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WIRELESS 17 YRS LEADERSHIP

RF design™

engineering principles & practices

June 1996

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Selecting A Wireless System

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RF design

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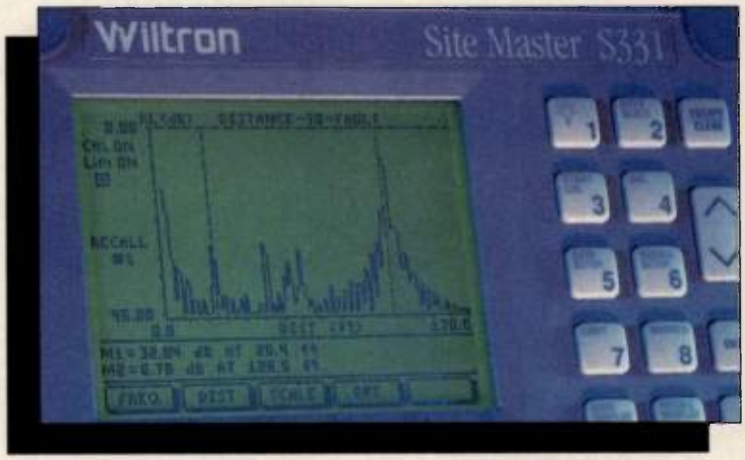
June 1996



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RF editorial

Telecommunications Growth Brightens the Future for RF Engineers

By Don Bishop
Editorial Director

When it comes to opportunity, hardly any other field compares with RF engineering. Burgeoning market demand for consumer devices that rely on RF allows entrepreneurs to start new manufacturing companies to make products for avariety of telecommunications services.

Wireless local loop services that replace wired exchange telephone service hold promise for growth in electronic products. The next-generation cellular, also known as wideband personal communications services (WPCS), requires fixed and portable RF products to carry voices and data messages. Advanced messaging services, also known as paging and as narrowband personal communications services (NPCS), blur the line between numeric, alphanumeric and voice paging and wireless computer networks. Direct broadcast services require additional RF support, as do vehicle location and monitoring services.

Passive devices for recording vehicle toll charges, monitoring over-the-road vehicle operating conditions and controlling inventory from ship to warehouse rely on short-distance sensors to carry and report data.

"Our graduates have plenty of offers to choose from," a professor at a university with a comprehensive RF engineering curriculum told me. That's good news for RF engineers and for the readers of *RF Design*.

More about editors

Our new technical editor, Gregg Miller, joined us during the week of the combined RF Expo and International Wireless Communications Expo trade shows and the April RF Design seminar series. What an introduction that was!

Gregg comes to us as a graduate of the University of Colorado with a B.S.E.E. His experience includes work at the U.S. Patent and Trademark Office in Washington, examining patent applications for various RF devices for both wired and wireless use, and work with a manufacturer of printed circuit boards.

At the same time we welcome Gregg, we have to say goodbye to our assistant editor, Stacey O'Rourke, who has been lured back to the video industry where she previously worked. She did a tremendous job with *RF Design*, and we wish her well in her new position.

Looking for RF?

The National Telecommunications and Information Administration has published an updated table of U.S. radio frequency allocations.

Copies of the 1996 spectrum wall chart cost $3.25 and can be obtained from the Government Printing Office, 732 N. Capitol St. NW, Washington, DC 20401; Tel: (202) 512-1993.

This is a terrific chart. Someone grabbed mine as soon as it arrived. I got a glimpse of it, though, and if you want to know where your slice of the spectrum (or someone else's slice) fits in the grand scheme of things, you'll find it on the NTIA chart. ***RF***

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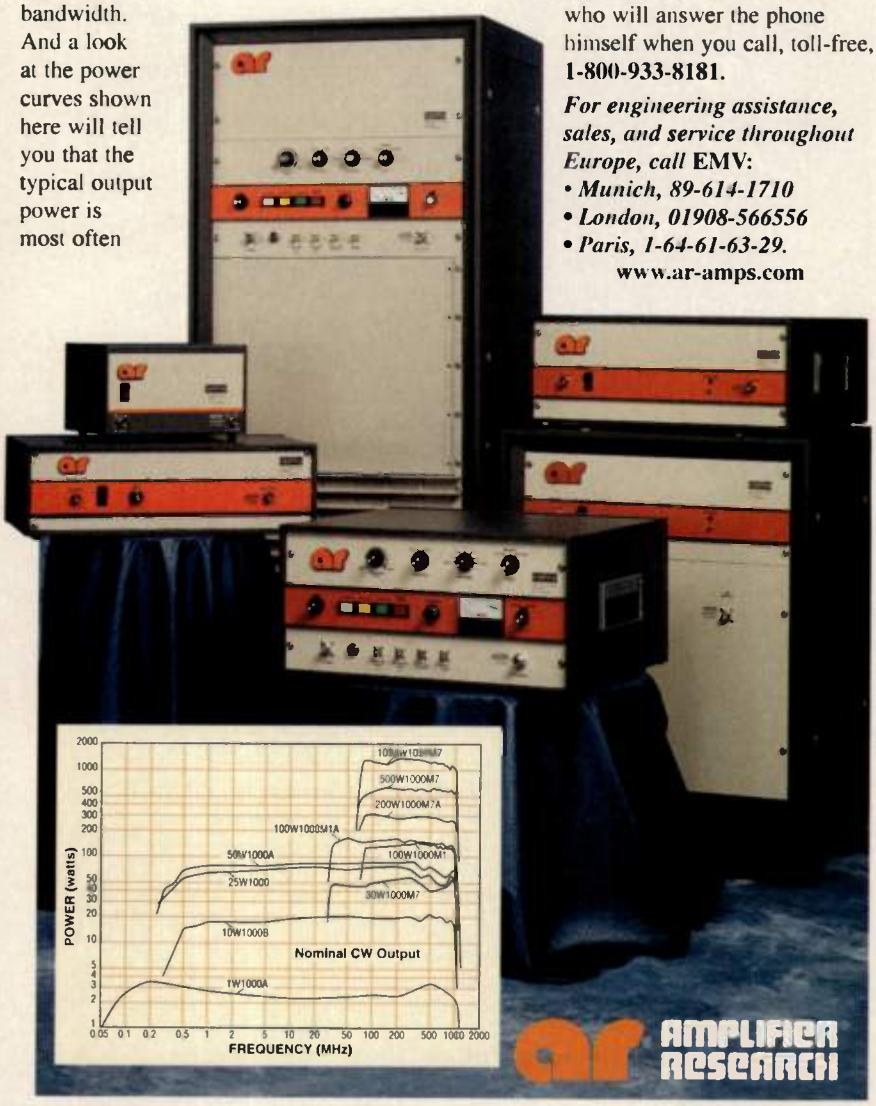
- ***Munich, 89-614-1710***
- ***London, 01908-566556***
- ***Paris, 1-64-61-63-29.***

www.ar-amps.com



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INFO/CARD 5

RF design

Established 1978

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Microwaves & RF
June 1995

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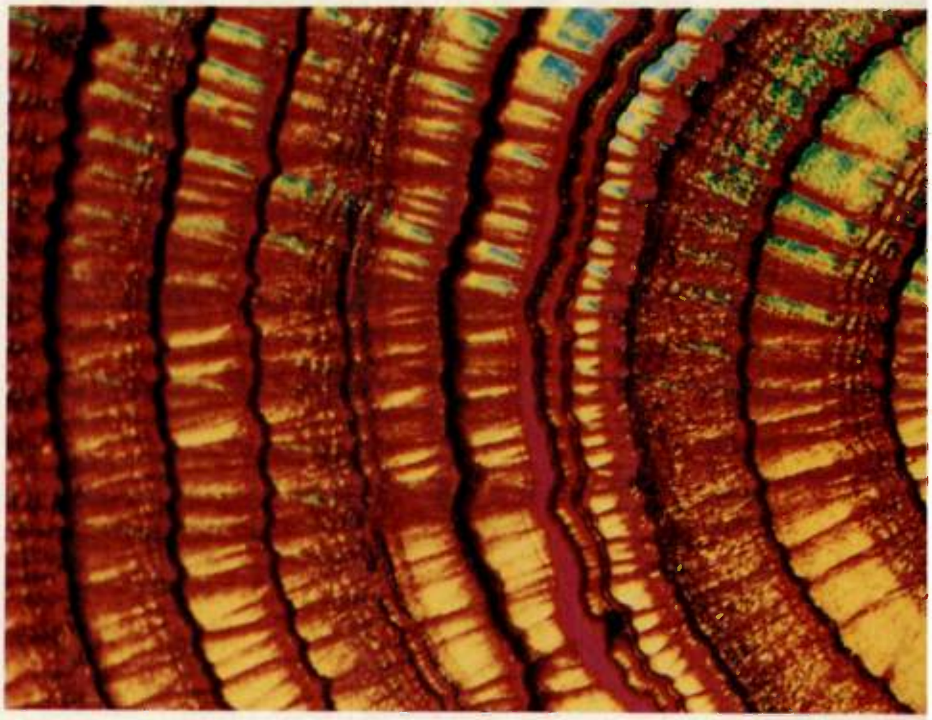

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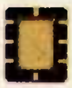

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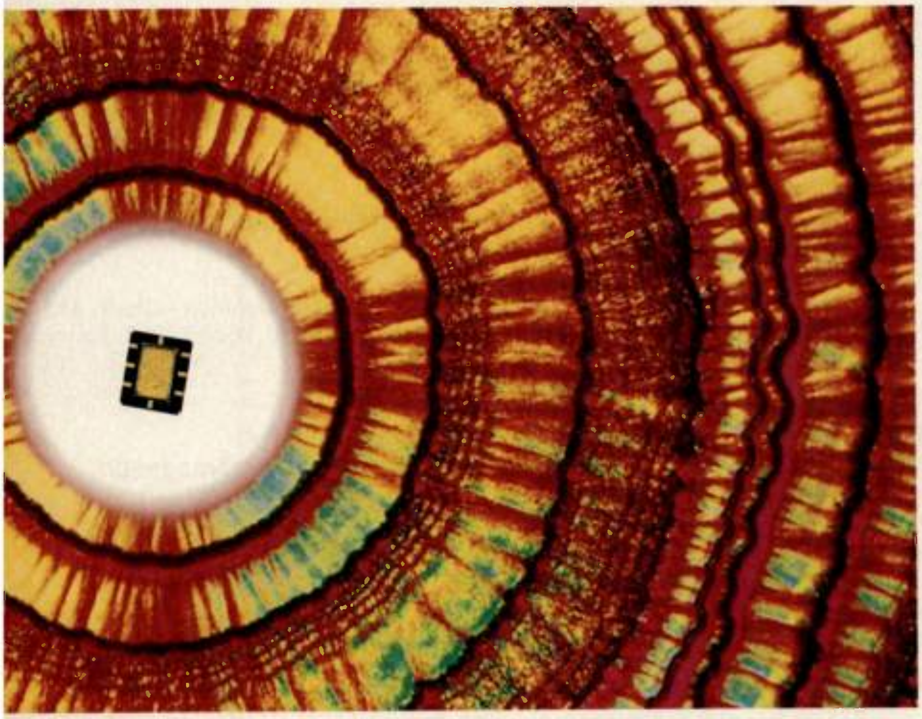

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RF calendar

June

24-25 Time and Frequency Seminars: Introduction-Level 1
Boulder, CO

26-28 Time and Frequency Seminars: Fundamentals-Level 2
Boulder, CO
Information: Wendy Ortega Henderson, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303-3328. Tel: (303) 497-3593; Fax: (303)497-6461; E-mail: ortegaw @boulder.nist.gov.

