a low voltage standing wave ratio (VSWR), and the electroformed construction ensures a –20 dB maximum cross polarization level. The DP240 is designed for the investigation of electromagnetic compatibility (EMC), antenna measurement and radar cross-section measurement.
Flann Microwave
INFO/CARD #168

Complete EU compliance test solution in a box

BEST 96 from Schaffner is an entire electromagnetic compatibility (EMC) test system in a single package. It is the first complete, self-contained solution to combine all the functions required for full compliance testing of residential, commercial and light-industrial elec-

trical and electronic products. Manufacturers can now complete the entire CE compliance and compliance test procedures in-house. BEST 96 comes complete with everything needed for the entire compliance procedure.
Schaffner
INFO/CARD #169

Ground station amplifier covers 1-10 MHz range

Frequency Electronics' FE-7923A is a 10-channel sinewave distribution amplifier that operates between 1 and 10 MHz. It is designed to meet stringent satellite ground-station requirements. It offers low phase and amplitude noise bursts with isolation in excess of 100 dB. Other features include a unity gain linear operation with a sinusoidal input signal, input and output voltage standing wave ratio (VSWR) less than 1.5:1, high isolation cascode amplifiers for output phase shifts less than 0.001° and operation from a 115 VAC line or 15 VDC.
Frequency Electronics
INFO/CARD #170

SIGNAL SOURCES

Surface mount VCXO fits crowded "real estate"

The F5000 surface-mount, voltage-controlled crystal oscillator (VCXO) from Fox Electronics offers the frequency control features of a traditional through-hole VCXO in a smaller, ceramic surface mount package (0.552" × 0.386" × 0.132"). The F5000 features frequency stability of less than ±50 ppm. The available frequency range is 1–30 MHz. A maximum current draw of 15 mA means low power consumption. The F5000 suits designs requiring a VCXO in a crowded surface mount design.
Fox Electronics
INFO/CARD #171

TCXO package complies with 14-pin applications

Networks International's temperature compensated crystal oscillator (TCXO) for surface-mount applications includes a package footprint that is compatible with standard 14-pin applications. It has a standard operating range of –30°C to 75°C in a frequency range of 9–25 MHz. The TCXO has a stability of ±2.5 ppm, a frequency adjustment of ±3 ppm minimum and clipped sine output waveform.
Networks International
INFO/CARD #172

T3 SMD clock oscillator limits error to 20 ppm

MF Electronics' surface mount design (SMD) clock oscillator for the 44.736 MHz data transmission standard (T3) transmission ensures 20 ppm maximum temperature error (0°C–70°C). It features a 5 × 7 mm footprint, 1.9 mm height and better than 45/55 symmetry. It is designed as a high-stability SMD frequency source for T3. The oscillator also incorporates a 0.1 µF bypass capacitor. The price is $4.05 in original equipment manufacturer (OEM) quantities.
MF Electronics
INFO/CARD #173

RF literature

Catalog includes High-power components

RF Power Components offers a 40-page catalog of high-power resistors and terminations, high-power attenuators, 90° hybrid couplers, high-power directional couplers, high-power dividers and combiners, and custom devices. Outline diagrams are accompanied by application notes and general notes. The catalog also contains resistor and termination technical notes, an inches and millimeters converstion chart and a product index.
RF Power Components
INFO/CARD #179

Catalog details RF, microwave filters

Lark Engineering has a 129-page catalog detailing RF and microwave filters and diplexers in ranges from 100 KHz to 18 GHz. Outline drawings and performance graphs are included.
Lark Engineering
INFO/CARD #180

Two catalogs cover RF, microwave components

Microlab/FXR has two catalogs detailing passive RF and microwave components. The wireless products catalog highlights high-power, low-pass filters; couplers; dividers; and tuners for use in wireless signal transmission applications. The full-line catalog details attenuators, terminations, dummy loads, couplers, DC-blocks, detectors and waveguide products.
Microlab/FXR
INFO/CARD #181

Components catalog includes control products

Micronetics' control components catalog offers solid-state switches, attenuators, phase-shifters, electromechanical switches and detectors. Specifications and descriptions are accompanied by photographs, graphs and diagrams.
Micronetics
INFO/CARD #182

Design guide offers VCO specification help

Wireless Radio's free design guide, *How to Specify Voltage Controlled Oscillators* helps engineers to include the various specifications necessary when selecting a voltage-controlled oscillator (VCO). A fill-in-the-blank guide helps the user to cover all the necessary bases. Applications help may be obtained by mail or fax. The guide is available on the Internet along with other application notes and links to additional technical resources. Wireless Radio offers a free catalog on disk for surface-mount VCOs from 25 MHz to 3 GHz.
Wireless Radio Communications
INFO/CARD #183

News bulletin includes articles, tech notes

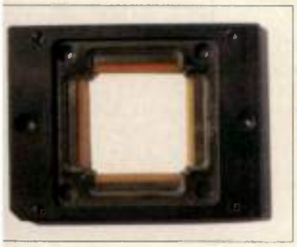
LCF Enterprises' spring news bulletin features technical articles, application notes, news and product infor- mation about small, high-efficiency modules, full turn-key rackmount systems and integrated transmit and receive subsystems with switches, control logic and preamps for mobile, hand-held, battery powered, satellite, laboratory, electromagnetic imaging (EMI), electromagnetic compatibility (EMC) and for general-purpose use.
LCF Enterprises
INFO/CARD #184

Brochure contains manufacturing capabilities

A 16-page, color brochure from Celeritek, discusses the company's engineering development, volume production and manufacturing capabilities and covers products designed for applications including: point-to-point radio; mobile satellite communication; cellular; personal communications systems; and fixed wireless. Also shown are functional block diagrams and electrical specifications of subsystems, transceivers, transmitters, receivers, radios and low-noise and power amplifiers. A section on GaAs-based semiconductor products for wireless commu- nications is included.
Celeritek
INFO/CARD #185

Beginner's guide to DSP

A Simple Approach to Digital Signal Processing (John Wiley & Sons and Texas Instruments) is a 236-page guide for those who need to know about DSP and who have no prior knowledge. The reader is led step-by-step from basic concepts to complex functions including sampling, filtering, transforming signals into the frequency domain, encoding waveforms, data compression, DSP hardware design issues and system design flow.
John Wiley & Sons and Texas Instruments
INFO/CARD #186



RFIC Test Sockets:

w you can test your RF devices and circuits to unmatched accuracy and peatability. Condel Technology offers test sockets with less than .4nH ntact inductance and bandwidths in excess of 10 GHz. Sockets are ailable for all the standard RFIC packages such as TSSOP, SSOP, QFP d we can also make custom machined sockets to fit your unique pack-e or module. These RF test sockets can be used for hand test and inside high volume automated device handler such as Multitest, Daymark or lta. So please call us for your next RFIC socket or fixture requirement.

