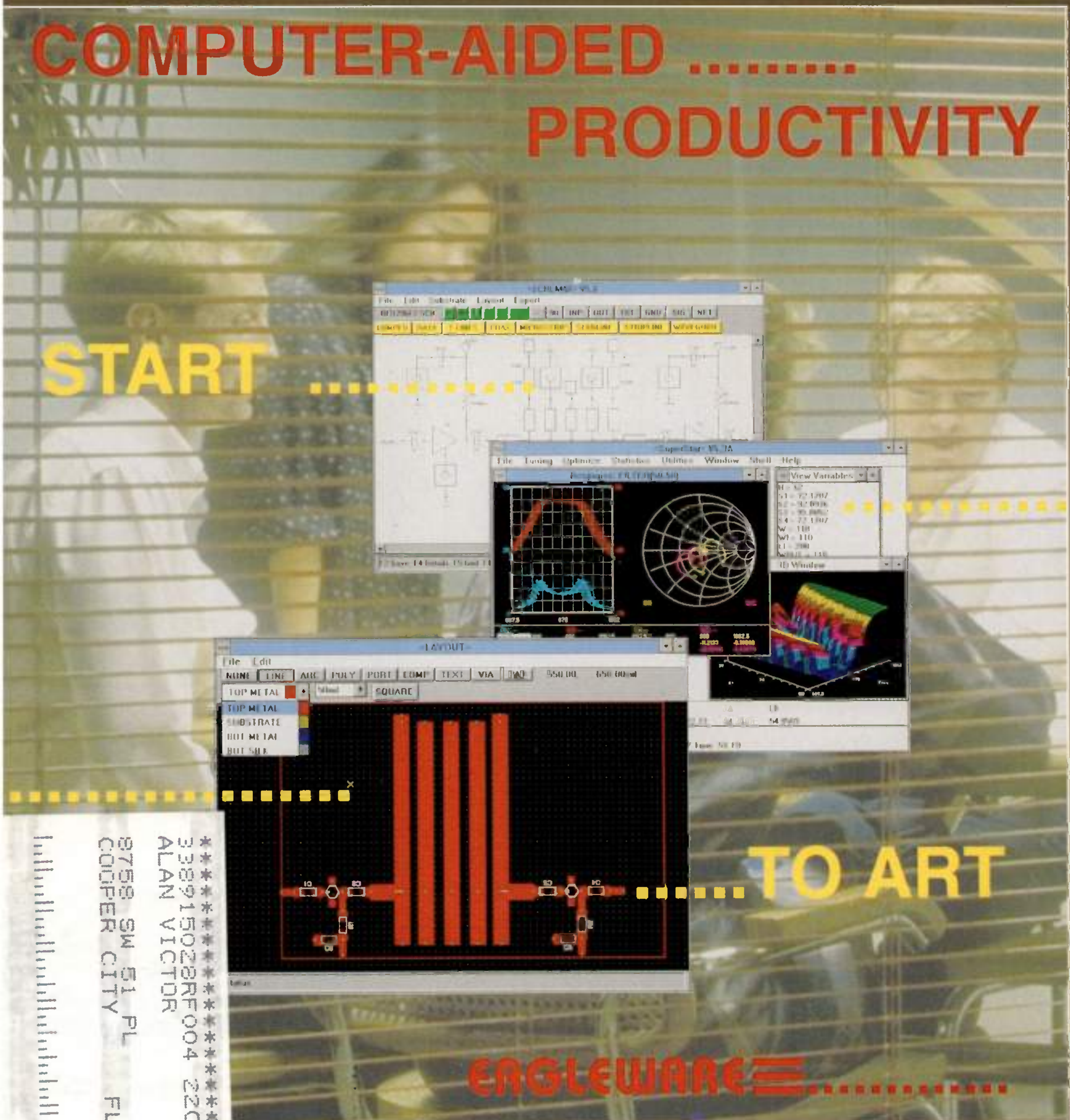
An INTERTEC® Publication

WIRELESS 17 YRS LEADERSHIP

RF design™

engineering principles and practices

February 1996



Featured Technology —
CAD/CAE Methods

Tutorial —
Inductor Behavior at RF

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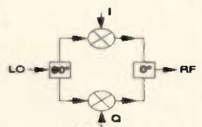
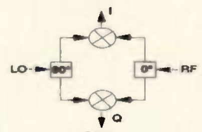


I/Q MODULATORS

MODEL	FREQ (MHz) f_L	FREQ (MHz) f_U	CONV. LOSS (dB) $\bar{x}$	CONV. LOSS (dB) σ	CARRIER REJ (-dBc) Typ.	SIDEBAND REJ (-dBc) Typ.	HARM SUPPRESS (-dBc) Typ. 3xI/Q	HARM SUPPRESS (-dBc) Typ. 5xI/Q	PRICE $ Qty. (1-9)
MIQA-10M	9	11	5.8	0.20	41	40	58	68	49.95
MIQA-21M	20	23	6.2	0.14	50	40	48	65	39.95
MIQA-70M	66	73	6.2	0.10	38	38	48	58	39.95
MIQA-70ML	66	73	5.7	0.10	38	38	48	58	49.95
MIQA-91M	86	95	5.5	0.10	38	38	48	58	49.95
MIQA-100M	95	105	5.5	0.10	38	38	48	58	49.95
MIQA-108M	103	113	5.5	0.10	38	38	48	58	49.95
MIQA-195M	185	205	5.6	0.10	38	38	48	58	49.95
MIQC-38M	34	38	5.6	0.10	48	37	54	65	49.95
MIQC-88M	52	88	5.7	0.10	41	34	52	66	49.95
MIQC-176M	104	176	5.5	0.10	38	36	47	70	54.95
MIQC-895M	868	895	8.0	0.10	40	40	52	58	99.95
MIQC-1785M	1710	1785	9.0	0.30	35	35	40	65	99.95
MIQC-1880M	1805	1880	9.0	0.30	35	35	40	65	99.95
☐ MIQY-70M	67	73	5.8	0.20	40	36	47	60	19.95
☐ MIQY-140M	137	143	5.8	0.20	34	36	45	60	19.95
Surface Mount Models									
☐ JCIQ-88M	52	88	5.8	0.1	40	35	45	65	49.95
☐ JCIQ-176M	104	176	5.8	0.1	35	35	45	55	54.95



I/Q DEMODULATORS

MODEL	FREQ (MHz) f_L	FREQ (MHz) f_U	CONV. LOSS (dB) $\bar{x}$	CONV. LOSS (dB) σ	AMP. UNBAL (dB) Typ.	PHASE UNBAL (Deg.) Typ.	HARM SUPPRESS (-dBc) Typ. 3xI/Q	HARM SUPPRESS (-dBc) Typ. 5xI/Q	PRICE $ Qty. (1-9)
MIQA-10D	9	11	6.0	0.10	0.15	1.0	50	65	49.95
MIQA-21D	20	23	6.1	0.15	0.15	0.7	64	67	49.95
MIQA-70D	66	73	6.2	0.10	0.15	0.7	56	58	49.95
MIQC-38D	34	38	5.5	0.10	0.10	0.5	60	65	49.95
MIQC-60WD	20	60	5.3	0.10	0.15	1.0	55	67	79.95
MIQC-895D	868	895	8.0	0.20	0.15	1.5	40	55	99.95
☐ MIQY-1.25D	1.15	1.35	5.0	0.10	0.15	1.0	59	67	29.95
☐ MIQY-70D	67	73	5.5	0.25	0.10	0.5	52	66	19.95
☐ MIQY-140D	137	143	5.5	0.25	0.10	0.5	47	70	19.95
Surface Mount Models									
☐ JCIQ-176D	104	176	5.5	0.1	0.15	2	52	65	54.95
☐ JCIQ-895D	868	895	8.6	0.1	0.2	1	45	65	99.95
☐ JCIQ-1785D	1710	1785	8	0.2	0.2	2	50	65	99.95
☐ JCIQ-1880D	1805	1880	8	0.2	0.2	2	50	65	99.95

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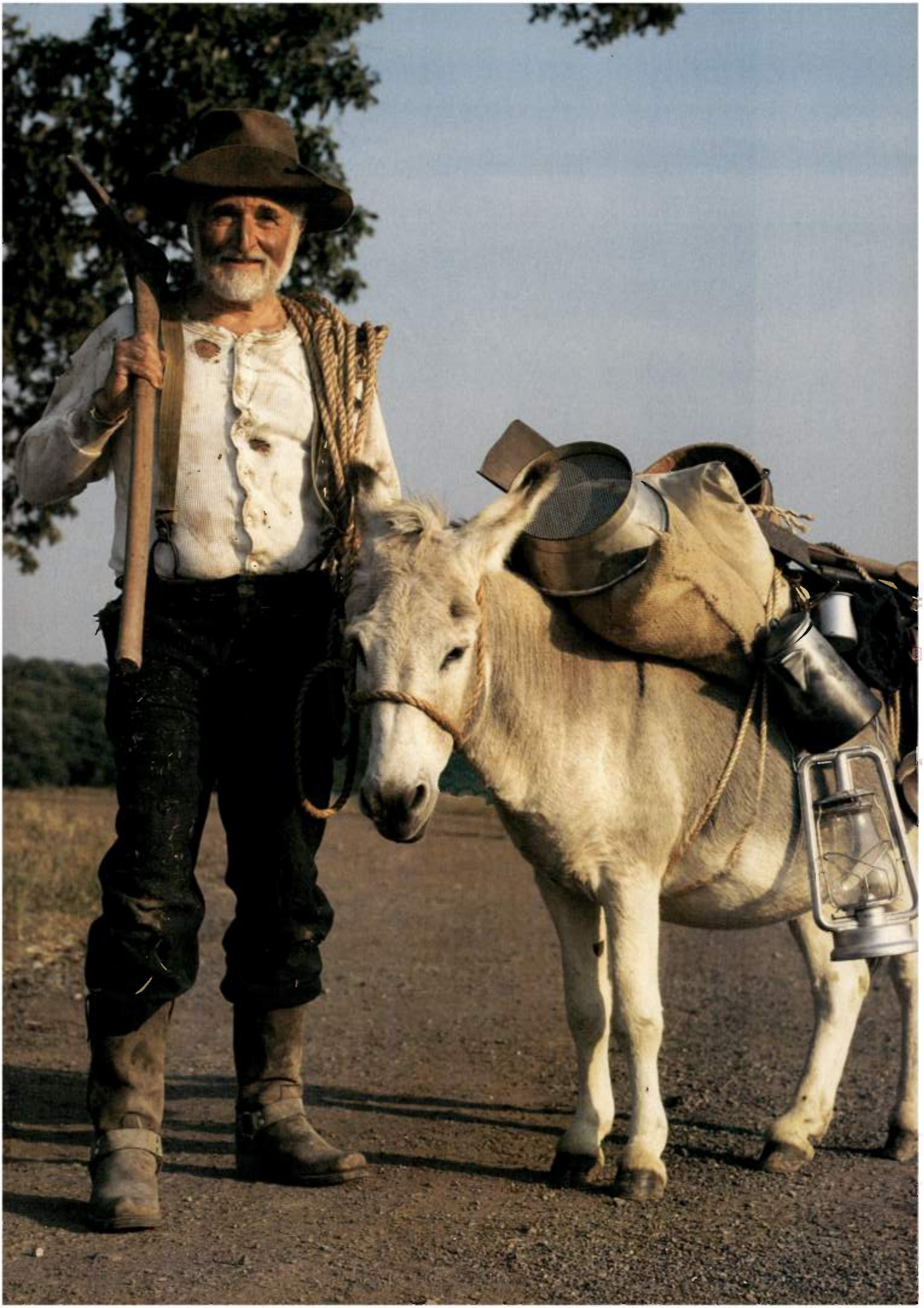

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Our fading emulation is stronger than ever.

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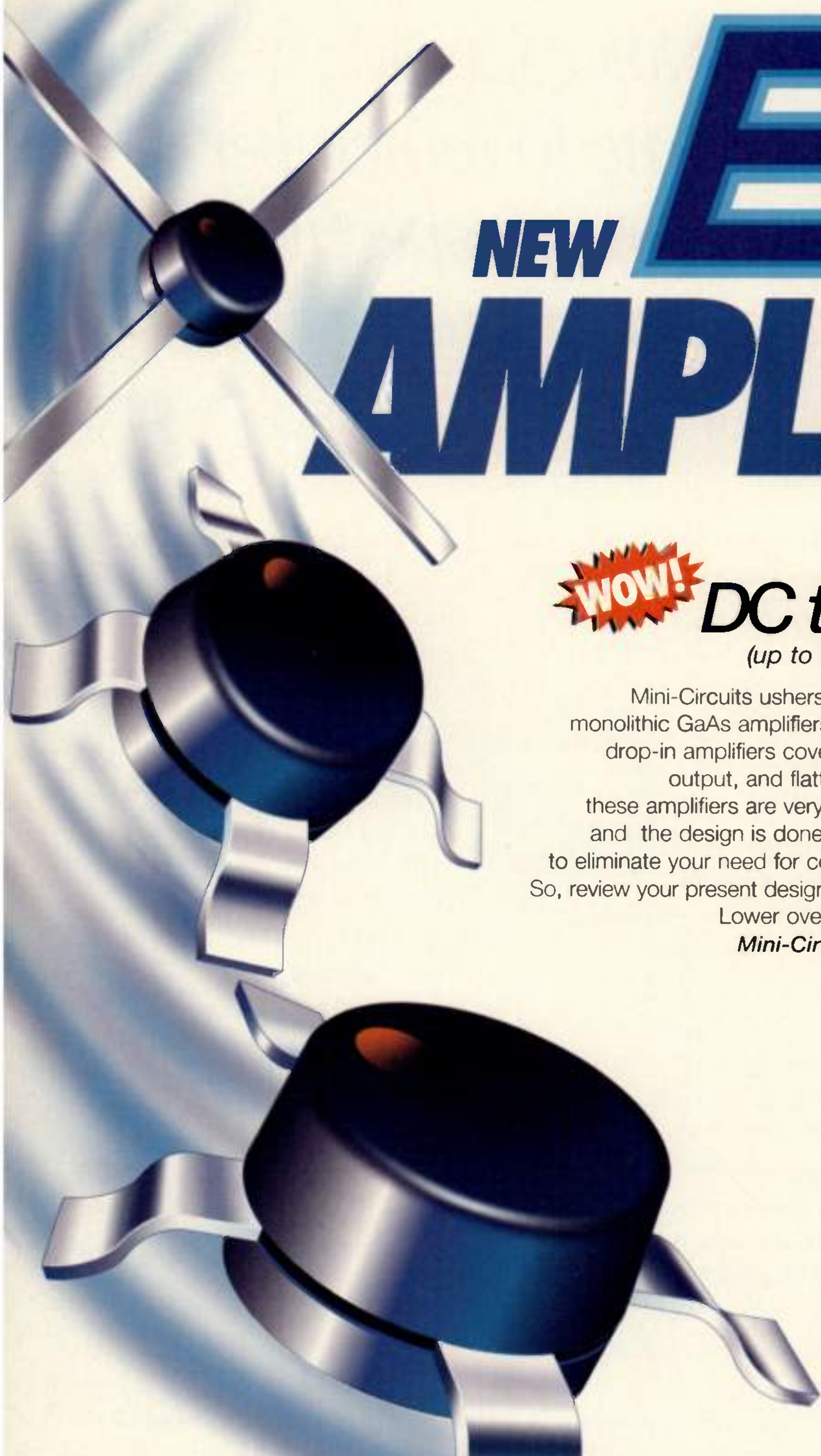
For information on: CDMA Test set circle #4, MP 2600 circle #74, UFX-BER circle #75



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	ERA-1 ERA-1SM	ERA-2 ERA-2SM	ERA-3 ERA-3SM
*Frequency (MHz) f_L-f_U	DC-8000 DC-8000	DC-6000 DC-6000	DC-3000 DC-3000
Gain, (dB)	11.6 11.0	14.9 13.1	20.2 19.4
Max. Power Out (dBm, @1dB comp.)	13 13	14 13	11 11
Dynamic Range	NF IP3 7dB 26dBm 7dB 26dBm	NF IP3 6dB 27dBm 6dB 27dBm	NF IP3 4.5dB 23dBm 4.5dB 23dBm
①Price ($ ea., Qty.10)	1.80 1.85	1.95 2.00	2.10 2.15

Note: All specifications typical at 2GHz, 25°C.
*Low frequency cutoff determined by external coupling capacitors.
①Price (ea.) Qty. 1000: ERA-1 $1.16, ERA-2 $1.31, ERA-3 $1.46
Add $.05 for SM option

Designer's Amplifier Kits
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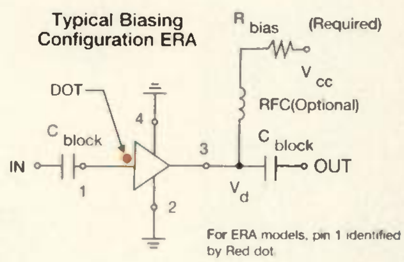
Typical Biasing Configuration ERA



For ERA models, pin 1 identified by Red dot

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RF design

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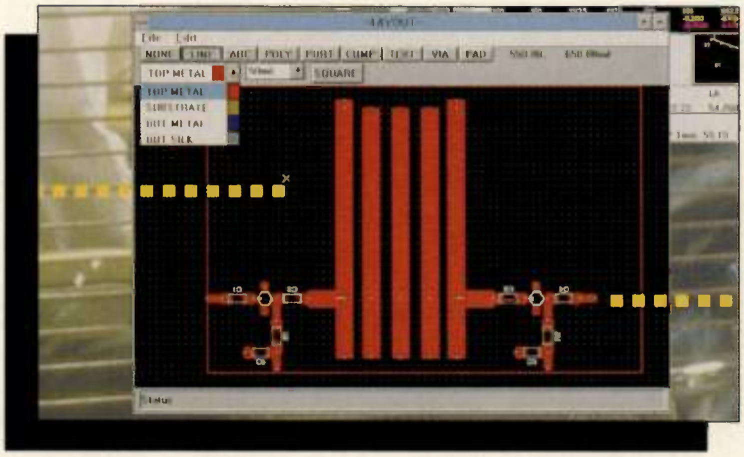
February 1996



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Next Month in *RF Design*

- RF Switching
- Intermodulation Distortion Tutorial, Part 2
- Tutorial on Small Antennas
- More Engineer's Notebook Ideas!

RF editorial

Our Commitment to RF Education

By Gary A. Breed
Editor

On our cover, the line under the *RF Design* logo says, "engineering principles and practices." This phrase was chosen carefully many years ago to represent the essence of our mission. That mission is to provide information the engineers find necessary to do their jobs. We view our job as providing continuing education for RF engineers, rather than classic journalism.

That mission helps us to stand apart from most other commercial magazines. Sure, we include industry news and analysis, and a large helping of new product information. But, the articles we publish are meant to offer a learning experience.

When various circumstances made us re-evaluate the form of our RF Expo trade shows, we kept the strongest part intact — our courses — and created the RF Design Seminar Series. Despite being held right after the holidays, and promoted with a rather slim marketing budget, last month's Dallas seminars got a good turnout. With the next seminars to be held as part of the big International Wireless Communications Expo in Las Vegas, we anticipate full classrooms.

We have always paid close attention to the efforts of various colleges and universities that provide RF education. For the past few months, I have been working with a major university that is exploring how to establish an RF education and research center. If their plan comes together as hoped, the industry will have one more resource for development of the next generation of RF engineers.

We value our contact with professors at colleges and universities, from small institutions like Messiah College and Walla Walla College, to the "big guys" like Georgia Tech, Ohio State, Virginia Tech and UCLA (and many others). RF technology is advancing faster then ever, and the need to learn the newest principles and practices is a never-ending process.

In Memoriam: Helge Granberg

On the morning of January 16, the RF industry lost one of its best-known engineers with the sudden, unexpected death of Helge Granberg. Most of us knew Helge as the author of classic applications notes on HF and VHF power amplifiers while he was with Motorola Semiconductor's RF power transistor group, his professional home from 1972 until his recent retirement to a slower-paced life of consulting.

Some of knew Helge as amateur radio operator K7ES, or another of his previous calls here in the U.S. and in Finland. Like many other hams, he found RF to be fun, and ham radio was a hobby that fit perfectly with his technical pursuits.

Above all, Helge was a gifted engineer when came to practical matters. His purpose was always to make power amplifier circuits *that work*. He was renowned for accomplishing this while keeping the mathematical analysis to a minimum. His dedication to making things work is another legacy, one of patient counsel to engineers who were having trouble getting their own designs to operate as they should.

Helge Granberg was one of a handful of pioneers who taught solid state power amplifier design to the RF community. Our heartfelt wishes go out to his wife, family and many friends. We will all miss him greatly.

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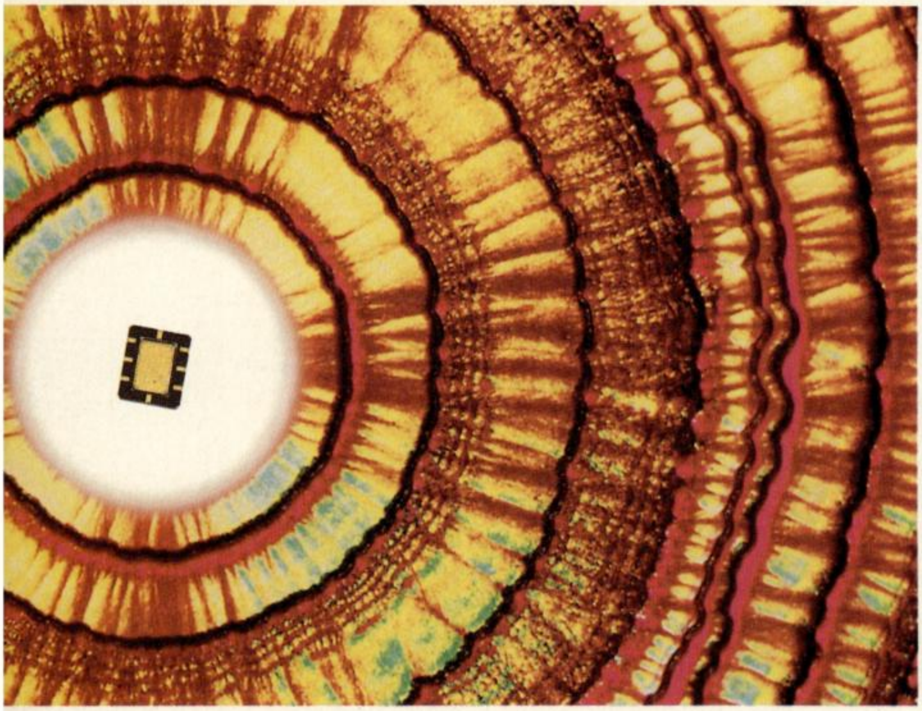
5 mm x 5 mm HIGH POWER ANTENNA SAW FILTERS



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RF letters

Send your letters to: Editor, RF Design, *6300 S. Syracuse Way, Suite 650, Englewood, CO 80111; fax: (303) 267-0234. Letters published may be edited to length or clarity.*

Photo Clarification

On the cover of RF Design's August 1995 issue, several types of equipment were used to illustrate applications of RF power transistors. Because they were meant to be generalized examples, the various specific equipment types were not identified. *RF Design* and Advanced Power Technology (APT), who provided the cover photo, would like to recognize one of the manufacturers whose equipment was used in that photo.

In the upper left of the August cover photo is an FM broadcast exciter manufactured by Itelco, an Italian manufacturer of radio equipment. In the U.S., they can be reached at: Itelco USA Inc., 8280 N.W. 27th Street, Miami, Florida 33122. A photo of the exciter is included here. *RF Design* and APT regret that the photo was used without proper credit to Itelco.

RF calendar

February

12-16 **Wireless Symposium & Exhibition**
Santa Clara, CA
Information: Mary Begley, Penton Publishing, 611 Route 46 West, Hasbrouck Heights, NJ 07604. Tel: (201) 393-6289.

March

3-7 **IPC Printed Circuits Expo '96**
San Jose, CA
Information: Institute for Interconnecting and Packaging Electronic Circuits (IPC), 2215 Sanders Road, Northbrook, IL 60062-6135. Tel: (708) 509-9700. Fax: (708) 509-9798.

18-22 **12th Annual Review of Progress in Applied Computational Electromagnetics**
Monterey, CA
Information: Richard W. Adler, ECE Dept./Code ECAB, Naval Postgraduate School, 833 Dyer Road, Room 437, Monterey, CA 93943. Tel: (408) 649-1111. Fax: (408) 649-0300. E-mail: rwa@mcimail.com

April

15-18 **NAB '96**
Las Vegas, NV
Information: NAB Conventions, 1771 N St., NW, Washington, DC 20036. Tel: (800) 622-3976. Fax: (202) 429-4180.

23-26 **International Wireless Communications Expo (including the RF Design Seminar Series)**
Las Vegas, NV
Information: Argus Trade Shows, 6151 Powers Ferry Road, N.W., Atlanta, GA 30339. Tel.: (800) 828-0420 or (770) 618-0499. Fax: (770) 618-0441.

June

5-7 **Frequency Control Symposium**
Honolulu, HI
Information: Michael Mirarchi, Synergistic Management, 3100 Route 138, Wall Township, NJ 07719. Tel: (908) 280-2024. Fax: (908) 681-9314.

11-12 **Radio Data Solutions Europe 1996**
Amsterdam, The Netherlands
Information: Radio Data Solutions Europe, The Old Vicarage, Haley Hill, Halifax, HX3 6DR, U.K. Tel: +44 1422 380397. Fax: +44 1422 355604.

17-20 **Conference on Precision Electromagnetic Measurements**
Braunschweig, Germany
Information: Sabine Rost, CPEM Conference Secretary, PTB, Bundesalle 100, D-38116 Braunschweig, Germany. Tel: +49 531 592 2129; Fax: +49 531 592 2105.

16-21 **MTT-S International Microwave Symposium**
San Francisco, CA
Information: Derry Hornbuckle, Hewlet-Packard; Tel: (707) 577-3658; Fax: (707) 577-2036, or Jerry Fiedziusko, Space Systems/Loral Corp. Tel: (415) 852-6868. Fax: (415) 852-5068.

RF courses

Designing for EMC
February 11-14, 1996, Orlando, FL
Information: Registration — Tektronix Seminars: (800) 763-3133. Content information — Kimmel Gerke Associates; Tel: (612) 330-3728.

51st Engineering + Management Program
March 24-29, 1996, Los Angeles, CA
Information: UCLA Extension, 10995 Le Conte Ave., Suite 542, Los Angeles, CA 90024. Tel: (310) 825-1047; Fax: (310) 206-2815. E-mail: mhenness@unex.ucla.edu

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Analog & RF Printed Circuit Design
February 14-16, 1996, Milwaukee, WI
Information: Center for Continuing Engineering Education, University of Wisconsin-Milwaukee, 161 W. Wisconsin Ave., Suite 6000, Milwaukee, WI 53203. Tel: (414) 227-3159.

Antenna Engineering
February 13-16, 1996, Atlanta, GA
Principles of Pulse Doppler Radar: High, Medium and Low PRF
February 13-15, 1996, Atlanta, GA
Radar Cross Section Reduction
March 26-29, 1996, Atlanta, GA
Principles of Electronic Counter-Countermeaures
April 9-11, 1996, Atlanta, GA
Phased-Array Radar System Design
April 29-May 2, 1996, Atlanta, GA
Information: Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel: (404) 894-2547.

Wireless Digital Communications
February 26-March 1, 1996, Tempe, AZ
Information: College of Engineering and Applied Sciences, Center for Professional Development, Arizona State University, P.O. Box 877506, Tempe, AZ 85287. Tel: (602) 965-1740. Fax: (602) 965-8653.

Mobile and Wireless Personal Communications Networks
February 12-16, 1996, France
Spread Spectrum/CDMA
February 12-16, 1996, France
Bandwidth-Efficient Coded Modulation: Theory and Application
February 12-14, 1996, France
Information: Tine Persson, CEI-Europe, P.O. Box 910, S-612 25 Finspong, Sweden. Tel: +46-122-175 70; Fax: +46-122-143 47.

Antennas: Principles, Design and Measurements
March 13-16, 1996, San Diego, CA
May 14-17, 1996, St. Cloud (Orlando), FL
Information: Kelly Brown, Northeast Consortium for Engineering Education, 1101 Massachusetts Ave., St. Cloud, FL 34769. Tel: (407) 892-6146. Fax: (407) 892-0406.

DSP Without Tears
March 6-8, 1996, Long Beach, CA
April 17-18, 1996, Fort Lauderdale, FL
May 1-3, 1996, Boston, MA
Information: Z Domain Technologies, Inc., 325 Pine Isle Court, Alpharetta, GA 30202. Tel: (770) 587-4812; Fax: (770) 518-8368.

RF and Wireless Engineering
April 23-25, 1996, Las Vegas, NV
Practical High Frequency Filter Design
April 23, 1996, Las Vegas, NV
Oscillator Design Principles
April 24, 1996, 1996, Las Vegas, NV
Digital Modulation and Spread Spectrum for Wireless Communications
April 23, 1996,
RF Power Transistors and Amplifiers
April 24, 1996, Las Vegas, NV
Wireless Communications for Non-Engineers
April 23, 1996, Las Vegas, NV
Information: RF Design Seminar Series, Argus Trade Shows, 6151 Powers Ferry Rd., N.W. Atlanta, GA 30339. Tel: (800) 828-0420.