July

21-26 1996 IEEE AP-S International Symposium and URSI Radio Science Meeting
Baltimore, MD
Information: Mr. Jon Moellers, Steering Committee Chair, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331. Tel: (410) 993-6774; Fax: (410) 993-7432.

August

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

21-23 Wireless Communications Workshop
Boulder, CO
Information: Dr. Roger Marks, National Institute of Standards and Technology, 325 Broadway, MC 813.06, Boulder, CO 80303. Tel: (303) 497-3037; Fax: (303) 497-7828; E-mail: marks@nist.gov.

September

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

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

October

21-23 RF Design Seminar Series
Wakefield, MA
Information: Kelly Huber, Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 741-8721; Fax: (303) 267-0234.

RF courses

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

RF and Wireless Made Simple
July 8-9, 1996,. Los Altos, CA
Applied RF Techniques I
July 15-19, 1996, Los Altos, CA
Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel:(415) 949-3300; Fax: (415) 949-4400.

Communications Technology Training
July 9-10, 1996, Orland Park, IL
August 6-8, 1996, Orland Park, IL
September 3-5, 1996, Orland Park, IL
October 8-10,1996, Orland Park, IL
November 5-7, 1996, Orland Park, IL
December 3-5, 1996, Orland Park, IL
Information: Andrew Corp., Dept 355, PO Box: 9000, San Fernando, CA 91341-9978. Tel: (800) 255-1479, ext. 117.

DSP Without Tears
June 19-21, 1996, San Jose, CA
Information: Z Domain Technologies, Inc., 325 Pine Isle Court, Alpharetta, GA 30202. Tel: (800) 967-5034; (770) 587-4812; Fax: (770) 518-8368; E-mail: dsp@mindspring.com.

Grounding & Shielding Electronic Systems, and Circuit Board Layout
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.

Switching to wireless PABXs
July 9-12, 1996, Toronto
July 9-12, 1996, Los Angeles
July 30-August 2, 1996, Washington, D.C.
Information: Learning Tree® International, Reston Town Center, 1805 Library Street, Reston, VA 22090-9919. Tel: 1-800-THE-TREE((R)) (1-800-843-8733); Free Fax 1-800-709-6405;E-mail: uscourses@learningtree.com.

Applied RF Techniques: Linear Circuits
September 30-October 4, 1996, Cambridge, UK
Adaptive Synchronous Receiver Structures for Mobile Communications
September 30-October 4, 1996, Cambridge, UK
Wireless Digital Communications: Mobile, Cellular, Personal, Voice and Data Networks
September 30-October 4, 1996, Baveno, Italy
Mobile and Wireless Personal Communications Networks
October 14-18, 1996, Baveno, Italy
Modern Digital Modulation Techniques
October 14-18, 1996, Baveno, Italy
Far-Field, Anechoic Chamber, Compact and Near-Field Antenna Measurement Techniques
October 15-18, 1996, Baveno, Italy
Frequency-Time Signal Processing: Applications and Algorithms for High Resolution Spectral Analysis and Time Series Analysis
October 15-18, 1996, Baveno, Italy
Bandwidth-Efficient Coded Modulation: Theory and Application
October 21-23, 1996, Baveno, Italy
Speech and Channel Coding for Mobile Communication
October 21-23, 1996, Baveno, Italy
Digital Cellular and PCS Communications: The Radio Interface
October 21-25, 1996, Baveno, Italy
Spread Spectrum and CDMA
October 21-25, 1996, Baveno, Italy
VSAT Networks
October 23-25, 1996, Barcelona, Spain
Mobile Cellular and PCS Telecommunications Systems
November 11-13, 1996, Barcelona, Spain
Personal Mobile Satellite Communications
November 18-20, 1996, Barcelona, Spain
Satellite Communication Systems
November 11-15, 1996, Barcelona, Spain
Information: CEI-Europe, PO Box: 910, S-612 25 Finspong, Sweden. Tel: 46 122 175 70; Fax: 46 122 143 47; E-mail: cei.europe@one.se.

Reliability: A Practical Approach
June 17-21, 1996, Washington D.C.
Digital and Analog Communication Systems for Non-Engineers: The Fundamentals
June 17-19, 1996 Washington, DC
Digital Cellular and PCS Communications: The Radio Interface
June 24-28, 1996, Washington, DC
Digital Cellular and PCS Communications
June 24-28, 1996, Washington, D.C.
Communications Satellite Systems
August 5-8, 1996, Washington, D.C.
Cellular and Wireless Telephony
August 12-16, 1996, Washington, DC
Wireless Infrastructure Network Engineering for Cellular, PCS, LEO, and WPBX
October 21-25, 1996, Washington, DC
Wireless Infrastructure Network Engineering for Cellular, PCS, LEO, and WPBX
October 21-25, 1996, Washington, D.C.
Satellite Communications Engineering Principles
November 5-8, 1996, Washington, DC
Grounding, Bonding, Shielding, and Transient Protection
November 11-14, 1996, Washington, DC
Satellite Communications WIth Emphasis on Mobile Systems
December 2-4, 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; E-mail ceepinfo@ceep.vpaa.gwu.edu.

Electromagnetic (EM) Simulators
July 9-12. 1996, Los Angeles, CA
Information: UCLA Extension, 10995 LeConte Ave., Suite 542, Los Angeles, CA 90024. Tel: (310) 825-1047; Fax: (310) 206-2815; E-mail: mhenness@unex.ucla.edu.

National Electronics Manufacturing Initiative Consortium

Richard C. Jensen, vice president and general manager, Assembly and Advanced Products, announced Dexter Electronics Materials' participation in a consortium created to ensure the sustained growth and competitiveness of U.S. electronics manufacturing. The National Electronics Manufacturing Initiative, Inc. (NEMI), located in Arlington, VA, is an industry-led, private/public partnership that brings together the largest electronics equipment manufacturers in the United States, their key suppliers and government agencies to foster development of the world's best electronics manufacturing supply chain. NEMI's mission, to rapidly advance the U.S. electronics manufacturing infrastructure, will improve manufacturing technology by establishing development and implementation projects between users and suppliers. Key research and development activities will be identified that require the coordination of its members and outside organizations. The initial projects will focus on five areas: interconnection substrates, board assembly, final assembly, flip chip packaging and energy storage systems. Dexter will participate in NEMI's Flip Chip Technology Implementation Group.

Patent Awarded For Cellular Directory Assistance Call Completion

VoiceTech Communications Inc. has been granted patent approval for its VoiceCue (trademark) Directory Assistance Call Completion (DACC). First introduced in August 1995, DACC offers cellular customers fast, easy-to-use call completion from a single, multi-application platform. The DACC application provides direct connection to the Regional Bell Operating Company's (RBOC) directory assistance service. By building a shell around the RBOC 411 service and utilizing speech recognition technology to determine the dialing digits, the DACC system provides the support for the carrier to complete the call using its own switching equipment. Carriers may also customize introduction messages with the DACC system, as well as choose from several methods for customizing the connection of the call, including the offer to complete the call for a fee. DACC also provides carriers with all necessary billing information.

Electronics Acquisition

The management of Schaffner Elektronik AG, the international electronics company, purchased the Schaffner Group of companies from Elektrowatt AG. The MBO team consists of four long-standing members of Schaffner's senior management with solid financial backing from investment institutions. The buy-out will enable further consolidation of the group's leading

Business Briefs

Call For Papers—The 1996 IEEE International Electron Devices Meeting (IEDM) will be held December 8-11, 1996 at the San Francisco, CA, Hilton & Towers. Papers are requested in the following areas: CMOS devices and reliability; detectors, sensors and displays; device and interconnect technology; integrated circuits; modeling and simulation; solid state devices; and quantum electronics and compound semiconductor devices. Deadline for receipt of technical paper abstracts is July 1,1996. Paper abstracts should be sent to: Melissa Widerkehr, IEDM, 101 Lakeforest Boulevard, Suite 270, Gaithersburg, MD 20877, USA.

Intelligent Traffic System for Today—Technology already widely used by American motorists is the basis for a low-cost safety warning system that will inform drivers of highway hazards such as traffic accidents, approaching emergency vehicles, construction delays or visibility problems. With support from a consortium of consumer electronics companies, researchers at the Georgia Tech Research Institute (GTRI) have developed a transmitter and messaging system capable of sending a wide range of emergency warning to motorists using advanced radar detectors. The Safety Warning System will also provide a general warning to the older radar detectors not capable of displaying text messages.

Wafer Sourcing Deal—Philips Semiconductors has signed a wafer sourcing agreement with TriQuint Semiconductor, a leading U.S. supplier of radio frequency, gallium arsenide (RF GaAs) components. Philips Semiconductors will develop all the GaAs ICs at Philips Microwave, Limeil, France, drawing on its 20 years of experience in GaAs IC R&D and foundry service. Wafer production will be carried out at TriQuint and Philips Microwave Limeil. TriQuint will produce wafers to Philips Semiconductors' specifications at its plant in Beaverton, OR. Philips will assemble and test the products and supply them, through its worldwide sales organization. The products will serve markets such as cellular and cordless phones, wireless local area networks, base stations, high-speed transmission equipment and satellite communications.