CONDEL TECHNOLOGY

19925 Stevens Creek Blvd.
Cupertino, CA 95014
Phone: 408-973-7832
Fax: 408-253-9463
e-mail: CondelT@aol.com

INFO/CARD 103

RF POWER AMPLIFIERS

1 MHz-2GHz 1W-1KW

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

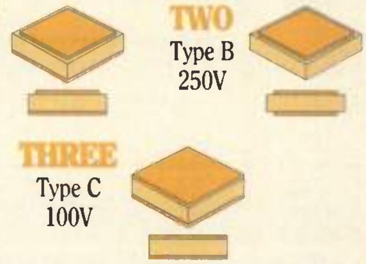
LCF ENTERPRISES
RF POWER AMPLIFIERS

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

INFO/CARD 104

Only TECDIA has THREE!

SINGLE LAYER CHIP CAPACITORS



FOR CAPACITORS WITH:
- Extremely smooth and uniform metalized surfaces
- Pt metalization to withstand 400°C die attach temperature up to 20 min max
- TiW adhesion layer to prevent diffusion and provide stability at very high temperatures

TECDIA

2672 Bayshore Parkway, Suite 702, Mountain View, CA 94043
Tel: (415) 967-2828 Fax: (415) 967-8428

INFO/CARD 105

WIREWOUND CHIP INDUCTORS

- Ideal for Wireless Products
- 1008 & 0805 Models
- High Q & Self Resonant Frequency
- S-Parameters data on disk

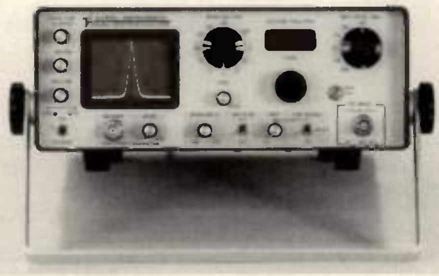
Pulse

USA • Tel: 619 674 8100 • FAX: 619 674 8262
Europe • Tel: 353 93 24107 • FAX: 353 93 24459
Asia • Tel: 65 741 5277 • FAX: 65 741 3013
World Wide Web • http://www.pulseeng.com

INFO/CARD 106

Portable Spectrum Analyzers

PS - 2A Series



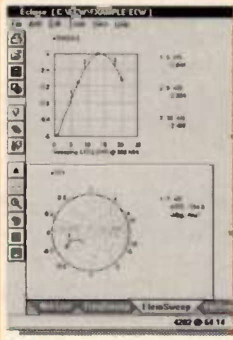
- 0.1 - 1060MHz range in one scan (0 - 100MHz in 11 span widths)
- Measurement range: -108 dBm to +20 dBm
- Fully portable for field operation
- 5 resolution bandwidths (10 KHz - 1 MHz)
- 50 dB input attenutor in 10 dB steps
- 2 / 10 dB scale display with base line clipper
- Multi-turn tuning
- Built-in AM / FM demodulation with speaker
- Digital controlled center frequency display
- Tracking generator (optional PS-2A TG-01)
- AC / DC / Battery powered (optional +12 V battery pack)
- Compact size (10.3" x 4.0" x 12.3") light weight (approx. 10 lbs)

List Price: $2175 *** $1895 *** Introductory offer

V.TECH Instruments, Inc. Tel (201) 546-7635
171 Burns Ave, Lodi, N J 07644 Fax (201) 546-7651

INFO/CARD 107

Eclipse 4.0 for Windows



- Comprehensive Element Library
- User-defined Equations
- Flexible Sweep Capability
- Multiple Graph Sheets
- Manual Element/ Variable Tuning
- Optimization
- Customizable Graphs
- Network Analyzer style Markers

An Unparalleled RF/Microwave Linear Simulator

only $495.00 http://www.ardentech.com for a fully functional demo

Arden Technologies, Inc.
PO Box 286 • Forest, VA 24551
Voice 804-525-6837 Fax 804-525-5376
e-mail: arden@ardentech.com

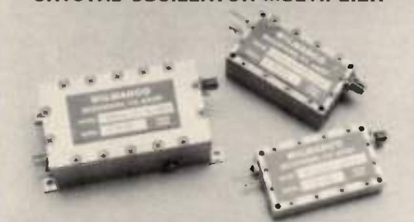
INFO/CARD 108

TARGET YOUR MARKETING!

CALL TERRI STENSON
303-220-4288
FOR RF LITERATURE/ PRODUCT SHOWCASE INFORMATION

LOW COST HIGH PERFORMANCE FREQUENCY SOURCES

CRYSTAL OSCILLATOR MULTIPLIER



✓ MODEL VSA – $195.00 .01 GHz TO 1.0 GHz
✓ MODEL USA – $245.00 1.0 GHz TO 1.8 GHz
✓ MODEL SSA – $295.00 1.8 GHz TO 4.2 GHz

RF OUTPUT: +8dBm min., at any spot frequency in above ranges
FREQ. STABILITY: ±30ppm, -20°c to +60°c
B+: +12 to +16 VDC

Wilmanco 5350 Kazuko Court, Moorpark, CA 93021
(805) 523-2390 FAX (805) 523-0065

INFO/CARD 109

Congratulations Jake!

You found the perfect Signal Generator!