Grounding & Shielding Electronic Systems, and Circuit Board Layout
February 26-28, 1996, Seattle, WA
June, 1996 (dates TBA), Chicago, IL
August 14-16, 1996, San Jose, CA
Information: Continuing Education, University of Missouri-Rolla, 103 ME Annex, Rolla, MO 65409-1560. Tel: (314) 341-4132; Fax: (314) 341-4992.

Electromagnetic Interference and Compatibility (EMI/EMC): A Practical Approach to Testing and Problem Solving
February 12-16, 1996, Washington, DC
Wireless Telecommunications: An Introduction
February 21-23, 1996, Washington, DC
Analog and Digital Cellular Networks: CDMA versus TDMA
March 6-8, 1996, Washington, DC
Lightning Protection
March 14-15, 1996, Washington, DC
Advances in Video Technology for Communications and Broadcasting
April 8-11, 1996, Washington, DC
Modern Receiver Design
April 15-19, 1996, London, U.K.
Wireless Infrastructure Network Engineering for Cellular, PCS, LEO and WPBX
April 15-19, 1996, Washington, DC
Grounding, Bonding, Shielding and Transient Protection
April 29-May 3, 1996, San Diego, CA
Mobile Satellite Communications Systems
May 13-15, 1996, Washington, DC
Modern Digital Modulation Techniques
May 13-17, 1996, Washington, DC
Global Positioning System: Principles and Practice
May 20-23, 1996, Washington, DC
Electromagnetic Interference and Control in Modern Communications Systems
May 20-24, 1996, Washington, DC
Mobile Communications Engineering
May 22-24, 1996, Washington, DC
Hazardous RF Electromagnetic Radiation: Evaluation, Control, Effects, and Standards
June 12-14, 1996, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Academic Center, Room T-308, 801 22nd Street, N.W., Washington, DC 20052. Tel: (202) 994–6106 or (800) 424–9773. Fax: (202) 872–0645.

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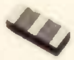

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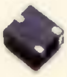

455KHz – 2nd I.F. Filter
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Consortium Forms to Develop Government RF and Microwave Technology

The MAFET Design Environment (MDE) Consortium, a newly-formed team of microwave electronics and electronic design automation companies, has entered into an agreement with the U.S. Government for a multi-year, multi-million dollar effort for the Thrust One Microwave and Analog Front-End technology (MAFET) program.

National Semiconductor Establishes Laboratory

National Semiconductor has formed a research laboratory to accelerate the companyís long-range development of advanced technologies and products for the communication, computer and transportation industries. The National Semiconductor Research Laboratory (NSRL) has a charter to develop technologies, processes and products key to National's long-term strategy of dominating the market for analog and mixed-signal products that move and shape information. The NSRL is dedicated to become a premier research facility, attracting eminent scientists and partnering with key universities, research organizations and customers. The laboratory will be headed by Dr. Juri Matisoo, who was recently appointed vice president of Research and who was most recently the director of IBM's Thomas J. Watson Research Center.

Over the next several years, National expects the NSRL to grow to provide 150 to 200 new research jobs in Santa Clara. The NSRL focus programs in three areas as it grows: computer science and systems research,

Business Briefs

ADC Forms Joint Venture With PCS Wireless — ADC Telecommunications, Inc. (ADC) has announced its intent to form a joint venture with PCS Wireless, Inc. of Vancouver, British Columbia. The equally-owned joint-venture company will be chartered in the U.S. and will manufacture, market and sell remote antenna drivers (RADs) and remote antenna signal processors (RASPs)) for use in hybrid fiber/coax (HFC) networks. The joint venture company is being capitalized at US$5 million. ADC will also purchase 5 million shares (15 percent) of PCS Wireless.

Electronic Technology and Digital Scientific Form Joint Venture — Electronic Technology Corp. (ETC) and Digital Scientific, Inc. have signed a joint venture agreement to produce technology that uses a new method of demodulating a spread spectrum signal. ETC will design, engineer, and manufacture the technology, and Digital Scientific will assist engineering and manufacturing and will market applications.

Pittencrieff Communications Completes Advanced MobileComm Merger — Pittencrieff Communications, Inc. (PCI) has completed its business combination with Advanced MobileComm, Inc. (AMI), a Fidelity Capital company. The transaction involves the contribution to PCI of the specialized mobile radio (SMR) assets from AMI and other parties, as well as changing PCI to a Delaware corporation.

Technical Research and Manufacturing Achieves ISO 9001 Certification — Technical Research and Manufacturing, Inc. (TRM) of Bedford, NH has been registered to ISO 9001 certification by the international registration company TUV Esse. TRM designs and manufactures a wide variety of signal processing devices and sub-systems for telecommunication and military applications.

URS Corp Forms Subsidiary — URS Corporation has formed a new subsidiary to address emerging wireless telecommunications markets. URS Telecommunications, Inc., headquartered in Washington D.C., focuses of URSís structural, electrical and mechanical engineering. URS also was awarded three contracts in the PCS market valued at $2.1 million.

Proxim and AMP to Deliver 2.4 GHz Wireless LAN — Proxim, Inc has announced a strategic technology and marketing agreement with AMP Incorporated. Under the agreement, AMP will market a family of 2.4 GHz frequency-hopping spread spectrum wireless LAN products based on Proxim's RangeLAN2 technology. The line will include PCMCIA and ISA adapter cards, as well as a compact network Access Point for Ethernet LANs.

Richardson, Ericsson Reach Distribution Agreement — Richardson Electronics, Ltd. has announced that it has reached a distribution agreement with Ericsson to market their RF components on a global basis.

GSM Alliance — Seven personal communications services companies have formed an interest group to promote Global System for Mobile Communication (GSM) technology. The companies will manage GSM technology standards throughout North America, deal with interoperability issues, and coordinate efforts with the international GSM community. The seven companies are: American Personal Communications, the American Portable Telecom unit of Telephone & Data Systems Inc., the BellSouth Personal Communications unit, Intercel Inc., Omnipoint Corp., the Pacific Bell Mobile Services unit of Pacific Telesis Group, and Western Wireless Corp.

Dexter, Advanced Plating Technologies Reach Business Agreement — A long-term business agreement between Dexter Electronic Materials and Advanced Plating Technologies enables Dexter to begin marketing three new high performance processes for use in the fabrication of printed wiring boards.

BTG and Licenses Amplifier Patents — BTG USA Inc (BTG) has announced a cross license agreement with Ericsson Radio Systems AB concerning certain patents and patent applications relating to highly linear, broadband power amplifiers held by both parties. BTG has also completed a license agreement awarding Phoenix Microwave Corp. the rights to develop ultra-linear base station amplifiers based on innovations in BTGís broadband linear power amplifier technology utilizing feedforward techniques and digital signal processing.

design sciences research and physical process research. Currently, research is focused on physical process.

Scholarships Available for Radio Amateurs

The Foundation for Amateur Radio, Inc., a non-profit organization with headquarters in Washington, D.C., plans to administer 57 scholarships for the academic year 1996-1997 to assist licensed radio amateurs. The Foundation, composed of over 75 local area amateur radio clubs, fully funds eight of these scholarships with the income from grants and its annual Hamfest. The remaining 49 are administered by the Foundation without cost to the various donors. Licensed radio amateurs may compete for these awards if they plan to pursue a full-time course of studies beyond high school and are enrolled in or have been accepted for enrollment at an accredited university, college or technical school. The awards range from $500 to $2,000 with preference given in some cases to the pursuit of certain study programs or to residents of specified geographical areas (Delaware, Florida, Maine, Maryland, New Jersey, Ohio, Pennsylvania, Virginia, and Wisconsin). Additional information and an application form may be requested by letter or QSL card, postmarked prior to April 30, 1996. Send to: FAR Scholarships, 6903 Rhode Island Ave., College Park, MD 20740.

ALK Engineering to Distribute S/FILSYN

S/FILSYN, a popular filter-design software package, will now be exclusively distributed by ALK Engineering. The package joins ALK Engineering's PCFILT filter design package, and the two packages overlap to provide broad coverage of the entire field. Technical support for the software and expanded consulting services will be provided by Al Klappenberger and Bill Lurie. Dr. George Szentirmai of DGS Associates will remain available on a part time basis to handle advanced problems.

Call for Papers: 29th Connector and Interconnection Symposium

A call for papers has been issued for the 29th (1996) Annual Connector & Interconnection Technology Symposium and Trade Show to be held at Boston Park Plaza Hotel, Boston, MA, September 16-18, 1996. The Symposium is co-sponsored by the International Institute of Connector and Interconnection Technology, Inc. (IICIT) and the Components Group of the Electronics Industries Association (EIA). Papers presenting new developments and knowledge in the following areas are invited: automation; ball grid arrays (BGA); high-speed connections systems; medical applications; quality; spaceflight connector technology; test methods; automotive interconnection; fiber optics; materials, finishes, and platings; PCMCIA memory

card interconnection; radio frequency interconnection; and surface mount technology.

To submit a paper, send a 200-word abstract to the Papers Chairman, P.O. Box 81, Sudbury, MA 01776-0081 no later than March 29, 1996. The abstract may also be faxed to (508) 440-2763. It must clearly describe the nature, scope, content, organization, key points and significance of the proposed paper. Only previously unpublished papers can be accepted.

Contracts

Antennaco Delivers Antenna for Stock Market — Antennaco has delivered a specialized antenna to be used in a wireless data transfer system installed on the New York Stock Exchange trading floor. The system enables traders to rapidly and accurately process their trades using hand-held data transmitters.

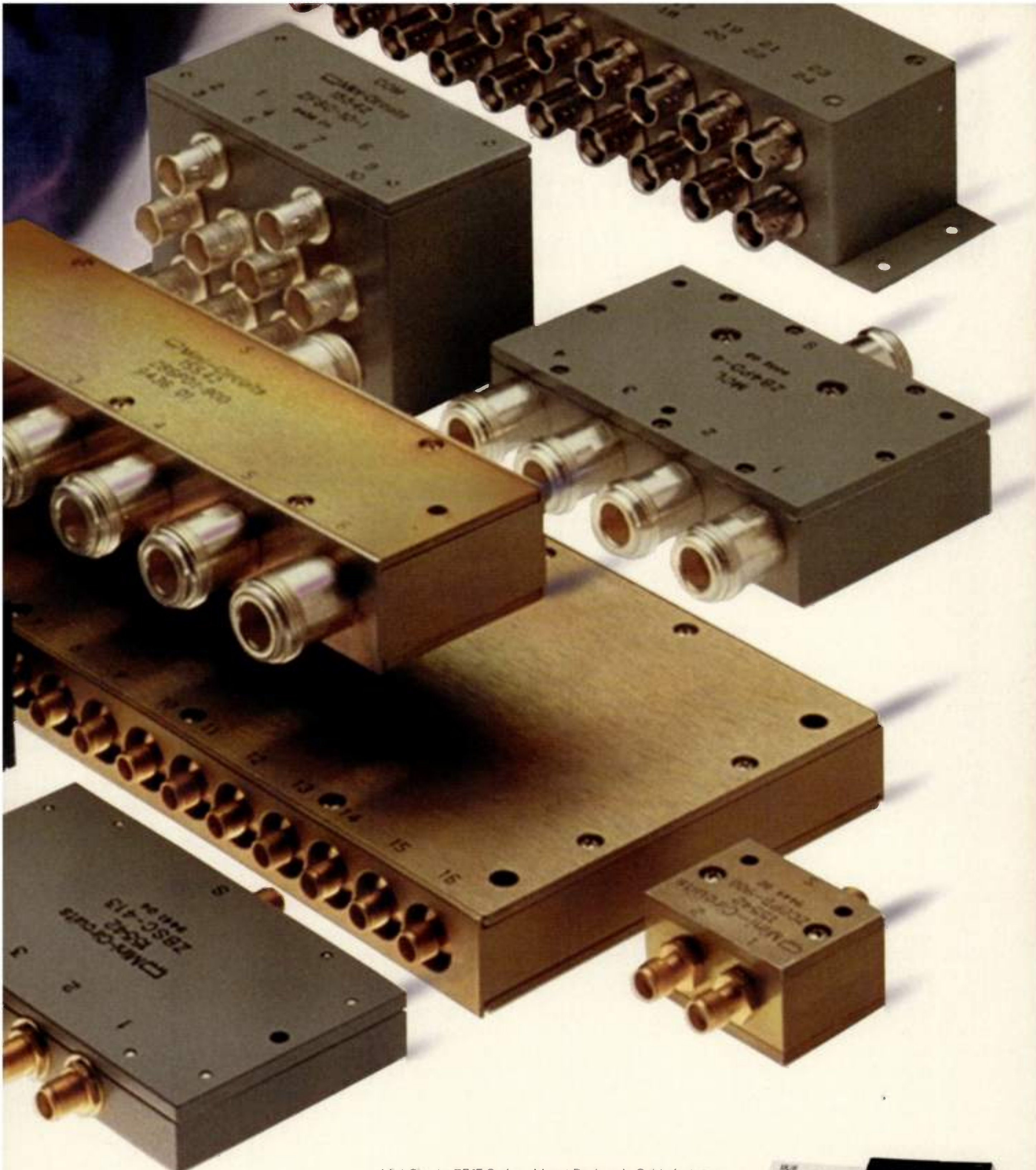
Microwave Solutions Wins Naval Air Warfare Contract — Microwave Solutions, Inc. has announced that it has received a contract award from the Naval Air Warfare Center in Indianapolis, IN. The contract award amount is $183,000 for hardware and software for high-power and low-noise microwave amplifiers and specialized testing for first articles.

Omnipoint, Nortel Up PCS Contract to $250 Million — Omnipoint Corp. has increased its five-year supply agreement with Northern Telecom (Nortel) from $100 million to $250 million for personal communications network equipment and services for the New York major trading area and other potential Omnipoint operating areas.

PCSI Wins Multimillion Dollar Base Station Contract — PCSI™, a wholly owned subsidiary of Cirrus Logic Inc., has announced it has received a multimillion dollar contract from AT&T Wireless Services for the development and supply of base stations for the newly-announced narrow-band PCS technology, pACT (personal air communications technology).

LNR Wins $27M Satellite Terminal Contract — LNR Communications, Inc. has been awarded a contract valued in excess of 27 million dollars, including four option years by the U.S. Army CECOM, PM SATCOM to deliver a quantity of Flyaway Triband Satellite Terminals (FTSAT). The FTSAT is designed to operate over C-, X- and Ku-frequency bands.

RF Industries Receives Radio Modem Orders — RF Industries, Ltd. has announced that it has received initial orders, valued at over $200,000 from three separate customers for its wireless digital data radio modems. RF Industries VHF transceivers will be used by Loral Defense Systems-East, the U.S. NEULINK 9600 digital data radio modems and MAVRIC 2000-based controllers will be used by the U.S. Air Force, and NEULINK 9600 modems will be used by Master Tek. *RF*




RF/IF Designer's Handbook

Wireless Telemetry Plays a Major Role in Market Growth

By Gary A. Breed
Editor

Radio communications has included telemetry applications for many years, but new developments in circuit design, modulation and component technology are providing impetus for even more uses. The recent realization within the electronics industry that "We can do it wireless!" includes telemetry, as well. Telemetry may well become the largest wireless application that is invisible to the general public.

By definition, *telemetry* means "measurement from a distance." Adding the term *wireless* further defines how those measurements are transported over that distance. Classic uses of radio telemetry have included aviation and the space program. Recent data from the Galileo probe that entered the atmosphere of Jupiter is an excellent example of telemetry.

At the National Center for Atmospheric Research, aircraft carry instruments that measure conditions within developing storms. Their measurements are transmitted by radio to scientists on the ground, who use the data to guide the pilots' flight patterns.

Other existing uses are less glamorous, but significant in their own ways. Oilfield well monitoring uses both satellite and point-to-point VHF, UHF or microwave communications to transmit data on well operation. Rivers prone to flooding often have unattended radio-linked monitoring of the rivers water flow and height.

New applications are being developed that will replace wire communications and even manual human data collection. The remainder of this note will describe some of these new telemetry systems.

Wireless Meter Reading

If sheer numbers are considered, meter reading must be considered to largest potential market for wireless telemetry. Virtually every home in the U.S. has one or more utility meter for electricity, water, and gas. Industry estimates are that one meter reader can manually read a few hundred meters in one day. With wireless telemetry, the same person could drive a truck with the necessary communications equipment, reading perhaps 20,000 or 30,000 meters in one day.

Telemetry may well become the largest wireless application that is invisible to the general public

The value of such a scheme is more than manpower. Shortening the billing cycle is always attractive to businesses that are, in essence, granting credit to their users until a reading is made and a bill prepared.

It is possible, however, that this technology may eventually be replaced by data reporting via two-way cable, or its fiber optic replacement. In this case, similar technologies will still be used, and it is possible that the link between the meter and the cable system will remain wireless.

Automated Vehicle Location

With the Global Positioning System, it is possible to identify a user's location to within a few meters. One way to put this information to practical use is for tracking the location of vehicles. For example, city buses can be followed during rush hour, and if delays are encountered, other buses can be re-routed, or at least waiting passengers can be advised.

Commercial vehicles are already using this technology. Dispatching taxicabs, tracking delivery vans and couriers is more efficient if the operator knows which vehicle is closest to the next customer's location. No cab driver wants to sit idle for very long!

Major trucking firms were the first to explore this technology, identifying when trucks cross state lines (for tariff calculations), spotting trouble quickly if a truck stops moving for an unusually long time, and being able to send the closest available driver to pick up the next load. Despite early objections of "big brother" watching over them, drivers have found the safety aspects comforting, and some have seen dramatic increases in the number of loads carried through efficient dispatching.

Increased "Conventional" Use

The existing application areas will benefit from large-scale, lower-cost telemetry products. Many telemetry users are still using telephone lines for communications. Others are getting by with manual monitoring. These users will have the opportunity to obtain wireless telemetry solutions proven in large, high-reliability applications.

Technology Leads the Way

Robust digital modulation schemes that have been developed over just the past few years are being combined with even more dramatic advances in low-cost component manufacturing. The result is communications that is designed to handle digital communications efficiently and affordably.

Additional research in propagation (at *all* frequencies, LF through microwaves) has been directed toward more reliable transmission at higher data rates. Digital techniques have been refined to code and recover data in the most error-free manner.

Together, they are making the "wireless revolution" possible. *RF*

Noise Figure Modeling of Bipolar Transistors Using Spice

By Keelan B. Jennings and J. Alvin Connelly
Georgia Institute of Technology

A methodology for SPICE modeling of noise variations in bipolar transistors is described. An efficient and quick method of producing the noise variations is developed to model the noise figures and noise contours of a bipolar transistor.

The 2N930 transistor is used as an example to describe the methodology for noise modeling. Data for this transistor were obtained from MicroSim's PSpice device library catalog [1]. In modeling the noise variations, a fixed collector-emitter voltage was established and the collector currents varied in decade steps between 1 μA and 10 mA.

Modeling Input Noise Voltage

The first noise modeled is the equivalent input noise voltage, E_n. In a 1 Hz noise bandwidth, E_n can be calculated from the SPICE model parameters R_B and R_E by:

$$E_n = \sqrt{4kT(R_B + R_E)} \quad \text{Volts}/\sqrt{\text{Hz}} \qquad (1)$$

where k is Boltzmann's constant and T is temperature in Kelvin, usually 290K. The calculated E_n value provides an easy and quick comparison with a measured E_n value. If the two E_n values do not agree, then the transistor is simulated with SPICE using the circuit in Figure 1. V_{BB} is adjusted to establish the desired Q point for I_C and V_{CE} for each collector current.

The basic transistor circuit is next simulated with $R_s = 0$, and the SPICE result of V(INOISE) is compared with the previous E_n value. In most cases, the V(INOISE) predicted by SPICE is lower than the measure E_n values at all current levels. Therefore, additional noise is added to the model using the techniques described in Motchenbacher and Connelly [2].

A diode as illustrated in Figure 2 is used to generate the additional noise voltage. Two elements in the diode network that adjust E_n are the flicker noise coefficient, KF, and the gain of the current-controlled voltage source. The flicker noise coefficient sets the 1/f noise corner frequency and the gain scales E_n up or down.

Biasing the diode at a DC current of 3.121 mA will produce a reference noise current level of 1pA/√Hz) from the equation:

$$I_{nd}^2 = 2qI_{DC} \qquad (2)$$

where q is electronic charge. The flicker noise coefficient is determined from equation (3):

$$KF=[(\text{reference noise level})2^* f_{nc}]/[I_{DC}{}^{AF}]$$

where f_{nc} is the noise corner frequency, and usually AF = 1. The necessary gain is determined by forming the ratio of the desired input noise voltage to the reference noise level. As an example, the 2N930 bipolar transistor has measured E_n value 4nV/√Hz. From Eq. (1), the calculated E_n value is 0.4 nV which is a decade below the measured noise voltage. The gain necessary to increase E_n to 4 nV is found from the ratio:

$$\text{Gain} = E_n/I_{nd}$$
$$= 4^*10^{-9}/1^*10^{-12} = 4000 \qquad (4)$$

The E_n corner frequency was measured as 60 kHz for I_C = 10 mA; therefore, the KF is determined using Eq. (3).

$$KF = [(1^*10^{-12})^2{}^*60^*10^3]/[(3.121^*10^{-6})]$$
$$= 1.93^*10^{-14} \qquad (5)$$

Using the calculated adjustments of KF and the gain values, a simulation is done to verify the correct E_n plot. Also the bias points are rechecked. Figure 3 shows the E_n variation with frequency.

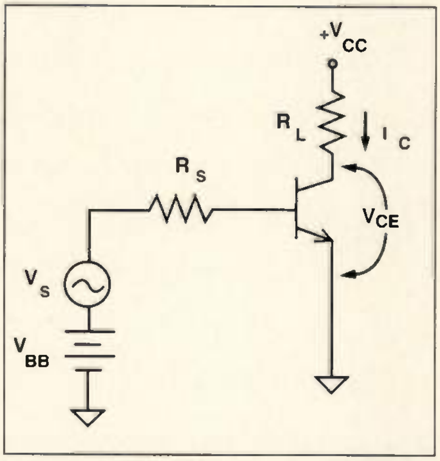


Figure 1. Transistor circuit for Q-point determination.

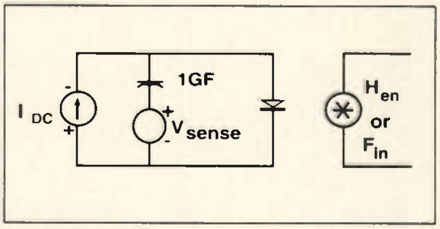


Figure 2. Diode current for 1/f noise.

Modeling Input Noise Current

The methodology for modeling the In noise is similar to that for the E_n noise. In modeling the spectral density of I_n, an estimate of I_n can be calculated from the following equation:

$$I_n = \sqrt{2qI_B} \qquad (6)$$

where $I_B = I_C/ß$. The total equivalent input noise, E_{ni}, includes all the transistor noise mechanisms referred to the input signal, and is given as:

$$E_{ni}{}^2 = E_n{}^2 + E_t{}^2 + I^{n2}R_s{}^2 \qquad (7)$$

where E_t is the thermal noise and $E_t^2 = 4kTR_s$. The $I_n{}^2R_s{}^2$ term must domi-

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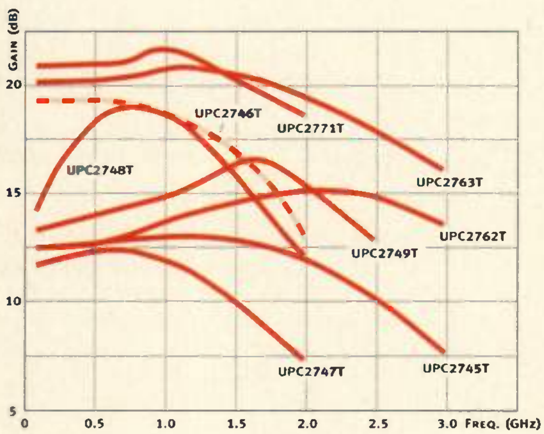

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PART	FREQ. RANGE	GAIN (dB)	NF (dB)	P_{1dB} (dBm)	I_{CC} (mA)	f_{TEST}
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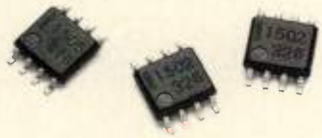
UPC1678G	50MHz–1.9GHz	23	6	+15	49	500MHz
UPC1688G	50MHz–1.0GHz	21	4	0	19	500MHz
UPC2708T	50MHz–2.9GHz	15	6.5	+7.5	26	1.0GHz
UPC2709T	50MHz–2.3GHz	23	5	+7.5	25	1.0GHz
UPC2710T	50MHz–1.0GHz	33	3.5	+7.5	22	500MHz
UPC2711T	50MHz–2.9GHz	13	5	-3	12	1.0GHz
UPC2712T	50MHz–2.6GHz	20	4.5	-2.5	12	1.0GHz
UPC2713T	50MHz–1.2GHz	29	3.2	-4	12	500MHz

3V WIDEBAND MMIC AMPS—FROM 55¢

PART	FREQ. RANGE	GAIN (dB)	NF (dB)	P_{1dB} (dBm)	I_{CC} (mA)	f_{TEST}
UPC2745T	50MHz–2.7GHz	12	6	-3.7	7.5	500MHz
UPC2746T	50MHz–1.5GHz	19	4	-4.5	7.5	500MHz
UPC2747T	100MHz–1.8GHz	12	3.3	-11	5	900MHz
UPC2748T	200MHz–1.5GHz	19	2.8	-8	6	900MHz
UPC2749T	100MHz–2.9GHz	16	4	-12.5	6	1.9GHz
UPC2762T	100MHz–2.9GHz	14.5	7	7	27	1.9GHz
UPC2763T	100MHz–2.4GHz	19.5	5.5	6.5	27	1.9GHz
UPC2771T	100MHz–2.1GHz	21	6	11.5	36	900MHz

Prices at 100K quantity



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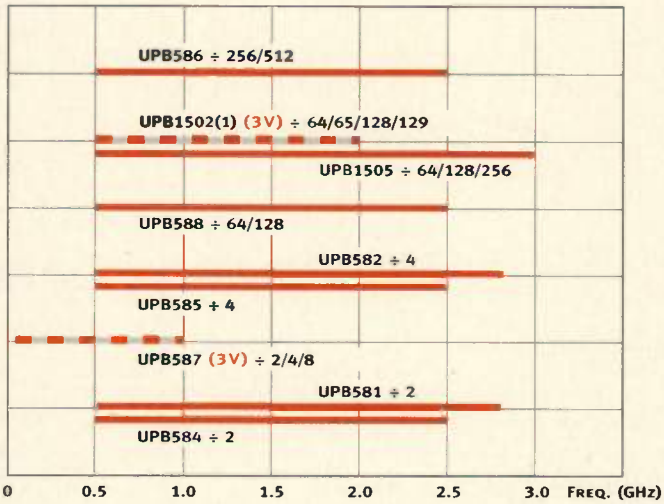

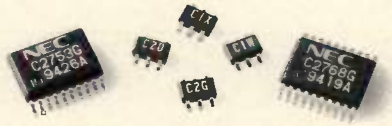

3V Frequency Converters—from 99¢

PART	RF Frequency (MHz)	ICC (mA)	Conversion Gain (dB)	Output IP_3 (dBm)
UPC2756T[1]	100 - 2000	5.9	14	0
UPC2757T[1]	100 - 2000	5.6	13	0
UPC2758T[1]	100 - 2000	11	17	+6
UPC2753GR[1]	DC - 400	6.9	79	-17
UPC2768GR[1]	10 - 450	7	80	-17
UPC8106T[2]	100 - 2000	9	9	+1
UPC8109T[2]	100 - 2000	5	4	-4

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2. Upconverter

NEC's UPC8104GR Quadrature Modulator with up converter

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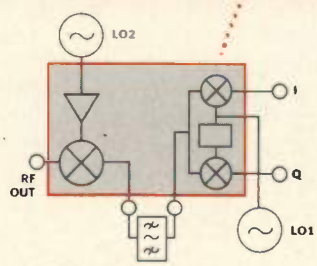

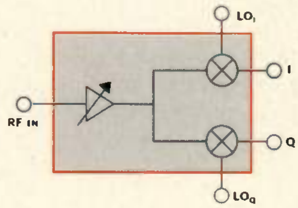

UPC8104GR

Quadrature Modulator w/Upconverter
- 3–5 Volt operation
- Ports for IF filter
- 10 MHz I/Q BW
- 400 MHz IF Bandwidth
- 1.9 GHz RF Output

UPC2766GR

Quadrature Demodulator
- RF & LO —DC to 1 GHz
- IF (IQ)—DC to 100 MHz
- 35 dB typ AGC dynamic range
- 30 dBc typ distortion

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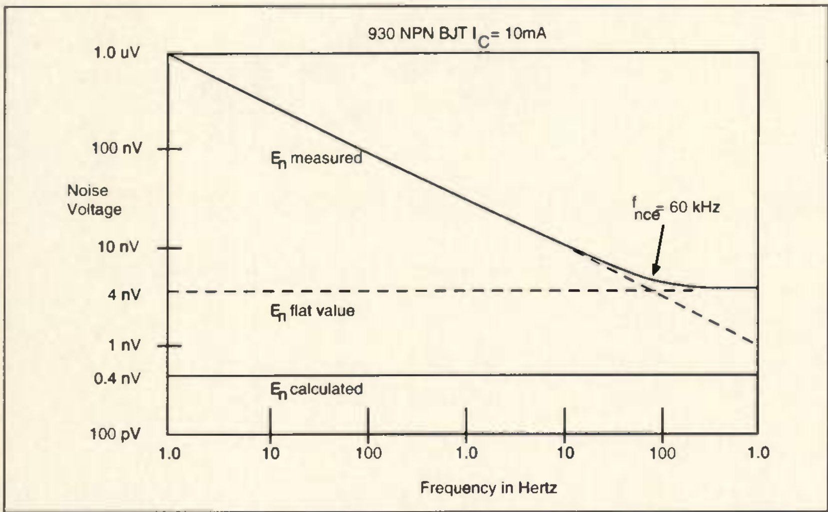

Figure 3. E_n as a function of frequency.