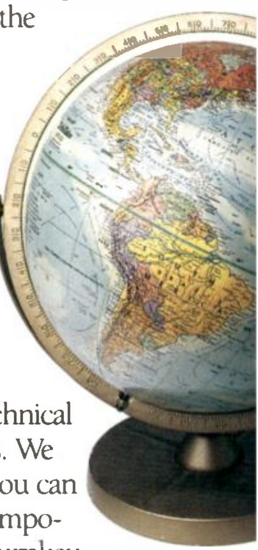
Printed Circuit Board Market—To cope with consumer demands, OEMs have increasingly relied upon home-grown components in building finished goods. In a report about to be issued by Allied Business Intelligence (ABI), a strategic consulting firm in Oyster Bay, New York, the printed circuit board industry is considered from several perspectives. "Printed Circuit Board Fabrication to 2001: US and World Markets, Technologies & Competitors" examines the influences that have shaped the continuing recovery of an industry that was about to be gobbled up by Pacific Rim countries.

Lab Group Formed to Address Europe's EMC Directive—American Council of Independent Laboratories (ACIL) has officially launched a new association to help U.S. independent and manufacturers' laboratories address technical questions relating to electromagnetic compatibility (EMC) regulations and standards for electronic and telecommunications devices used in Europe. The group, the United States Council of EMC Laboratories (USCEL), has already held organizational meetings in Washington and Chicago. For more information contact ACIL, 1629 K Street, N.W., Washington, D.C. 20006; Tel: (202) 887-5872; Fax: (202) 887-0021; E-mail acil@ix.netcom.com.

Global solutions... for all your communications testing needs.

Noise Com noise products and test instruments are being used throughout the world to evaluate the performance of cellular, satellite, and radar communications and data transmission systems.

Whether you require noise sources, modules, or generators, or are interested in our state-of-the-art test instruments such as our multipath fading emulator or Interference Test Set™, we have the products to suit your application.



Every Noise Com product is backed by years of research and testing where it counts...*in the field*. That translates to products that deliver outstanding stability and quality...in the toughest applications.

At Noise Com, the only thing better than our products is our dedication to providing the best technical service and support in the business. We also realize that time is money, so you can count on receiving your custom component, test equipment, or an entire turnkey system on time...every time.

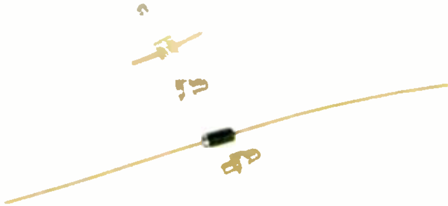
Pictured here are some of our standard products. For more details, ask for our *Complete Line of Broadband Noise Products* catalog. If you're interested in our critically-acclaimed test equipment, make sure you request a copy of our *Test Equipment For Wireless & Telecommunications* catalog. Whatever you decide...we'd love to hear from you.

Noise Com. Your global partner for noise, wireless, and telecommunications testing solutions.

For more information and a quick response, call NOISE COM, the experts in testing, at 201-261-8797.

When you need a company to provide solutions to your noise testing needs... all points lead to
NOISE/COM

Chips and Diodes



All Noise Com diodes deliver symmetrical white Gaussian noise and flat output power versus frequency. Noise Com diodes are available in a wide variety of package styles, and in special configurations on request.

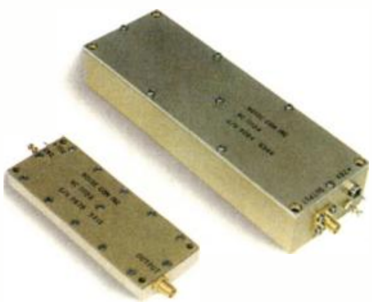
TYPICAL STANDARD MODELS	
MODEL	**FREQUENCY RANGE**
NC 302	10 Hz – 3 GHz
NC 305	10 MHz - 11 GHz
NC 401	100 MHz – 18 GHz
NC 406	18 GHz – 110 GHz

BITE Modules

The NC 500 series drop-in noise modules in TO-8 cans and flat packs for surface mounting are an economical solution for built-in test requirements. These devices contain complete biasing networks and need no external components. Also available are TO-39 packages.

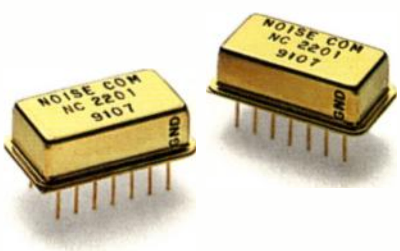
TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT ENR**
NC 501/15	0.2 MHz – 500 MHz	31 dB
NC 502/15	0.2 MHz – 1000 MHz	31 dB
NC 503/15	0.2 MHz – 2000 MHz	31 dB
NC 506/15	0.2 MHz – 5 GHz	31 dB
NC 511/15	0.2 MHz – 500 MHz	51 dB
NC 513/15	0.2 MHz – 2 GHz	51 dB

Broadband Amplified Modules



The NC 1000 series amplified noise modules produce white Gaussian noise from -14 dBm to +13 dBm at frequencies up to 6 GHz. They are designed for coaxial test systems, and are available with several bias voltages and connector options.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT**
NC 1101A	10 Hz – 20 kHz	+13 dBm
NC 1107A	100 Hz– 100 MHz	+13 dBm
NC 1112B	20 MHz – 2 GHz	0 dBm
NC 1126A	2 GHz – 6 GHz	-14 dBm



The NC 2000 series amplified noise modules are an excellent choice when a high level noise output is desired and the noise source is to be mounted on a circuit board. 24 pin packages are standard; 14 pins are also available.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT**
NC 2101	100 Hz – 20 kHz	0.15 Vrms
NC 2105	500 Hz – 10 MHz	0.15 Vrms
NC 2201	1 MHz – 100 MHz	+5 dBm
NC 2601	1 MHz – 2 GHz	-5 dBm

NOISE/COM A Wireless Telecom Group Company

Broadband Precision, Calibrated Coaxial

Noise Com's NC 346 series is designed for precision noise figure measurement applications. These products are available with coaxial or waveguide outputs. For OEM applications, the NC 3200 series provides high performance in a small ruggedized package.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 346A	0.01 GHz – 18 GHz	6 dB
NC 346B	0.01 GHz – 18 GHz	15 dB
NC 346C	0.01 GHz – 26.5 GHz	15 dB
NC 346D	0.01 GHz – 18 GHz	25 dB
NC 346Ka	0.1 GHz – 40 GHz	15 dB

Broadband Calibrated Millimeter-wave

The NC 5000 series noise sources feature outstanding stability and convenience in waveguide bands up to 110 GHz.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	WAVEGUIDE
NC 5142	18 GHz – 26.5 GHz	WR-42
NC 5128	26 GHz – 40 GHz	WR-28
NC 5122	33 GHz – 50 GHz	WR-22
NC 5115	50 GHz – 75 GHz	WR-15
NC 5110	75 GHz – 110 GHz	WR-10

Broadband Noise Generators

The NC 6000 and NC 8000 series noise-generating instruments are designed for applications on the test bench or incorporated with other equipment to provide a wide variety of functions. Each instrument contains a precision noise source, amplification, and step attenuators to provide repeatable symmetrical white Gaussian noise with variable output power.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT POWER
NC 6107	100 Hz – 100 MHz	+13 dBm
NC 6108	100 Hz - 500 MHz	+10 dBm
NC 6110	100 Hz – 1500 MHz	+10 dBm
NC 6124	2 GHz – 4 GHz	-10 dBm
NC 8107	250 kHz – 100 MHz	+30 dBm
NC 8111	5 MHz - 1 GHz	+30 dBm

The new UFX-7000 series noise-generating instruments are extremely easy to use, combining dedicated keys for control of operations and programming, with a large 4 x 20-character LCD display. Control of output power, filter settings, and attenuator step size for both the noise and the signal (for units with internal combiners) is performed from the front panel or by remotely using the IEEE-488 interface.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT POWER
UFX-7107	100 Hz–100 MHz	+13 dBm
UFX-7108	100 Hz – 500 MHz	+10 dBm
UFX-7110	100 Hz – 1500 MHz	+10 dBm
UFX-7218	2 GHz – 18 GHz	-20 dBm
UFX-7909	1 MHz – 300 MHz	+30 dBm

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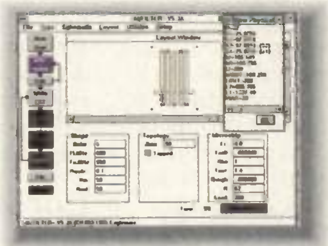
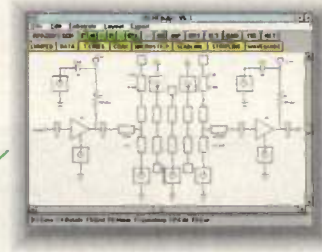
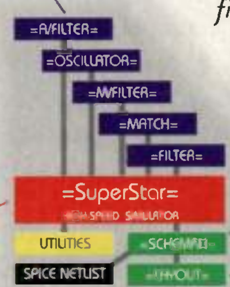
DESIGN FROM START-TO-ART

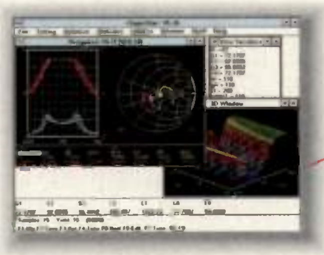
1 GENESYS synthesis modules make it easy to create initial designs for L-C filters, matching networks, active filters, oscillators, printed and machined filters, amplifiers and group delay equalizers. The many design alternatives and quick evaluation of each help you save time and achieve higher performance.



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







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

NEW!

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

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Private Financing Completed

Digital Radio Communications Corporation, a local leader in wireless and wired communications, and electronics manufacturing, announced it has secured more than $500,000 in a round of private placement financing. The financing has been allocated to continue funding of Digital Radio's research and development projects related to its core wireless communications business, in addition to its design, development, and manufacturing services. Formerly known as Electronic Technology, Digital Radio Communications Corp. was founded in 1992 and specializes in designing and manufacturing wired and wireless communications products, as well as providing contract design, development, and manufacturing services.

European Office

Bird Electronic Corporation has opened a new European sales office in Hertfordshire, England. The new office will support the company's customers and manufacturer's representatives throughout Europe. The opening of the Hertfordshire office will provide direct technical sales support, product training and applications assistance to Bird's European customers and representatives.

Plant Expansion

3M announced that it will be investing an additional $40 million in its recently expanded manufacturing plant in Columbia, MO. According to 3M plant manager Martyn Tiplady, the $40 million will expand the building just completed last year and install more equipment to supply the electronic interconnect market. The investment will increase the size of the plant by more than 30,000 square feet. 3M expects the number of jobs at the plant to increase by between 80 and 100 over the next two years.