$795
Quantity 1
Made in USA

Features:
- DC-20 MHz, .1Hz steps
- Fully synthesized
- 10 Setup save/recall
- DC offset
- RS232 remote ctrl
- Field upgradable

Modes:
- Sinewave
- Int/Ext AM
- Int/Ext FM
- Int/Ext PM
- Int/Ext SSB
- Int/Ext BPSK
- Linear/Log Sweep
- Int/Ext FSK
- Burst
- DTMF Generation
- DTMF Detection
- Power Level Meas

Telulex Inc. 2455 Old Middlefield Way S
Mountain View, Ca. 94043
Tel: (415) 938-0240 Fax: (415) 938-0241
http://www.telulex.com

INFO/CARD 110

RF marketplace

Classified display ads are available at $125 per column inch. Frequency rates available for multiple insertions. Please call for further information, 303-220-4288. Or fax your ad copy for a rate quote to: (303) 793-0454.

CAREER OPPORTUNITIES

RF ENGINEERS

Aztech Recruitment provides recruiting services to technical clients mainly in the West & South West, but also to other parts of the US, Canada, Europe & the Pacific. We charge no hiring fees to either applicants or employers. If you have a BS/MS/AA degree with relevant experience then mail/fax us your resume with salary indicator.

RF DESIGN/SYSTEMS + RF IC ENGINEERS

This highly successful part of a major international group, a leader in wireless communication systems, seeks qualified, experienced Engineers to help combine core signal processing with advanced VLSI & systems engineering.

RF IC Engineers - for simulation/layout supervision/evaluation of RF IC devices for wireless applications from concept to operation. BS/MSEE with analog/RF integrated circuit design experience, Spice or Harmonic based simulations.

RF DESIGN/SYSTEMS ENGINEERS - design experience in either RF circuits or systems for battery-powered portable systems. Design includes RF amplifiers, mixers, oscillators, etc. (DC to 3GHz); Systems includes RX/TX systems planning, analysis and simulation; both require experience with the latest CAD tools. TDMA/CDMA preferred.

RF/POWER SUPPLY DESIGNERS

For an expanding Rocky Mountain company the technical leader in hi rel plasma, ion and magnetron power processors for the semiconductor/thin film industries. They seek experienced engineers to design RF generators, solid state amplifiers and matching networks; or in high power DC/low frequency AC output SMPS design (30kw-200ks range); or medium power DC SMPS design (300w-10kw range). Candidates require BS/MSEE and a minimum of 5 years relevant design experience, with strong RF skills, knowledge of regulations (UL. VDE. CSA. etc.) and expertise in magnetic, EMI and control loop designs.

AzTech Recruitment Co.

4131 N. 24th Street, Suite A116 • Phoenix, AZ 85016
Call (602) 955-8080 or Fax (602) 955-9639
Email: *aztech@amug.org*
Web Site at: *www.azrecruit.com*

Contact Terri Stenson Today To Find Out More About Classified Display Advertising.

303-220-4288
FAX
303-793-0454

RF design

Join The PCS Revolution!

Join the world's leading companies with Teleconsult. Teleconsult, Inc. is an established international engineering company and has been providing services to its Fortune 500 clients for over 25 years. Great compensation and career opportunities available immediately for experienced wireless professionals (1+ yrs exp.).

DOMESTIC & INTERNATIONAL POSITIONS
PERMANENT AND CONTRACT

CELLULAR-PCS-GSM

- **Design Engineers**
- **Systems Engineers**
- **Switch Engineers**
- **Interconnect Engineers**
- **RF Engineers**
- **RF Technicians**
- **Network/Traffic Engineers**
- **Program Mgrs./Directors**

Send confidential resume to:

Director - Wireless
Fax: (202) 337-7534

Email: 7222652@mcimail.com

Teleconsult Inc.
Teleconsult, Inc. 2715 M. Street, N.W.
Washington, DC 20007

RF ENGINEER

Tegal Corporation is a worldwide leader in the development and manufacture of plasma etch systems for the semiconductor industry and winner of Semiconductor International's 1994 Editor's Choice for Best Product. Tegal is located just north of San Francisco in beautiful Petaluma, CA.

This position is responsible for all aspects of the RF system - including design, development modification impedance metering and evaluation of parts and components.

Qualified candidates will have a BSEE degree with 3-5 years equipment/circuitry experience. Previous related RF communications or semiconductor industry experience preferred. Demonstrated competence in all functional areas is a must.

Tegal offers excellent working conditions. This is an excellent opportunity for the right candidate to join a challenging, progressive and innovative company. For consideration, please send your resume along with salary history to: Tegal Corporation, Attn: PJL, P.O. Box 6020, Petaluma, CA 94953-6020. **Fax** (707) 765-9311. E-mail: plucido@tegal.com. We are an Equal Opportunity Employer.

YOUR RECRUITMENT EFFORT SHOULD START HERE

Go with one of the nation's most established search firms, the leader in the Wireless Industry. We have earned the respect of America's Wireless organizations through a reputation built on experience, integrity and results. Let F-O-R-T-U-N-E work for you.
800.875.2230

f-o-r-t-u-n-e
Communications Group
Div. of Fortune Personnel Consultants
18552 MacArthur Blvd. #345
Irvine, CA 92715
Fax: 714.250.8535
Fax: 714.250.8046

If it's happening in wireless communications, it's happening at Rockwell Semiconductor Systems.

Opportunities in Newport Beach, California and Nice, France.

Rockwell Semiconductor Systems has been an innovator in wireline communications devices for over 15 years. Today, we are the global leader in the data and facsimile modem market. That's just one of the reasons why Rockwell Semiconductor Systems in NEWPORT BEACH, CALIFORNIA and SOPHIA ANTIPOLIS, FRANCE (5 miles west of Nice on the French Riviera) is the place to impact the future of wireless and multimedia communications.

CONNECT with Rockwell

Enjoy exciting challenges as we combine our core signal processing competency with advanced VLSI and systems engineering, supported by our new 200mm wafer fabrication facilities.

If you are qualified in one of the following areas and would like to help us create tomorrow's technology, contact us now!

VLSI ENGINEERING

(Dept. Code: RFD-0801-MB)

RF IC Design Engineer

Responsible for simulation/layout supervision/evaluation of RF IC devices for wireless applications (cellular, cordless and Personal Communication systems). Ensure testability/manufacturability of device designs and successful implementation of RF ICs from concept to operation in the radio module. We prefer a Ph.D. or MSEE (or equivalent) with 3+ years of experience in Analog and RF integrated circuit design (frequency range 0.1-3 GHz using Silicon Bipolar and/or BICMOS processes). Background in Spice and/or Harmonic balance simulators desired.