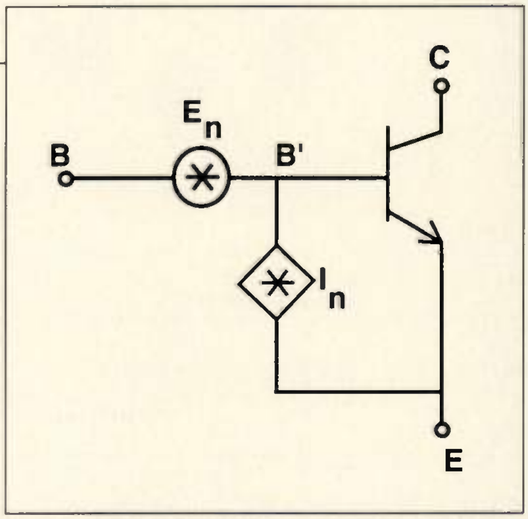

Figure 4. Transistor with extra noise sources.

nate Eq. (7) in order to obtain an accurate In value with SPICE. Therefore, the source resistance is chosen to be large enough to make the term $I_n^2R_s^2$ dominant. For example, the 2N930 transistor has an I_n of approximately 4 pA at I_c = 10 mA. If R_s is chosen to be 80 kΩ, then the $I_n^2R_s^2$ will be approximately two orders of magnitude larger than E_n^2 or E_t^2. After an appropriate R_s resistor is selected, the DC input voltage is adjusted to have the same bias points as the E_n model. The new input voltage is calculated by the following expression:

$$V_{BB}(new) = V_{BB}(old) + I_BR_s = V_{BB}(old) + (I_C/ß)*R_s \qquad (8)$$

where ß is the DC beta value given in the .OP Spice analysis, and I_B is the base current. The ß term is a function of I_C, and varies for each collector current.

If the calculated value for I_n does not agree with the measured value, then the transistor is simulated using SPICE with V_{BB}(new) as the V_{BB} value for the circuit in Figure 1. The SPICE result V(INOISE)/R_s is compared with the measured I_n plot, and the bias points are verified. If the simulated I_n result is less than the measured I_n, then additional noise must be added. The diode network for 1/f noise is implemented by the same means as for E_n noise. This network (Figure 2) is the same as the one for E_n except the current-controlled voltage source used for E_n is replaced by a current-controlled current source. The elements KF and the gain perform the same operations as before, adjusting the corner frequency and scaling up or down. The transistor now has input noise voltage and current equivalents as shown in Figure 4.

I_C (amps)	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
E_n (nv/√Hz)	4	3	3	6	15
f_{lnce} (Hz)	60k	1.1k	80	0	0
f_{hnce} (Hz)	>1M	>1M	>1M	>1M	700k
I_n (pA/√Hz)	4	1	0.5	0.2	0.08
f_{lnci} (Hz)	200k	100k	70k	6k	900
f_{hnci} (Hz)	>1M	>1M	>1M	800k	100k
Denoise-KF	1.93e–14	3.525e–16	2.563e–17	0	0
Hen-gain	4000	3000	2400	2000	2000
Dinoise-KF	6.408e–14	3.204e–14	2.243e–14	1.922e–15	2.884e–16
Fin-gain	3	0.5	0.3	.012	0.05
Beta	256	295	222	149	94.5
V_{BB} (V)	0.758	0.669	0.606	0.546	0.4865
R_L (Ω)	10	100	1k	100k	1M
R_s (Ω)	80k	1M	8M	20M	500M
V_{BB}new (V)	3.883	4.0588	4.2096	1.888	5.7775

Table 1. Model parameters for the 2N930 NPN transistor.

Noise Contours

Contours of constant narrowband noise figures are generated by plotting the source resistance values as a function of the collector current on a log-log scale. Each contour is dependent upon a noise figure level (in dB) and a frequency (in Hz). Table 1 shows parameters of the 2N930 transistor used in obtaining noise contours.

The value or values of source resistance that produces a specified NF at a given bias current and frequency must be obtained to generate the noise contours. Using Eq. (7), the noise figure is described by (9):

$$NF = 10*\log[E_{ni}^2/E_t^2] = 10*\log[1+(E_n^2/E_t^2) + (I_n^2R_s^2/E_t^2)]$$

The input noise voltage is modeled as a function of frequency by (10):

$$E_n^2 = E_{nflat}^{2}*[1+(f_{lnce}/f)]*[1+ (f/f_{hnce})^2]$$

where E_{nflat} is shot noise portion of E_n, f_{lnce} is the lower noise corner frequency, f_{hnce} is the upper noise corner frequency, and f is the operational frequency. The input noise current is frequency dependent according to (11):

$$I_n^2 = I_{nflat}^2 * [1+(f_{lnci}/f)] * [1+(f/f_{hnci})^2]$$

where I_{nflat} is shot noise portion of I_n, f_{lnci} is the lower noise corner frequency, f_{hnce} is the upper noise corner frequency, and f is the frequency of operation. Substituting equations (10) and (11) into equation (9) produces a quadratic equation in terms of R_s (Eq. 13):

$$R_s^2 - \{[1.61 * 10^{-20} * (10^{NF/10} - 1)] / [2 * I_{nflat}^2 * [1 + (f_{lnci}/f)] * [1 + (f/f_{hnci})^2]\} R_s + \{(E_{nflat}^2 * [1 + (f_{lnce}/f)] * [1 + (f/f_{hnce})^2]) /$$

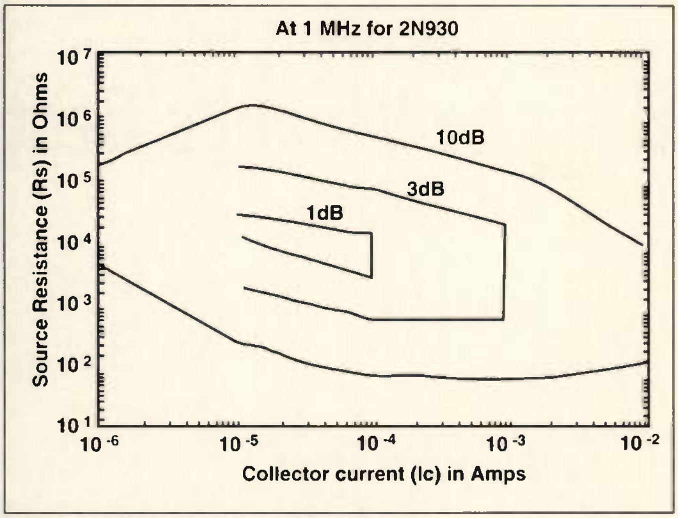

Figure 5. Matlab plot of noise contour.

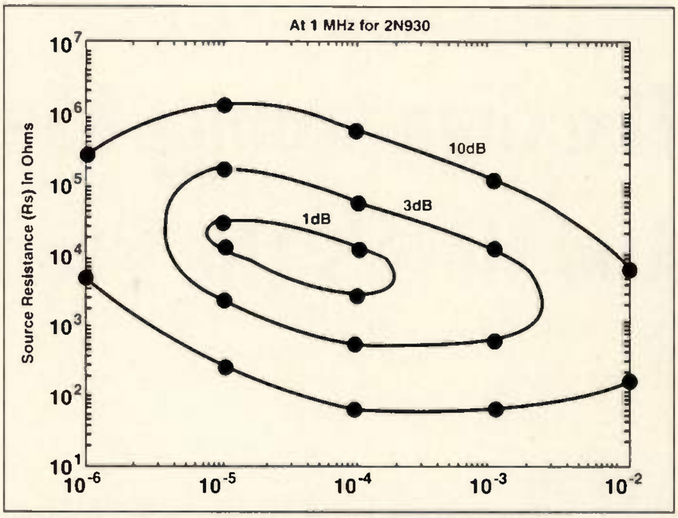

Figure 6. Noise controur with extrapolated curves.

$(I_{nflat}{}^2 * [1 + (f_{lnci}/f)] * [1 + (f/f_{hnci})^2])\} = 0$

A software program was written for generating noise contours. First, the Student Edition of Matlab [3] was used to solve Eq. (13) for R_s. A Matlab function called sfres.m was written to solve Eq. (12) for collector current values of 1 µA, 10 µA, 100 µA, 1 mA, and 10 mA. The inputs of the Matlab function are noise figure (NF) in decibels, frequency (f), and the transistor parameters, which are placed in a 5×6 matrix. For example, the matrix for the 2N930 transistor was setup as shown in Table 2:

The function takes the corresponding element values for a collector current in the matrix and solves Eq. (12). Then the function rearranges the source resistance values found so that they match the current orderings of increasing decade levels from 1 µA to 10 mA and then decreasing from 10 mA to 1 µA. The source code for the Matlab function sfres.m is provided in the Appendix.

Once the source resistance values are found and placed in the correct order, they are plotted where the col-

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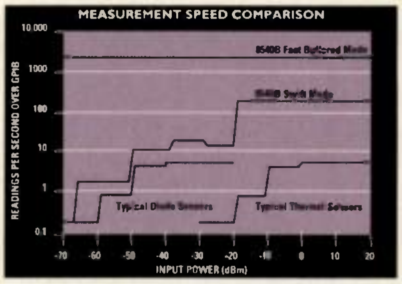

	f_{lnce}	E_{nflat}	f_{hnce}	f_{lnci}	I_{nflat}	f_{hnci}	
t930 = [	0	15e-9	7e5	900	8e-14	1e5	I_c = 1 µA
	0	6e-9	5e6	6e3	2e-13	8e5	I_c = 10 µA
	80	3e-9	5e6	7e4	5e-13	5e6	I_c = 100 µA
	1.1e3	3e-9	5e6	1e5	1e-12	5e6	I_c = 1 mA
	6e4	4e-9	5e6	2e5	4e-12	5e6]	I_c = 10 mA

Table 2. Matlab parameter matrix for the 2N930.

lector current is a vector with the values ordered as previously stated. The Matlab function loglog(a,b) is used to plot the data. Using the hold option, different noise figure levels can be plotted on the same graph. Noise contours are shown in Figures 5 and 6 for an operating frequency of 1 MHz.

Conclusions

A method for matching experimental input noise voltage and current of bipolar transistors with Spice simulations has been presented. Also, the method has been extended to generate noise contours for bipolar transistors. These methodologies provide a quick and efficient method of producing the input noise voltage and current curves used in determining the noise contours. Although the data obtained are not continuous for any arbitrary bias point, it could easily be extended to cover closer spacing. Even with this limitation, the results provide useful design insight for Q-point selection for low noise operation over variations in collector current and frequency.

Utilizing Matlab to generate the noise contours provides a quick, semi-automated method of generating the noise contours for each transistor. All that is needed is the matrix with the transistor parameters, the collector current vector, and the Matlab function sfres.m. The Matlab function takes the parameters NF, frequency, and transistor matrix, and outputs a source resistor vector corresponding to current so that this vector is ready to be plotted against the collector current vector. *RF*

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2. C.D. Motchenbacher and J.A. Connelly, *Low-Noise Electronic System Design*, John Wiley & Sons, Inc., NY, 1993.
3. The Math Works Inc., *The Student Edition of Matlab*, Prentice Hall, Englewood Cliffs, NJ, 1992.

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Appendix – A Matlab function (sfres.m) to solve for source resistance for different collector currents.

```
function [resistance] = sfres(nf,f,Ic)
%This function will take the noise figure,nf(db), the frequency,f, the
%transistor matrix and will compute the source resistances for each collec-
tor
%current at the db level and frequency specified. It also rearranges the
%source resistance into a row vector that corresponds to the following
%collector currents [1u 10u 100u 1m 10m 10m 1m 100u 10u 1u].

ensq = Ic(1,2)^2*(1+Ic(1,1)/f)*(1+f^2/Ic(1,3)^2);
insq = Ic(1,5)^2*(1+Ic(1,4)/f)*(1+f^2/Ic(1,6)^2);
q = [1 -1.6e-20*(10^(nf/10)-1)/insq ensq/insq];
resist1 = roots(q);
if imag(resist1) == [0 0]'  %checks to see if there is an imaginary part
  resist1 = roots(q);       %if so assigns the resistance to zero
else
  resist1 = [0 0]';
end

ensq = Ic(2,2)^2*(1+Ic(2,1)/f)*(1+f^2/Ic(2,3)^2);
insq = Ic(2,5)^2*(1+Ic(2,4)/f)*(1+f^2/Ic(2,6)^2);
q = [1 -1.6e-20*(10^(nf/10)-1)/insq ensq/insq];
resist2 = roots(q);
if imag(resist2) == [0 0]'
  resist2 = roots(q);
else
  resist2 = [0 0]';
end

ensq = Ic(3,2)^2*(1+Ic(3,1)/f)*(1+f^2/Ic(3,3)^2);
insq = Ic(3,5)^2*(1+Ic(3,4)/f)*(1+f^2/Ic(3,6)^2);
q = [1 -1.6e-20*(10^(nf/10)-1)/insq ensq/insq];
resist3 = roots(q);
if imag(resist3) == [0 0]'
  resist3 = roots(q);
else
  resist3 = [0 0]';
end

ensq = Ic(4,2)^2*(1+Ic(4,1)/f)*(1+f^2/Ic(4,3)^2);
insq = Ic(4,5)^2*(1+Ic(4,4)/f)*(1+f^2/Ic(4,6)^2);
q = [1 -1.6e-20*(10^(nf/10)-1)/insq ensq/insq];
resist4 = roots(q);
if imag(resist4) == [0 0]'
  resist4 = roots(q);
else
  resist4 = [0 0]';
end

ensq = Ic(5,2)^2*(1+Ic(5,1)/f)*(1+f^2/Ic(5,3)^2);
insq = Ic(5,5)^2*(1+Ic(5,4)/f)*(1+f^2/Ic(5,6)^2);
q = [1 -1.6e-20*(10^(nf/10)-1)/insq ensq/insq];
resist5 = roots(q);
if imag(resist5) == [0 0]'
  resist5 = roots(q);
else
  resist5 = [0 0]';
end

r(1:2) = resist1';      %builds a row vector of source resistances
r(3:4) = resist2';
r(5:6) = resist3';
r(7:8) = resist4';
r(9:10) = resist5';

r2(1) = r(1,1);
r2(2) = r(1,3);         %rearranges resistances to correspond to currents
r2(3) = r(1,5);
r2(4) = r(1,7);
r2(5) = r(1,9);
r2(6) = r(1,10);
r2(7) = r(1,8);
r2(8) = r(1,6);
r2(9) = r(1,4);
r2(10) = r(1,2);

resistance = r2;
```

A New Statistical Method for Designing Circuits and Systems

By Peter Vizmuller
RHR Laboratories

We are accustomed to designing circuits and systems using the Upper Specification Limit (USL) and Lower Specification Limit (LSL) criteria, such as "the RF amplifier gain shall be between 10 and 11.5 dB". The new method presented here changes the specifications to a graphical format, taking into account variations in the device's properties.

In the absence of any other information, a specification such as "Gain shall be between 10 and 11.5 dB" would most likely be satisfied by a aiming a design at a nominal 10.75 dB, the mid-point between the limit specifications, since the largest variation could be accommodated there. If the amplifier gain has a Normal (Gaussian) distribution, the most common assumption is that the specification limits represent the three-sigma points. In such a case, there would be a 0.14% failure rate for circuits whose gains fall outside of the 10 to 11.5 dB window. As we will see later in this article, the failure rate can itself become a design parameter, meaning that the specification limits can be any desired number of standard deviations away from the mean.

For gains other than 10.75 dB, the relationship between average gain and allowed standard deviation would look similar to Figure 1. The allowed standard deviation of gain drops linearly from a peak of 0.25 at 10.75 dB to zero at the specification limits. As nominal gain approaches the specification limits, the distance to one of those limits decreases. Since the allowed standard deviation is one-third of this distance (for 3 sigma designs), the allowed standard deviation decreases as the mean gain approaches the specification limits, reaching zero when the average gain coincides with one of the limits.

The amplifier designer's task is to design a circuit whose Monte-Carlo performance lies along, or below the lines. For convenience, let us refer to the format of Figure 1, where average is plotted versus standard deviation, as a "μ/σ graph" (mu-sigma graph). Although we are using amplifier gain as an example, a μ/σ graph can be generated for any specification, as we will see later.

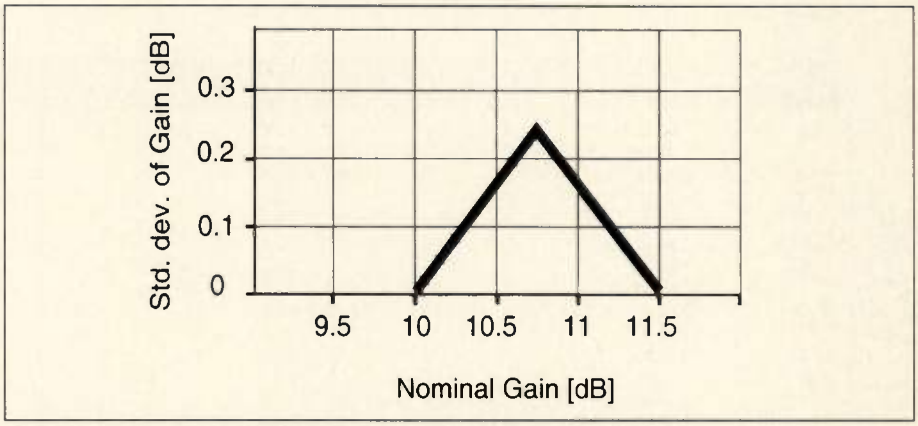

Figure 1. Average amplifier gain related to its standard deviation.

Definition of C_{pk}

Before we proceed further, an important statistical convention needs to be clarified: A common way of quantifying the amount of performance margin is by evaluating a process capability index [5], C_{pk}.

$$C_{pk} = (\mu - LSL)/(3\sigma) \quad (1)$$
$$C_{pk} = (USL - \mu)/(3\sigma) \quad (2)$$

C_{pk} = process capability index with respect to LSL or USL
μ = mean value
σ = standard deviation
LSL = lower specification limit
USL = upper specification limit

The actual C_{pk} number is the lower of the two numbers given by equations (1) and (2). C_{pk} thus quantifies the "distance" between the mean and the specification limit in terms of 3σ. Thus C_{pk} = 1 indicates that the mean is three standard deviations from the specification limit. C_{pk} = 1.5 requires that the mean be 4.5 standard deviations from the specification limit. Negative C_{pk} means that the average is out of specification.

The μ/σ graph of Figure 1 is actually a composite of two curves. When the average gain is below 10.75 dB, the LSL is more difficult to meet and the line with the positive slope is a plot of C_{pk} = 1 with respect to the LSL, while the negative-sloping line is a curve of C_{pk} = 1 with respect to the USL. Please note that the μ/σ graph will look different, depending on the chosen C_{pk}. Smaller standard deviations would be required for higher C_{pk}'s. We can draw μ/σ graphs for several C_{pk}'s, as shown in Figure 2. One could potentially design for different amounts of margin with respect to the two specification limits.

Importance of System Simulations

Most circuits do not work in isolation, and additional information is available from the system that they

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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.(Rp//Cp) OHM/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.(Rp//Cp) OHM/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.(Rp//Cp) OHM//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.(Rp//Cp) OHM//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

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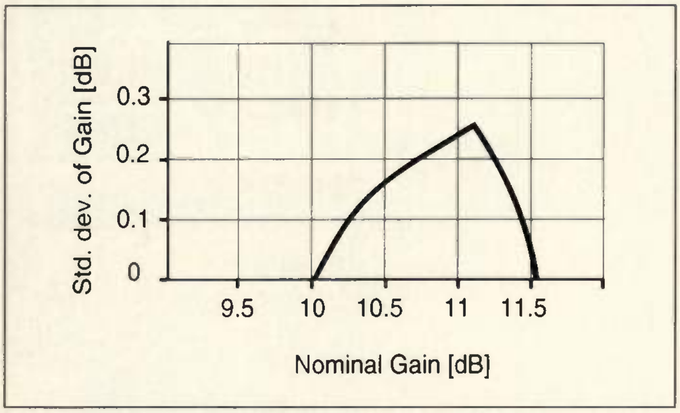

Figure 3. More realistic μ/σ graph resulting from system simulation.

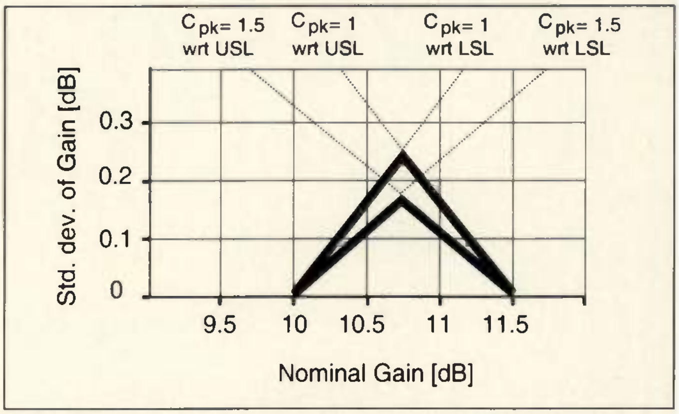

Figure 2. μ/σ graphs for different performance margins.

operate in. This is really the key point of this article: Set the circuit specifications such that they have some correlation to system requirements. Let us take the case of a receiver RF preamplifier. What sets limits on its gain? In the broadest terms, the amplifier should have as much gain as possible in order to meet receiver sensitivity with good margin, and as little gain as possible to ensure good intermodulation distortion (IM). As a result, we have the interesting case that the μ/σ graph for the amplifier gain still consists of two segments, but they are governed by different system requirements: The lower gain segment is controlled by sensitivity restrictions, while the higher gain portion is controlled by IM requirements. Its μ/σ graph may look like the one shown in Figure 3. Note that the two segments are no longer linear, as there are other contributors to sensitivity and IM, and the peak of standard deviation may not be at the mid-point between the two limits.

The conceptual leap between Figures 1 and 3 is that instead of looking at the circuit in isolation, we have correlated its specifications to actual system requirements. This fundamental shift in approach requires the capability to perform statistical system simulations on such parameters as sensitivity, IM, selectivity, hum and noise, spurious responses for receivers, and transmitter power output, distortion, hum and noise, etc. for transmitters.

While most of us have developed spreadsheet formulas, or BASIC programs for calculating these system parameters, another level of abstraction is needed to calculate C_{pk}'s on system parameters: We need the capability to feed the relevant formulas with carefully specified random inputs, and gather statistics on the calculated outputs for thousands of trials. In short, we need Monte-Carlo simulation of systems.

There are several possible alternatives: Hewlett-Packard's MDS [1] has the capability to accept formulas and feed them with random numbers, as does Microsoft Excel with @RISK from Palisade, Inc., but the one most suited to the task is Extend™ from Imagine That, Inc. [2], together with a suite of libraries called R*f* Intercept [3], developed specifically for statistical evaluation of communication system performance. The example described next was developed in Extend using R*f* Intercept libraries.

Generating the μ/σ Graphical Specification

The μ/σ graphical specification is not restricted to only gain. Any parameter which affects system performance can be thus specified. The following example demonstrates how to use the technique in a particular receiver application.

Assume that your task is to develop a set of relevant circuit specifications ensuring that you achieve less than 0.14% failure rate ($C_{pk} = 1$) for a specification of 70 dB for receiver adjacent channel selectivity. This specification is theoretically single-ended; therefore, the μ/σ graphs will consist of only one curve, the one with respect to LSL. Practically, there is always another constraint, one of cost, that bounds how "good" a performance can be obtained out of a circuit.

The first task is to come up with a formula for calculating selectivity [4]:

$$\text{Selectivity} = -CR - 10\log\left[10^{(-IFsel/10)} + 10^{(-Spurs/10)} + BW \times 10^{(SBN/10)}\right] \quad (3)$$

Selectivity = amount of adjacent channel selectivity relative to nominal receiver sensitivity [dB]

CR = co-channel rejection [dB]

IFsel = IF filter rejection at the adjacent channel [dB]

Spurs = LO spurious signals present, in relative IF bandwidth at a frequency offset equal to the channel spacing [dBc]

BW = IF noise bandwidth [Hz]

SBN = SSB phase noise of local oscillator at a frequency offset equal to the channel spacing [dBc/Hz]

This formula is then programmed with all the input quantities on the right side of Equation (3) represented by random number generators. Some means of capturing statistics on the calculated parameter are also required. Figure 4 shows how to do this in the Extend environment; *Rf* Intercept's 'RX Selectivity' block encodes Equation (3). This model is run for thousands of trials to calculate the mean and standard deviation of selectivity. Since Extend's blocks (even the ones you create) are compiled, the execution speed is only seconds on a 486, Pentium, or Macintosh Quadra.

For simplicity, all inputs have been assigned Normal (Gaussian) distributions, but other distributions are available if required.

The next step in the process is the most difficult one: Come up with a set of input parameters which describe typical nominal receiver performance. In other words, choose a set of Mean values and Standard Deviations for the five input parameters that will produce C_{pk} = 1 for the calculated selectivity. The values shown on the left in Figure 4 represent just one such starting point. Some trial and error iterations, combined with past experience will be required to thus define a nominal receiver performance. Prelim-

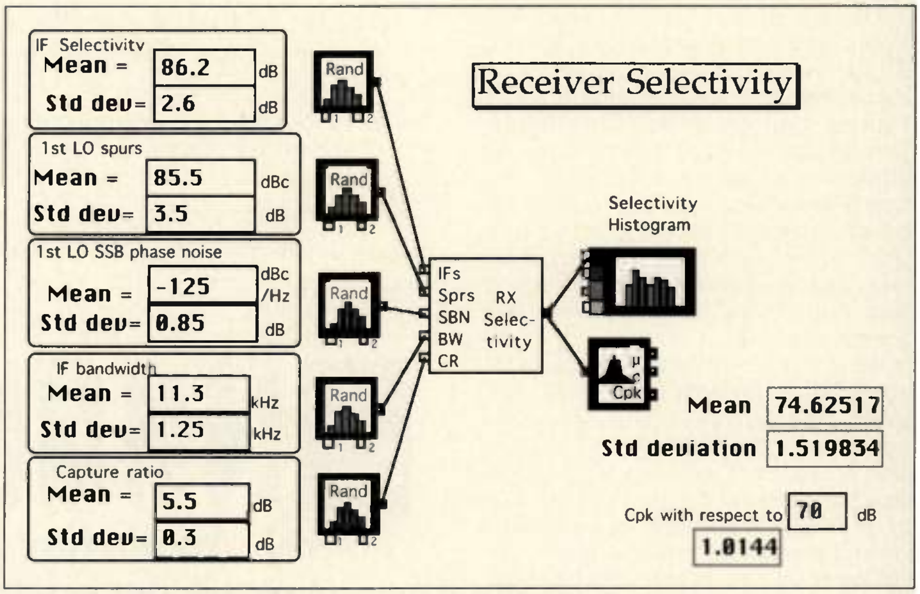

Figure 4. Selectivity calculation setup in Extend™.

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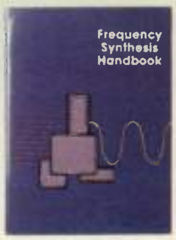

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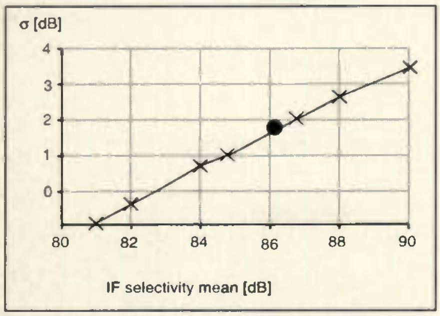

Figure 5a. IF filter skirt selectivity at the adjacent channel.

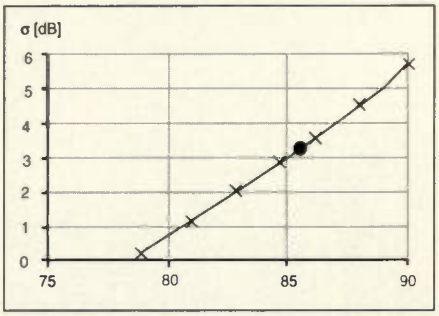

Figure 5b. First LO synthesizer spurious outputs.

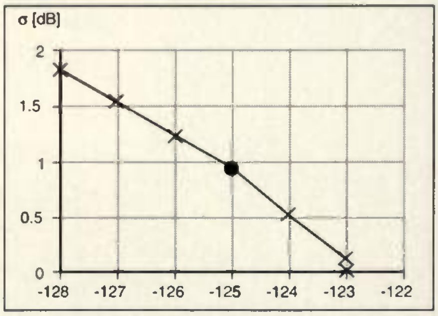

Figure 5c. VCO SSB phase noise at offset equal to chennel spacing.