Wetted Reed Switch Business Acquired

CP Clare Corporation, a world leader in the semiconductor and electromechanical relay marketplace, announced the acqusition of the wetted reed switch business of NEC, Japan. This purchase positions the company as the last major supplier and manufacturer of mercury wetted Form C reed switches. CP Clare currently markets solid state relays, dry and wetted reed switches and relays, surge protection and magnetic products.

New Communication Services Division

E.F. Johnson Company announced the formation of E.F. Johnson Services, a wholly owned division which will offer a variety of communications facility installation and construction-

(continued on page 55)

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902-928 MHz ISM Products

The VCO-191-915U VCO tunes from 902-928 MHz with a tuning voltage of 0.8-2.2 volts typically. Input supply voltage may range from 2.5V to 4.0V. Typical phase noise at 10kHz offset is -108 dBc/Hz. The VCO is housed in a 0.375" x 0.375" x 0.117" surface mount LCC package which is pick and place, and reflow compatible.

INFO/CARD 26

The PLL-400-915 synthesizer spans the range of 902-928 MHz in 200 kHz steps. The unit requires a +5V supply, serial 3 wire interface and a reference oscillator input for complete operation. The synthesizer is housed in a 0.6" x 0.6" x 0.138" surface mount LCC package which is pick and place, and reflow compatible.

INFO/CARD 27

2400-2500 MHz ISM Products

The VCO-190-2450AT VCO tunes from 2400-2500 MHz with a tuning voltage of 1-4 volts. The input supply voltage is +5V. Typical phase noise at 10 kHz offset is -90dBc/Hz. The VCO is housed in a 0.5" x 0.5" x 0.100" surface mount LCC package which is pick and place, and reflow compatible.

INFO/CARD 28

The PLL-400-2450 synthesizer spans the range of 2400-2500 MHz in 1 MHz steps. The unit requires a +5V supply, 3 wire serial interface and a reference oscillator input for complete operation. The synthesizer is housed in a 0.6" x 0.6" x 0.138" surface mount LCC package which is pick and place, and reflow compatible.

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Broadcast Industry Eyes New Transmission Technologies

By Gary A. Breed
Consulting Editor

After a long period of anticipation, new program transmission methods for broadcasting are imminent. HDTV (High Definition Television, also referred to as Advanced Television, or ATV) and DAB (Digital Audio Broadcasting) have reached the final stages of technical and regulatory development.

HDTV promises to deliver picture quality roughly equivalent to 35 mm film, a dramatic improvement over current television transmission standards. The viewer will no longer find it easy to see the individual lines that make up the picture. DAB will combine Compact Disc (CD) quality sound with transmission of additional data. Although current FM broadcasting can provide excellent quality in strong-signal areas, and can handle data transmission, DAB will be noticeably higher in quality throughout a station's coverage area, even where reception conditions are not perfect.

Development with Difficulty

The road to development of new radio and television broadcasting formats has been a minefield of engineering challenges and domestic and international regulations. Particularly in the case of HDTV, the technological evolution has been far too rapid for either regulators or marketplace analysts to keep up with. On the technical side, problems with image compression, data format, occupied bandwidth and interference have arisen, been addressed, and sometimes reappeared. It has seemed that, as soon as an acceptable standard has been developed, someone had come up with a better way to get the job done, making some part of the previous work obsolete. Even after competing HDTV proponents joined forces in the Grand Alliance, disagreements concerning technical standards continued.

Field testing of HDTV and DAB exposed additional technical issues. One was the coverage area within which acceptable picture or sound quality could be received. A broadcasters' market potential is based on the number of people served. To establish appropriate transmission power levels and antenna height standards, minimum signal levels must be determined. In HDTV, trial transmissions did not effectively reach as far as predicted. DAB had similar evaluations to re-think after field testing. Both systems appear to have those issues resolved, and are ready to move into the final stages of the regulatory process.

The Regulatory Battleground

Like other new radio-based communication services, HDTV and DAB need spectrum space. Even if the old technology channels are later vacated, both old and new need to be accommodated for a period of several years. DAB will be implemented in L-Band by most countries. In this frequency range, coverage will be a bit less thorough than in the current 100 MHz region, but the effects of the difference in propagation characteristics will also depend on authorized power levels and the quality of the receivers.

HDTV has a more elegant approach, permitting HDTV on unused UHF television channels. This, of course, gives rise to arguments on the subject of potential interference between HDTV and current TV broadcasting. Are the two systems dissimilar enough to minimize interference, as is generally claimed, or will some viewers see degradation of quality? There is no real consensus, but most HDTV experts think this arrangement will work acceptably.

Getting the Federal Communications Commission and the equivalent agencies in other countries to give final authorization for HDTV and DAB is another part of the story. Canada, and soon much of Europe, is ready to implement DAB. In recent weeks, it looks like the final hurdles for HDTV in the U.S. have been cleared and the FCC only needs to put the technical and business requirements into codified form. However, even if the technical issues have been addressed successfully, there is much disagreement on how the transition to HDTV or DAB should be accomplished. What priority do existing broadcasters have? What about new entrepreneurs? Do we have auctions or fixed fees? What is the timetable for licensing, construction, and eventual phase-out of the "old" technology? Tough questions still must be answered.

Marketplace Acceptance

All the discussion so far assumes that consumers will buy new HDTV sets and DAB receivers! While this is inevitable, the rate at which those consumers will make the changeover is only a guess. One view is that consumers are especially excited about new technology right now, following the boom in personal computers, video games and cellular phones. Acceptance of the CD as a replacement for vinyl records started slowly, but accelerated faster than many experts expected.

The contrary view is that consumers have spent a lot of their income on these high-tech toys, and new products will dilute the market even further. Direct Broadcast Satellite (DBS) systems, expanded cable service, a monthly Internet access bill, and new PCS phone service are new entries into the market. Their effects on the implementation of HDTV and DAB can only be guessed.

The rebuttal is that hardware is getting cheaper, and quickly. The costs come from the services provided. The key example is cellular telephones, which are often free (or nearly so) when the customer signs up with a service provider. An avid movie and sports fan can have an annual cable TV bill that exceeds the cost of a 27-inch set. A dozen CDs matches the cost of the disc player. The indirect charges of "free" TV and radio advertising may actually be welcomed by the consumer. The improvements brought by HDTV and DAB won't require a monthly fee. (Although we must see what cable companies do to their rates when they add HDTV and DAB programming!)

Where does this leave us? At the risk of being proven wrong by more technical and regulatory wrangling, we are on the verge of getting these new broadcast services. As one more part of the continuing growth of wireless communications, we will all find HDTV and DAB fascinating to watch as their markets develop. *RF*

INFO/CARD 15

Considerations and Trade-offs for Specifying, Designing and Installing Wireless Systems

By David J. Beal
Axonn Corporation

This article addresses considerations and trade-offs which are important when selecting a wireless system, specifically unlicensed spread spectrum, for any specific application. Though many of the issues discussed here are intuitive, they are often either assumed or completely overlooked, resulting in poor system performance and/or increased time to the field. The ability to identify and define these issues during the system requirements and definition phase will reduce many of the problems associated with getting a new product to market.

Basic System Definition

Low cost wireless systems often replace wired systems which provide unidirectional status information from an application specific sensor to the outside world. This type of wireless system, as shown in figure 1, can be very cost effective since numerous low cost transmitters are supported by a single receiver which interfaces to the world through either the standard interface of the receiver, or through a custom system controller and interface assembly such as a security panel.

Another common type of wireless system is necessary when bi-directional command and status information is required within the system. This type of system utilizes multiple transceivers and is illustrated in figure 2.

Before attempting to purchase or design any system, the engineer must adequately define the specific system requirements based on: cost (manufac-

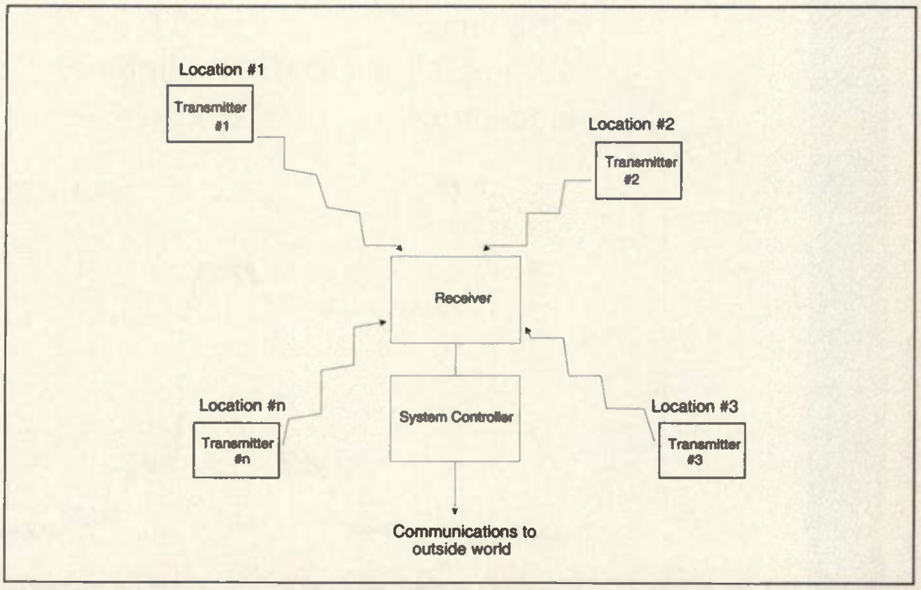


Figure 1. A wireless system with unidirectional flow of information from many transmitters to a single receiver.