RF IC Layout Designer

Responsible for custom layout of RF ICs using Silicon Bipolar technology. Knowledge of layout parasitics and their effect on electrical performance is desirable. Must be familiar with UNIX Workstations and Cadence verification tools (DIVA or Dracula). Requires ability to interface effectively with Engineers and work interactively on custom RF IC layouts (including mask set generation).

Senior Logic Design Engineer

Responsible for design of Logic functions in the embedded Flash memories. Flash state machine design experience preferred. A BS/MSEE plus 2-4 years experience in CMOS logic or Memory design required.

Flash Memory Device Engineer

Responsible for performing circuit/logic design on embedded Flash modules, supervising layout design and performing product debugging. Requires MSEE with 2-4 years experience. Hands-on experience in sub-micron Flash memory design preferred.

Mixed Signal/RF Design Methodologist

Proactively champion and evolve the mixed-signal and RF design methodology with a goal of shortening design interval and improving product quality. The individual must have either mixed signal or RF design experience and a background in using commercial CAD tools (capturing, simulation, and layout). We prefer an MS or Ph.D. in Electrical Engineering plus at least 5 years of industrial experience in mixed signal/RF designs.

WIRELESS ENGINEERING

(Dept. Code: RFD-0801-PH)

RF Design Engineers

Requires design experience in RF circuits for low cost, battery-powered portable systems, including RF amplifiers, mixers, oscillators and synthesizers in the range of DC to 3GHz. Experience in the latest RF CAD tools essential. Strong knowledge in communication theory, digital modulation and TDMA/CDMA standards a plus.

RF Systems Engineers

Requires design experience in RF systems for low-cost, battery-operated portable systems, including receiver and transmitter system planning, analysis and simulation using the latest CAD tools. Strong knowledge in communication theory, digital modulation and TDMA/CDMA standards required. Knowledge of RF circuit design techniques a plus.

Rockwell Semiconductor Systems offers an excellent salary and benefits package, and a relocation program tailored to suit your needs. Please forward resume with salary history (indicating position of interest, your geographical preference and the appropriate Dept. Code) to: **Rockwell Semiconductor Systems, Professional Staffing, Dept. Code: (indicate appropriate code from above), 4311 Jamboree Blvd., Newport Beach, CA 92660, USA. FAX (714) 221-6092 or E-mail to resume@nb.rockwell.com**

An Equal Opportunity Employer.

Visit us on the World Wide Web at http://www.nb.rockwell.com/

Rockwell *Semiconductor Systems*

DSP Without Tears®

Learn DSP and put your knowledge to work IMMEDIATELY!

To receive an informative brochure on this popular seminar, call Z Domain Technologies, Inc. at **1-800-967-5034**, 770-587-4812. Hours: 9 - 5 EST. Or E-mail dsp@mindspring.com
Also, a 3-day ADVANCED class in DSP is available on a limited basis -- call for more details.

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

Coming to a City Near You:
Reston VA - San Jose CA - Richardson TX

APEX Wireless, Inc., a leader in the field of low cost Part 15 data communications design, is expanding in Boulder, CO and is seeking a talented . . .

RF Design Engineer:

- 3+ years experience in the design of low cost RF transmitters and receivers.
- Circuit level experience from UHF to low microwave frequencies.
- Familiar with PLL synthesizers, spread spectrum, and FCC Part 15 regulations.
- BS/MSEE required.

Please respond to:

APEX
WIRELESS, INC.
A subsidiary of Apex Systems, Inc.
2465 Central Ave., Suite 106, Boulder, CO 80301
(303) 443-6699 FAX (303) 443-4974
E Mail: 75017.3120@compuserve.com

Engineering Opportunities

Scientific-Atlanta, headquartered in metro Atlanta, GA, is a Fortune 500 company with 1995 sales in excess of $1 billion. Scientific-Atlanta is at the forefront of today's telecommunications revolution and currently has opportunities for the following:

RF ENGINEERS

Will specify and design new CATV products. Requirements include an MSEE degree (PhD preferred), experience with CATV or similar advanced consumer products for high volume productions, as well as thorough knowledge and experience in analog and digital A/V circuit design, mixed-cods ASIC design, DSP and microprocessors. Strong understanding of this CATV market is a plus.

- RFSR Staff Engineer requires 12+ years experience ***(Job Code: RFSRSK)***
- RF Staff Engineer requires 8+ years experience ***(Job Code: RFSFSK)***

TEST ENGINEER

Responsible for developing test systems and procedures that guarantee performance of new products for CATV. Requires an MSEE degree coupled with 5+ years experience in developing and testing complex products with extensive software, RF and analog components. Thorough knowledge of PC test software packages, testing methodologies, and statistics, as well as exposure to analog and RF products are also required. ***(Job Code: RFTESK)***

We offer a competitive salary and exceptional benefits package. For consideration, mail, fax or e-mail resume with salary history and appropriate job code to: **Scientific-Atlanta, Attn: Staffing, 4311 Communications Drive, MS ATL 30-K, Norcross, GA 30093-2990; FAX: 770-903-3902; sa.staffing@sciatl.com. See our Home Page at www.sciatl.com.**

We are an equal opportunity employer dedicated to diversity in the workplace (M/F/D/V).

Scientific Atlanta

Atlanta 1996

Paging · PCs · Cellular · SatCom

CNI Career Networks
Recruiters for the Wireless & Telecom Industries
800-JOB LINK™
Specializing in Sales, Marketing, Technical, Engineering, Operations & Executive Placements
Gables One Tower, Suite 801
1320 S. Dixie Highway
Coral Gables, FL. 33146
joblink@aol.com

Fax Resume to (800) JOB-FAXX

ENGINEERING OPPORTUNITIES

Nationwide positions available for Engineering, R & D and Management candidates with our Communications Clients in Venture Capitol to Fortune 100 corporations.