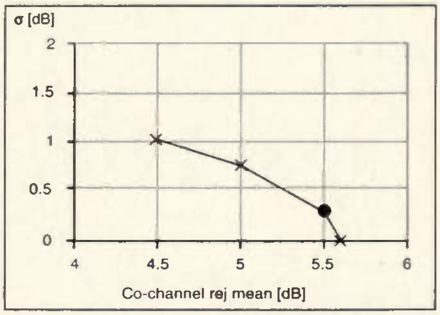

Figure 5d. Required detector S/N ratio for sensitivity.

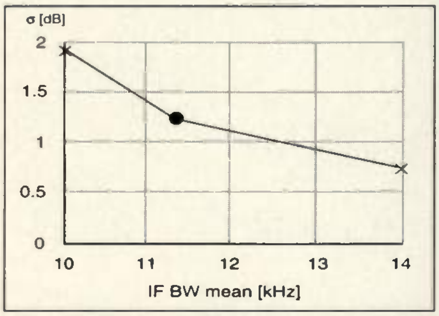

Figure 5e. IF filter noise equivalent bandwidth.

inary circuit Monte-Carlo analysis may also be needed to validate the chosen values.

Once a nominal set of input values is obtained, find other combinations of Mean and Standard Deviation for one parameter at a time, which also produce $C_{pk} = 1$. For example, while keeping IF selectivity, Spurs, IF bandwidth and Co-channel Rejection at their nominal values, you will find that more than one combination of Mean and Standard Deviation for SSB phase noise will result in $C_{pk} = 1$, defining the curve that you are after. Another way of looking at the m/s graph is to realize that the different possible m and s values define contours of C_{pk}, and we are interested in one particular contour, where $C_{pk} = 1$.

Extend™ has a mode of operation called Sensitivity mode, which makes these contours easy to locate. It lets you automatically change one parameter at a time in predetermined steps, so that you can easily pick out the one which produced $C_{pk} = 1$. You could also generate C_{pk} contours by using software such as DeltaGraph, provided that enough different μ/σ combinations are available for interpolation.

Figure 5 shows μ/σ graphs for all of the five circuits affecting selectivity, with the nominal starting values identified by black dots. All of these μ/σ graphs were generated by taking one parameter at a time, and while keeping the other four at their nominal distributions, finding μ and σ combinations which result in $C_{pk} = 1$.

Figure 5 shows circuit specifications for meeting 70 dB selectivity with 3σ margin. ($C_{pk} = 1$). The five μ/σ graphs of Figure 5 can now be used by designers of the IF filter, VCO, synthesizer, and detector circuitry as guidelines for their own Monte-Carlo circuit simulations. If all the circuits' performances are on, or below their respective μ/σ graph lines in Figure 5, then the required margin on selectivity will be obtained.

Since the μ/σ graphs are dependent on the defined initial nominal values, they may have to be re-generated if any circuit strays too far from its assigned nominal performance; requirements may have to be fine-tuned as the project proceeds. Some engineers, especially those involved with software, may initially object to changing requirements in the middle of a project, but the "spiral approach" to hardware development has merit: you periodically re-visit the requirements, each time with better information, in order to reduce overall risk.

Benefits of the New μ/σ Graphical Method

This new statistical method has proven to be very effective in predicting and ensuring margins on electrical performance for the following reasons:

- Design engineers prefer the graphical approach, since it allows them to evaluate different circuit topologies very quickly. The circuit's performance is a dot on the μ/σ graph: Is it above, or below the line?
- By emphasizing statistical properties, it forces designers to perform Monte-Carlo analysis of their circuits very early in the design cycle. This has two secondary benefits: A realistic computer model has to be developed, since the only way to get initial statistics is by computer simulation, and certain topologies with too much variation are rejected immediately.
- Communication among the design groups is encouraged, since different tradeoffs are easy to evaluate, such as often arise between the RF amplifier's and mixer's third order intercept points in a receiver design, for example. Let's say the mixer designer comes up with a breakthrough, and his performance is much better than required. Then the amplifier's specification can be relaxed to make the amplifier designer's job a little easier.
- Performance margin can be treated as a design parameter. You design circuits up front for the desired amount of margin on system performance.
- Impossible or conflicting specifications are identified early. Figure 6 shows such a situation with an RF preamplifier; the sensitivity and IM constraints are contradictory. Recall that the aim is to be below both curves at the same time.

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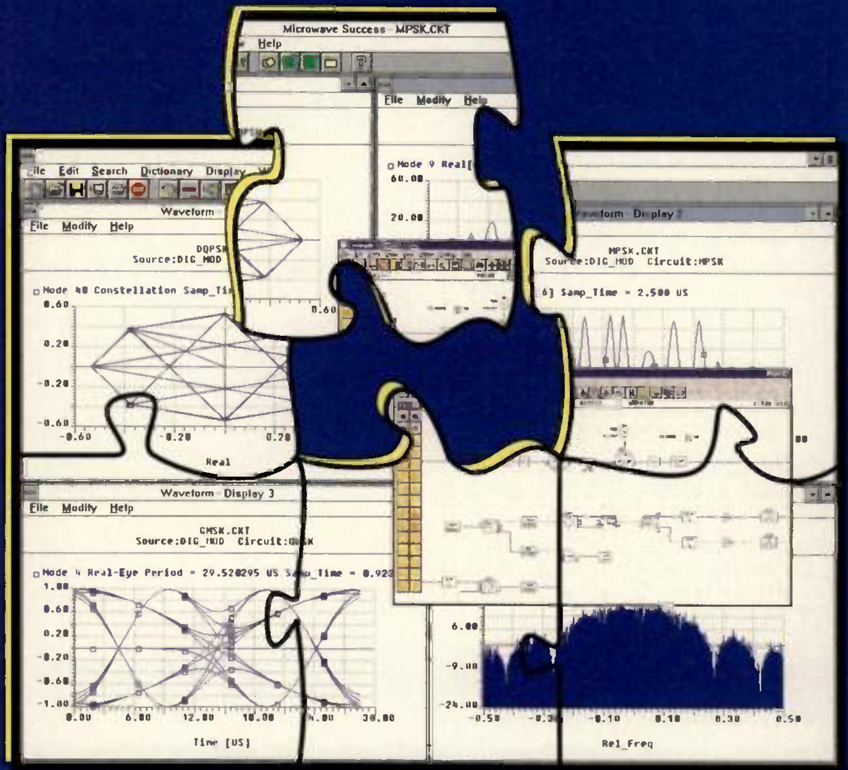

Analysis Types

- Single-Sweep Analysis
- Dual-Sweep Analysis
- Intermodulation Analysis
- Mixer Spur Analysis
- Budget Analysis
- Waveform Analysis
- Spectrum Analysis
- BER Analysis

Output Capabilities

- Budget Plots/Tables
- Constellation Plots/Tables
- Eye Diagrams
- Frequency-Domain Plots/Tables
- Time-Domain Plots/Tables

Channel Models

- Multipath Rayleigh Fading
- Additive & Bandlimited Gaussian Noise

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- Antennas
- Circulators
- Filters
- Lumped Elements
- Mixers
- Multipliers
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- Oscillators
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Summary

The μ/σ graphical method represents a new way of specifying circuit performance, in the sense that each circuit's performance target is derived from its effect on system specifications. Generation of μ/σ graphs requires an investment in time by engineers throughout the duration of a project, especially at the beginning. This time investment more than pays for itself in the long run by shortening the overall design cycle. Furthermore, the performance margin becomes just another design parameter; circuits can be tailored for a specific amount of margin. It is not necessary to measure large production quantities to validate a design. *RF*

References

1. Hewlett-Packard, *HP Microwave and RF Design Systems*, Santa Rosa Systems Division, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403.
2. Imagine That, Inc., Extend Software, 6830 Via Del Oro, Suite 230, San Jose, CA 95119, (408) 365-0305. Extend is a trademark of Imagine That, Inc.
3. RHR Laboratories, R*f* Intercept, (905) 884-2392. Macintosh version also available from ingSOFT, 213 Dunview Ave., North York, Ont., M2N 4H9, (416) 730-9611.
4. Vizmuller, P., *RF Design Guide: Systems, Circuits, and Equations*, Artech House, 1995, p. 24.
5. Sullivan, L. P., "Reducing Variability: A New Approach to Quality." *Quality Progress*, July 1984.

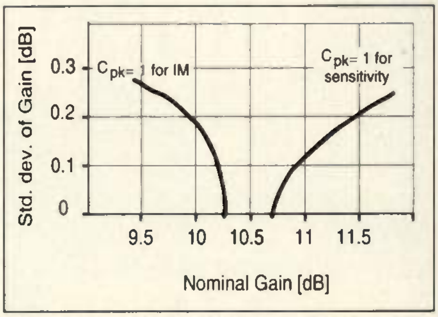


Figure 6. Unrealizable amplifier gain specification.

Author Information and Application Booklet Availability

If you would like to get more information on the μ/σ graph technique, an application note book is available from the author, explaining the technique in more detail, and covering such items as: relationship between C_{pk} and failure rate, the meaning of standard deviation for non-Gaussian distributions, estimating failure rates for non-Gaussian distributions, application of the technique to digital circuits, and other related topics. The included software estimates the number of prototypes that you need to build and measure, in order to verify your statistical design margins.

Contact the author: Peter Vizmuller, 207 Harding Blvd. W., Richmond Hill, Ont., Canada, L4C 8X6. tel. (905) 884-2392.

Software System Adds New RF Layout Capability

By the staff of
Eagleware Corporation

Fully integrated, high-performance, RF and microwave computer-aided design software is often expensive, complex to use and requires expensive computer hardware. In contrast, GENESYS is an inexpensive and easy to use "start-to-art" solution which operates under DOS, Windows 3.1, Windows 95 or Windows NT on IBM and compatible personal computers. GENESYS incorporates synthesis, schematic based simulation and layout modules into one easy-to-learn interface.

The previous release of GENESYS provided layout capability only for printed filters synthesized by the =M/FILTER= module. The emphasis of this article is on the new =LAYOUT= module which provides layout editing and artwork output for all circuits created by the user or any GENESYS synthesis module.

Design flow using GENESYS is diagrammed in Figure 1. Circuit design begins with a set of circuit specifications. Typically the user must manually design a proposed circuit. This option is available within GENESYS and is shown as the top right path. However, GENESYS also includes a number of synthesis modules which design a wide range of network structures. A simplified listing is given in Table 1. During synthesis, first a general structure such as an interdigital filter is selected. Next, performance specifications such as the number of sections and corner frequencies are entered. Finally material specifications such as PWB dielectric parameters are entered. The synthesis module then computes a complete design and displays a schematic.

Schematic Interface

At the completion of the synthesis process, each module displays an on-screen schematic. Next the synthesis module creates a schematic file (or a text net-list if the user prefers) and automatically launches the simulator environment. This schematic becomes a possession of the user and the GENESYS =SCHEMAX= module is used to view or modify the design as desired. =SCHEMAX= and the GENESYS simulator =SuperStar= Professional are tightly linked so as to streamline the exploration of design modifications, provide back annotation and deal with transmission line physical dimensions and discontinuities. The latter is difficult with third-party schematic entry programs.

Shown in Figure 2 is a schematic of a printed five-section interdigital 800-950 MHz bandpass filter with Mini-Circuits MAR3 integrated monolithic buffer amplifiers at the input and output. This schematic was created in =SCHEMAX= by manually adding the input and output buffers to the microstrip interdigital filter schematic automatically created by the =M/FILTER= synthesis program. This circuit is a

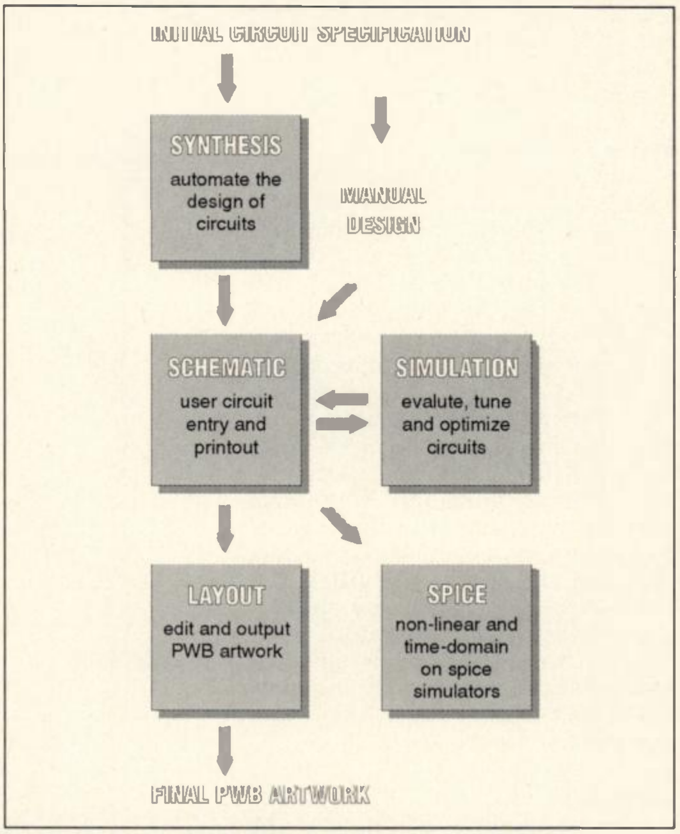


Figure 1. GENESYS sfotware design flow diagram.

hybrid of lumped and distributed elements. The square objects with round centers represent viaholes to ground. The side-by-side five-section transmission line section is split into a pair to create the input and output taps. The five small square objects at the ungrounded end of the transmission line sections are schematic symbols representing the open-end model for the lines. The length and spacings of the transmission line objects can be viewed by simply double-clicking on the transmission line object. The substrate used for this circuit is 1/16 inch thick, one ounce copper, FR-4 laminate with a dielectric constant of 4.8 and a loss tangent of 0.008.

After the user adds the input and output buffers to the =M/FILTER= generated schematic, simply pressing F9 invokes translation of the =SCHEMAX= file and launches the simulator =SuperStar= Professional. Shown in Figure 3 is a 25 sample =SuperStar= Professional Monte Carlo analysis of the buffered filter with ±2 mil physical tolerances and a dielectric constant tolerance of ±5%. The left grid displays the gain (right vertical axis from –70 to +30 dB) and group delay (left vertical axis from 0 to 50 ns). The right grid is a Smith chart plot of S_{11} and S_{22} (the original computer screen plots are color coded for easy identification).

Spice Simulation

The GENESYS schematic module =SCHEMAX= writes net lists for Spice simulators, therefore integrating both non-linear and time-domain simulation in the environment. P-Spice from Microsim and I-Spice4 from Intusoft are directly supported and tested. Generic support is provided for Berkeley Spice 2 and Spice 3 based simulators. Although Spice simulators are weak for distributed elements, both Spice and harmonic-balance simulators provide harmonic waveform analysis. Spice has the advantage of providing bias network simulation, time-domain analysis of filter and other structures and true startup transient analysis of oscillators. Since GENESYS creates Spice netlists, the user is freed from the need to redraw the circuit to check non-linear and time-domain performance.

Layout

After simulator verification of the circuit, the GENESYS =SCHEMAX= program launches the =LAYOUT= module. An initial layout screen is given in Figure 4. Each object in the schematic is automatically drawn and placed in the =LAYOUT= screen workspace. The transmission line objects are drawn with all dimensions taken from values in the schematic. This is a primary benefit of an integrated schematic, simulation and layout environment which recognizes the special needs of RF and microwave circuit design. Other objects are drawn using footprint libraries and an association list which identifies a footprint for each schematic object. The user may edit and create footprint libraries and the association list. For example, the object in Figure 4 which is second furthest from the upper-right side of the

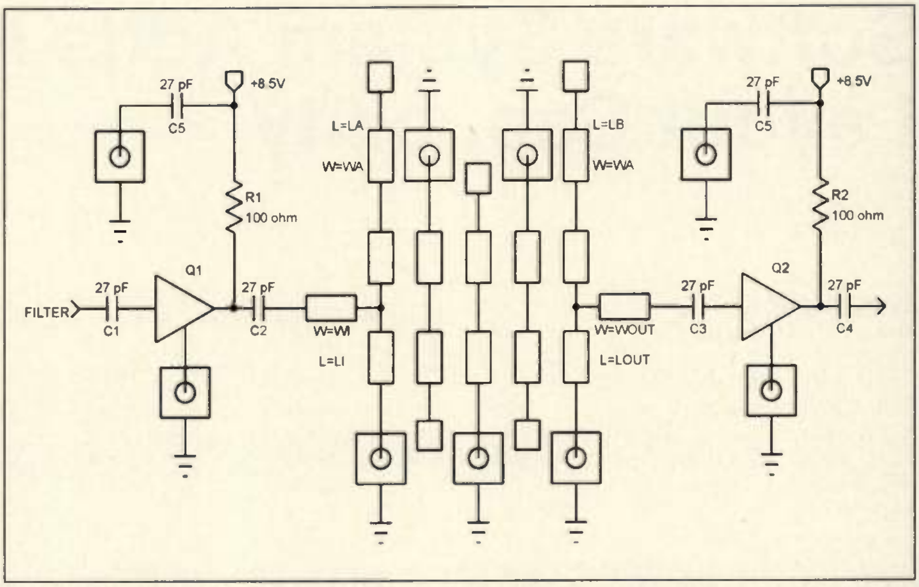


Figure 2. Schematic of an example interdigital filter with input and output buffer amplifiers.

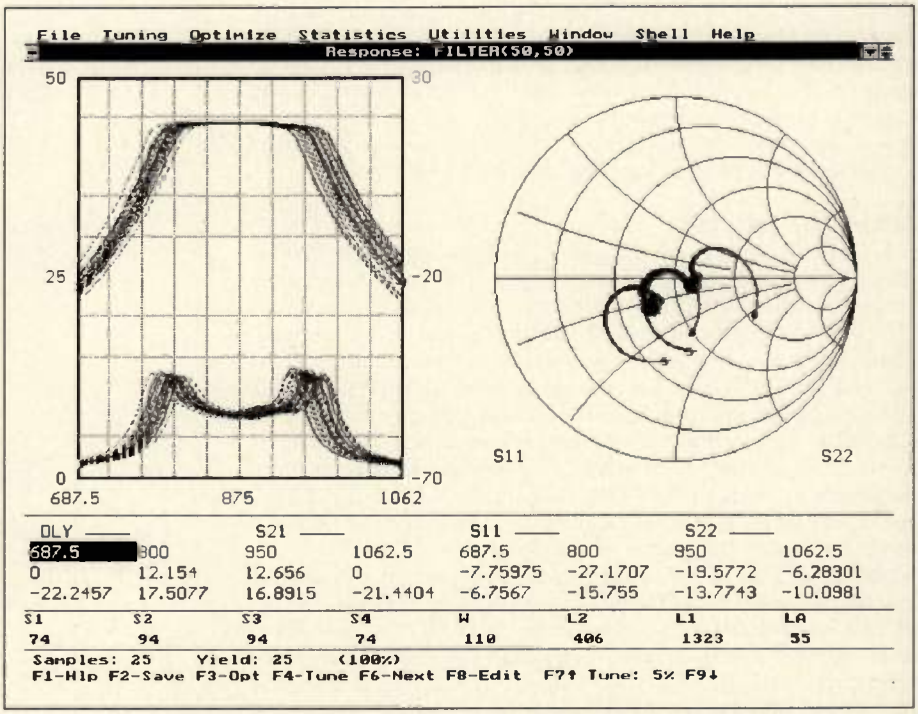


Figure 3. Monte Carlo statistical simulation of the buffered interdigital filter.

workspace is the footprint associated with the Mini-Circuits MAR3 monolithic amplifier.

Because the size of physical objects is not related to the space occupied by a symbol in the schematic, it is impossible to finalize the layout using schematic information. Therefore the algorithm which places footprints on the layout workspace simply places them in the general orientation of components in the schematic. Component connections are then completed using rubber band lines. The user may then select a footprint or a group of footprints and drag them to the desired location and the rubber band lines follow. When a component node is dragged directly onto another component node the rubber band line is deleted. In general it becomes necessary to add new printed lines to resolve all connections. Laying a new line between nodes also deletes a rubber band line. A line to be included in the simulation is added by returning to =SCHEMAX= and adding that line. It is important to note that the previous layout effort is not lost when it is necessary to return to =SCHEMAX= to add or delete an object. Lines which do not effect circuit performance may be added directly in =LAYOUT= and do not appear in =SCHEMAX=.

Shown in Figure 5 is a final layout after resolution of all rubber band lines. The rectangular box represents the specified board outline which is 3 × 2 inches. The final layout is slightly shorter than the PWB outline and the input/output lines could be lengthened or a smaller PWB could be used. The power supply lines were brought to the bottom of the PWB.

Libraries

=LAYOUT= includes a library of footprints (land patterns) for active and passive circuits based on the IPC-SM-782 Surface Mount Design and Land Pattern Standard [1]. Also included is a smaller library for active devices drawn from manufacturer data books.

=LAYOUT= includes a built-in footprint editor for editing existing footprints and creating new footprint library sets. The footprint editor is similar to the =LAYOUT= editor which minimizes the learning effort. The dates of library objects are automatically tracked and the user is notified if library objects were modified after the layout was created.

General Features

Certain attributes and features are required in any efficient layout program. A layout program designed for RF and microwave circuits should possess additional capabilities. =LAYOUT= was created to address the special needs of high-frequency analog circuit design while retaining the ability to handle digital and low-frequency PWBs. A brief list of =LAYOUT= features includes:

- Automatic schematic to initial layout conversion
- Layout effort is retained when schematic is modified
- Arbitrary metalization shapes with arcs and polygons
- Automatic dimensional tracking of

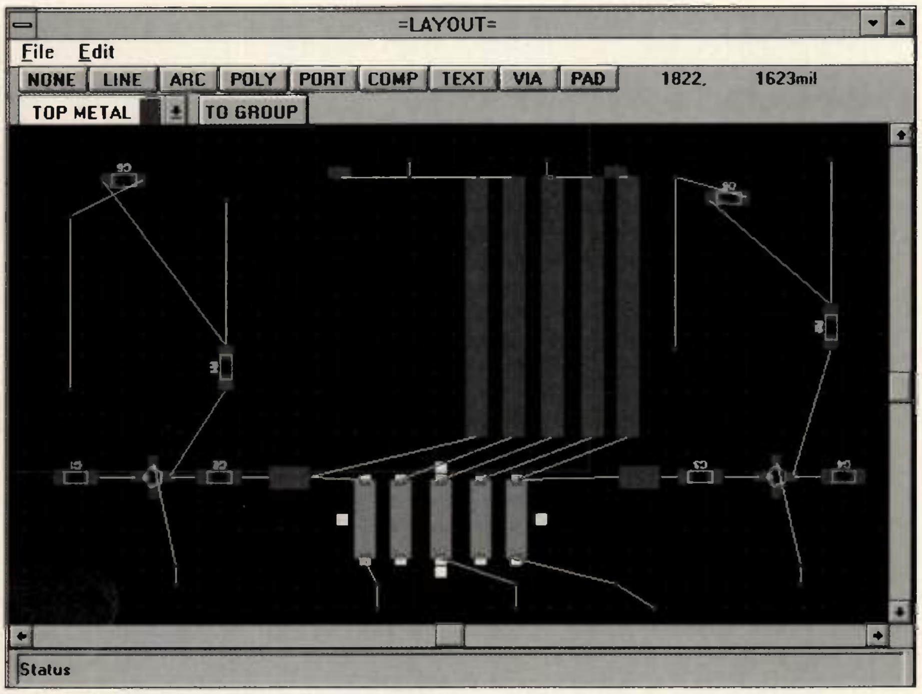


Figure 4. Initial layout of the example interdigital filter, including the input and output buffer amplifers.

transmission lines and discontinuities

- Rich set of movement, grouping and transformation functions
- Multiple metal, silk screen and mask layers
- Automatic ground pour with user specified clearance from objects
- Libraries with multilayer support and date tracking
- Printer, plotter, postscript, HPGL and DXF (AutoCad) output formats
- Gerber 274X and other output formats with optimized line widths

Optimized Output Files

=LAYOUT= supports virtually all standard printer devices and a variety of file formats. Typical layout programs and Gerber files were not originally designed for RF and microwave circuits. Transmission lines and filled coplanar ground areas are typically filled with a constant line width which results in very large files. =LAYOUT= optimizes these objects by filling with variable aperture sizes. They are first outlined with a small pen and then

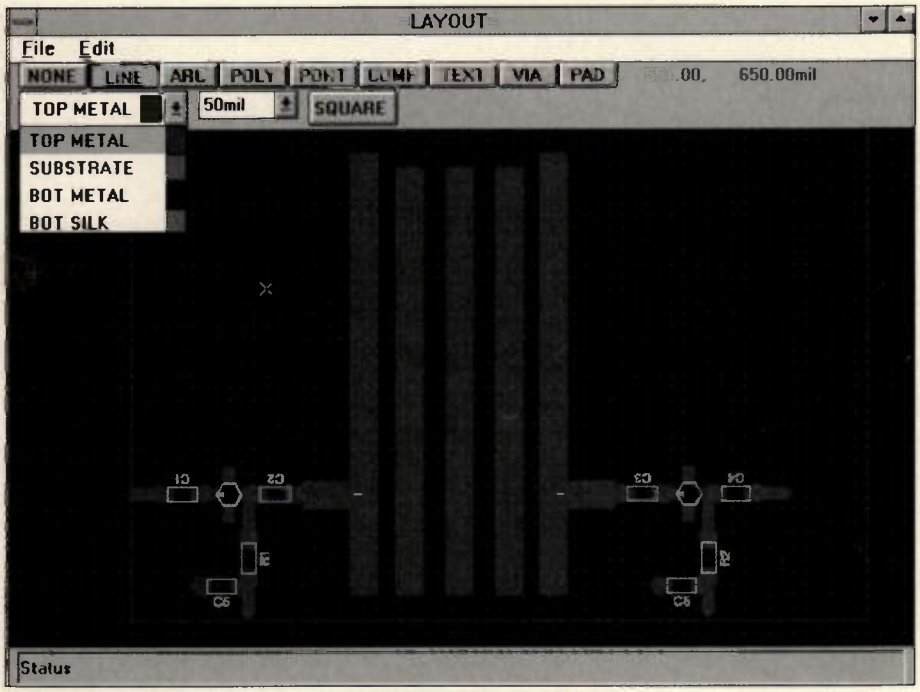


Figure 5. Final layout of the example buffered filter.

filled with progressively larger pens until the polygon is filled.

Summary

The integration of synthesis, simulation and layout allows to user to explore design alternatives, quickly evaluate each approach and finalize the design with minimum effort. GENESYS provides this functionality in one easy-to-learn environment using cost effective IBM and compatible personal computers running under DOS and Windows operating systems. The Windows 3.1, 95 and NT versions are true 32-bit applications for fast execution on 80386 and later CPUs including the new Intel Pentium Pro. 8 Mbytes of RAM and 15 Mbytes of hard disk space are recommended. The Windows GENESYS module =LAYOUT= is $699. Current customers please contact Eagleware for discounted pricing until June 30, 1996. The GENESYS simulation, schematic and layout module set is $1999. A full GENESYS package with synthesis is $5990 and includes free technical support. Eagleware does not charge annual fees.

Readers interested in obtaining more information can contact Eagleware at 1750 Mountain Glen, Stone Mountain, GA 30087. Telephone: (770) 939-0156; fax: (770) 939-0157. Information can also be obtained by circling Info/Card #250. **RF**

References

1. *Surface Mount Design and Land Pattern Standard*, The Institute for Interconnecting and Packaging Electronic Circuits, IPC-SM-782 (Revision A - August 1993), Lincolnwood, IL, 1993.

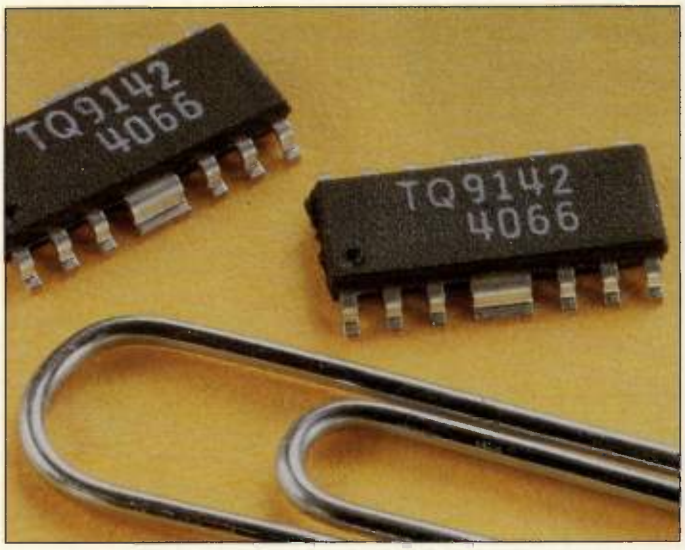
GENESYS Synthesis Modules and Algorithms

=OSCILLATOR=	=M/FILTER= (distributed filters)	=EQUALIZE= (group-delay equalizers)
L-C series, Colpitts & Clapp L-C and t-line VCO Cavity (2 types) Coaxial dielectric resonator SAW (3 types) Pierce & Colpitts crystal Driscoll crystal Butler overtone Butler with multiplier	End coupled Edge coupled Hairpin Stepped-Z Combline Interdigital Elliptic LP & BP Stub LP, BP & BS Edge BS	L-C Types 1-4 for Q>1 L-C types 5-6 for Q>0 Op amp types 7-9
=FILTER= (L-C element filters)	**=MATCH=**	**=A/FILTER=** (active filters)
Conventional all-pole Conventional elliptic Coupled resonator (3 types) Tubular Blinchikoff flat delay Zigzag Eagleware symmetric	Simple pi, tee & L T-line quarter wave T-line single/double stub General order bandpass L-C and T-line pseudo LP Stepped-Z Custom	GIC transform Single feedback Multiple feedback Low sensitivity State variable (biquad) VCVS Dual amplifier

High-Efficiency, 1W PA IC

TriQuint Semiconductor has introduced the first in a line of high-power RF power amplifier integrated circuits for the wireless communications market. The TQ9142 is a monolithic, GaAs IC using MESFET technology. It is optimized for use as the front-end transmit amplifier in analog cellular (AMPS) telephones and CDPD wide area network applications. It operates over the 824 to 849 MHz, achieving a typical efficiency of over 60 percent for a power output of 30.5 dBm while operating at the 4.8 V typically provided by four NiCd or NiMH battery cells. As a result of its low cost and high efficiency at high power, the TQ9142 provides a cost-effective means to achieve the long talk-times users demand in cellular telephones. The TQ9142 integrates most of the RF matching on-chip - the input is matched to 50 ohms and the output is matched with a simple network. The part has three gain stages and achieves gain of 30.5 dB. The device's bias lines are accessible to provide maximum flexibility, and it supports variable power output and high-speed on/off control. The TQ9142 is packaged in a low-cost power SO-16 plastic package and is available from stock at a unit price of $4.25 in order quantities of 50,000 per year.