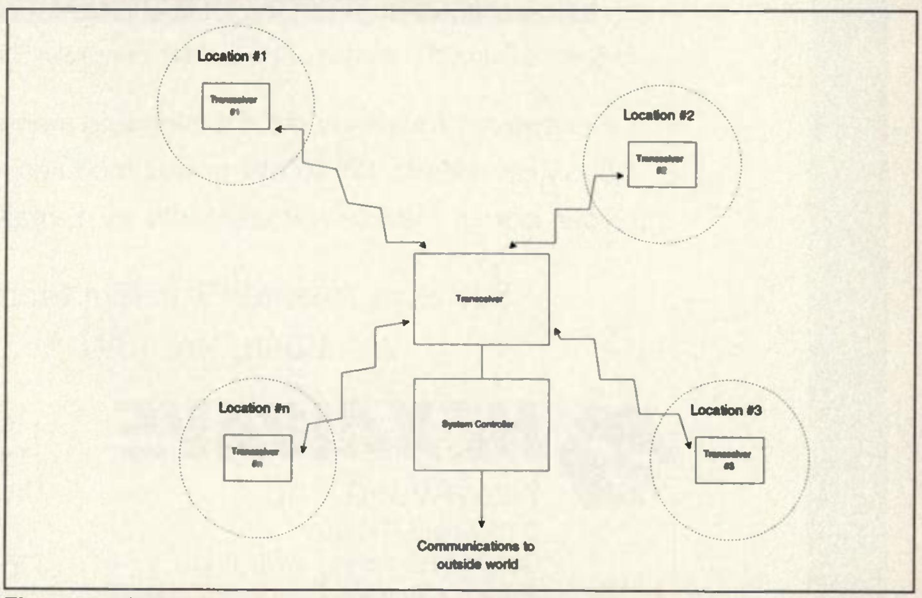


Figure 2. Bi-directional system in which many transceivers transmit information to and receive information from a central transceiver.

turing, maintenance and lifetime), performance, size, the problem to be solved, and the feasible solutions with respect to regulatory and other issues.

Spread Spectrum Wireless System Fundamentals

As a greater number of wireless devices are deployed, the airwaves are becoming increasingly crowded, increasing the chances of interference and jamming since each device forms a potential jamming threat to the others.

In order to correctly receive and decode the transmit message, every receiver requires that the strength of the desired signal (relative to the strength of background noise) meets or exceeds the noise level. The amount by which the signal exceeds the noise level is called the signal to noise ratio (SNR). SNRs lower than the threshold result in substandard communications performance, while higher SNRs increase the communications link reliability.

Communications systems effectively discern undesired signals as noise. As a consequence, it is good to reduce the level of interfering signals in every way possible. Through the same process which is used to receive the wanted signal, spread spectrum systems lower the level of interfering signals. This decrease in noise power allows the receiver to more easily detect and demodulate signals from its own transmitters and provides an inherent resistance to unwanted signals.

As a result, spread spectrum techniques are well suited for applications where the need to operate in dense environments exists and when conservation of frequency spectrum is important.

What types of spread spectrum techniques are employed? – There are three types of unlicensed spread spectrum transmission allowed by the FCC per part 15.247, Direct Sequence, Frequency Hopping, and Hybrid (a combination of the two).

During transmission, the circuitry artificially increases (spreads) the signal's bandwidth by modulating the signal (either in phase or frequency) with a pseudo-random sequence which occurs at a rate far greater than the rate required for the data alone. During signal reception, the receiver requires synchronization of its internal pseudo-random generator to the pseudo-random sequence of the transmit signal in order to fully recover the available power and to decode the data message. This synchronization is generally referred to as correlation.

Direct sequence systems pseudo-randomly modulate the phase of the RF carrier signal at a rate at least ten times that of the data rate. This results in a signal spectrum which is much broader than would be occupied if the RF carrier signal were modulated by only the data stream. Direct sequence techniques tend to result in low cost transmitter designs since only the phase of the transmitted signal is modulated and the carrier frequency remains constant. Consequently, the transmitter's oscillator can be of a fixed frequency crystal design. Cost savings are also evident in the receiver since a fixed Local Oscillator (LO) frequency can be used there as well.

Frequency hopping systems dwell at one frequency for a portion of the message before tuning (hopping) to the next frequency. Frequency hopping systems are divided into two categories, fast and slow.

Fast hopping takes place at a rate much faster than the data rate. This method is very secure, highly resistant to multipath, requires quick and precise frequency control at both the transmitter and receiver ends, and is unfortunately expensive.

Slow hopping, traditionally used by low cost, spread spectrum systems, takes place at a rate much slower than the data rate. Multiple data bits are transmitted at each dwell frequency.

Both fast and slow hopping systems require that the frequency source for each transmitter be tunable, and that the receiver is able to tune in synchronization to maintain correlation. This frequency agility requirement leads to higher transmitter and receiver costs than is typically exhibited by a direct sequence system.

Hybrid techniques combine properties of both direct sequence and frequency hopping systems and are, in general, implemented at high cost.

Process gain, What is it? and How much does the system really need/get? – Process gain essentially indicates the amount of observed SNR increase when comparing the signal amplitude measured before correlation to the signal amplitude measured after correlation.

Process gain provides spread spectrum's immunity to jamming from unwanted co-channel (adjacent) radio sources, where a higher value indicates greater immunity to jamming. The same mechanism which raises the amplitude of the spread spectrum signal (during correlation) also causes a decrease in the amplitude of a co-channel CW signal. Unfortunately, the level of a non-correlated spread signal (of similar code length and chipping rate) is not generally further decreased in amplitude by this process.

When discussing process gain with wireless vendors, the designer should be aware that there are two types: Code process gain and system process gain.

Code process gain is essentially meaningless when determining the system's resistance to jamming and is simply a mathematical calculation of 10 log (chipping frequency/data frequency) which typically equals 18 dB in many low cost systems.

System process gain accounts for real-world implementation and is always lower than code process gain. System process gain includes the degradation caused by the receiver's actual IF filter which must be wider than the ideal filter in order to pass all desired signals with respect to unit-to-unit frequency variations over temperature and aging.

System process gain can be closely approximated based on 10 log (chipping frequency/final IF bandwidth) and is mandated by the FCC (Part 15.247), to be no less than 10 dB. One method accepted by the FCC for determination of process gain (G_p) is given by the following equation [1]:

$$G_p = S/N + M_j + L_{sys} \quad (1)$$

where:
S/N = signal to noise ratio required for a specified bit error rate
M_j = J/S ratio (equivalent to the level of the CW jamming signal relative to the correlated signal peak minus the required signal to noise level)
L_{sys} = system losses (FCC requires this number to be ≤2 dB).

How can a Direct Sequence Spread Spectrum link take advantage of Time Simultaneous Multiplexing? – A common misconception with direct sequence spread spectrum systems is the belief that the use of different pseudo random chipping codes from unit to unit will automatically allow time simultaneous (code multiplexed) operations. In fact, this is not practical without the addition of real-time transmitter power control.

Recall that a specified Signal to Noise Ratio (SNR) is required to demodulate data; that the desired signal is, upon correlation, increased by the system process gain value; and that another spread spectrum but non-correlated signal remains at essentially the same level.

If two signals (the desired signal Pd and the undesired signal Pj) of different pseudo random sequence arrive at the receiver at the same time, then Pd will increase by the process gain (Gp) and Pj will remain at approximately the same level (ignoring cross correlation). In order to decode data, the sum of Pd plus Gp must exceed Pj by the required SNR (plus any link margins). This can be simplified to the following equation:

$$Pd + Gp - SNR \geq Pj \quad (2)$$

where:
P_d = Power of the desired signal (dBm)
G_p = System Process Gain (dB)
SNR = SNR required to decode data to the specified BER (dB)
P_j = Power of the non-desired signal (dBm).

Given a system with a process gain of 18 dB, a required SNR of 12 dB, and given a desired signal level (Pd) of -105 dBm, we can determine that the level of Pj must not exceed -99 dBm. Thus, in order for both signals to be received simultaneously, neither must exceed the signal level of the other by more than 6 dB. In practice, without real-time power control, this is impossible to execute due to each transmitter's varying losses due to distance from the receiver, multipath/shadowing effects, and unit-to-unit output power variation.

How secure is the system? – FM and AM transmissions may easily be recorded or otherwise captured from standard receivers in an effort to decode the message contents later. Spread spectrum signals are much more difficult to capture since intimate knowledge of the pseudo random spreading code, data modulation and message format is required in order to extract the original data signal.

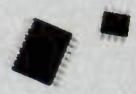
A mature wireless system should include built-in provisions which stop or greatly reduce interference between similar systems on the same frequency. These provisions should additionally allow the system controller to determine if a false transmission has been substituted for a real transmission.

Won't Direct Sequence spread spectrum eliminate multipath interference and fading? – One of the frequently noted advantages of direct sequence spread spectrum communications is its ability to discriminate against reflected (multipath) signals which travel further and arrive at a later time and with a different phase than the desired signal.

Multipath interference results when two (or more) reflected components of the same signal arrive at an antenna at the same time but out of phase. The two signal phasors add, resulting in a composite signal of weaker, unchanged, or greater amplitude when compared to either of the two components. Signal fading is defined as multipath interference in which the signals combined amplitude is lower than either of the individual signal amplitudes.

Direct sequence spread spectrum signals offer immunity to multipath since, during the receiver's process of correlation, synchronization between the receiver and the incoming signal provides an increase in the desired signal while maintaining or reducing the level of reflections which arrive at a different time and thus out of correlation. To see maximum benefit, the reflected signal must arrive at least one chip (a chip is one bit of the pseudo-random sequence which applies the spreading modulation) offset from the desired signal. Direct sequence systems have the ability to reduce the level of fading due to multipath over the full duration of the message. However, when multipath that cannot be separated by the chipping rate is present, reception of the complete message can be degraded.

Frequency hopping systems reduce the effect of multipath information by virtue of the desired signal's varying wavelength (changing inversely to the frequency at every hop) which combine at each hop with different phasor addition results. Slow frequency hoppers must adopt different redundancy and forward error correction schemes than do fast hoppers since multiple bits of information can be lost on each hop due to an unfortunate phasor addition. Slow frequency hopping systems are more likely to miss a portion of the data message (which could be significant at 0.4 seconds dwell time). However, it is statistically unlikely that the complete message will



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	1510 - 1660	0.4	20	1.3:1	0.05	1	DS52-0004
	1700 - 1900	0.3	20	1.3:1	0.05	2	DS52-0005
	1850 - 1990	0.5	21	1.2:1	0.05	1	DS52-0002
	2200 - 2500	0.3	20	1.3:1	0.05	3	DS52-0003
4-Channel							
	824 - 960	1	23	1.2:1	0.30	2	DS54-0001
	1200 - 1660	1	23	1.2:1	0.30	2	DS54-0003
	1700 - 2000	1	23	1.4:1	0.30	3	DS54-0002
New	2200 - 2500	1	21	1.4:1	0.20	2	DS54-0004
6-Channel							
	824 - 960	1.3	25	1.4:1	0.30	6	DS56-0001

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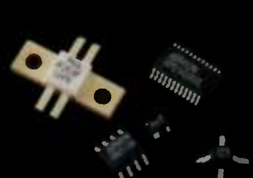

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become degraded.