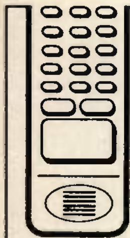
Reply confidentially to:

EXECUTIVE SEARCH NETWORK
7 1/2 E. Milner St. · Dept. RF3
Arlington Heights, IL 60004
Fax (847) 394-1841 / 1891 (alternate)
E-mail: esn@ais.net

MR MANAGEMENT RECRUITERS® OF BOULDER, INC.
The search and recruiting specialists

WINDY BRADFIELD
RF / MICROWAVE SPECIALIST

CONTINENTAL BLDG., SUITE 301
1401 WALNUT STREET, P.O. BOX 4657
BOULDER, COLORADO 80306
(303) 447-9900
FAX(303) 447-9536



...YOUR CAREER

Mgr. Component Products: Responsible for P&L of 30mm component business providing RF/MW product modules to the wireless communications industry.

Product Marketing Manager: Lead the technical marketing effort for the Wireless Communications Group, develop business/marketing plans, manage customer relationships, perform market analysis, develop sales/marketing material.

CATV Design: Rf Design experience should include LC filter, microstrip, amplifier, circuit modeling and system analysis in the 5-1000Mhz range. BS/MSEE fiber optics a plus.

Project Leader Base Station: Design, fabricate, test and develop rf/mw components, circuits and subsystems for cellular basestation front-ends. BSEE/MSEE.

Baseband Analog Circuit Design: Baseband analog circuit designers for cordless telephony systems at 900 MHz and 46/49 MHz. BSEE 5 yrs.

Regional Field Sales: Aggressive individuals to create and serve new accounts. Positions are located throughout the U.S.A. An engineer who wants to enter sales world is acceptable. Base salary, commission and car. BSEE.

RF Microwave Test Engineers: Develop and refine automated RF/Microwave test methodologies for product characterization, production test, system test and FCC Certification. BSEE

RF/Analog Hardware Design: Develop state of the art cordless telephony systems at 900 MHz and 46/49 MHz. Experience with synthesizers, LNA, mixers, IF receivers, transmitter circuit, Power amplifiers and receiver designs. BS/MS 5 plus years.

Sr. Project Antenna Design: Lead the conception, design and development of a wide variety of antennas and antenna systems, including both reflector and array systems using microstrip, stripline and waveguide technologies. BS/MS with 5 years experience.

RF Design Manager: Lead a team of RF engineers from initial design and implementation through product integration and testing into high volume production. 8+ years of RF design with emphasis on low cost radio design. BS/MS

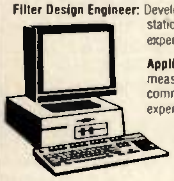
Sr. MMIC Design: Design highly integrated GaAs MMICs for advanced cellular products. Circuits to be designed include power amplifiers, LNAs, mixers, IF amplifiers, buffer amplifiers. RF frequencies are 900 and 1800 MHz.

Product Line Manager Wireless: Specific responsibilities include product line strategic planning, establishing revenue and price objectives, setting internal cost targets and oversight of internal product realization schedules.

RF PA Engineers: Requires 3+ years experience in design, test and manufacturing of high efficiency GaAS MESET and HBT class A and C power Amplifiers (c2watts) in the frequency range (-2GHz). Experience in both discrete and MMIC design a plus

Sr. Analog IC Designers: Responsible for conceptual circuit design and developing new analog/mixed signal ic's. BS/MS experience in A/D D/A, ASIC's bipolar and BiMOS.

Filter Design Engineer: Development of microwave high 'Q' coaxial cavity and machine filter designs for PCS base stations. BS/MS familiar with simulation and modeling tools, three plus years filter design experience with direct 'Q' designs (6-8000 Q's).



Applications Engineer: 5 years of directly relevant RF/MW engineering applications and measurement techniques. Strong presentation and instructor skills; must be able to communicate effectively with individuals and groups of all levels of technical expertise and experience.

RF Systems Design: RF system design for low cost battery operated systems, battery powered systems, including receiver and transmitters system planning, analysis and simulation using CAD tools. Experience with CDMA/TDMA. BSEE.

MICRO COMMUNICATIONS EXECUTIVE SEARCH

We specialize in the placement of wireless, RF, microwave communications nationally.

FOR THESE AND OTHER OPENINGS CALL COLLECT: TEL: 508-685-2272
800 Turnpike St. • North Andover, MA 08145
E-mail: micsearch@aol.com
FAX: 508-794-JOBS

Be part of a growing team where you'll have the opportunity to offer high-quality, timely, well-respected solutions to our clients in the Raleigh/Durham, Research Triangle Park (RTP) area. Resting between the Atlantic beaches outer banks' and a stunning stretch of the Appalachian mountains, RTP is the world's largest planned research and development park in the United States.

TELECOM ENGINEERS

From entry level to upper managerial, we're looking for engineers with experience in RF, Wireless and Switching Design. You'll need a BSEE; MS in Communications a plus. Upper level positions require one or more of the following: TMN, ATM, Sonet, VRU, DMS, Cellular and Circuit Design, Digital Call Processing, Protel, SL1 and ISDN.

Join us in an area where exciting opportunities are in abundance - an area where you can grow and prosper! Call us @ 800-486-5289 or mail your resume to: Metro Information Services, Attn: Telephony, 2626 Glenwood Avenue, Suite 550, Raleigh, NC 27608-1004. If you prefer, fax to: 919-783-9305 or email us MetroRTP@nando.net.

METRO
Information Services

Equal Opportunity/ Affirmative Action Employer.

ENGINEERS

Northrop Grumman's Electronic Systems Integration Division, recognized for its leadership and achievements in the design and development of leading-edge high technology electronic countermeasures systems, is achieving new dimensions in engineering and you can be part of it. The following positions are currently available:

SENIOR ENGINEERS

▲ Design, assemble and test RF vacuum power devices. Minimum of 5 years experience with CAD, high power testing and vacuum tube technology required.

▲ Responsible for tasks on electron tube R&D programs, including CAE of microwave tubes, design of devices, setup and test tubes and interpret data. Minimum 2-5 years related experience. Advanced degree required.

▲ Digital design, implementation via programmable logic, ASIC, FPGA, DSP development, software for prototype development.

▲ Analog and RF circuit and system design.

▲ Digital circuit and system design.

ENGINEERS

▲ RF receiver/control system design. Design and analysis of phase lock loops, crystal oscillators, modulators and detectors; and CAD, necessary.

▲ Digital design of microprocessor based systems. Microprocessor design, C language & programming in a UNIX environment; and CAD (CADENCE, Alegro, WARP) necessary. BSEE with minimum of 3 years experience required. MSEE desired.