TriQuint Semiconductor, Inc.
INFO/CARD #184



Surface Mount Lowpass Filter

KEL COM has introduced a new surface-mount lowpass filter, model number SL-500. This filter has a minimum 3 dB cutoff of 500 MHz, and features a typical VSWR of 2.0:1. Minimum stopband rejection is specified as 25 dB at 550 MHz, increasing to 50 dB at 655 MHz. Package outline dimensions are 1.10 × 0.60 × 0.27 inches. Contact KEL COM for pricing, and for the availability of additional standard and custom filters.

KEL COM
INFO/CARD #185

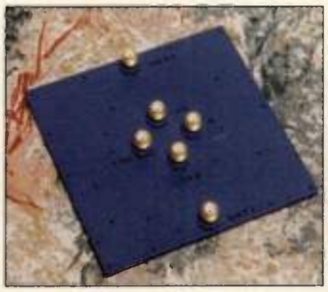
Low-Jitter, 1 GHz Clock Oscillators

Micro Networks announces two precision clock oscillators for 300 MHz to 1 GHz, with less than 3 ps phase jitter for high-performance computer, telecommunications, ATE, and data communications applications. Both oscillators are packaged in 24-pin, double-wide, metal DIP packages. The M101 series provides a customer-specified output frequency from 300 to 1000 MHz. Complementary PECL or ECL outputs are available. The M201/211 series is a family of frequency multipliers with outputs from 300 to 1000 MHz. Multiplication factors are 32, 33, 64, or 65. The M201 series accepts single-ended inputs; the M211 models accept differential inputs. Both families operate from a single +5 VDC supply. Pricing for a basic M201 with multiplication factor of 32 is $121.00 in sample quantities.

Micro Networks Corp.
INFO/CARD #186

GPS Antenna Feed Network

Anaren's GPS antenna feed network operates at both GPS frequency bands: 1.20 to 1.25 and 1.55 to 1.60 GHz. Quadrature inputs allow it to feed a circularly polarized antenna. Antenna ports are located at optimum feed points for a patch antenna (connectors can be replaced with a directly-mounted antenna). An optional internal diplexer allows for separation of bands at the output. In the lower frequency band, insertion loss is 1.3 dB, phase balance is ±3°, isolation is 20 dB, and return loss at the antenna ports is 16 dB. For the higher band, insertion loss is 1.5 dB, phase balance is ±3°, isolation is 20 dB, and return loss at the antenna ports is 16 dB. The caseless package is 2.5 inches square by 0.075 inches thick.



Anaren Microwave, Inc.
INFO/CARD #187

Radiating Cable for UHF

Andrew Corp. announces a new 7/8-inch high-performance RADIAX™ radiating cable optimized for frequencies from 900 to 2500 MHz. This includes all current and proposed PCS bands throughout the world. The cable has low coupling variations in the optimized bands, resulting in more uniform signal distribution. It is well suited to provide two-way voice, high-rate data, and code division multiple access (CDMA) communications in buildings, tunnels, and other enclosed areas. Other benefits of the cable include: enhanced signal containment and no single-point, peak power outputs; low-power distribution of signal, minimizing near-far variations in power level; continuous coverage along the length of RADIAX cable minimizes shadowing and blocking from structures and people.

Andrew Corporation
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SEMI-CONDUCTORS

CDPD Reference Design

VLSI Technology offers a complete two-chip CDPD reference design. The Geode™ CDPD refernce design integrates VLSI's Ruby™ II chip and a separate radio interface IC, code named Topaz. The Geode product is a CDPD-only modem designed for use where short data bursts are required. By using the Geode reference design, engineers can accelerate both design and verification. Ruby II is a 32-bit advanced RISC machine (ARM) processor.
VLSI Technology, Inc.
INFO/CARD #189

High-Speed, Low-Power Op Amp

National Semiconductor's LM7121 draws just 5.3 mA and has a 3 dB bandwidth of 235 MHz. The voltage-feedback op amp can drive unlimited capacitive loads and is contained in a TinyPak SOT-23, 5-pin package. The LM7121 is priced at $0.99 in quantities of 1,000.
National Semiconductor Corp.
INFO/CARD #190

500 MHz Video Amplifiers

The Maxim MAX4100/MAX4101 and MAX4112/MAX4113, ±5V, 500 MHz wideband op amps are designed using Maxim's proprietary 9.3 GHz complementary bipolar process. The op amps require only 5 mA supply current, yet have a 500 MHz 3 dB bandwidth (MAX4100/MAX4112) and include a robust output stage guaranteed to drive ±3.1 V into 100 ohms and is capable of delivering ± 80 mA out. The different models are optimized for open- or closed-loop operation and for different minimum gains. Prices start at $1.95.
Maxim Integrated Products
INFO/CARD #191

Universal Cordless Phone ICs

Motorola has introduced two universal cordless telephone

subsystem ICs that integrate nearly all the major functions required for a cordless telephone on a single integrated circuit. Both the MC13109 and MC13110 cordless combo ICs integrate the dual conversion FM receiver, compander, dual universal programmable PLL and supply voltage monitor on a single integrated circuit. The MC13110 also integrates a frequency inversion voice scrambler/descrambler. In quad flatpack packaging and 10k quantities, the MC13109 is $3.00, and the MC13110 is $4.80.
Motorola Semiconductor
INFO/CARD 192

Transmit- and Receive-only ICs

American Microsystems has announced the availability of sample quantities of a transmit-only and a receive-only version of its proprietary direct-sequence spread spectrum technology. The S20041 permits transmit-only and the S20042 is a receive-only IC. The parts both address FCC Part 15 applications. Both provide thousands of possible programmable pseudo noise code words in lengths up to 2047 chips/bit and allow-

ing data rates from 100 bps to 4 Mbps. Volume pricing is projected to be $8.10 for the S20041 and $17.8 for the S20042.
American Microsystems, Inc.
INFO/CARD #193

Wideband Quad Op-Amp

Burr-Brown's OPA4650 is the quad version of its OPA65X Speed Plus, low cost, low power, wideband voltage-feedback family of operational amplifiers. The OPA4650 has 360 MHz bandwidth and a 12-bit settling time of 20 ns to 0.01%. The device is available in 14-pin DIP and SO-14 surface mount packages, and operates over the –40 to +85°C temperature range. The OPA4650 is priced from $5.12 in 1000-piece quantities.
Burr-Brown Corp.
INFO/CARD #194

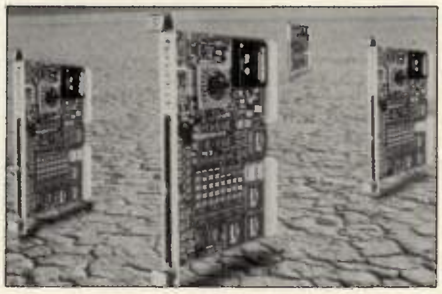
MPEG2 Decoder

Toshiba America Electronic Components has announced the TC81211, a one-chip video and audio decoder that is fully compliant with the MPEG2 standard. The chip includes glueless system interfaces for a host, bitstream, memory, video encoder and audio DAC. Packaged in 208-pin plastic quad flat packs, the TC81211 works with a single 27 MHz clock for decoding and uses a 3.3 V power supply, with 5V-tolerant inputs. Price is $150/chip in lots of ten.
Toshiba America Electronic Components, Inc.
INFO/CARD #195

SUBSYSTEMS

VME Waveform Capture Board

With an advanced VME design, the VDA500 waveform capture board from Signatec features an analog bandwidth of DC to 500 MHz, a 500 MHz 8-bit digitizer, 256k bytes of onboard memory and a data transfer rate of 200 MB per second. Memory is expandable to 1 GB or more with external memory modules. The VDA500 offers two input channels and a multiplexer. A C/C++ library is included. The VDA500 is priced at $7,450.00 each.



Signatec, Inc.
INFO/CARD #196

Frequency Translators

A series of MITEQ tri-band frequency test translators is designed to translate the C-, X-, and Ku-band satellite communication frequency transmit bands to their respective receive frequency bands. The translators feature minimum amplitude and delay distortion, high frequency stability, low intermodulation distortion and low phase noise contribution. The unit is available in local-only or local/remote controlled versions.
MITEQ Inc.
INFO/CARD #197

Wideband Cellular Receiver

Interad introduces the Model 9401 M/S, 4/8 channel, wideband cellular band receiver/translator. The 9401 accepts input from 824 to 894 MHz and produces an output from 1.5 to 11.5 MHz. The M model

receives four channels, while the 9401S receives eight. Minimum TOI on the output is +90 dBm, minimum instantaneous dynamic range is 80 dB, and minimum image/IF rejection is 80 dB. The 19-inch rack mount receiver is controlled via an RS-232 interface.
Interad Ltd.
INFO/CARD #198

VXIbus Communications Receivers

Racal Instruments introduces two, high performance single-slot VXIbus communications receivers for radio transmitter evaluations or signal monitoring. The Model 251 covers the frequency range of 10 kHz to 30 MHz with 1 Hz tuning resolution and 51 standard bandwidths, while the 2561 covers 30 to 1200 MHz with 10 Hz tuning resolution and 15 standard bandwidths. Both receivers provide quadrature outputs and AM, FM, LSB, USB, ISB, and CW detection. Price starts at $7,500.
Racal Instruments, Inc.
INFO/CARD #199

SM Transverter

California Amplifier now offers a 900 to 2450 MHz integrated antenna/transverter. The product includes a 16 dBi Yagi antenna with an integrated downconverter/upconverter. Integrated receive gain is 44 dB, and output power is 4 W EIRP. The downcoverter translates 2450 - 2474 MHz to 903 - 927 MHz, and the upconverter does the reverse. A stand-alone transverter for use with industry-standard antennas is also available.
California Amplifier
INFO/CARD #200

DISCRETE COMPONENTS

High Voltage Chip Caps

Johanson Dielectrics now offers surface mount, high-voltage chip capacitors with voltage ratings of 500 to 5,000 VDC, including a 1000-volt, 0805-size chip. The chip capacitors are compact and have low ESR. NPO and X7R dielectrics are offered in 0805, 1206, 1210, 1808, 1812, 1825, and 2225 sizes. They feature a solder-plated nickel-barrier termination. Price is $0.15 to $0.95 in quantities of 100,000.
Johanson Dielectrics, Inc.
INFO/CARD #201

Ultra-Low-Value Chip Resistors

Ohmtek's L Series chip resistors have extremely low resistance and are small SMT devices. Using a homogeneous nickel alloy element, these resistors range from 0.03 to 10.0 ohms. Minimum tolerance for the 0.1 ohm chip is ±2.0 percent and ±1.0 percent for values greater than 0.25 ohms. Other features include stable film/high power capability (up to 2.0 W at +70°C), very low inductance for high frequency applications, alumina substrates.
Ohmtek, Inc.
INFO/CARD #202

SAW Resonator in TO-39 Package

The KAR-CK Series from AVX offers surface acoustic wave (SAW) resonators in a hermetically sealed TO-39 metal can. The series is available at 315 MHz and in custom frequencies up to 450 MHz. The resonators have a standard stability of ±250 kHz; ±100 kHz is also available. Typical pricing for the KAR-CK Series is $1.50 in quantities of 1,000 for the KAR-315-CK.
AVX Corp.
INFO/CARD #203

New Trim Cap Series

Five new series of trimmer capacitors from the North American Capacitor Company are designed to meet the needs of a broad range of RF and microwave applications. The MAV Series of air dielectric trimmers are designed for maximum stability and high Q. The MTR Series uses a sapphire dielectric and rugged construction. The MVC-03 Series of disc ceramic trimmers are appropriate fro surface mount applications. The MVC-07 Series of disc ceramic trimmers meet the needs of micromodule and hybrid circuit designers through its leaded packages. The MPT Series of piston trimmer caps are reliable under extreme vibration and shock.
North American Capacitor Company
INFO/CARD #204

RF products *continued*

TEST EQUIPMENT

Automted Audio and Radio Tester

Panasonic Factory Automation has released the VP-7611A audio and radio

tester, also known as the ART-ONE system. The new system is a stand alone semi-automatic measuring instrument containing the necessary measuring functions for measurement of radio receivers, amplifiers, CD players and tape recorders. The ART-ONE system produces both AM (100 kHz to 22 MHz) and FM (75 MHz to 110 MHz) signals.
Panasonic Factory Automation Co.
INFO/CARD #205

Multi-Function Electronic Test Station

The Multiple Instrument Station (MIS) from ABI Electronics Ltd incorporates six instruments — frequency counter, digital storage oscilloscope, DC voltage probe, function generator, programmable analog outputs and a power supply — in a single unit. The unit fits into the standard 5 1/4-inch drive bay of a standard PC. Operation is in the Windows environment.
ABI Electronics Ltd
INFO/CARD #206

Pocket-Sized Frequency Counter

Optoelectronics' CUB frequency counter measures 3.7 × 2.75 × 1.2 inches and weighs only 7.5 ounces. Its 9 digit LCD display shows frequency counts from 1 MHz to 2.8 GHz. The counter uses a 10 MHz timebase and has a digital filter to reduce false counts. The CUB sells for $149.
Optoelectronics, Inc.
INFO/CARD #207

Time Code Generator

Absolute Time™ has announced the introduction of its Model 103 GPS-synchronized time code generator. The Model 103 combines Absolute Time's highly accurate GPS Clock™ with the ease of software selection of accurate and stable timing and time code information. Time accuracy is specified at 150 nanoseconds (ns) and pulse-to-pulse jitter is less than 1 ns. The Model 103 is list priced at $3,565.
Absolute Time Corp.
INFO/CARD #208

500 MHz to 67 GHz Synthesizers

Anritsu Wiltron introduces 24 new models in its 68-Series microwave synthesizer line. These models offer frequency coverages from 500 MHz to 67 GHz and feature a new digital down-converter to improve spectral purity in the critical 500 MHz to 2.2 GHz frequency range. The digital down converter provides specified SSB phase noise < –92 dBc/Hz at 2 GHz, 2 kHz offset from the carrier, and spurious levels < –50 dBc. Prices start at $21,500, U.S. list.
Anritsu Wiltron
INFO/CARD #209

Comparative Measurement System

The comparative measurement system, TS9958V, from Rohde & Schwarz is

designed for simultaneous network quality analysis on up to three mobile test telephones. The system may be fitted with any combination of GSM900, DCS1800, and PCN1900 test mobiles. The system can be used to compare different network parameters, to detect gaps in coverage and to detect interference in several networks at the same time, as well as simultaneous measurements with different antennas in the same network.
Rohde & Schwarz GmbH
INFO/CARD #210

PCS Test Transmitter

The PCS Transmitter from Berkeley Varitronics Systems covers 1.85 through 2.1

GHz in 50 kHz steps and has a 10 W power amplifier with continuously-adjustable power output. Contained in a weatherproof, 18 × 15 × 6 inch ABS plastic case, the microprocessor-controlled transmitter can be controlled via a front panel or a 1200 baud modem. The transmitter is protected from excessive VSWR and it includes a CW IDer for FCC CP identification.
Berkeley Varitronics Systems Inc.
INFO/CARD #211

Product Focus — Power Transistors

100 Watt, 900 MHz MOSFET

California Eastern Laboratories announces the NEC NEM0995F01-30 silicon MOSFET for base station applications. This device operates from a 30-Volt supply and provides 95 watts output (typical) in the 900 MHz range. The MOSFET also provides >12 dB gain and high linearity (–37 dBc IM_3 at 42 dBm P_{out}).
California Eastern Laboratories
INFO/CARD #215

LDMOS RF Transistors Currently in Development

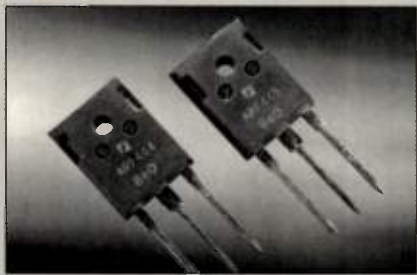
Polyfet RF Devices is developing a line of LDMOS (lateral DMOS) high power transistors for release in the 3rd quarter of 1996. The devices wil cover frequencies from 10 MHz to 1.2 GHz, with power outputs from 5 to over 100 watts. LDMOS places the source on the bottom of the transistor, eliminating the need for a BeO dielectric insulator. As a result, cost is reduced through simpler packaging, and thermal performance is expected to be improved. Also, the lack of source bonding wires reduces unwanted feedback, increasing gain by up to 3 dB.
Polyfet RF Devices
INFO/CARD #216

HF Power MOSFETS

The DE-series of power MOSFETs from Directed Energy provide power at 5 times the frequency range of conventional power MOSFETs. The family of devices also features high power dissipation, high gain, and low inductance leads for maximum switching speed. The DE-150 series has 80 W P_D and 3-5 ns switching speed. The DE-275 series has 270 W P_D and 4-5 ns switching speed. The DE-375 offers 340 W P_D and 6-8 ns switching speed. Devices are available in 100, 200, 500 and 100 Volt supply ratings.
Directed Energy, Inc.
INFO/CARD #217

300 V RF MOSFETS

Advanced Power Technology offers the ARF444 and ARF445 "symmetric pair"



capable of producing 300 watts RF power output per device. In 13.56 MHz Class C service, four devices can produce 1000 watts output with 17 dB gain. This combination is available as a 1 kW RF Pallet, model ISM1K300. In OEM quantities, the ARF444/445 are priced at $32 each.
Advanced Power Technology
INFO/CARD #218

Bipolar Power Transistor Data Book

Temic, Telefunken Semiconductors, has just released the 1996 Data Book describing the company's line of bipolar power transistors. This line of high-voltage devices has F_T ratings from 4 to 20 MHz, suitable for switching power supply and control applications.
Temic Semiconductors
INFO/CARD #219

SIGNAL SOURCES

High-Stability OCXO

Featuring an SC-cut crystal, Oak Frequency Control Group's 4834 OCXO has the highest stability of any member of Oak's OCXO product family. Available from 4 to 10 MHz, the 4834 has temperature stability of $\pm 3 \times 10^{-9}$ over –20 to +70°C and features aging of only $\pm 3 \times 10^{-8}$/year. Its footprint measures 3.020 × 2.020 inches and has a height of 1.350 inches. Start up power 10 W and steady state power is 1.3 W. Output is stable over input voltages from 9 to 13 VDC.
Oak Frequency Control Group
INFO/CARD #212

VCOs in SMT and TO-8 Packages

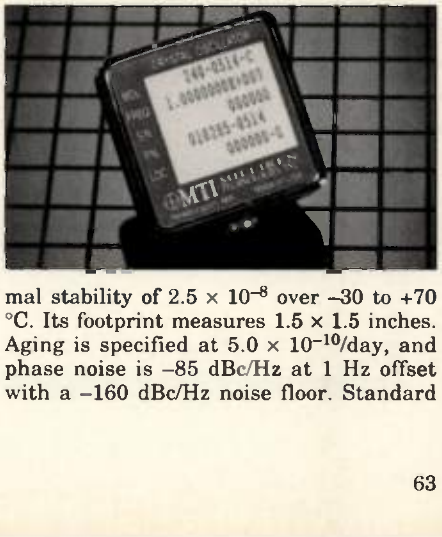
Wireless Radio offers low-cost, high-performance voltage controlled oscillators (VCOs) in surface mount and TO-8 packages. A family of low phase noise components designed for wireless communications is available immediately for standard frequency bands in digital cellular applications.
Wireless Radio
INFO/CARD #213

Small SMT Clock Oscillator

The T-Oscillators from MF Electronics have a 5 × 7mm footprint, a quarter the size of many other SMT oscillators. The oscillators are available from 1.5 to 66.6 MHz. T-Oscillators are compatible with CMOS, TTL and other logic families. They operate from 3 to 5 VDC. Stabilities are 10 ppm to 100 ppm from 0 to 70 °C (industrial grade stabilities also available). Typical height is 2.3mm. Price is $1.90 in quantities of 50,000.
MF Electronics
INFO/CARD #214

Low-Profile OCXO

The 240-series from MTI offers a 0.52 inch height package suitable for applications requiring low profile oscillators. The 240-0514 10 MHz SC-cut OCXO offers ther-



mal stability of 2.5×10^{-8} over –30 to +70 °C. Its footprint measures 1.5 × 1.5 inches. Aging is specified at 5.0×10^{-10}/day, and phase noise is –85 dBc/Hz at 1 Hz offset with a –160 dBc/Hz noise floor. Standard

frequencies are available from stock with AT and SC-cut resonators.
Milliren Technologies, Inc.
INFO/CARD #220

SIGNAL PROCESSING COMPONENTS

SMT Bias-Tee

Mini-Circuits has introduced a surface mount bias-tee for applications in the 10 to 6,000 MHz frequency range. The JEBT-6G offers typical insertion loss of 0.7 dB typical mid-band isolation of 40 dB. The small J-lead package provide strain relief for high temperatures encountered during surface mount solder assembly. Maximum RF power for this device is 30 dBm. Maximum DC voltage and current are 25 V and 500 mA.
Mini-Circuits
INFO/CARD #221

Ceramic Filters

KP Microwave Components introduces ceramic filter products to their RF/microwave line. Typical products are 1, 2, and 3 pole miniaturized surface mount ceramic filters at 2.4 GHz, GPS frequencies, and 900 to 2,400 MHz. Minimum height is 0.200 inches.
KP Microwave Components
INFO/CARD #222

Chip Filters

The TDFM2B Series of chip dielectric filters is designed to be used as the RF filter for 1.9 GHz personal communications systems in the U.S. Package size is only 6.5 × 4.3mm with a 2.25mm height. The filters have three-pole selectivity, 50 ohm input/output impedances and extremely stable temperature characteristics. The TDFM2B-1880L-10 is centered at 1880 MHz with a passband of 30 MHz and 2.5 dB insertion loss.
Toko America, Inc.
INFO/CARD #223

High Power Attenuators and Terminations

Barry Industries offers a complete family of resistors, attenuators, and terminations to meet high power demands. All-brazed

construction enables power dissipation capability of 10 to 1,000 W (derated to 250°C). They have low broadband VSWR. Resistance ranges from 0.1 to 1000 ohms, and attenuation ranges from 1 to 20 dB. Frequency range for the family is DC to 6.0 GHz, depending on circuit parasitics and mounting.
Barry Industries
INFO/CARD #224

SMT Couplers and Terminations

RF Power Components has developed 90 degree hybrid couplers for use in high- volume cellular and wireless applications. Power ratings of 100 and 200 W CW are available. The 100 W couplers measure 0.35 × 0.56 inches, and the 200 W couplers measure 1.0 × 0.5 inches.
RF Power Components, Inc.
INFO/CARD #225

Dual Receiver Multicoupler

Narda's dual receiver multicouplers are available in two stock models. A standard catalog model (RMC-WN8BF24) and a high performance OEM model (DRMC-WH8BF24). Both models offer superior IP3 and low noise figure, superior transmit band rejection, wide dynamic range, excellent output isolation, complete alarm/monitor circuits, and high MTBF.
Loral Microwave-Narda
INFO/CARD #226

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J MIXERS UNPRECEDENTED IN VALUE.

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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.

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INFO/CARD 52

Inductor Behavior at Radio Frequencies

By Gary A. Breed
Editor

Last month, capacitors were examined for their "real world" beavior at RF. This month's tutorial offers the same information on inductors. These common RF components must be understood in order to accurately model and design practical circuits.

Passive components are no longer simple at radio frequencies. Reactance is frequency-dependent, circuit dimensions can be a significant percentage of a wavelength, and radiation becomes part of the system, as well. How these effects require an inductor to be considered differently from an ideal pure reactance is the subject of this tutorial.

At RF, an inductor is a combination of resistance, capacitance and inductance, as diagrammed in Figure 1. L_N is the "normal" or nominal inductance, including all inductance from one mounting terminal to the other. This inductance is not the actual inductance seen by the circuit. L_N is affected by the frequency-dependent effects that are noted below.

C_P is the parallel capacitance, which is the sum of capacitance between adjacent windings, plus any other stray capacitance. C_P changes the net inductance, and when its reactance is equal to the inductive reactance, the inductor exhibits parallel resonance, just as a capacitor becomes series resonant with its parasitic inductance.

R_P is a single resistance representing all losses in the inductor. Ohmic loss is one contributor, which increases with frequency, according to the skin effect. Magnetic core loss is the other major contributor to R_P. Inductors that intentionally use a magnetic core have predictable losses based on the core size and material. An air-wound coil will have no inherent magnetic losses, but the magnetic field created by the inductor may interact with nearby materials if care is not taken in circuit layout, introducing unexpected losses. Although beyond the scope of this tutorial, radiation also contributes to inductor loss. Designers should be aware that this behavior exists — occasionally, coupling occurs between an inductor and nearby circuitry or interconnecting wiring, greatly increasing the energy radiated from the inductor.

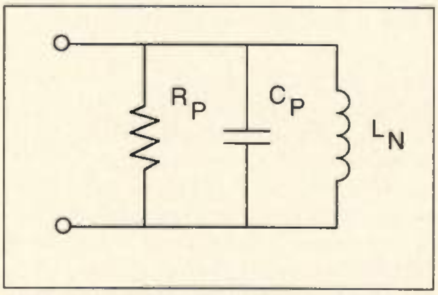

Figure 1. Basic equivalent circuit of an inductor.

Stray Inductance and Capacitance in Circuits

Figure 2 is a more detailed equivalent circuit diagram. This time, the placement of the inductor in a circuit is included. Stray inductance from interconnecting leads or circuit board traces, L_S, adds to the total inductance of the component. Stray capacitance between the inductor and the ground plane (or nearby components, shield cans, equipment case, etc.), C_S, creates a pi-network effect, which has the frequency response characteristics of a low pass filter.

The designer must include these unwanted reactances in the circuit analysis, or at least make good estimates of their magnitudes. Years ago, adjustable components might have been specified to allow manual compensation for stray capacitance or inductance. However, in today's competitive marketplace, products must be capable of manufacture with a minimum number of design iterations, and with a minimum amount of assembly-line adjustment and testing. This can only be accomplished when actual circuit behavior is well-characterized.

Resonance and Q

As with a capacitor, an inductor exhibits resonance when the capacitive and inductive reactances of its equivalent circuit are equal. Inductor resonance is parallel-resonant, presenting a very high impedance to the circuit instead of the desired inductive reactance. Table 1 shows the change in effective value of an inductor versus frequency. The example uses a 79 nH inductor with 2 pF of parallel capaci-

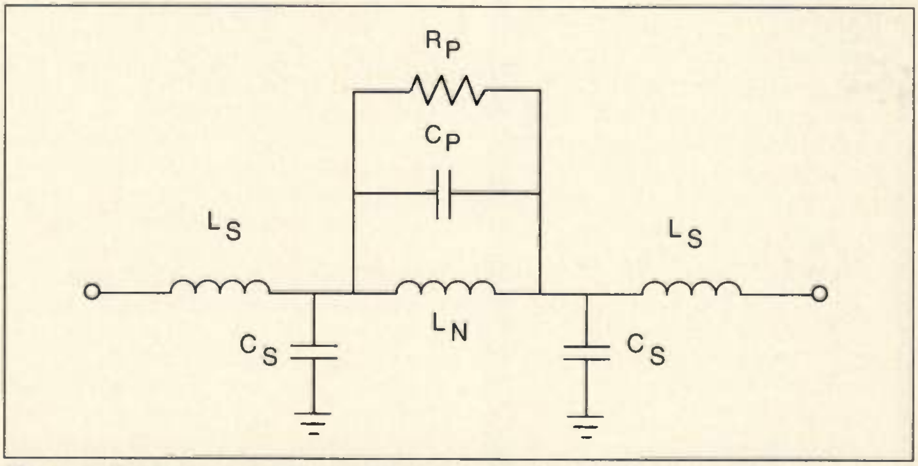

Figure 2. Equivalent circuit of an inductor as it is installed in a circuit.