Research indicates that the signal delay spread (due to reflections) in a building will generally vary from 15 to 200 nSec [2], and in an urban location from about 1.2 μSec to 10 μSec [3]. These figures allow the designer to determine the bounds for requirements best suited to multipath reduction in specific applications.

While spread spectrum transmission is not the perfect answer, it does provide a degree of immunity to a multipath environment. Additional techniques such as antenna diversity can also be used to mitigate the effects of multipath interference and fading.

What is Antenna Diversity? – Sufficient link margin must be provided to maintain communications even in the presence of signal variations caused by fading. Antenna diversity techniques take advantage of the fact that a change to the physical location or polarization of an antenna results in a composite signal (of the multipath components) of a different amplitude than was seen before the change. Since physically moving an antenna is not practical, common antenna diversity techniques switch between two (or more) fixed antennas which are placed spatially apart or are positioned with different polarizations. The receiver samples each antenna to determine which provides the strongest signal or best signal to noise ratio, and remains on that antenna until the next antenna switch and comparative sample is performed.

When using a single antenna at 915 MHz, signal fade depths can exceed 21 dB. A good dual antenna diversity algorithm can reduce signal fading to about 10 dB. As a consequence, only 12 dB of fading margin is required for systems which employ a robust antenna diversity algorithm and over 23 dB of margin for those systems which do not.

In what frequencies may the system operate? – It is important to ensure that the selected license free wireless system is compliant with the latest FCC rules and regulations. Presently: 902-928 MHz, 2400-2483.5 and 5725-5850 MHz each allow for license free spread spectrum communication. As a rule, both device cost and complexity increase with frequency.

PR Docket No. 93-61, which was recently passed by the FCC, places additional restrictions on the Part 15 wireless community operating in the 902-928 MHz band (shown in Table 1).

Multilateration systems are designed to locate vehicles or objects by measuring the difference in time-of-arrival or a difference in phase of signals transmitted from a unit to a number of fixed points or from a number of fixed points to the unit to be located.

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Non-multilateration systems are defined as systems that employ any technology other than multilateration to transmit information to or from vehicles. The most common example of a non-multilateration system is an electronic toll reader that automatically interrogates a tag on a vehicle and debits the owner's account.

Frequency(MHZ)	Band	Use
902.000 - 904.000	A	Non-multilateration
904.000 - 909.750	B	Multilateration
909.750 - 919.750	C	Non-multilateration
919.750 - 921.750	D	Multilateration and Non- multilateration
921.750 - 927.250	E	Multilateration
927.250 - 927.500	F	Narrow band associated with sub-band E
927.500 - 927.750	G	Narrow band associated with sub-band D
927.750 - 928.000	H	Narrow band associated with sub-band B

Table 1: Additional FCC restrictions placed on the Part 15 wireless community operating in the 902-928 MHz band.

Transmitter Considerations

There are many key parameters which specifically address the requirements or characteristics of a low cost wireless system's transmitter.

What information should the transmit message contain? – The transmit message should minimally answer the questions who, what, and how.

Who is readily answered with a family ID and transmitter ID number, both of which are programmed uniquely for each individual transmitter.

A family ID number can be very helpful in a situation where two separate and independent systems are installed adjacent to and within reception range of each other. The family ID allows the receiver to immediately ignore the remainder of that message if the transmitter is not from the same family as the receiver. The transmitter ID tells the system controller which individual within that family broadcast the message.

What is answered by including the status of all external sensors which are attached to the transmitter. This ensures that the system controller is able to determine the status of each individual element and perform all necessary action.

How refers to the health of the transmitter and should include an indication of low or normal battery conditions.

Ideally, the transmitter will also have the capability to calculate and append additional data which may be specific to the customers protocol or implementation and to append a Cyclic Redundancy Check (CRC) word to the message for receiver error detection and correction.

Supplementary information can include a sequence number which increments by one for each subsequent transmission. The sequence number provides the ability to determine if messages have been missed and adds another variable to enhance system security.

How much RF output power is required? – Unless system requirements are very well known and repeatable from site to site, the systems designer generally wants as much power as possible. RF output power, like many other parameters, revolves around three essential points: battery life, board space and cost.

Determination of required RF output power should be based on the answers to a few primary considerations:

1. What is the environment in which the system will operate?
2. How much range is required?
3. What is the receiver's sensitivity at the specified Bit Error Rate?
4. How much battery life is required?
5. What type of battery and power supply is used?
6. How much link margin is required for fading and performance degradation over time?

What type of external interface does the transmitter require? – The transmitter may require any combination of on-board sensors (e.g., tamper switch and magnetic reed switch) and off-board sensor inputs.

Many systems need to detect only a contact closure, opening, or change at the transmitter interface. These systems are lowest in cost since analog to digital (A/D) inputs are not required and a very basic microcontroller can be used (provided that some of the tasks can be off-loaded to external components). In these applications, it is critical that the device wake-up and transmit the alarm condition immediately upon any of the defined conditions.

Many systems need to measure an analog level and then either immediately transmit that value or perform a calculation to determine what further action to take. These systems are equally as easy to implement as those described above. However, the transmitter cost is increased due to the requirements for either an external or on-board A/D converter. The disadvantage with the simplest implementation of these systems is that the circuit must wake-up and take a sample to determine whether an alarm condition has occurred (as opposed to the above circuit which wakes itself on an alarm condition). Fortunately, there are alternative methods, such as the inclusion of an on-board comparator, or by basing the next wake-up and sample time on the previous sampled reading, which may be used to either work completely around or greatly reduce this limitation.

How should the data stream be modulated onto the RF frequency? – Data can be modulated on a spread spectrum signal using many of the tradi-

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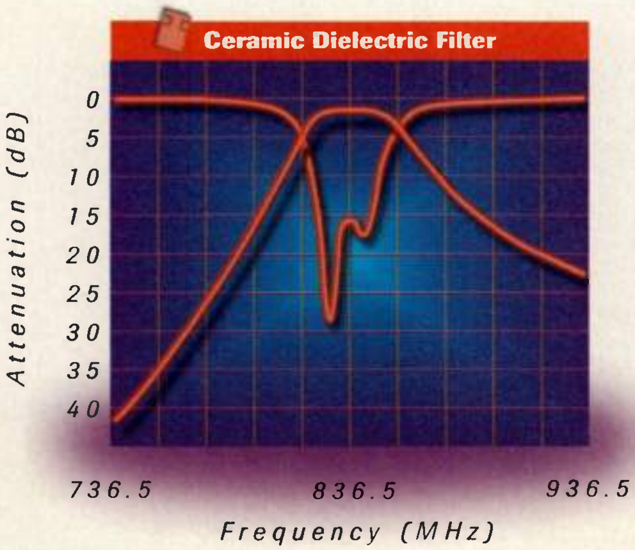

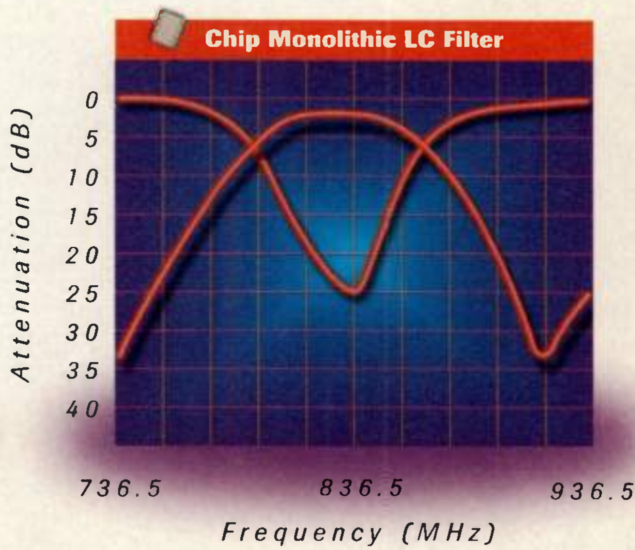

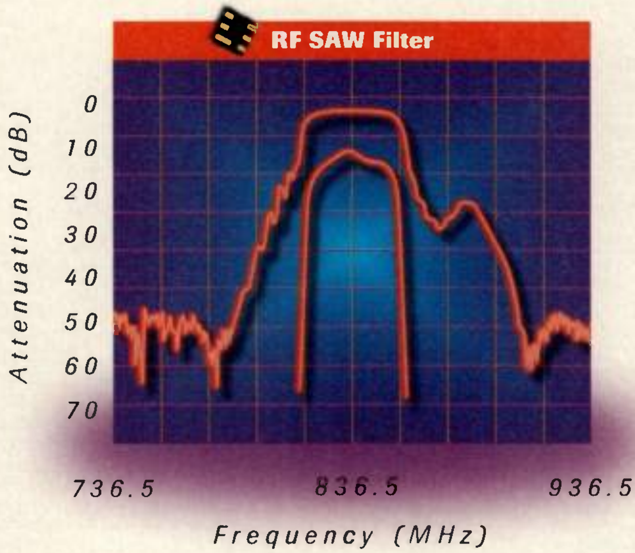

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2	TE5000	3	3.75	20	18.0	-	-	2	1.0	50	1800//+4
4	TE5010	3	3.75	30	14.0	-	-	3	2.0	60	1500//+3
6	TE5020	6	3.75	60	12.5	-	-	4	2.0	70	1500//+3
8	TE5030	6	3.75	60	10.0	90	12.5	5	2.0	80	1500//+3
2	TE5040	3	6.50	20	30.0	-	-	1	1.0	50	2700//0
4	TE5050	3	6.50	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. Ω/PF
2	TE5180	3	3.75	15	12.5	-	-	2	1.0	50	850//+6
4	TE5190	3	3.75	30	12.5	-	-	3	2.0	70	850//+5
6	TE5200	6	3.75	60	12.5	-	-	4	2.0	90	850//+5
8	TE5210	6	3.75	60	10.0	80	12.5	5	2.0	100	850//+5
2	TE5220	3	6.50	15	20.0	-	-	2	1.0	50	1300//+2
4	TE5230	3	6.50	30	22.5	-	-	3	2.0	70	1400//0
6	TE5240	6	6.50	60	22.5	-	-	4	2.0	90	1400//0
8	TE5250	6	6.50	60	17.5	80	22.5	4	2.0	100	1400//0
2	TE5260	3	7.50	15	25.0	-	-	2	1.0	50	1500//0
4	TE5270	3	7.50	30	25.0	-	-	3	2.0	70	1600//0
6	TE5280	6	7.50	60	25.0	-	-	4	2.0	90	1600//0
8	TE5290	6	7.50	60	20.0	80	25.0	4	2.0	100	1600//0
2	TE5300	3	15.0	15	50.0	-	-	2	1.0	45	3000//0
4	TE5310	3	15.0	30	45.0	-	-	3	2.0	60	3000//-1
6	TE5320	6	15.0	60	45.0	-	-	3	2.0	90	3000//-1
8	TE5330	6	15.0	60	33.0	80	45.0	4	2.0	100	3000//-1