▲ Microwave circuit design, simulation, layout and test of microwave and RF circuits.

▲ Perform threat analysis and EW system requirements and effectiveness analysis using digital simulations. Solve EW systems engineering problems.

TECHNICAL ADVISOR

▲ Perform engineering assignments utilizing knowledge of theory and expertise of electron beam power vacuum devices. PhD or Masters degree with 5 years experience in Physics or EE, required.

For detailed additional openings, view us through the net: http://www.cweb.com/resources/northropgrum/ or send resumes as ASCII text to: resumes@dsd.northrop.com or fax (847) 590-3189 or mail resume to: Northrop Grumman EIWS Dept MM/T76, 600 Hicks Road, Rolling Meadows, IL 60008

We offer a competitive salary/benefits package including: Health/major medical/dental/life insurance, 401(k) and pension plans. Excellent relocation package. We are a smoke-free workplace. U.S. citizenship required for most positions. An equal opportunity employer m/f/d/v.

NORTHROP GRUMMAN

RF design Buyers' Guide

The Buyers' Guide is a convenient guide to suppliers of products and services available for design and development engineers. Buyers' Guide listings are sold on an annual basis at the rates shown.

	Per Issue	Total/Year
Regular Listing	$22.00	$264.00
Additional Line	$19.00	$228.00
Bold Listing	$25.00	$300.00
Additional Line	$21.00	$252.00
1" Ad	$200.00	$2,400.00
Drop Out In White	$25.00	$300.00

All orders must be prepaid. You can forward your check or charge your ad to:

For information on closing dates and details on a special Introductory Offer, call **1-800-848-4237**. Ask for your yellow page representative.

DISCRETE COMPONENTS

CAPACITORS

Vacuum

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231

Surcom Associates, Inc., 2215 Faraday Ave., Suite A, Carlsbad, CA 92008 ..... (619) 438-4420

Variable

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231

CRYSTALS/RESONATORS

Quartz

Oak Frequency Control Group,
100 Watts St., PO Box 8, Mt. Holly Springs, PA 17065 .... (717) 468-3411

DIODES

Loral Semiconductor Division, 75 Technology Dr., Lowell, MA 01851...(508) 256-4113 ext 3311

Varactor

Knox Semiconductor, Inc.
13 Quarry Rd., P.O. Box 609, Rockport, ME 04856 ... (207) 236-6076 Fax (207) 236-9558

HIGH POWER DIODE SWITCHES

Hill Engineering, 461 Boston Rd., Topsfield, MA 01983 .. (508) 887-5754 Fax 887-7244

INTEGRATED CIRCUITS/MCM

California Eastern Laboratories,
4590 Patrick Henry Dr., Santa Clara, CA 95054-1817(408) 988-3500 Fax (408) 988-0279

Micro Hybrids, Inc., 2864 Route 112, Medford, NY 11763 .... (516) 732-3448

MODULAR COMPONENTS

AMPLIFIERS

Broadband

Dressler HF Technik Gmbit,
Werther Str. 14-16, D-52224, Stolberg, Germany .... +49-2402-71091 Fax: (-71095)

FILTERS

Delta Microwave Inc., 840 Vira Alondra, Camarillo, CA 93012 .... (805) 987-6892

Crystal

Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013 .... (717) 243-5929

RF Microwave

Microwave Circuits, Inc., 6856 Eastern Ave., NW, Washington, D.C. 20012 ..... (800) 642-2587

FILTERS

SAW

Phonon Corp., 7 Herman Dr., PO Box 549, Simsbury, CT 06070 .... (203) 651-0211
SAW Components & Subsystems .... Fax (203) 651-8618

OSCILLATORS

Crystal

Oak Frequency Control Group,
100 Watts St., PO Box 8, Mt. Holly Springs, PA 17065 .... (717) 486-3411

Saronix, 151 Laura Ln., Palo Alto, CA 94303 .... (415) 856-6900 (800) 227-8974

Wenzel Associates, Inc., 1005 La Posada Dr., Austin, TX 78752 .... (512) 450-1400

Phase Locked

Mode Space Digital
235 Circle Drive, State College, PA 16801 .... (814) 466-3327 FAX: (814) 466-6577

SYSTEM SUBASSEMBLIES

PRINTED CIRCUIT BOARDS

Harmon Electronics, Inc., 601 N. Main, Warrensburg, MO 64093 .... (816) 747-2236

ANTENNAS

Sinclair Technologies, Inc., Oriskang Dr., Tonawanda, NY 14150 .... (800) 288-2763

RF TRANSMISSION COMPONENTS

Custom & Specialty

Myers Engineering International Inc
P.O. Box 15908, Ft. Lauderdale, FL 33318 .... (954) 345-5000 Fax: (954) 345-5005

Site

DAPA, Deleware Park Centre, Suite 6, Olean, NY 14760 .... (800) 325-DAPA

CABLE ASSEMBLIES

SRC Cables, 5590 Skylane Blvd., Santa Rosa, CA 95403 .... (707) 573-1900

FILTER ASSEMBLIES

Low Pass

Coil Specialty Co.
2730 Carolean Ind. Dr., PO Box 978, State College, PA 16801 .... (814) 234-7044

RF TRANSMISSION COMPONENTS

SOLATORS/CIRCULATORS

irtron Corp., 200 E. Hanover Ave., Morris Plains, NJ 07950 .... (201) 539-5500

MICROWAVE CONNECTORS

oaxial Connectors, Inc.
1500 N.W. 62nd St., Ste. 501, Ft. Lauderdale, FL 33309 .... (305) 772-2664
outhwest Microwave, Inc., 2922 S. Roosevelt St., Tempe, AZ 85282 ... (800) 587-5995

PRECISION RF CONNECTORS

Aolex, Inc., 2222 Wellington Ct., Lisle, IL 60532 .... 800-MOLEX78
pecialty Connector Company,
2100 Earlywood, Franklin, IN 46131 .... (317) 738-2800 Fax: (317) 738-2858

SURGE & TRANSIENT PROTECTORS

SWITCHES

Electromechanical

Dow-Key Microwave Corp., 1667 Walter St., Ventura, CA 93003 .... (805) 650-0260
MBF Microwave, Inc., Rt. 2, Box 252A, Hardy, AR 72542 .... (501) 856-2685