Frequency (MHz)	X_L Ω	X_C Ω	X_{SUM} Ω	Equivalent Value
100	+49.6	–796	+52.9	84.2 nH
150	+74.5	–531	+86.7	92 nH
200	+99.3	–399	+132	105 nH
250	+124	–318	+203	129 nH
300	+149	–265	+339	180 nH
350	+174	–227	+736	334 nH
400	+199	–199	very high	open circuit
450	+223	–178	–871	0.41 pF
500	+248	–159	–444	0.72 pF

Table 1. Behavior of a 79 nH inductor with 2 pF of total parallel capacitance.

tance. For simplicity, no losses are included in this calculation. It is only meant to illustrate the general pattern of behavior near resonance.

The magnitude of the peak impedance depends on the Q of the inductor. Q is generally defined as the ratio of stored versus dissipated energy:

$$Q = \frac{R_P}{X_P}$$

which is given in parallel form, since the inductor equivalent circuit is expressed in that form. R_P is the equivalent parallel resistance, and X_P is the parallel reactance, including all parasitic effects. At resonance, only the parallel resistance remains, since the inductance and capacitance are equal and opposite, canceling one another.

Q is a frequency-dependent characteristic. At low frequencies, Q increases with frequency, since the reactance of an inductor increases with frequency and the losses do not become significant until very high frequencies are reached. As a rule of thumb, skin effect begins to be a factor around 30-50 MHz, but the magnitude of the loss it introduces depends on conductor diameter, or more accurately, surface area. The rate of increased loss versus frequency is accelerated by the presence of a magnetic core, a shielding can, or other materials in the inductor's magnetic field. When these losses exceed the rate that inductive reactance changes with frequency, the Q value will begin to decrease.

Measurement of Real Inductors

For current engineering practice, the most important reason for understanding component behavior is to generate accurate computer-simulated performance of RF circuits. If modeled performance can be made to closely emulate actual performance, then fewer design revisions will necessary at the prototype stage of development. Modeling can also be used to evalute performance for a range of expected component value, temperature, and manufacturing variations.

The characterization of a particular inductor is essential for accurate computer simulation of circuit behavior. As noted earlier, self-capacitance, losses and stray circuit effects must be included in any simulation. Measuring the inductor value alone, without these effects, requires careful attention to measurement techniques and fixtures.

Usually, a test fixture is constructed with great mechanical precision, and is then calibrated by a combination of open-circuit, short-circuit and through-circuit techniques. The fixture may include compensating circuitry to minimize its effect on the measurement of a component, or fixture characteristics may be measured and stored for mathematical correction.

With proper test methodology, components can be accurately characterized at high frequencies. Components, circuit board traces, connectors, solder joints, and all other elements of a circuit can also be modeled and incorporated into the mathematical models.

Summary

Hopefully, this tutorial has shed some light on the behavior of inductors at RF, and demonstrated the need for understanding the characteristics of practical components. RF

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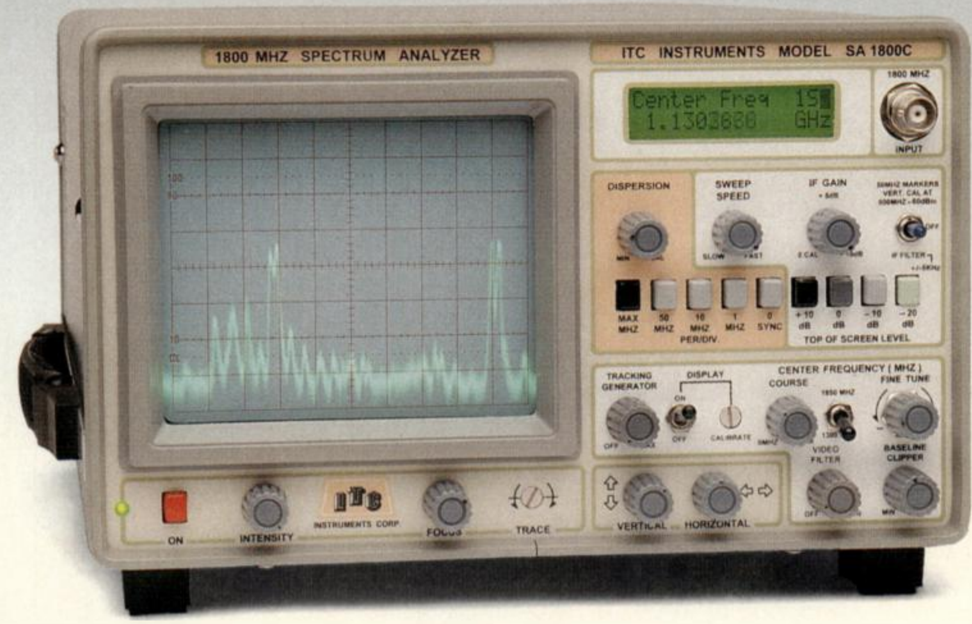
Simply An Affordable 2 GHz Spectrum Analyzer



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INFO/CARD 54

A Tutorial on Intermodulation Distortion and Non-Linearity In RF systems

By Jeffrey Pawlan
Pawlan Communications

It would make the task of a system engineer much easier if the RF engineer could produce an amplifier that was perfect: "a piece of wire with gain." Unfortunately, this is very far from reality. This tutorial article describes the nature of imperfect (nonlinear) behavior in practical circuits, and the distortion it ultimately creates.

All amplifiers have limited frequency response, finite dynamic range, noise, and produce distortion. Distortion means that unwanted signals appear at the output of the amplifier that were not presented to the input. These unwanted signals can cause significant problems in the communications system where they originate, and can sometimes cause interference to other systems as well. The distortion may be any or all of three types: harmonic distortion, intermodulation distortion, and cross modulation distortion.

Harmonic distortion is defined as the production of integer harmonics of one or more input signals. For amplifiers with an octave or more bandwidth, this can be a problem.

Intermodulation distortion is defined as the production of new output signals created from the non-linear combination of two or more input signals mixing together. The "order" of the intermodulation product depends on how many input signals are mixed and which harmonics of each of those input signals have mixed. Some examples of second and third order intermodulation products are illustrated next:.

2nd Order Intermodulation Products:

$F_1 + F_2 = F_3$
$F_1 - F_2 = F_4$
$F_2 - F_1 = F_5$

Note that F_3, F_4, and F_5 are the undersireable distortion products that

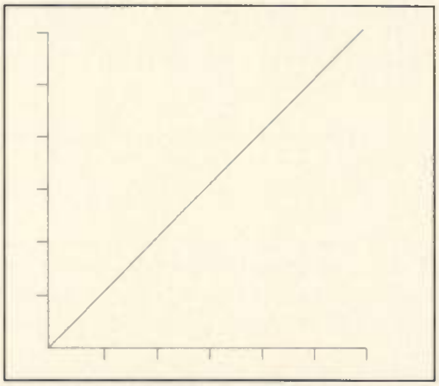

Figure 1. Output power versus input power for an ideal amplifier.

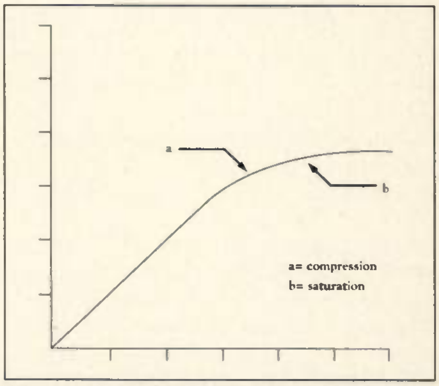

Figure 2. Output power versus input power for a real amplifier.

appear at the output.

3rd Order Intermodulation Products:

$2F_1 + F_2 = F_6$
$F_1 + 2F_2 = F_7$
$2F_1 - F_2 = F_8$
$2F_2 - F_1 = F_9$

If F_1 and F_2 are very closely spaced, then the 3rd order products $2F_1–F_2$ and $2F_2–F_1$ are the most troublesome. These spurious signals fall in the vicinity of F_1, and may appear in the receiver passband with sufficient amplitude to become interfering signals.

Among the many possible higher order products are the following:

4th Order Intermodulation Products:

$3F_1 - F_2 = F_{10}$
$3F_2 - F_1 = F_{11}$

5th Order Intermoduation Products:

$3F_1 - 2F_2 = F_{12}$
$3F_2 - 2F_1 = F_{13}$

You can see that all of the above possible intermodulation products were produced with just two input signals. Imagine the possible problem of three or more signals!

Cross modulation is the result when the amplitude modulation on one carrier is transferred to another carrier at the output. An example of this is seen when one uses a TV antenna pre-amplifier in a location where there is one very strong nearby signal. You will see modulation bars on other channels as a reult of the non-linearity of the pre-amplifier.

Examples of How IMD Can Affect You

An HF example — Anyone who has listened to an HF communications receiver or shortwave radio can attest to the fact that there are tens of thousands of signals simultaneously broadcasting worldwide. Depending on your location and propagation, many of these may be millivolts at your receiver input, while others are sub-microvolt. Non-linearity in the receiver generally occurs in the first RF amplifier (pre-amplifier) or in the first mixer. If you are in a good location or have a reasonable outdoor antenna, it is likely that you will hear "ghost" signals which are actually intermodulation products of two or more real signals.

Television and CATV example — Both over-the-air television and cable systems must be capable of a decade or more frequency range. The television video carriers are generally high level; usually a *minimum* of 1mV across 75 ohms (0 dBmV). Depending on how many channels are present in your service area or cable system, the intermodulation possibilities are very high, and many of them will cause picture and sound interference. Horizontal or slanted bars in the picture are very common.

VHF-UHF example — Most urban areas in the US and Europe have two-way radio or pager systems spaced at 12.5 kHz intervals over dozens of MHz. The receivers in pagers and two-way radios are often capable of receiving signals below 0.5 μV in strength. This means that even a very weak intermodulation product will compete with a desired signal. Since the channels are evenly spaced, if two channels that are adjacent to each other create third order products, then these products will appear directly on channels that are on either side of the two that have mixed.

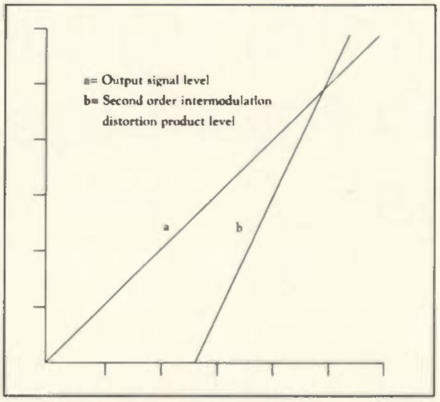

Figure 3. The slope of the second order intermodulation is two times the slope of the output signal level.

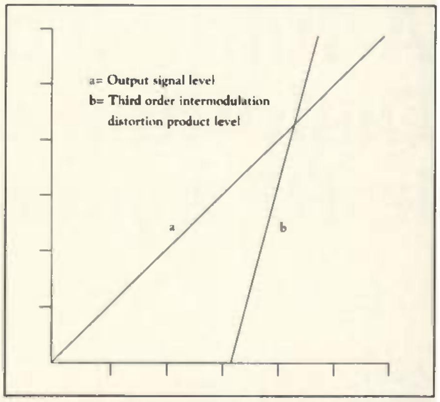

Figure 4. the slope of the third order intermodulation is three time the slope of the output signal level.

Cellular and Part 15 examples — The tower mounted cellular base station has the same problem as the two-way UHF receiver. It must be capable of simultaneously receiving all of the cellular channels and downconverting these to independent IFs or demodulators. Since many cellular phones may be operating in close proximity to the antenna tower, the signals could be quite strong and cause intermodulation if the RF amplifier is not properly designed. The cellular base station transmit amplifier has the same problem in reverse. All of the cellular channels must be amplified simultaneously for transmission. Any intermodulation distortion would be transmitted. Since the cellular channels are evenly spaced, all third order products produced would fall directly on other cellular frequencies.

Part 15 receivers are a particularly difficult challenge as the permitted frequencies are usually sharing a frequency band with high power licensed stations. The Part 15 transmitters are restricted to a very low power level necessitating sensitive receivers which are susceptable to the high power transmissions. Usually, Part 15 devices must be designed for very low cost and low power consumption which rarely allows wide dynamic range.

In all radio services, the most susceptable areas are the input amplifiers and the first mixer. These must be designed to handle the number and the levels of signals at their inputs. In high RF environments, such as at a high power transmitting station, or on a mountaintop two-way radio site, even some non-obvious passive connections will become non-linear and produce intermodulation distortion or harmonics. Some well-known examples of this are metallic guy wires and nickel plated coaxial connectors.

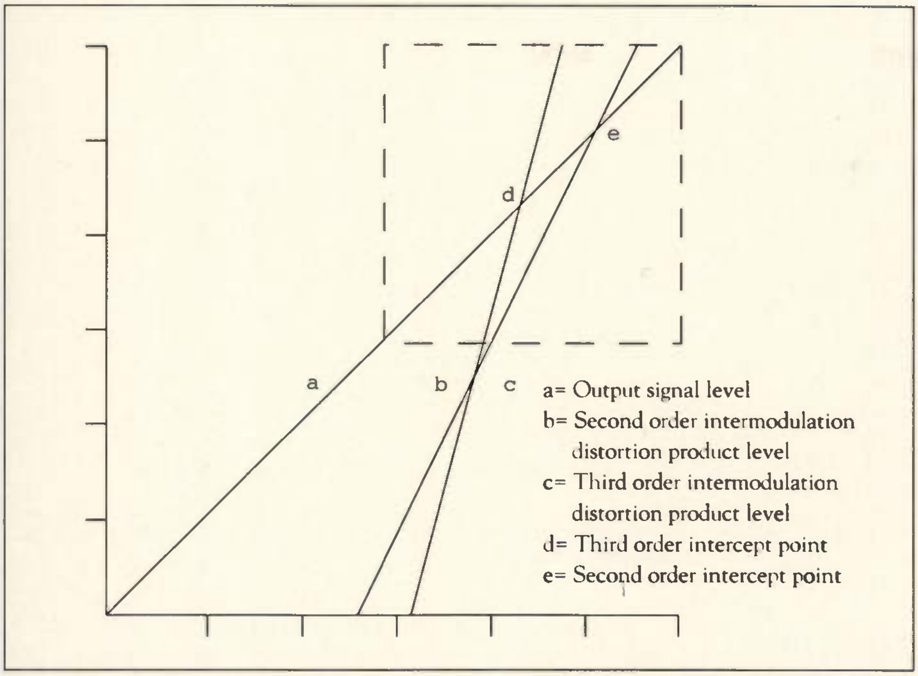

Figure 5a. The slopes of the output signal, second order and third order distortion products plotted together.

Visualizing the Behavior of Intermodulation Distortion and Gain of an Amplifier at Different Signal Levels

In an ideal amplifier (the wire with gain), the output levels of the signals are directly proportional to the input signal levels, hence, the plotted output versus input levels would be a straight line with a slope equal to the gain of the amplifier. The Y-axis, representing output level, may be conveniently scaled to produce a slope of 1, as shown in Figure 1.

In a real amplifier, as opposed to an ideal one, the output will clearly level off rather than climb to infinity with an increasing input level. The amplifier output is said to *compress* as the increase in power out lags the increase in input level. Eventually, the amplifier is said to be in *saturation* when the output does not increase at all with an increased input, as shown in Figure 2.

The intermodulation products of a real amplifier will increase at a order equal to the order of the intermodulation product, with respect to the level of the input signals, provided that the sum of the powers of all output signals, including the distortion products, is below the compression knee. Since decibels are a logarithmic representation, if the axes are plotted in dB then the *slope* of the plotted distortion level versus input signal levels will be an integer times the slope of the output level plot and this integer will equal the *order* of the intermodulation product being plotted. As shown in Figure 3, the slope of the second order intermodulation products will be two times the slope of the desired signal output.

Figure 4 illustrates that the third order intermodulation products will rise at a rate of three times that of the output signals. Note that both Figure 3 and 4 assume that the amplifier is operating below compression.

Figure 5 again assumes that the amplifier is not in compression, which is not true for real amplifiers. Note that both of the intermodulation plots intersect the output level because they are offset from and at different slopes than the output level. The points where the intersection occur are called *intercept points*. To better visualize the intercept points, it is convenient to zoom in on this area by re-scaling the plots. This is done by shifting the X and the Y axes up and to the right as shown in Figure 5a as dashed lines and the finished plot in 5b. In Figures 5a and 5b, point d is called the Third Order Intercept Point, which may be abbreviated IP3. Point e is called the Second Order Intercept Point, which is abbreviated IP2. These two points are important specifications for practical

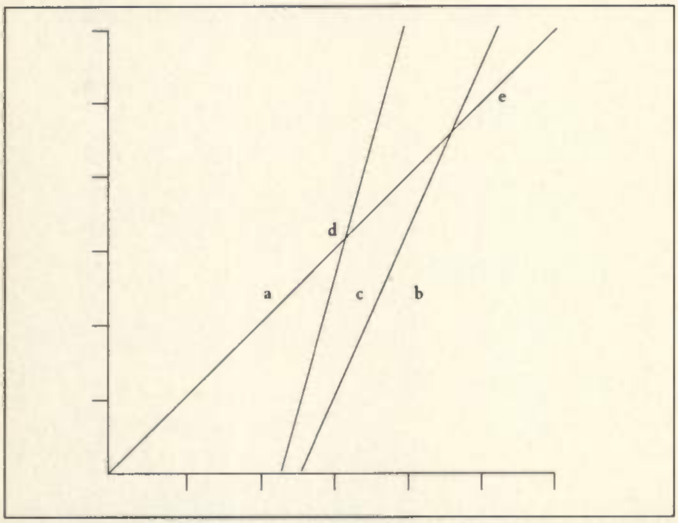

Figure 5b. Expanded view of the boxed area shown within Figure 5a.

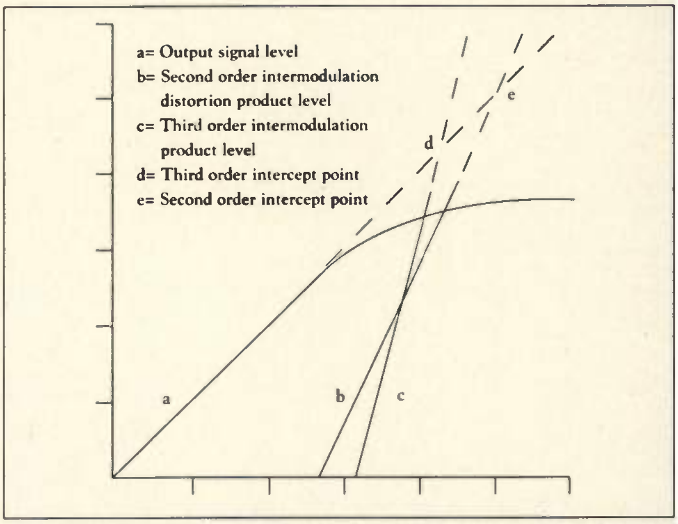

Figure 6. Second and third order intercept points of a real amplifier.

linear amplifiers. Real amplifiers do go into compression and even saturation at lower output levels than either of these intercept points; in reality, they are inferred by extrapolation.

Figure 6 shows this by including the compression and saturation of a real amplifier.

Non-linearities Within Transistor Amplifiers

This series of articles will concentrate on the intermodulation distortion within an amplifier. By definition, an amplifier must be non-linear to produce distortion of any kind. The mathematical analysis of an amplifier, whether by hand or by computer, cannot be done using S-parameters as these are static (time invariant) and represent purely linear behavior of a transistor. An accurate analysis must include non-linear models for the semiconductors.

In amplifiers designed around bipolar junction transistors, most of the non-linearity is caused by a dynamic time-dependent change in gain over the cycle swings of the input signals. This produces most of the harmonic distortion and second order intermodulation distortion. It is less responsible for the third and higher orders of intermodulation products. The third and higher order intermodulation products are generated by the non-linearity of the junctions themselves. The junction capacitances are all voltage dependent, hence, dynamically vary in time with the input signals. The base-collector junction capacitance is the most important contributor to the generation of third and higher order intermodulation products in a linear amplifier. This is because the base-emitter and the collector-emitter junctions are always forward conducting if the amplifier is class A; whereas, the base-collector junction is always reverse biased. Both the base voltage and the collector voltage are dynamically varying over time with an applied input signal. The junction may be thought of as a voltage-variable capacitor. As it changes in capacitance, the signal at the base is vector modulated as well as summed with the small signal returning from the collector through this capacity.

The most practical solution is to design the amplifier with strong negative feedback so that the amplifier self-corrects. The use of lossless feedback with transformers as directional couplers gives the best dynamic range and the lowest noise. This technique was developed and patented by David Norton in 1969 and 1971. He and Allen Podell later patented a simpler method of providing lossless feedback around a bipolar transistor using a transformer with three windings.

Next month, an actual working wide dynamic range amplifier circuit will be presented using the three winding transformer method, and the focus will be on accurately modelling this circuit using the non-linear circuit simulator, Microwave Harmonica® [3]. It will become apparent that one must have a good non-linear model for the transistor. A method for representing the non-ideal three winding transformer will also be presented. *RF*

References

1. U.S. patents 3,426,298 and 3,624,536, respectively. These are more than 19 years old, hence expired.
2. U.S. patent 3,891,934 in 1975, also expired.
3. Microwave Harmonica is available from Compact Software, Paterson, NJ; tel: (201) 881-1200.

About the Author

Jeffrey Pawlan began his study of electronics at age 12 and became a licensed amateur radio operator in 1960. At UCLA, he studied engineering, chemistry, physics, and music. His work history includes TRW Semiconductors, Hughes Electron Dynamics, Datron Systems, Varian, Stanford Telecom, and several others. He taught microwaves at San Jose City College for a year, and has taught advanced analog circuit design and SPICE at San Jose State University for 1-1/2 years. For the last 5 years he has been an independent consultant and has designed wireless LANs, RFID tag systems, and handheld products. His favorite research areas are low noise wide dynamic range amplifiers, and low phase noise oscillators. Jeffrey can be reached at: Pawlan Communications, 14908 Sandy Ln., San Jose, CA 95124-4340. Tel: (408) 371-0256, fax: (408) 371-4302.

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INFO/CARD 29

Computing Image Filter Requirements for Digital Cellular Radios

By Alex Glatfelter
Texas Instruments

Image filter requirements for Digital Cellular Radio applications are difficult to determine due to the uncertain nature of the RF/digital interface. A formula for the required attenuation of spurious signals is developed and a design example is given.

The problem in image filter design comes when the designer must compute RF filter parameters when the receiver consists of both an RF section and a digital baseband section.

Figure 1 shows a simple digital radio block diagram. The RF and spurious signals enter the antenna, after which they are amplified, filtered and converted to baseband I and Q signals. The I and Q signals are then sampled by A/D converters in the baseband codec and converted to digital data.

The key to the problem is knowing the minimum discernable signal-to-noise+distortion (S)/(N+D) ratio that is readable by the A/D converter. This can be found in the specification of the baseband codec.

In order to compute the filter requirements, we need a relationship between the spurious signal attenuation offered by the image filter (A), the designed sensitivity of the radio (S_d), and the wanted signal level (P_w). The S/(N+D) ratio (SNR) can be expressed in dB by:

$$SNR = P_w - 10\log(p_n + p_d) \qquad (1)$$

where P_w is the power (dBm) of the wanted signal, p_n (mW) or P_n (dBm) is the noise power, and p_d (mW) or P_d (dBm) is the power of the distorting signal.

Since in receiver blocking tests the power of the distorting signal (P_d) is much greater than the noise power:

$$P_d \approx 10\log(p_n + p_d), \quad P_d >> P_n \qquad (2)$$

The amount of attenuation required (A in dB), to reduce the interfering signal power P_i (dBm) is therefore:

$$A = P_w - P_i - SNR, \; P_w > S_d, \; P_i >> P_n \qquad (3)$$

P_i in this case is the power of the distorting signal (ie: $P_i = P_d$). Equation 3 gives us the needed expression for calculating the out of band rejection requirements for the image filter.

A Design Example

A GSM radio has a receive band from 935 MHz to 960 MHz, and a 71 MHz IF frequency. It has a designed sensitivity of −109 dBm for a required signal to noise ratio of 9 dB (as needed by the A/D converter). A high side injection 1st LO is used. Compute the number of resonators required for the image filter/duplexer combination.

A mixer chart [1] for the 1st mixer is required to determine the expectedspurious responses. This can be obtained from the manufacturer, or (preferably) measured in the lab. The mixer spurious responses are measured at the worst case desired frequency of 935 MHz and summarized in Table 1a. The associated spur frequencies (in MHz) are shown in Table 1b.

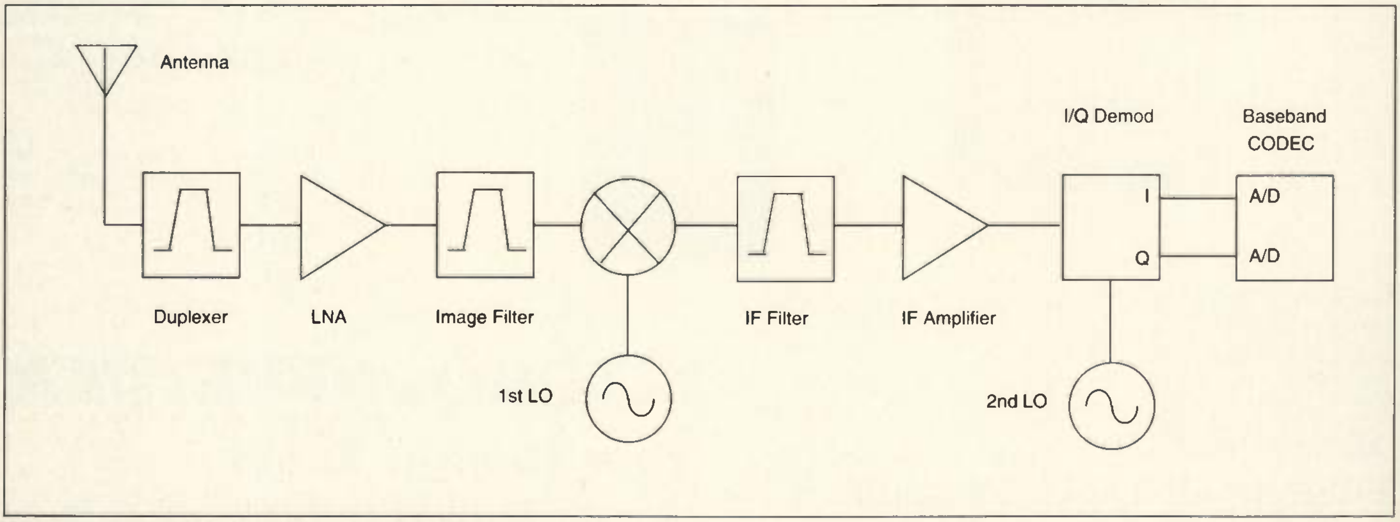

Figure 1. Block diagram of a simple digital radio.

		m	
n	1	2	3
−3	−70	−70	−42
−2	−63	−35	−43
−1	−5	−26	−51
0	−5	−47	−48
1	0	−28	−52
2	−50	−30	−45
3	−56	−66	38

Table 1a. Measured mixer chart for the 1st mixer with the input frequency tuned to 935 MHz.

		m	
n	1	2	3
−3	3089.0	1544.5	1029.7
−2	2083.0	1041.5	694.3
−1	1077.0	538.5	359.0
0	71.0	35.5	23.7
1	935.0	467.5	311.7
2	1941.0	970.5	647.0
3	2947.0	1473.5	982.3

Table 1b. The corresponding spur frequencies in MHz.

Referring to Table 1b, we observe that the frequencies of the spurs at (m,n) = (2,2), (3,3) and the image frequency (1,−1) are significantly close to the upper edge frequency of the receive band (960 MHz).

From the GSM test spec [2], we know that the power of the interferer can be at either P_i = −23 dBm (test frequency +3 MHz to 980 MHz and >1000 MHz to 12.75 GHz), P_i = 0 dBm (>980 MHz to 1000 MHz), or P_i = −43 dBm (if either of the other tests fails). Also from the GSM test specification we set the wanted signal level P_w = −100 dBm. So from equation 3, the total amount of attenuation required is:

$$A_0 = -100 - 0 - 9 = -109 \text{ dB} \quad (\text{for } P_i = 0 \text{ dBm})$$

$$A_1 = -100 - (-23) - 9 = -86 \text{ dB} \quad (\text{for } P_i = -23 \text{ dBm})$$

and,

$$A_2 = -100 - (-43) - 9 = -66 \text{ dB} \quad (\text{for } P_i = -43 \text{ dBm})$$

Referring to Table 1a, note that for each of the products, the mixer has a different conversion loss, so the attenuation requirement for each product can be reduced by the amount of the conversion loss. Table 2 summarizes the results for each product.

The amount of loss (L) of a Tchebyshev filter with R dB of ripple and n resonators is given by [3]:

$$L = \qquad (4)$$

$$10\log_{10}\left\{1+\varepsilon\cos^2\left[n\cos^{-1}(x)\right]\right\} \quad (\text{for } x<1)$$

$$10\log_{10}\left\{1+\varepsilon\cosh^2\left[n\cosh^{-1}(x)\right]\right\} \quad (\text{for } x\geq 1)$$

where,

$$\varepsilon = \log_{10}^{-1}\left(\frac{R}{10}\right) - 1$$

Spur	Attenuation Requirement (dB)		
	P_i=0 dBm	P_i=–23 dBm	P_i=–43 dBm
(2,2)	–79*	–56	–36
(3,3)	–71	–48*	–28
(1,–1)	–104*	–81	–61

Table 2. Reduced attenuation requirements for spurs due the conversion loss of the first mixer. An asterisk (*) indicates that this condition is not tested, but is includedfor information only.

$$x = \left| \frac{1}{w} \left(\frac{f}{f_0} - \frac{f_0}{f} \right) \right|$$

$$f_0 = \sqrt{f_L f_H}$$

$$w = \frac{f_H - f_L}{f_0}$$

f_H and f_L are the upper and lower band edge frequencies of the filter and f is frequency (above f_H or below f_L) at which the filter response is to be calculated.