45.0 MHz

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

70.0 MHz

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

90.0 MHz

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

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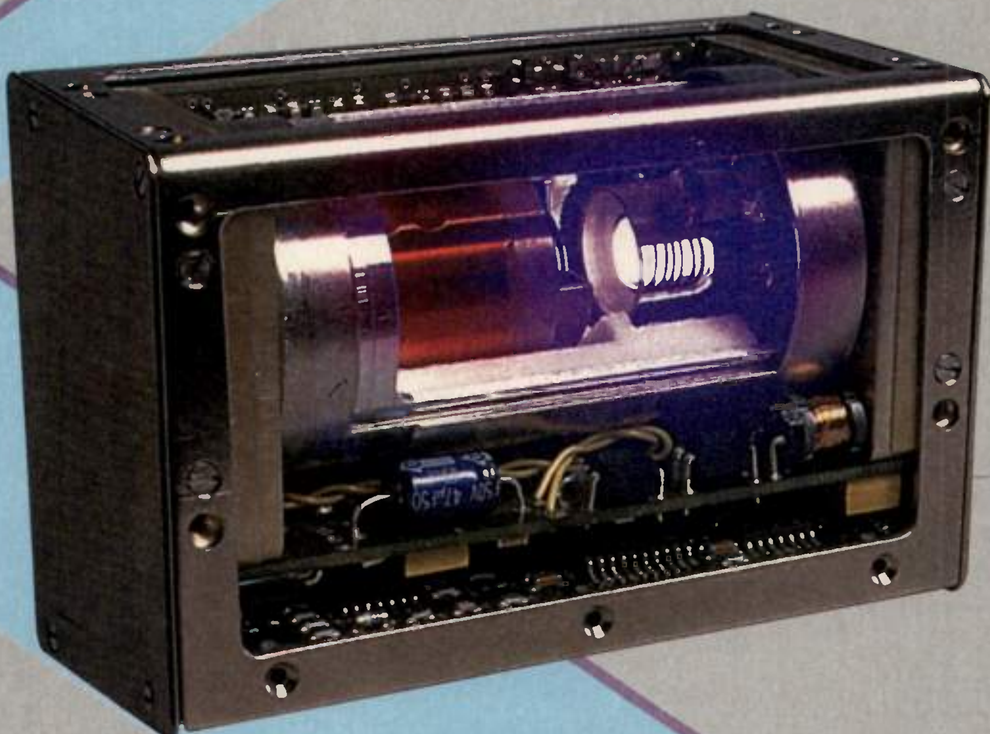

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INFO/CARD 22

tional techniques used for non-spread spectrum communications.

Typically, one of three techniques is used by a low cost wireless system.

The first technique is used in direct sequence spread spectrum systems and consists of the data stream which is exclusive-or'd with the much faster pseudo random spreading code. This results in a continuous transmission of the spreading modulation superimposed with 0/180 degree phase shifts corresponding to the data stream. This technique provides excellent security since no data information can be extracted without full knowledge of the spreading code. This also means however, that the receiver must include an analog or digital phase tracking loop.

The second technique can be used by direct sequence or by frequency hopping systems and consists of on/off keying (OOK) of the data on top of the pseudo-random spreading code. Typically, a zero data bit is represented by the absence of the RF carrier and a one data bit is represented by the presence of the RF carrier. Phase tracking is not necessary since the receiver needs only to detect a specific amplitude change from the previous bit to the current bit to determine if the current bit is a zero or a one. This offers the advantages of lower transmit current consumption (since for an average packet 50% of the data is a zero and consequently outputting no RF power), improved receiver sensitivity (phase tracking loops generally require a higher signal to noise in order to extract data), and the ability to operate well above the compression point of the receiver's RF front-end for more effective dynamic range (since the amplitude change imposed by the OOK greatly exceeds the amount by which the receiver is saturated). The largest disadvantage of OOK is that is lacks the security of BPSK modulated data. Since the data is on/off keyed, it is possible for a person to decode data output from the transmitter if they are located sufficiently close to the transmitter with the proper test equipment (e.g., a spectrum analyzer), and they are fully aware of the transmission packet protocol and timing. However, in order to duplicate that transmission in a manner as to fool the receiver, they still must determine the spreading sequence which is a non-trivial task.

The third technique is generally used by frequency hopping systems and involves frequency shift keying (FSK) where at each dwell frequency, the frequency will be further modulated at an offset to the expected frequency to indicate the value of the corresponding data bit.

What data rates should be used by

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5530 UNION CENTRE DRIVE • WEST CHESTER, OHIO 45069 • PHONE (513) 870-9060 • FAX (513) 870-9064 • http://www.polezero.com *the transmitter?* – The data rate must be determined as a function of several items including system throughput and latency requirements, system process gain, battery life, and potentially. FCC issues revolving around on-air message duration and its effects on restricted band emissions. Since higher data rates require a wider final IF filter bandwidth, it is inadvisable to specify a data rate higher than what is actually required. This increased bandwidth results in an increased noise floor which decreases the sensitivity of the radio.

The system designer should be aware that any increase in the data rate should be met with an equivalent (%) increase in chipping rate. If this does not occur, then the radio will exhibit decreased process gain and reduced jamming margin at higher data rates.

What is the estimated battery life for each transmitter? – The fundamental parameters which affect battery life are of course operating, sleep, and transmit mode currents. However, transmitter parameters such as operating temperature, supervisory transmission interval, active mode wake-up interval (during which time the transmitter may emerge from sleep mode to sample each of its sensors and perform some housekeeping chores before going back to sleep), how frequently an alarm burst occurs, how many messages are broadcast on each alarm burst, battery type, battery capacity, and the minimum operating voltage all play an important role in the expected battery life. Consequently, when a vendor quotes battery life estimates, care must be taken to find out exactly what operational and hardware parameters have been specified.

Since replacement of the battery is an expensive proposition in terms of time, battery cost, and customer nuisance level, transmitter battery life is especially critical when determining system costs. If a fresh battery is

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required too frequently, or if the user neglects to change the battery when required, the system is perceived poorly. Unfortunately, even when the system is down due to neglect on account of the user, the user generally considers the product to be unsatisfactory rather than consider their own negligence.

What type of battery should the transmitter use? – Battery type is contingent on six main parameters: Cost, physical packaging, temperature range, peak and average current requirements, voltage output, and battery capacity.

Due to their high volumetric capacity and low self discharge rates, lithium batteries have seen extensive use in wireless designs. The cost of these batteries can be quite attractive if the transmitter can be designed around a battery which is already in very high volume production and has multiple sources (such as a standard 2/3 A size camera battery).

When selecting a lithium battery, you must ensure that it is capable of supplying the needed currents over the full temperature range. Also, be sure to investigate both the bobbin wound construction (which operates at very low temperature due to decreased ESR) and the spiral wound construction (which is less expensive than the bobbin) batteries as they both have very different cost and temperature parameters.

With the advent of low voltage RF devices and microcontrollers, transmitter circuits can be designed to operate at 3.0 VDC, however these devices are still relatively expensive and thus unattractive for the high volume, low cost commercial markets.

Many vendors are producing designs which use two 3.0 or 3.6 VDC cells in series to provide the needed voltage to the circuit. The disadvantage of this method is two fold: a voltage regulator (at additional cost and current consumption) is required, and the sleep mode current is greatly increased (since the CMOS devices increase their current consumption non-linearly with respect to operating voltage).

To work around the limitations described above, an on-board DC to DC converter is extremely useful. The converter provides low sleep currents at 3 VDC as well as, typically, 4.5 VDC for normal circuit operation.

A decrease in sleep current may seem insignificant given the circuit's low current consumptions, but battery life calculations show the first operating at 6 VDC and with 20 μA of sleep current, would operate for approximately 4 years. The second circuit with the DC-DC converter and 4.5 μA of sleep current would operate for about ten years from the same type camera battery.

When should a low battery be detected? – It is important to detect and transmit a low battery message prior to complete discharge and the failure of the supervisory/status transmissions. To ensure that the user has adequate time to replace the battery before full battery failure, the low battery voltage trip point should be set such that a specified amount of minimum capacity (and consequently transmitter operational life) remains at time of the first low battery alarm. This level should be adjustable so that changes in battery selection can be supported by a change in the low battery indication.

Since the open circuit voltage of a lithium-manganese-dioxide cell drops very little as the storage capacity decreases, measurement of the battery terminal voltage should be conducted while the transmitter draws the highest current, which generally occurs during transmit mode.

Receiver Considerations

This section addresses key parameters regarding the requirements or characteristics of a low cost wireless system's receiver.

What parameters should the receiver output to the system controller? – At first it appears that only the demodu-

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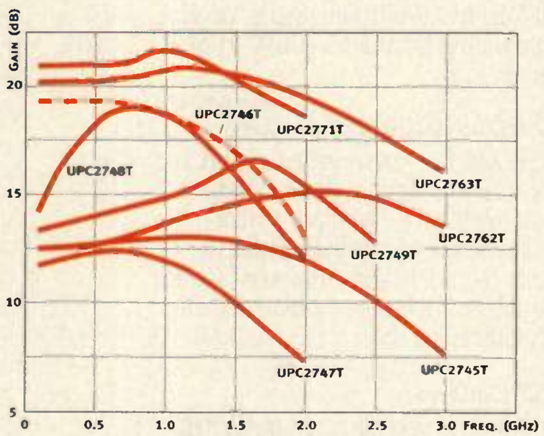

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UPC1678G	50MHz–1.9GHz	23	6	+15	49	500MHz
UPC1688G	50MHz–1.0GHz	21	4	0	19	500MHz
UPC2708T	50MHz–2.9GHz	15	6.5	+7.5	26	1.0GHz
UPC2709T	50MHz–2.3GHz	23	5	+7.5	25	1.0GHz
UPC2710T	50MHz–1.0GHz	33	3.5	+7.5	22	500MHz
UPC2711T	50MHz–2.9GHz	13	5	-3	12	1.0GHz
UPC2712T	50MHz–2.6GHz	20	4.5	-2.5	12	1.0GHz
UPC2713T	50MHz–1.2GHz	29	3.2	-4	12	500MHz

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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

lated data stream is required as output from the receiver. However, additional data can greatly simplify system installation, performance, and trouble-shooting.