TEST SOCKETS & TEST FIXTURES

ondel Microwave Technology
19925 Stevens Creek Blvd., Cupertino, CA 95014 .... (408) 253-1811

VACUUM CAPACITORS

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231

VACUUM TUBES

WATTMETERS & LOADS

WAVEGUIDES & COMPONENTS

Electromechanical

MBF Microwave, Inc., Rt. 2, Box 252A, Hardy, AR 72542 .... (501) 856-2685

MATERIALS AND HARDWARE

CRYSTAL BLANKS

Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013 .... (717) 243-5929

MOBILE DATA TERMINALS

inet, Inc. (AVL/GPS) .... (619) 724-5355 Fax: (619) 724-6209

PACKAGING/CRYSTAL HOLDERS

Crystal Holders

United Glass to Metal Sealing, Inc.,
11A Executive Park Dr., North Billerica, MA 01862 .... (508) 670-6494

Components/Hybrid Packages

Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013 .... (717) 243-5929

PC BOARDS

Laminates, Polyester Copper Clad

Glasteel Industrial Laminates, P.O. Box 910 Collierville TN 38027 .... (901) 853-5070

TEST EQUIPMENT

Racal Instruments, 4 Goodyear St., Irvine, CA 92718 .... (800) 722-2528

ANTENNA TEST & RF INSTRUMENTATION

Anritsu Wiltron Co.,
490 Jarvis Dr., Morgan Hill, CA 95037 .... (408) 776-8300 Fax (408)776-1744

RF TEST & MEASUREMENT EQUIPMENT

COAXIAL DYNAMICS, INC.,
15210 Ind. Pkwy., Cleveland, OH 44135 .... (216) 267-2233 Fax (216) 267-3142
Grayson Electronics,
306 Enterprise Dr., Forest, VA 24551 .... (800) 800-7463 Fax (804) 385-7692

SERVICES

RF DESIGN CONSULTANTS

Matrix Micro Systems, Inc., P.O. Box 675 Northport, NY 11768 .... (516) 754-1155
RF/Microwave Circuit Design, PC Design, Prototyping .... email: fk@ix.netfcom.com

OEM PRODUCTS

Locus, Inc., 1842 Hoffman St., Madison, WI 53704 .... (608) 244-0500

TELEMENTRY SYSTEMS & ENGINEERING

Telemetry Technologies, Inc., 3307 West St., Rosenberg, TX 77471 ..... (713) 344-9000

SOFTWARE & SYSTEMS, CAD/CAE

Circuit Simulation

ingSoft Ltd.-the providers of the RF Designer® Solution .... (416) 730-9611
213 Dunview Ave., North York, ON M2N-4H9, Canada .... Fax: (416) 226-0861

SYSTEM SIMULATION

RHR Laboratories, 207 Harding Blvd. W., Richmond Hill, Ontario, CN L4C 8X6 ..... (905) 884-2392
Tesoft, Inc., 205 Crossing Creek Ct., Roswell, GA 30076 .... (800) 631-1113
Makers of TESLA Com Simulator .... Fax (770) 664-5817 Intl (770) 751-9785

ELECTRONIC COMPONENTS AND EQUIPMENT

EMI SUPPRESSION COMPONENTS

EMI/RFI Filters

RtroN Corp., P.O. Box 743 Skokie, IL 60076 .... (708) 679-7180

ESD AND SURGE CONTROL COMPONENTS

Lightning Arrestors

Fischer Custom Communications, 2905 W. Lomita Blvd., Torrance, CA 90505..(310) 891-0635

CABLE AND CONNECTORS

Connectors And Adapters

ADC Telecommunications, 4900 W. 78th St., Minneapolis, MN 55435 .. (800)366-3891 X3000

Optical Fibers And Connectors

ADC Telecommunications, 4900 W. 78th St., Minneapolis, MN 55435 .. (800)366-3891 X3000

EMC TEST EQUIPMENT - EMISSIONS

Absorbers

Advanced Electromagnetics, Inc., PO Box 711719, Santee, CA 92072-1719 .. (619)449-9492
Microsorb Technologies, Inc., 14A Airport Dr., Hopedale, MA 01747 .... (508) 634-1900

Anechoic Chambers

Advanced Electromagnetics, Inc., PO Box 711719, Santee, CA 92072-1719 .. (619)449-9492

Current Probes

Fischer Custom Communications, 2905 W. Lomita Blvd., Torrance, CA 90505..(310) 891-0635
Ion Physics Corp., 11 Industrial Way, Atkinson, NH 03811 .... (603) 893-6687

Line Impedance Stabilization Networks

Fischer Custom Communications, 2905 W. Lomita Blvd., Torrance, CA 90505..(310) 891-0635

Power Amplifiers

Applied Systems Engineering Inc., 8623 Hwy. 377 S., Fort Worth, TX 76126 .... (817) 249-4180

ESD TEST EQUIPMENT

ESD Event Detectors

TREK INC., 3932 Salt Works Rd., P.O. Box 728, Medina, NY 14103 .... (800) FOR-TREK

Surface & Volume Resistivity Meters

TREK INC., 3932 Salt Works Rd., P.O. Box 728, Medina, NY 14103 .... (800) FOR-TREK

MATERIALS, HARDWARE AND PACKAGING

SHIELDING MATERIALS

Conductive Adhesives

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 .. (800)343-1076 Fax: (617)871-0065

Conductive Fiber/Fabric

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 .. (800)343-1076 Fax: (617)871-0065

Gasketing Materials

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 .. (800)343-1076 Fax: (617)871-0065

Laminates

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 .. (800)343-1076 Fax: (617)871-0065

Sheilding Foils and Tapes

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 .. (800)343-1076 Fax: (617)871-0065

ESD PACKAGING

Antistatic and Conductive Polyurethanes

Pad-Tastics, Inc., P.O. Box 50479, Ciercero, IL 60650 (708)780-8402 FAX (708)780-1636

TEST LABORATORIES AND CONSULTANTS

LABORATORIES

TUV Product Service, Inc., 1775 Old Hwy. 8, New Brighton, MN 55112 .... (800) 888-0123

CONSULTANTS

Kimmel Gerke Assoc. Ltd., 1544 N. Pascal, St. Paul, MN 55108 .... (612) 330-3728
EMC Design/Troubleshooting-Medical, Industrial, ITE, Vehicles & More-50+ years exp.