Spur	Number of filter resonators needed		
	P_i=0 dBm	P_i=–23 dBm	P_i=–43 dBm
(2,2)	11*	8	6
(3,3)	7	6*	4
(1,–1)	6*	5	4

Table 3a. Bandpass filter resonators needed to attenuate each spur in Table 2.

Spur	Spur attenuation associated with Table 3a (dB)		
	P_i=0 dBm	P_i=–23 dBm	P_i=–43 dBm
(2,2)	–84*	–57	–39
(3,3)	–73	–60*	–35
(1,–1)	–124*	–101	–77

Table 3b. Filter spur attenuation due to the filters in Table 3a. An asterisk (*) shows conditions that are not tested, but are included for completeness.

The frequency information from Table 1b and the attenuation requirements of Table 2, are all of the information needed to calculate the number of resonators needed for the image filter using equation 4. The author simply programmed equation 4 into a computer and calculated the number of resonators needed by trial and error for each case in Table 2.

Tables 3a and 3b summarize the number of resonators needed to attenuate each of the spurs in table 2. In equation 4, f_H = 960 MHz, f_L = 935 MHz and R = 0.5 dB are used. The value of f used is the frequency in Table 1b that corresponds to the spur in Table 2.

Since the (2,2) spur is tested at P_{in} = -23 dBm, 8 resonators are required in order to pass the test. All other test combinations would pass since they require less than 8 resonators to achieve the desired SNR. Therefore the combination of the duplexer and the image filter (preselector), should have at least 8 resonators. A typical combination would be a duplexer with 3 resonators (on the receive side) and a SAW image filter with 5 resonators.

Summary

Preselector/duplexer filtering specifications for digital radios can be approximated using the method described in this article. The calculations are straightforward and simple.

About the Author

Alex Glatfelter is an RF Systems engineer with the Wireless Communications Systems group of the Texas Instruments Semiconductor Division. He has been a lead engineer in the design of a GSM radio receiver RF section which is being used in digital cellular baseband DSP development. He is currently involved in the design of a GSM transmitter. Alex received his BSEE degree (cum laude) in 1986 from Northeastern University where he was elected to both Tau Beta Pi and Eta Kappa Nu Engineering Honor Societies. In 1991 he received his MSEE degree from the University of Texas at Dallas. Alex can be reached at Texas Instruments Inc. P.O. Box 660199 MS 8723, Dallas Texas 75266-0199; telephone (214) 480-6049; fax: (214) 480-6552.

Acknowledgment

A grateful acknowledgement is given to Graham Bell and Bill Bacon for their helpful suggestions. *RF*

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ENGINEER'S NOTEBOOK

One-Transistor Transmitter Circuits

This month's Engineer's Notebook features circuits first published in 1985 issues of RF Design*. These simple circuits are designed for test, telemetry or fun applications in the FM broadcast band.*

The first circuit [1] was designed for testing FM broadcast receivers that were part of a digital data transmission system. A quick, subjective test of the receivers' tuning accuracy and sensitivity was required to assure system reliability. The unit had to be small for easy field testing. The original receiver test version included a one-transistor 1000 Hz phase shift audio oscillator as the modulation source. Another unit was simply built for fun, with a carbon microphone providing the modulation source. Both units had identical RF oscillator sections. The latter unit's diagram is shown in Figure 1.

This circuit uses a Hartley oscillator, designed around the common MPF102 JFET. The TCG-610 varactor diode (6 pF at 4 V) varies the frequency at the modulation rate. The input level controls the deviation. If not enclosed, the oscillator will be relatively stable as long as it doesn't use an antenna. The transmitter can also be placed in a shielded box, but an external antenna must be used, coupled to the oscillator coil with a small loop.

The next circuit [2] is shown in Figure 2. Using a sprial inductor designed using Dill's formula [3] as both resonating coil and antenna, this transmitter will send good quality audio a distance of up to 50 meters. The Clapp-Gouriet type oscillator uses a BF256L/B JFET. This FET is designed to operate at a gate-source voltage of about –1.5 V, thus biasing the BB105 varicaps without additional components. Audio level is adjusted by the potentiometer to achieve the desired deviation.

When building and using this type of transmitter, be sure to follow FCC regulations regarding allowable radiation levels and interference. *RF*

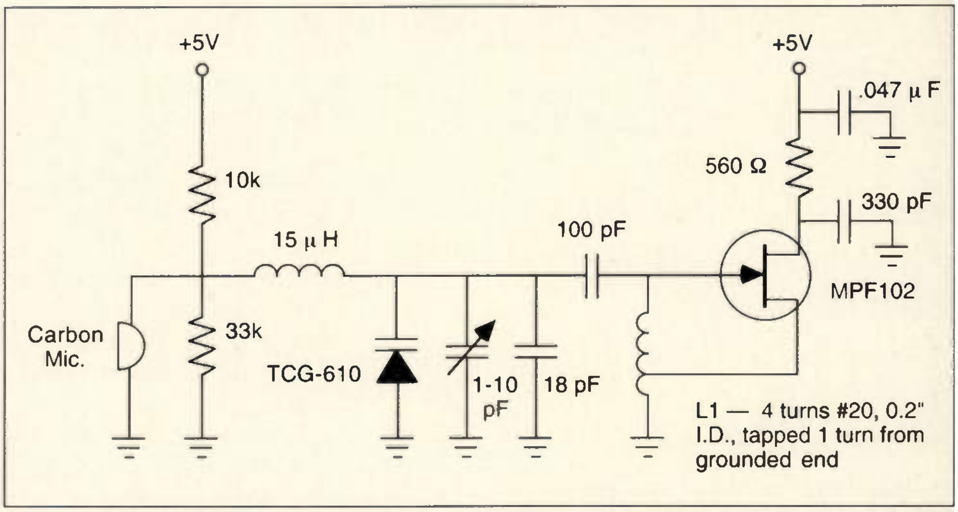


Figure 1. A one-transistor transmitter [1] designed for operation in the FM broadcast band. The carbon microphone shown makes this a complete unit, part of toy "walkie talkie." External audio can be applied in place of the microphone, AC-coupled to the junction of the varactor bias resistors. In this case, the resistor values should be increased to 100k each.

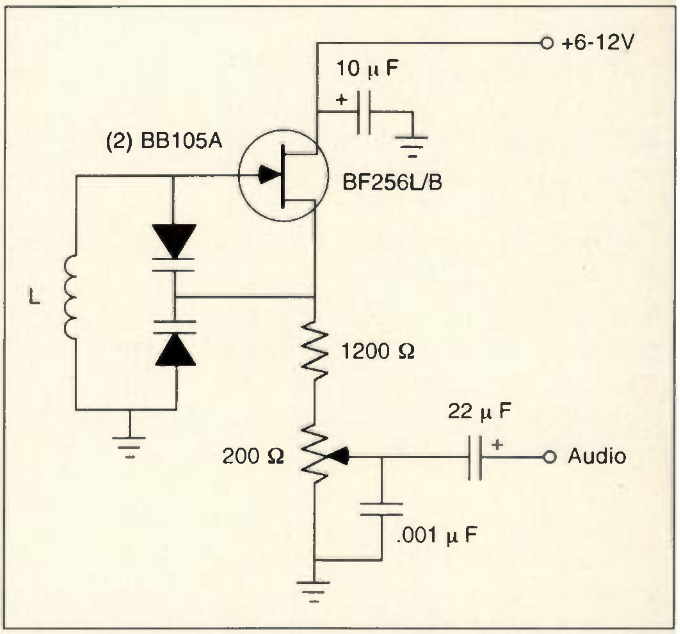


Figure 2. A simpler design suggested by Kan [2], also designed for the FM broadcast band. This circuit uses the gate-source voltage of the FET to bias the varicap diodes, and includes a potentiometer to control the audio level.

References

1. William Rynone, "A One Transistor FM Transmitter," *RF Design*, February 1985, p. 64.
2. S. Kan, "Another One-Transistor FM Transmitter," *RF Design*, October 1985, p. 53.
3. H.G. Dill, "Designing Inductors for Thin-Film Applications," *Electronic Design*, Feb. 17, 1964, pp. 52-59.

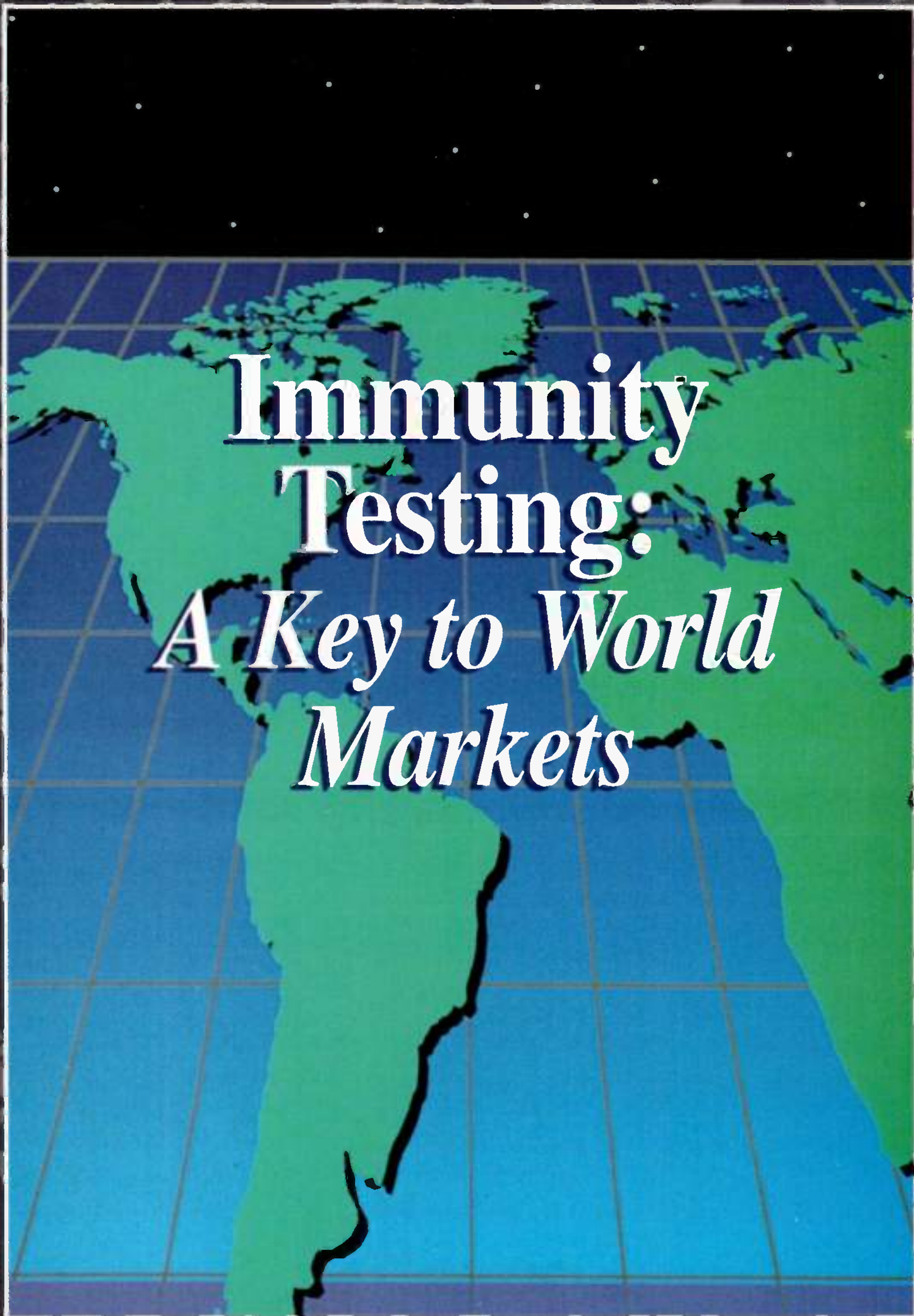
February 1996

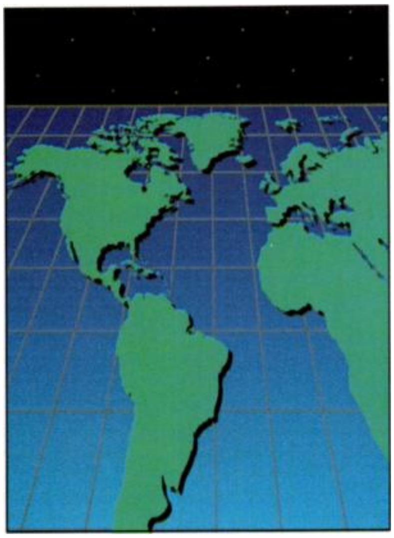
EMC®

TEST & DESIGN

An INTERTEC® Publication

- Harmonization of Standards Hinges on Immunity Testing
- A Study of ESD Through Persons and Objects
- EMC News and Events





Immunity Testing and International Standards

The "new part" of the European Union EMC Directive is immunity testing — to assure the reliability of electronic equipment in the presence of radio interference, electrostatic discharge, and power line surges and transients. Technically aware professionals and consumers have openly wished for robust performance in electronics for a very long time. Now, it appears that regulations are on the way to address these concerns.

Work is proceeding without a lot of hoopla on *international harmonization* of EMC standards. In recognition of a steady march toward a true world economy, the FCC and its counterparts around the world are on a course toward universally-applied product testing and performance requirements, certain to include imunity.

I applaud and encourage those efforts. Immunity performance required by those standards in electronics will fend off the threat of interference. Wireless communications markets are growing at 20% or more, and all types of electronics are becoming ubiquitous. If we don't assure a minimum level of immunity performance, growing markets will fade as consumers reject poorly-performing products.

Gary A. Breed
Editorial Director

February 1996

EMC® TEST & DESIGN

FEATURE

Electrostatic Discharge Through Persons and Objects — 6

Here is a review of the parameters of electrostatic charge accumulation and discharge. Discharge current waveforms for various conditions of discharge path resistance and inductance are shown at various levels of charge. Spectral characteristics of the discharge waveform are also presented, along with measured field intensities.

— *Francisc Salamon, I.C.E. SA*

DEPARTMENTS

*Info/Cards, Company Index, and Advertiser Index can be found on the designated pages in the issue of *RF Design* which contains this *EMC Test & Design* supplement.

EMC. TEST & DESIGN

Coming in April

- **Update on EU Requirements — How Businesses are Adjusting to Changes**
- **Focus on EMC Test Equipment — Pre-Compliance and Full-Feature Systems**

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EMC TEST & DESIGN. **Directory Issue – June 1996**

Request for Product/Company Information

The 1996 *EMC Test & Design* Directory is currently being researched, with information updated from past years' editions. If you have not been included in our Directory before, if your company has made changes during the past two years, or if you haven't given us updated information recently — we need to hear from you! Contact the Directory Department at (770) 618-0170, or reach us at the *RF Design/EMC Test & Design* editorial offices: (303) 220-0600; fax: (303) 267-0234.

Be sure our readers find you when they need EMC products and services!

■ Calendar

March 25-29

12th Annual Review of Progress in Applied Computational Electromagnetics
San Francisco, CA
Information: Richard W. Adler, ECE Dept./Code ECAB, Naval Postgraduate School, 833 Dyer Road, Room437, Monterey, CA 93943. Tel: (408) 649-1111

April 16-17

Minnesota EMC Event
Bloomington, MN
Information: Judie Anderson, ERA, 3001 Harbor Lane, Suite 150, Plymouth, MN 55447. Tel: (612) 559-0332; fax: (612) 553-9326

April 23-26

International Wireless Communications Expo (including the RF Design Seminar Series)
Las Vegas, NV
Information: Intertec Presentations, 6151 Powers Ferry Rd., N.W., Atlanta, GA 30339. Tel: (800) 828-0420.

June 17-20

Conference on Precision Electromagnetic Measurements
Braunschweig, Germany
Information: Sabine Rost, Conference Secretary, Physikaliche-Technische Bundesanstalt, Bundesalee 100, D-38116 Braunschweig, Germany. Tel: +49 531 592 2129; fax: +49 531 592 2105; e-mail: erich.braun@ptb.de

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July 21-26

1996 IEEE AP-S International Symposium and URSI Radio Science Meeting
Baltimore, MD
Information: Ms. Libby Croston (1 W 316), The Johns Hopkins University, The Applied Physics Laboratory, Johns Hopkins Road, Laurel, MD 20723-6099. Tel: (301) 953-5225.

News

Council of EMC Laboratories Formed

ACIL has announced its sponsorship of the Council of EMC Laboratories (CEL), an association of U.S.-based laboratories providing EMC testing services in accordance with European Community norms. The purpose of the Council is to provide peer review in the application of the European rules, and is solely technical in nature. For additional information, contact: Joe O'Neil, ACIL, 1629 K Street, NW, Washington, DC 20006. Tel: (202) 887-5872; fax: (202) 887-0021.

One-Day EMC Event Scheduled for Los Angeles Area

The Los Angeles, San Diego and Orange County chapters of the IEEE EMC Society are hosting a one day EMC event on April1, 1996. The event will feature an overview of pertinent EMC requirements, with an emphasis on pre-compliance testing problems and solutions. Speakers include Henry Ott, Herb Mertel, Joe Fischer, Steve Jensen, Bill Parker, Scott Roleson, Bill Ritenour and Bill Rhoades. Advance registration is $50. For information, contact either of the co-chairs: Ray Adams at TRW; tel: (310) 813-7152, e-mail: ray_adams@qmail4.sp.trw.com; or Janet O'Neil at Lindgren RF Enclosures, tel: (310) 348-9665; fax: (310) 348-9683.

U.S. and Canada Agree on Acceptance of Measurement Reports for Equipment Authorization

The Federal Communications Commission (FCC) and the Department of Industry Canada have agreed to accept, as part of their equipment authorization/certification, measurement reports made in either the US or Canadian format. In this way, a copy of the report prepared for one country can be used in filings for authorization in the other country. Where differences in the technical standards are present, supplemental information should be supplied for the second filing.

JASTECH Offers EMC Courses

Courses in EMC are scheduled for May in Novi, Michigan. "Electronic Design Techniques and Analysis Required to Meet Electromagnetic Compatibility Requirements" will be held May 1-2, and "Advanced EMC Printed Circuit Board Techniques" will be offered on May 3. Contact JASTECH at (810) 553-4734.

Semiconductor Industry Starts Exit Charge Group

The Exit Charge Working Group has been formed by semiconductor manufacturers to address ESD-related problems in the handling and processing of semiconductor wafers. Data scrambling, robotic handling failures and intermittent problems have all been traced to ESD. The group is working with the ESD Association and SEMI (Semiconductor Equipment and Materials International) to establish revised standards for ESD in the semiconductor manufacturing environment.

FCC Proposes to Expand Operation of Biomedical Devices on Unoccupied Television Channels

The FCC is proposing to amend Part 15 of its Rules to expand the available frequencies and increase the permitted power for unlicensed biomedical telemetry devices operating on VHF and UHF television channels. The proposed rules would allow these devices to operate with 5 mW power, on channels 7-13 and all UHF channels, provided no interference is caused to existing or future television transmissions.

U.K. Universities Launch New EMC and RF Courses

New courses in Electromagnetic Compatibility and Radio Frequency Communications are being launched at the University of York, in conjunction with the University of Hull. The course for part of the Integrated Graduate Development Scheme, and include a selection of modules which can be taken individually, or together with an industrial project which can lead to an MSc qualification. The modules cover areas as diverse as spectrum conservation, EU legislation, and aspects of equipment design.

Electrostatic Discharge Through Persons And Objects

By Francisc Salamon
I.C.E. SA

Francisc Salamon graduated from the Technical University Bucharest, The Faculty of Electronics and telecommunications in 1975. Since 1980 he has worked at I.C.E. SA in the field of medical electronics, Cluj-Napoca Department.

He is the Department Manager and teaches Medical Electronics at the Technical University of Cluj-Napoca. He has three patents in Romania, two in the field of medical electronics. He is preparing his doctor's degree paper in the field of electromagnetic compatibility.

He can be reached at: I.C.E. SA FILIALA CLUJ-NAPOCA, Str. Gh. Bilascu 109, 3400 Cluj-Napoca, Romania.

This paper presents a special case when the electric current passes through the body of human beings. The electric charge accumulated on an object or a person can be discharged through another person. Different forms of the discharge current are shown by simulating the solution of the discharge equation and the changes appearing in the parameters that define the current are shown. On the basis of the results, conclusions can be drawn in order to make the phenomenon of the electric discharge compatible with the environment and the human body, respectively.

The origin of electrostatic discharge is drawn from the accumulation process of electric charges on the surface of different human bodies or objects. The appearance of static charges, a process known from electrostatics, can be a desired an undesired phenomenon. Among the undesirable results are:

- discharge followed by fire or explosion;
- discharge as a disturbing phenomenon of the electromagnetic environment
- undesired discharge through human body

The most well-known process of loading an electrostatic charge onto a human body is friction. The electric discharge then stimulates the creation of an electric field, of a voltage, respectively, that can be calculated by integration along a field line between the two points.

Experimentally it has been stated that the density of the superficial electric charge that can appear by friction is:

$$\rho_s = 15 \times 10^{-6} (\varepsilon_{r1} - \varepsilon_{r2}) \qquad [\mathrm{C/m^2}]$$

where ρ is the density of superficial charge and ε_{r1}, ε_{r2} are the relative dielectric constants of the bodies that are touched

Experimental Determinations

The equivalent circuit of persons submitted to electrostatic charging and discharging respectively, is given in Figure 1. The voltage on a person can reach values from 1 to 20 kV.

In Table 1, some examples of experimentally determined voltages can be followed; they appear by accumulation of charges due to human activity.

Table 2 illustrates the charge that can appear during a person's movement on insulating ground. Table 3 shows equivalent resistance values for different bodies.

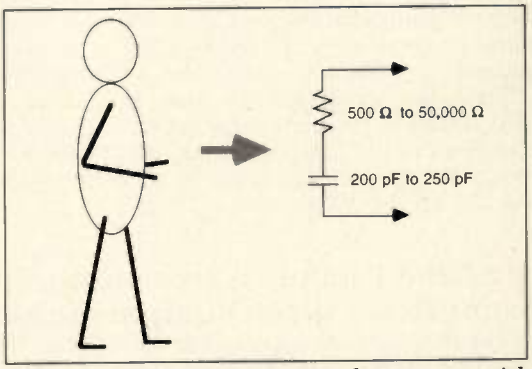


Figure 1. Equivalent circuit of a person, with regard to ESD behavior.

Person with rubber shoes moving on the ground	10_3 Volts
Person with rubber shoes moving on carpet	10^4 Volts
Synthetic fibers by friction	9×10^3 Volts
Heliographic paper	75×10^3 Volts

Table 1. Values of accumulated charge on people and object.

	Person moving	Person at rest
C (body-to-ground)	25 pF	220 pF
C (accumulation)	220 pF	220 pF
Q charge	1 μC	1μC
Voltage	8.8 kV	150 V
Accumulated energy	8.5 m*j*	—

Table 2. Charge and voltage on a person.

Defect insulator	1 MΩ
Healthy adult (dry skin)	10 kΩ to 100 kΩ
Ill, perspiring, or infant	100 Ω
Short-circuit	10 mΩ

Table 3. Resistance of different bodies.

Electrostatic Discharge Simulation Between Two Persons or a Person and an Object

The equivalent electric circuit is a current shock generator presented in Figure 2, where C is the shock capacity that accumulates the electric charge, R and L are the overall equiva-

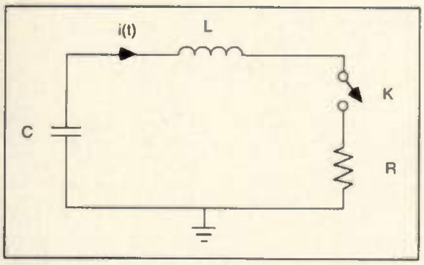


Figure 2. Equivalent circuit of a shock geneator

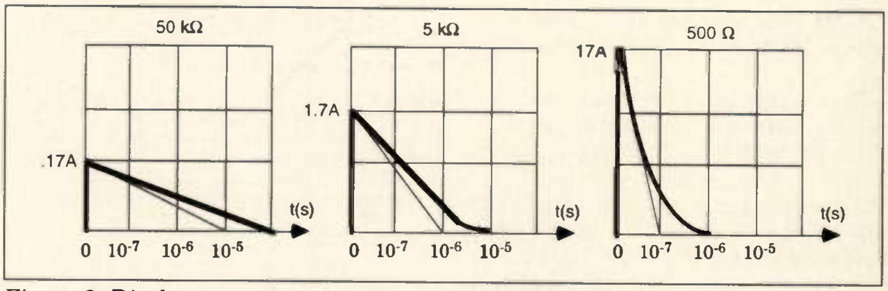


Figure 3. Discharge current waveforms for different resistances.

lent inductance and resistance of the discharge circuit, and K is a switch.

The studied equation is:

$$L\frac{d^3i}{dt}+R\frac{di}{dt}+\frac{1}{C}i=0 \qquad (2)$$

The mathematical solution is known and it is:

$$I(t)=I_a e^{1/\zeta_a}+I_b e^{1/\zeta_b} \qquad (3)$$

The initial conditions determine the integrating constants I_a and I_b. The mathematical solution and the tracing of the current's diagram can be done by a computer program.

The discharge of charges accumulated on a person are simulated for a person characterized by 8.8 kV voltage, 220 pF capacitance and a charge of l/μC. The overall inductance of the circuit is considered to be 1 μH, which corresponds to 1 m of conductor connected to the ground.

Figure 3 is a plot of the current waveform. It can be remarked that in the case of small short circuit resistances the current becomes a damped oscillation of high amplitude.

"ζ_a" and "ζ_b" are the constants of the equation (3) and "ζ" and "f_0" are constants related with the damped oscillating condition that results as a solution of the equation (2).

The conclusions of the discharge at a constant voltage and variable resistance are related to the increase of the resistance, as follows:

- the voltage peak decreases;
- the rise time of current decreases;
- the current slope near I = 0 is approximately constant.

For a resistance of R = 5 kΩ, C = 220 pF, and 8.8 kV voltage, a current is simulated for different values of inductance. Figure 4 illustratess the results of the simulation for L = 1, 4, 10 μH.

With the increase of the inductance, the conclusions are as follows:

- the current peak decreases
- the rise time is prolonged
- the current slope decreases.

The influence of the discharge voltage (U = 4; 8, 8; 15 kV) on the form and amplitude of the discharge current through persons for R = 5 KΩ, L = 1 μH, C = 220 pF can be followed in Figure 5.

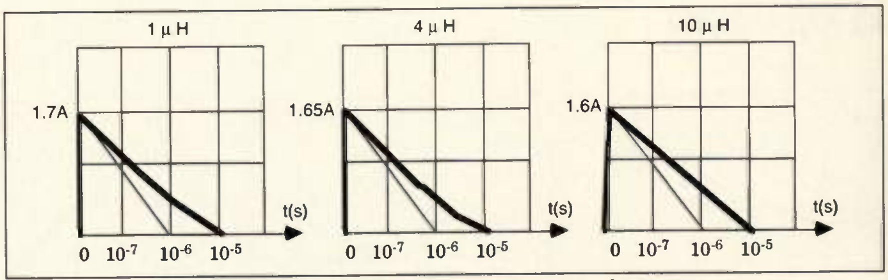


Figure 4. Discharge current waveforms for different inductances.

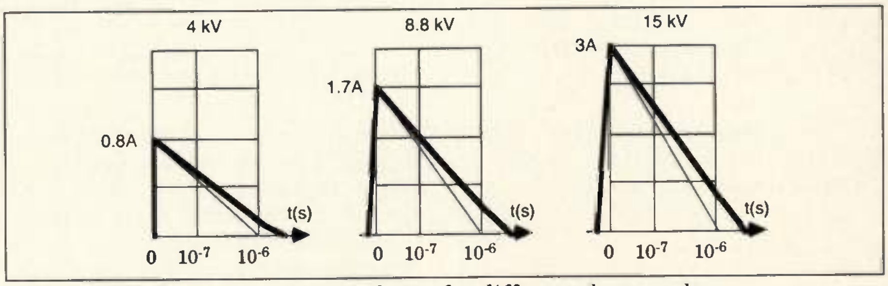


Figure 5. Discharge current waveforms for different charge voltages.

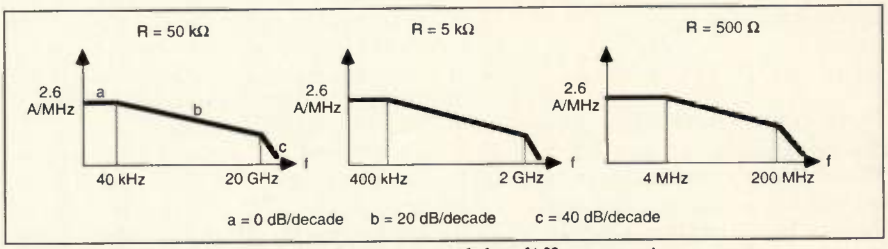


Figure 6. Spectrum of the discharge signal for different resistances.