RF guide to editorial coverage

RF advertising index

RF DESIGN (ISSN:0163-321X USPS: 453-490) is published 13 times a year, including monthly issues and a buyers' guide published in October. August 1996 Vol.19, No. 8. *RF Design* is a registered trademark of Intertec Publishing Corp. Copyright 1996 by Intertec Publishing Corp., 9800 Metcalf Ave., Overland Park, KS 66212-2215. Editorial and advertising offices at 5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111, 303-793-0448. Printed in USA. Periodicals Postage paid at Overland Park, KS, and at additional mailing offices. Subscription office: *RF Design*, P.O. Box 1077, Skokie, IL 60076. Subscriptions are $48 per year ($82 for two years) in the United States; $68 (surface mail) or $108 (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 $10.00 each (in the United States). This publication is available on microfilm/fiche from UMI, 300 Zeeb Road, Ann Arbor, MI 48106 USA. Tel.: 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. For those seeking 100 or more copies, please contact Ed Laborwit at 770-618-0481.

SUBSCRIPTION INQUIRIES: 847-647-0756.

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

NEW!

J-LEAD

J MIXERS UNPRECEDENTED IN VALUE.

All Ceramic 2 to 1900MHz

from $4.25 (qty. 10-49)

JMS mixers mean unparalleled performance and reliability. Solder plated J leads provide improved reliability of the solder connection while significantly reducing thermal stress and leaching. All-welded internal construction withstands reflow temperatures up to 240°C for 5 minutes, and rugged construction enables JMS mixers to pass tough MIL-M-28837 shock and vibration tests. Additionally, the all-ceramic surface mount package has a cover pull strength of 20 pounds! Other quality features include 4.5 sigma repeatability unit-to unit, automated assembly for low-cost and fast, guaranteed 1 week shipment, tape and reel availability plus a 5 year Ultra-Rel™ guarantee. If value is a must...specify JMS mixers from Mini-Circuits.

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

SPECIFICATIONS

MODEL	LO (dBm)	FREQUENCY (MHz) LO/RF	I F	MIDBAND (dB, typ.) Conv. Loss	Isolation L-R	L-I	$ea. (qty. 1-9)
JMS-1	+7	2-500	DC-500	5.75	45	45	4.95
JMS-1LH	+10	2-500	DC-500	5.75	55	45	8.45
JMS-1MH	+13	2-500	DC-500	5.75	60	45	9.45
JMS-1H	+17	2-500	DC-500	5.90	50	50	11.45
JMS-2L	+3	800-1000	DC-200	7.0	24	20	7.45
JMS-2	+7	20-1000	DC-1000	7.0	50	47	7.45
JMS-2LH	+10	20-1000	DC-1000	6.5	48	35	9.45
JMS-2MH	+13	20-1000	DC-1000	7.0	50	47	10.45
JMS-2H	+17	20-1000	DC-1000	7.0	50	47	12.45
JMS-2W	+7	5-1200	DC-500	6.8	60	48	7.95
JMS-11X	+7	5-1900	5-1000	6.7	35	37	4.25*

Note: *10-49 qty.

Mini-Circuits®

US INT'L
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 INTERNET http://www. minicircuits. com

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

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

F 205 Rev Orig

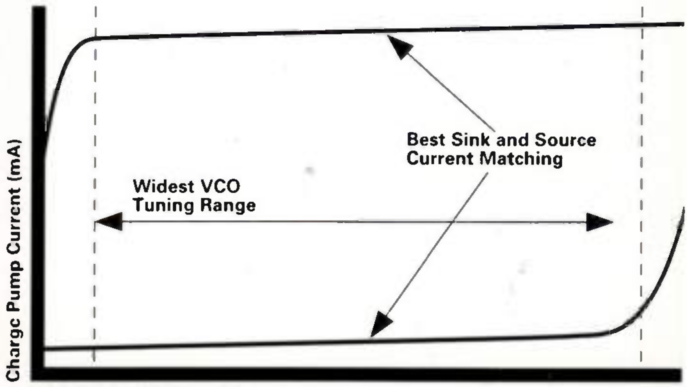
CHARGE PUMPS GO PLLatinum.

SINGLES	LMX1501A	LMX1511	LMX2315	LMX2320	LMX2325
RF Input-Main PLL	1.1GHz	1.1GHz	1.2GHz	2.0GHz	2.5GHz
I_{cc} (typ) @3V Powerdown (typ)	6mA N/A	6mA N/A	6mA 30µA	10mA 30µA	11mA 30µA

DUALS	LMX2330A	LMX2331A	LMX2332A	LMX2335	LMX2336	LMX2337
RF Input-Main PLL RF Input-Aux PLL	2.5GHz 510MHz	2.0GHz 510MHz	1.2GHz 510MHz	1.1GHz 1.1GHz	2.0GHz 1.1GHz	550MHz 550MHz
I_{cc} (typ) @3V Powerdown (typ)	13mA 1µA	12mA 1µA	8mA 1µA	9mA 1µA	13mA 1µA	9mA 1µA

http://www.national.com

PLLatinum™: the industry's highest performing PLLs.



(PLLatinum PLLs feature exceptional charge pump balance and tuning range.)

How do you build the world's best PLL? You start with the world's best charge pump. Just check out the spurious output of National Semiconductor's single and dual frequency synthesizers.

Because you need a low leakage charge pump, National has designed the best. We guarantee the lowest TRI-STATE® leakage spec in the industry.

With wider VCO tuning range and highly repeatable PLL loop performance, you can turn the volume down. No need for extra filtering requirements that add more parts.

Plus, our PLLatinum family of PLLs are so well balanced, they absolutely eliminate dead-zone.

Pumped? Call us for a complete information kit with a product selection guide and free samples.

1-800-272-9959, Ext.671*

*In Europe call +49 (0) 180 532 78 32 (English) or +49 (0) 180 530 85 85 (German); in Japan call 81-43-299-2300; in Southeast Asia call 852-2737-1600.

National Semiconductor®

Moving and shaping the future™

INFO/CARD 92