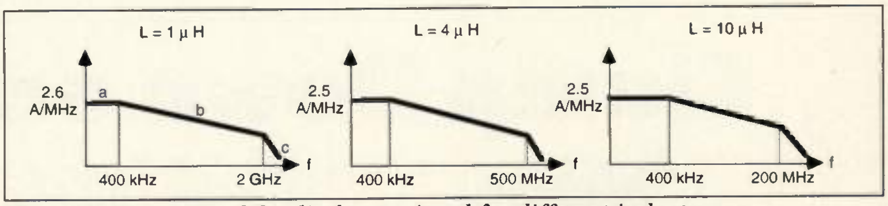


Figure 7. Spectrum of the discharge signal for different inductances.

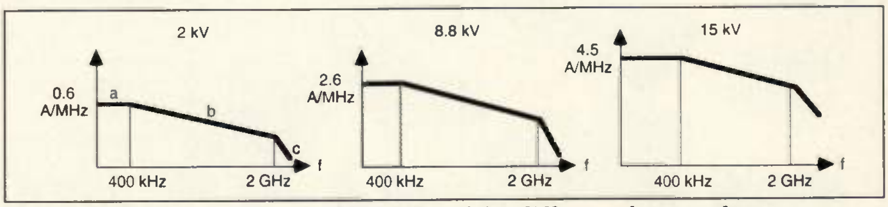


Figure 8. Spectrum of the discharge signal for different charge voltages.

R(Ω)	50 k		5 k		500	
Distance (m)	E (V/m)	H (A/m)	E (V/m)	H (A/m)	E (V/m)	H (A/m)
0.1	2×10^3	5	12×10^3	30	110×10^3	280
1.0	100	0.35	205	0.6	1200	3.4
10	10	0.02	12	0.03	35	0.1

Table 4. Measured E and H field intensities for different discharge resistances.

Evaluation of The Electrostatic Discharge Signal's Spectrum

From the presented signal forms two important constants result. They determine the discontinuity points of the frequency spectrum's envelope. The average duration of the signal "ζ_1" (50% amplitude) approximately gives us the first discontinuity point "f_1" and the period of increase of the signal "ζ_2" between 10% and 90% amplitude approximately indicates the second discontinuity point "f_2".

$$f_1 \cong \frac{1}{\pi\zeta_1} = \frac{1}{\pi\cdot 0.7\cdot\zeta_a} = \frac{1}{\pi\cdot 0.7\cdot RC}$$

$$f_2 \cong \frac{1}{\pi\zeta_2} = \frac{1}{\pi\cdot 0.7\cdot\zeta_b} = \frac{1}{\pi\cdot 0.7\cdot L}$$

The spectral density of the current is

$$2I\cdot 0.7\cdot RC \quad [A/Hz]$$

Figure 6 illustrates the spectrum envelope corresponding to Figure 3.

The conclusions regarding the discontinuity frequences of the spectrum occupied by the discharge signal are:

- as resistance R increases f_1 decreases and f_2 increases
- as inductance L increases: f_1 remains constant and f_2 decreases
- as the initial charge increases: f_1 and f_2 do not change considerably.

These changes of the values of f_1 and f_2 can be observed by a sensitive receiver with shielding that attenuates a frequency range.

Electromagnetic Field Interferences as a Result of Electrostatic Discharge Through a Person

In Table 4 the average results are presented obtained by electric E [V/m] as well as magnetic H [A/m] field measurements on a simulation circuit according to Figure 2 for frequencies up to 50 MHz. The electric field E as well as the magnetic field H were received with the help of a 1 meter long aerial.

Conclusions

The conclusion is that the ensurance of an adequate discharge load, and sufficient distance, is equivalent to a shielding of the surrounding circuit or protecting people. Increasing the resistance of the discharge path has the greatest effect on current and radiation.

New Products

Modular Shielding Specification Guide

Ray Proof has introduced an updated guide for EMC and TEMPEST applications. The guide reviews electrical, mechanical and architectural considerations in the modular shileding design process. Ray Proof enclosures are built to MIL-STD-285 and NSA 65-6 standards, and provide excellent attenuation of magnetic fields, electric fields, plane waves and microwaves
EMC Test Systems/ Ray Proof
Info/Card #175

300 Watt Broadband Amplifer

ENI's model A-300 RF Power Amplifier produces

up to 300 watts of linear Class A power over the frequency range of 300 kHz to 35 MHz for HF and VHF communications, RFI/EMI testing, plasma equipment and other uses. The unit has 55 dB gain and low disotrtion. Harmonics are –25 dBc at 250 watts output.
ENI
Info/Card #176

Voltage Suppressor Technical Guide

AVX Corporation announces a catalog and technical guide for their TransGuard® line of transient voltage suppression products. The 16-page Volume I of the guide contains reference information on ESD phenomena in humans and equipment, data on vulnerability of semiconductor devices to ESD damage, and background information on common types of transient and surge suppression devices. The upcoming Volume II will cover details of the TransGuard products.
AVX Corporation
Info/Card #177

Amplifier Covers 10 kHz – 250 MHx

Amplifier Research announces a solid state power amplifier for immunuity and EMC testing, NMR, plasma and RF heating applications. Model 250A250 has 54 dB gain, and ±0.5 dB gain flatness with the internal leveling. Pulse input and gated output provide minimum rise/fall times essential for NMR.
Amplifier Research
Info/Card #178

Frequency Inverter Output Filters

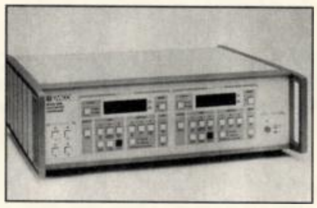
Schaffner has launched a new series of output filters for frequency inverters which provide solutions for EMC, acoustic noise and reliability issues associated with the control of AC motors. Typically, three-phase motor control systems can experience high peak currents or ringing, which are controlled in these units. Acoustic noise is reduced by the low harmonic content of the sine wave output waveform.
Schaffner EMC Inc.
Info/Card #179

SMT EMI Filter

Spectrum Control announces a new surface mount EMI/RFI filter rated at currnets up to 20 amps. The PSM filter series offers EMC solutions for high-current p.c. board circuits. The devices can be installed with conventional pick-and-place assembly equipment. Capacitance up to 10,000 pF is available at a rated voltage of 200 V.
Spectrum Control, Inc.
Info/Card #180

Tower/Turntable Positioning Controller

EMCO introduces the Model 2090 controller for EMC test antennas towers and turntables. The unit si-



multaneously controls any paired combination of EMCO towers and turntables, plus the switching functions of up to four auxiliary devices, all via fiber optic lines. Numerous control features include inertia overrun compensation, upper/lower position limits, and an optional hand-held control unit.
EMC Test Systems/EMCO
Info/Card #181

D-Sub Connector EMI Covers

WPI introduces a zinc cover which protects military and commercial D-subminiature connectors from EMI/RFI when not in use. The connectors are available with jackscrews and a chain retainer.
WPI Connector Prod.
Info/Card #182

Thermoformable Shielding

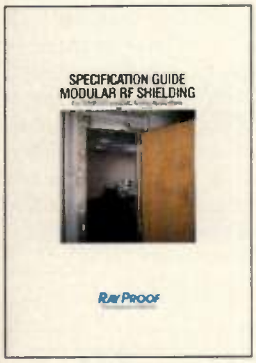
The new 3M 6100 thermoformable EMI shielding material allows recent advances in thermoforming to be used where EMI shielding is required. 6100 material is a thin, porous laminate of two nonwoven layers, the bottom sheet is hot-melt laminated to the plastic sheet being formed.
3M Company
Info/Card #183

EMC TEST & DESIGN®

Literature & Product Showcase

For quick response, circle number on Reader Service Card; page 111, 114.

RF Shielding Specification Guide for Architects & Engineers



Newly updated thirty-two page guide reviews electrical, mechanical and architectural considerations in the modular RF shielding design process. For EMC & TEMPEST applications, Ray Proof Series 81 enclosures are built to MIL-STD-285 and NSA 65-6 standards. Innovative design provides excellent attenuation to magnetic fields, electric fields and plane waves. Options reviewed include fire rated doors, power and signal filters, waveguide penetrations, and light fixtures.

Ray Proof
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INFO/CARD 75

Conductive Thermoplastics Brochure

RTP Company has carved out a special niche as an independent compounder of thermoplastics. RTP Company compounds thermoplastics with a variety of conductive fillers to provide protection from electrostatic discharge (ESD) or shielding from electromagnetic and radio interference (EMI/RFI). In our conductive thermoplastics brochure, you'll learn about the materials we make and their role in your applications.

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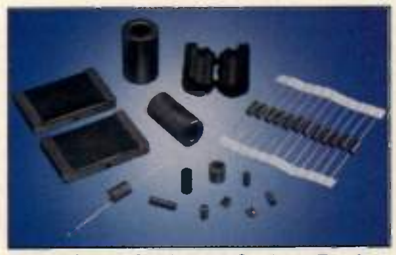

CHO-SORB® Cable and Surface Ferrites Reduce Radiated Emissions

Chomerics offers 29 forms of CHO-SORB EMI suppression ferrites for reducing emissions on signal lines, power cables and PCBs without affecting data transmissions. CHO-SORB attenuators possess high magnetic permeability, which concentrates magnetic fields. Their high electrical resistivity limits current flow in the field.

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INFO/CARD 78

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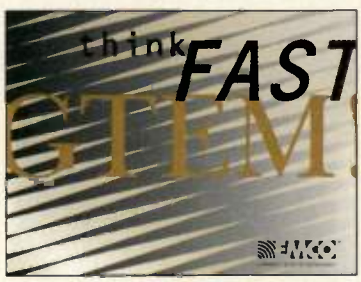

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INFO/CARD 79

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New Full Line catalog features ferrite D-subs for EMI/RFI suppression (right angle, vertical, high density and stacked), shielded modular jacks, and fully shielded snap and lock mini-DINs. Full specification and technical drawings are included and samples are available upon request.

Kycon Cable & Connector, Inc.
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INFO/CARD 80

Literature & Product Showcase

N E W

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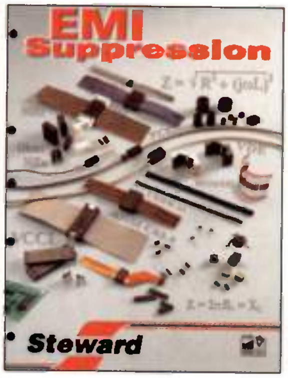

STEWARD is a leading producer of ferrite and related materials used in the electronics, copier, telecommunications, military and automotive industries. Steward manufacturers ferrite EMI shielding and filtering components, wide band transformer and filter cores, copier developer materials, custom ferrite powders, and iron silicide powders.

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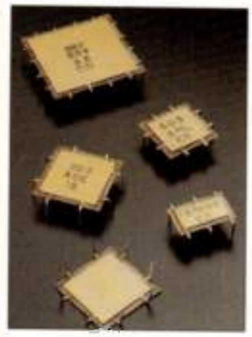

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INFO/CARD 83

Career Opportunities

EMC Design Engineers

QUALCOMM in San Diego is the leader in wireless communications. Our continued growth and success has created opportunities for EMC Engineers.

You will be responsible for EMC of products from design inception through EMC test to final production. Minimum BSEE; MSEE preferred, with at least 5 years EMC design experience essential. NARTE certification and direct experience in telecommunications and wireless communications desired. Requires knowledge of PCB EMI/EMC design, cable and connector selection, system EMC analysis, transient immunity design, grounding methods, and filter design. Experience in FD-TD modeling and other numerical analysis techniques preferred.

QUALCOMM offers competitive salaries, excellent benefits and opportunities for advancement. Send your resume via Internet to resumes@qualcomm.com, or fax to (619)658-2110.

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Fax (817) 491-3699

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Fax (512) 719-4211

EMC Antenna Tower Improves Test Accuracy

New Model 2071 Tower complies with antenna pointing requirements of CISPR 16 for EN 55022, also ANSI C63.4. Patented "Bore Sight" design continuously aims antenna directly at designated test point during height scans. Other features include fiber optic control lines and centerline polarization.

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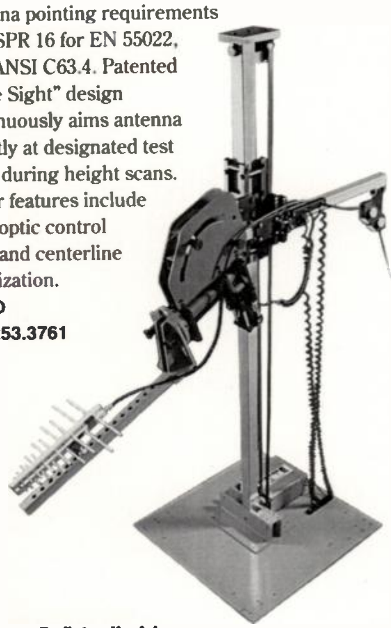
800.253.3761



BiConiLog™ Antenna Saves Time and Reduces Errors

Sweeps from 26 MHz to 2 GHz without bandbreaks. New model 3142 ideal for testing to IEC 1000-4-3 immunity, EN 55022 emissions. Compact design fits in small chambers.

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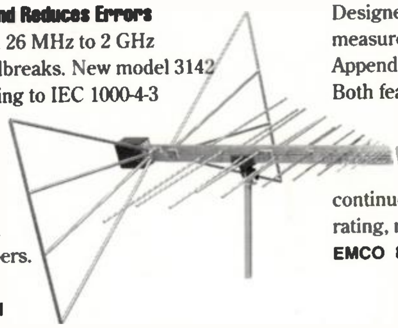

Two New LISNs Meet European Standards

Designed for conducted emissions measurements to CISPR 16, Appendix E, for EN 55022. Both feature earth line choke and artificial hand connection. CSA approved Model 3810 provides 10 A continuous current rating. Model 3816 has 16 A rating, remote switching and high pass filter.

EMCO 800.253.3761

Reference Radiator Useful For Performance Evaluations

New Model 4630 "RefRad" is a field strength transfer standard that performs evaluations of RE test sites, chamber comparison testing, shielding effectiveness testing, normalized site attenuation, antenna calibration and more. Features 10 kHz to 1 GHz frequency range with user-selectable frequency spacing. Includes remote control, fiber optic link and GPIB.

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GTEM! performs ANSI C63.4, IEC 1000-4-3, EN 55022 and other tests quickly, accurately and repeatably. Results accepted by FCC. DC to 20 GHz total frequency range. Five models available for various EUT sizes.

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Digital Modulation Analysis

Option 16 (Universal $\pi/4$ DQPSK software) from Anritsu Wiltron extends the MS8604A digital modulation analyzer to test several new industry standards used by digital mobile radio developers and manufacturers, including WCPE, D-MCA, PACS and TETRA. The option also offers greater flexibility and functionality to test standards such as PDC, PHS, and NADC. Pricing is set at $5,110.
Anritsu Wiltron Co.
INFO/CARD #227

Multi-Platform Software for Wireless

Motorola has introduced MagicPipe™, a software tool kit that uses messages to communicate between applications across wireless networks. The software provides developers with a multi-platform toolset that allows them to develop and integrate MagicPipe-enabled application components. Messages carry information and action requests between components on the same devices and across wireless networks.
Motorola Land Mobile Products Sector
INFO/CARD #228

Analog Simulation

Avista Design Systems announces the 1B release of Avista Spectre/XL. Avista Spectre/XL embeds accurate circuit simulation inside Microsoft Excel. New features include fast measurements for oscillator circuits, linear noise analysis, S-parameter analysis, and MOSFET and advanced bipolar device support. Avista Spectre/XL pricing begins at $795, including shipping.
Avista Design Systems
INFO/CARD #229

System Simulation

Rf Intercept from RHR Laboratories analyzes non-linear and statisical properties of radio communications systems and circuits. The software allocates channels for minimum intermodulation distortion interference; reduces a chain of devices to an equivalent single device described by its gain, equivalent noise figure, and send and third order intercept points; obtains the statistical distributions of various system parameters; and simulates the response of non-linear devices to an arbitrary input. Price ranges from $390 to $2,400.
RHR Laboratories
INFO/CARD #230

Block-Level Communications Simulation

Visual Solutions is shipping VisSim/Comm, an add-on to the VisSim block diagram laguage, which permits modeling analog, digital and mixed-mode communication systems, adding over 50 specialized communications blocks. Capabilities of VisSim/Comm in conjunction with VisSim include complex envelope analysis, FIR and IIR filter design, channel modeling and PLLs. The products run under Microsoft Windows, Windows 95, Windows NT, and UNIX/X operating systems. VisSim ranges in price from $495 to $3,590.
Visual Solutions Inc.
INFO/CARD #231

Expanded Low-Cost Design Software

ICAP/4Lite Xtra from Intusoft includes all the features of the low-cost ICAP/4Lite product and adds a full-featured graphical waveform post processor and model libraries with over 6,000 parts. It also provides an integrated schematic entry front-end and a version of the IsSpice4 simulator with unlimited circuit size. List price for a single copy is $995.
Intusoft
INFO/CARD #232

Linear Simulator for Windows

Eclipse 4.0 is a linear RF/microwave simulator for the PC. The program uses an intuitive tabbed-notebook interface with "drag and drop" capabilities. Each page contains simulation, tuning and optimization results in the form of multiple graphs and tables. Eclipse's element library includes a wide variety of lumped and distributed elements, active devices, microstrip, stripline, and control-block models. Pricing is $795.
Arden Technologies, Inc.
INFO/CARD #233

PCB Layout With RF Features

Ivex Design International has released WinBoard v. 2.10. The program now automatically removes floating copper from copper zones, includes an indicator for total track length, and allows placement of mounting holes and tracks at exact X-Y coordinates. WinBoard 2.10 includes an all new reference manual and is priced starting at $250. WinBoard runs under Windows 3.1, WFW 3.11, Windows NT and Windows 95.
Ivex Design International
INFO/CARD #234

Supplementary Components Catalog

Synergy Microwave announces the 1996 Supplementary Catalog to compliment their "1992-1993 Product Catalog." Filled with complete design information, technical articles and mechanical information, this catalog features all the new products released since the previous 1992-1993 Synergy Microwave catalog. Highlighted in this catalog are new miniature VCO products and integrated frequency synthesizers.
Synergy Microwave Corp.
INFO/CARD #235

SPICE Newsletter

The Intusoft Newsletter is a free publication dedicated to discussing topics related to the SPICE circuit simulation program. A recent issue discussed the Berkeley SPICE 3 B (behavioral) element, modeling transient voltage suppression devices, and a model for capacitors that includes parasitics and frequency, DC bias and temperature dependencies.
Intusoft
INFO/CARD #236

Data Acquisition Handbook

Intelligent Instrumentation has released the eighth edition of their Handbook of Personal Computer Instrumentation. The new 238-page edition features a number of data acquisition tutorials, as well as proven techniques and practical application notes. The handbook also describes Intelligent Instrumentation's wide variety of data acquisition hardware and software, along with system configuration guidelines. The handbook is available free-of-charge to qualified individuals.
Intelligent Instrumentation
INFO/CARD #237

NASA Technology Info on CD-ROM

The NASA Technology CD-ROM includes 5,700 NASA Tech Briefs published over the last eight years, abstracts for more than 90,000 NASA technical reports, front pages and claims from 2,800 NASA patents, computer programs, and other information relating to aerospace. The CD-ROM is available from JB Data for $195.
JB Data
INFO/CARD #238

In-House Technical Journal

The October issue of *News from Rohde & Schwarz* highlights the development of the VHF-UHF search receiver, ESMA; a radio communication test set, the CRTC02; and a universal tester for GSM and DCS mobile phones. The issue also included an article about the 100th anniversary of radio communication.
Rohde & Schwarz GmbH
INFO/CARD #239

Wireless Telemetry Catalog

RF Neulink, a division of RF Industries, has a new 30-page wireless telemetry products catalog. The transceiver modems described in the catalog are offered in VHF, UHF, and 900 MHz frequency ranges and in synthesized, crystal controlled, and spread spectrum versions.
RF Neulink
INFO/CARD #240

Timing Solutions Data Book

Motorola has published the Motorola Timing Solutions Data Book (BR1333/D) for designers who need high-speed clocking solutions. This 336-page book includes clock distribution circuits and timing solutions spanning all logic technologies - TTL, CMOS, ECL 10H, ECLinPS™, ECLinPS Lite™, PLL, and BiCMOS. The book is available free-of-charge.
Motorola Semiconductor
INFO/CARD #241

New Books From IEE

The Institution of Electrical Engineers (IEE) offers two new books. High-frequency circuits is a translation of the German text Hochfrequenztechnik by F. Nibler and co-authors. The 428-page book covers basic principles of HF semiconductor electronics and costs $95.00 hardbound and $48.00 paperback. Transmission systems, edited by J.E. Flood and P. Cochrane, aims to provide the engineer with a sound knowledge of telecommunications transmission and how the complete network functions. The 524-page book is priced at $45.00.
IEE/INSPEC Dept.
INFO/CARD #242

Ceramic-to-Metal Product Guide

Both domestic and international versions of the 1996 Ceramaseal Product Guide have been released. The catalogs describe the company's extensive line of precision-engineered feedthroughs, connectors, viewports, thermocouples and other specialty components. The guides incorporate technical guidelines, applications and products. The international edition uses metric dimensions.
Ceramaseal
INFO/CARD #243

EM-Field-Safety Measurements

Wandel & Goltermann has issued a four-color guide titled, "Precision Measurement Technology for Safety in Electromagnetic Fields." The guide examines the measurement of electric and magnetic fields in connection with personal safety and standards imposed by IEEE/ANSI, IEC, IRPA, and WHO.
Wandel & Goltermann
INFO/CARD #244

New Book, Software and Video Course for the Smith® Chart

Noble Publishing has announced availability of *Electronic Appklications of the Smith Chart* by Phillip H. Smith, re-published posthumously. All of the original material has been included in this new editions, plus an additional chapter describing the *winSMITH* software written by Eagleware to accompany the book. The new chapter also includes numerous examples and tutorial problems to help readers learn to use the Smith chart. A 50-minute tutorial video is also available for guided instruction. The book is $59.00, winSMITH is $79.00 and the video course is $99.00. All three are package-priced at $199.00.
Noble Publishing
INFO/CARD #245

GaAs Manufacturer Newsletter

The Third Quarter 1995 edition of GaAsLine - News About Anadigics contains a brief history of gallium arsenide, a spotlight on new fiber optic products, an analysis of cost-saving opportunities in wireless product manufacturing, and a report on Anadigics' third quarter results.
Anadigics
INFO/CARD #246

Radar and RF Catalog

The Radio-Research Instrument Reference Guide 1296 contains 25 pages of RF and radar equipment and is certified to supply governmental customers. The Reference Guide lists available antenna systems, microwave links, radar systems, transponders and other RF systems.
Radio-Research Instrument Co., Inc.
INFO/CARD #247

Coaxial Product Catalog

Pasternack Enterprises' #1995A catalog contains specifications for their lines of coaxial connectors, coaxial cable assemblies, attenuators, coaxial switches, adapters, power dividers, terminations and other devices. The 70-page catalog contains prices and ordering information.
Pasternack Enterprises
INFO/CARD #248

Glass-to-Metal Seal Brochure

A four-color brochure introduces Electronic Products, Inc., a source of standard headers and packages using glass-sealing processes, and their subsidiary, Multipak, which provides high-end engineering design support and manufacturing for tight-tolerance hybrid and microelectronic packages.
Electronic Products, Inc.
INFO/CARD #249

RF marketplace

Classified display ads are available at $125 per column inch. Frequency rates available for multiple insertions. Please call for further information, 1-800-443-4969, ask for Shannon Shuman. Or fax your ad copy for a rate quote to (770) 618-0342.

CAREER OPPORTUNITIES

Detection Systems, Inc. manufactures security equipment, which includes RF data links. The opening listed below is at our facility in Fairport, NY, which is located outside of Rochester.

RF DESIGN ENGINEER

We are looking for an individual with experience in low power Part 15 design of receivers and transmitters. Both narrow band and spread spectrum experience is desired, with additional experience in low cost, long life battery powered gear.

Experience with electrically small antennas in hand held and fixed environments is a plus.

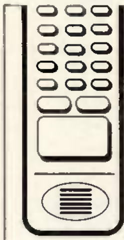
Required experience includes a minimum of 8 years of RF circuit design from 300 Mhz to 2.4 Ghz.

Qualified candidate should send resumes to:

ds ®

Detection Systems, Inc.
130 Perinton Parkway
Fairport, NY 14450

or fax to: (716)421-4263



...YOUR CAREER

Pacific Rim Marketing Specialists: Knowledge of cellular systems. Understanding of market forces in cellular (consumer). Needed skills include: writing business plans, formulation fundamental business strategies, coordinating advertising.

Strategic Account Manager: Promote sales of all products and capabilities at assigned strategic accounts. Will devote significant engineering, and product development resources to these accounts, it is essential that the Strategic Account Manager develop extensive contacts within the Customer, Engineering, Purchasing, and Product Management organizations.
RF PA Engineers: Requires 3+ years' experience in design, test and manufacturing of high efficiency OaAs MESFET and HBT class A and C power amplifiers in the frequency range 1.2GHz.

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.

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

Wireless Engineers
RF Design Engineers: Design of Si RF-ICs for wireless communication applications (AMPS, DAMPS, GSM, DECT, POS). Si RF-IXC design experience in the 400-2400 Mhz; fast RF PLL synthesizer design experience, RF receiver/transmitter/design experience using Si bipolar and MOS technologies.
RF Small Signal and RF Power AMP System Engineers: Requires detailed technical knowledge of cellular and PCS systems with experience designing RF XMTRS and RCVRS. Need 5+ years' related experience in RF.

Design Engineer Communications ICs: Requires B.S.E.E. (M.S.E.E. preferred) and 5+ years experience. Individual will be responsible for leading the design and characterization of high frequency transceiver ICs for wireless communications applications. Design includes circuit integration of baseband, converter and RF/IF circuitry.

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

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.

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 BiCMOS

Rf Systems Engineer PCS: Responsible for developing radio system performance requirements including modulations/demodulations, coding, channel models, deployment models, hardware performance requirements, interference rejection, blocking power control, handover ect.. BS/MS

RF DESIGN GPS: The successful candidate must have a B.S.E.E. with a minimum 12 years of experience in the design of Lband LNAs, Mixers, VCOs, and Microstrip Matching circuits. Knowledge of spread spectrum and modulation/demodulation schemes highly desirable. M.S.E.E. and/or VHF/UHF background a plus.

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BSEE	SR	Microwave Antenna Systems Test Eng.	to 70k
BSEE		Section Head RF Wireless Comm. Product Design	to 65K
BSEE	SR	RF Design - Receivers/Synthesizers/VCO/Power Amp	to 65K
BSEE	RF	Product Support Eng.	to 55K
BSEE	SR	Power Supply Design Eng.	to 65K
BSME		Mechanical Component Eng.	to 60K

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CAREER OPPORTUNITIES

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ANALOG/RF DESIGN ENGINEER

Requires BSEE/MSEE and 8+ years of RF/analog circuit and system design experience. In addition, position requires strong analytical and simulation capabilities, knowledge of CAE tools, modem/communication system modelling, PLLs, communications theory and detailed hardware design experience from DC to 2Ghz. Knowledge of video and consumer product design are preferred. **(Code: KHSRF)**

RF/MODEM ENGINEER

Requires BSEE/MSEE with 8+ years of experience responsible for design of cable modems. Must also have experience with QPSK and 64 QAM modems, digital modulators and demodulators, high-volume consumer products, RF design (0 to 750 Mhz), noise/gain analysis, and test. **(Code: KRMRF)**

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Please send your resume with salary history/requirements, indicating Code, to: **General Instrument, Attn: HR Dept., Code____, 6262 Lusk Blvd., San Diego, CA 92121; E-mail in ASCII Text only to: jobs@gi.com** Equal Opportunity Employer. Principals Only, Please.

GI General Instrument

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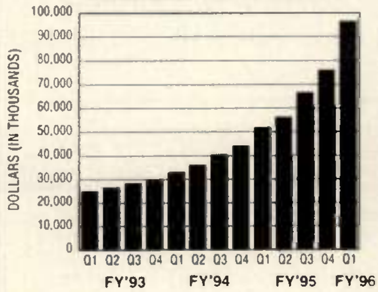

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Send or FAX resume and salary history to:

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MIDWEST OPENINGS

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Sr. Design Engineer Lumped Element Microwave Components/Subsystems

Merrimac is a leader in the engineering and manufacturing of state-of-the-art passive microwave components for aerospace, hi-rel, defense and commercial applications covering DC-65GHz. Our diversified product line includes I&Q Modulators/Demodulators, mixers, phase shifters, couplers, dividers, modulators and microwave subsystems.

We are seeking a top level individual for a position of Sr. Design Engineer to complement our team in the design of lumped element circuits within the range of DC-18GHz. This position requires a strong theoretical background in component and production support. The successful candidates should have a BSEE (MSEE preferred), 10 yrs exp in component design is desired.

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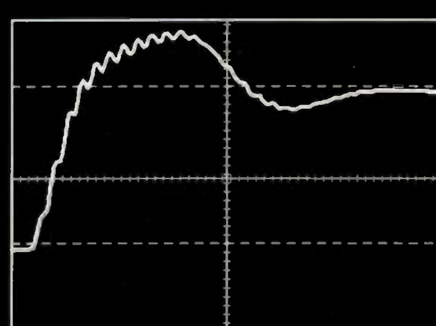

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