Ideally, the receiver should provide the following information to the system controller for each received message:

1. Demodulated data stream
2. CRC check information
3. Signal level: Knowledge of the signal level allows you to plot trends to determine fast and slow signal fading and a general RF health status of each transmitter.
4. Noise level: The noise level allows you to easily determine if the system is being jammed (intentionally or unintentionally) without the need for expensive test equipment.
5. Key-off level: For on/off keyed systems, the key-off level provides an indication of the transmitter's RF health by displaying the signal level present during a zero bit interval. This level should normally be: the higher of the received signal level minus the on/off isolation provided by the transmitter circuitry, or the receiver noise level.
6. Signal to noise level: This value shows how much communications margin exists during that transmission.
7. Correlation level: This value shows the increase in signal strength after correlation relative to that signal strength before correlation; this is a rough indication of process gain.
8. Low battery indication: To ensure that the battery can be replaced prior to full discharge, it is important to advise the system controller each time any of the transmitters (or the receivers) experience a low voltage condition.

What is the significance of receiver sensitivity? – Receiver sensitivity is generally specified as the minimum signal level presented to the receiver which is necessary to give a specified Bit Error Rate. In more fundamental terms, it defines how low of a signal can be received and decoded with the specified level of success.

During system specification, the designer must determine what the vendor's quoted Bit Error Rate (or Packet Error rate) at the specified sensitivity level is, and if that bit error rate is inclusive or exclusive of system protocol inserted data.

Generally, as fate would have it, each manufacturer specifies receiver sensitivity levels at different Bit Error Rates (BER). When two manufacturer's reference two separate BER values, and a direct comparison between specifications is required, the appropriate BER vs. Eb/No curves (available in many digital communications texts) can be consulted to determine, with pretty good accuracy, what the performance of each radio will be at the other's BER value.

Why is a radio with superior sensitivity performing poorly in the real-world? – Receiver sensitivity is always measured within an environment providing maximum isolation to real-world signals which may form a jamming threat resulting in degraded receiver performance.

In a quiet RF environment, increased receiver sensitivity obviously results in longer range which means that fewer receivers are required to support the same number of transmitters. Unfortunately, the 902-928 MHz unlicensed spread spectrum band (as well as the other ISM bands) is located far from a quiet RF environment. Licensed services within and adjacent to this band (paging, cellular, SCADA, amateur radio, and Automatic Vehicle Location and Monitoring systems, to name a few) can easily raise the noise floor in the receiver far above that noise floor which is present during an ideal laboratory sensitivity measurement. In a mid-city area, ambient noise levels of -75 dBm into a 300 kHz bandwidth have been observed within the 902 to 928 MHz ISM band. This high noise level emphasizes the need for narrow channel bandwidths which are facilitated by the specifying the application's minimum data rate rather than taking the more is better approach.

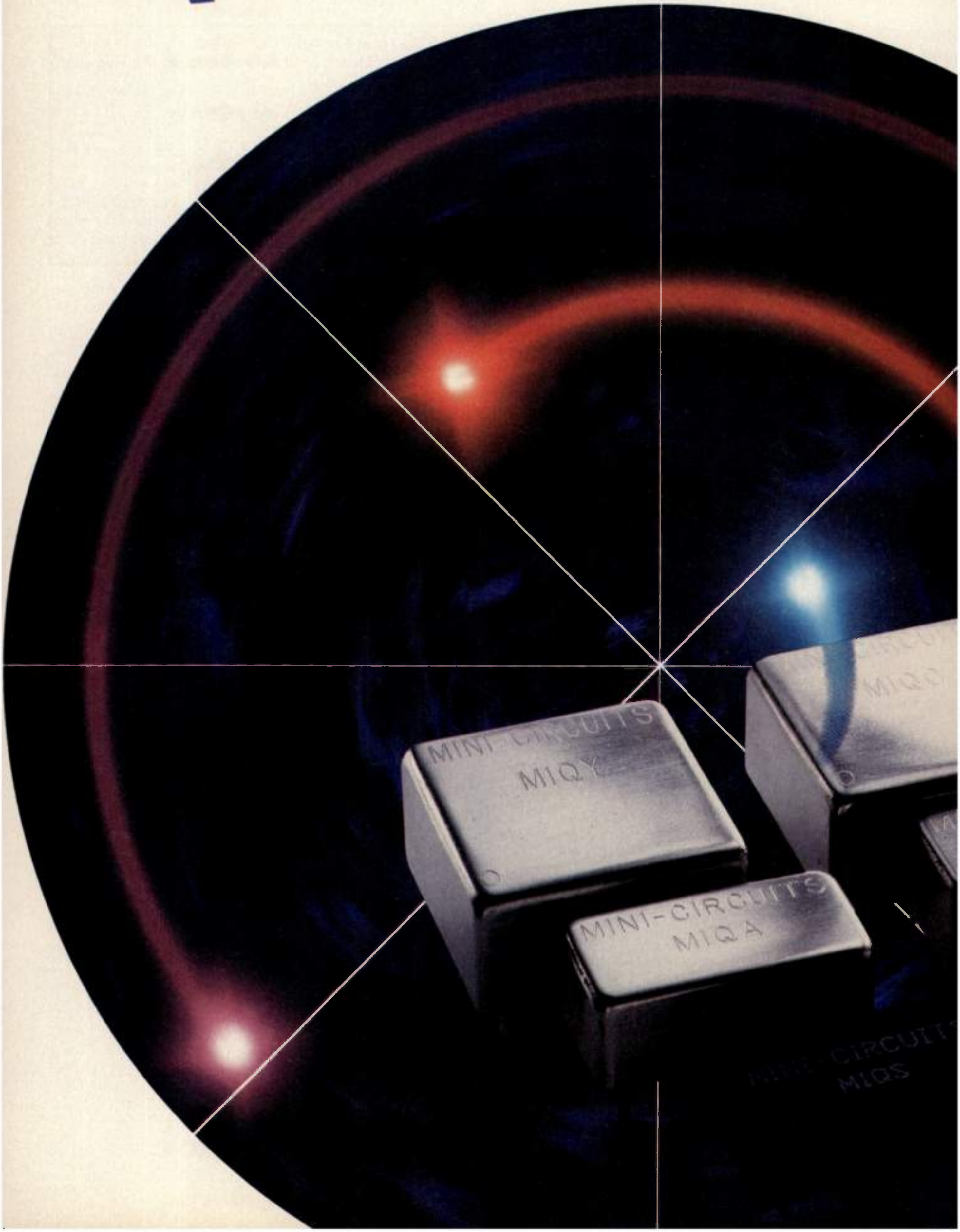
Calculation of Bit Error Rate from Packet Error Rate:

The Bit error and Packet error rates can then be related using the following formula:

$$\text{Packet Error Rate} = 1 - (1-\text{BER})^N$$

where N is the packet length in Bits. When N is relatively large, this can be approximated by PER=BER * N. Note that N the packet length consists of all the data contained in the message including system protocol (e.g. transmitter ID) or other coded information. If the user inserts 16 bytes of data into a stream consisting of 7 additional bytes of system protocol data the bit error rate should be calculated based on a packet of 8*(16+7) or 184 bits per packet.

I&Q MODULATORS



In the same mid-city area, adjacent cellular, paging and SCADA signals peaked at -30 dBm, further emphasizing the need for robust receiver front-end design since a poorly designed receiver front-end can also quickly become saturated and desensitized due to these adjacent, high power signals.

The receiver must include good engineering principles which limit intermodulation and the effects of adjacent channel interference on the noise level of the receiver. If these measures have not been taken, then copious amounts of sensitivity will yield no additional performance advantage.

Antenna Considerations

What polarization should the receiver and transmitter antennas have? – In a typical non-line-of-sight environment (such as indoors or outside below building top level), the polarization of the transmit signal is quickly lost because the signal undergoes multiple reflections before finally arriving at the receiver. Since additional signal paths can arrive at the receiver with different polarizations altogether, it is highly advisable to employ antenna polarization diversity techniques as previously described.

Should the transmitter/receiver use internal or external antennas? – The answer to this question lies with the answer to three further questions:

What will the added performance advantage of an external antenna be? With a good antenna design and with proper plastics selection for the receiver or transmitter housing, an internal antenna's radiation and efficiency characteristics meet and in some cases exceed those characteristics of available external antennas.

Will the installation allow the use of an external antenna? Generally, an external antenna is ugly and calls attention to the fact that a wireless system is installed.

What is the additional cost associated with this antenna vs. the cost of an internal wire or planar antenna? External antennas procured through an outside supplier and installed at time of system installation are generally more expensive than an wire or planar antenna fabricated and installed at time of unit manufacture.

Miscellaneous Considerations

What error detection and correction is provided by the system? – Like any communications system, it is important to identify messages which have been received but include one or more bit errors. Depending on the specific application, the system may decide to correct or discard those messages showing errors. Any system should minimally include error detection provisions and ideally include error correction capability.

What is the expected operational temperature and life span of the wireless system? – The designer must have a good grasp on the wireless device's environmental and lifetime operational requirements and must ensure or verify that the receiver has been designed to function even after temperature and aging induced frequency variation in the transmitter oscillator, the receiver's Local Oscillator(s), and the front-end and IF filter circuitry. Alternatively but at increased maintenance cost, frequency drift caused by aging (but not by temperature variation) may be ignored or minimized if periodic transmitter and receiver frequency re-tuning/maintenance is scheduled.

What is the intended RF environment foreseen for this wireless system and is a wired solution available as a contingency for specific environments which prove to be unsuitable for wireless systems? – For any system operation, it is critical at the time of installation to determine specific areas of RF coverage and shadowing. Due to differing construction layouts and techniques, RF waves propagate very differently within any building, from building to building, or from neighborhood to neighborhood. Consequently, it is highly advisable to conduct systems pretesting in environments similar to the typical and worst case installations to determine the required system performance issues such as receiver sensitivity, receiver selectivity, transmitter RF output power, and antenna placement. Line of sight testing should only be used as a benchmark for relative system performance since this testing has little applicability to the propagation of radio waves in the real world. A system which performs very well in a line of sight environment could suffer severely degraded performance in a real world environment if measures to reduce interference due to high powered adjacent channel signals and multipath are not incorporated into the design.

What is the probability of success for each transmit message? – Many wireless (and wired) networks function within the constraints of the ALOHA equation which allows you to determine the statistical probability of success of any one message being received based on: how many transmitters are within reception range, the length of each message, how frequently each transmitter broadcasts, and how many redundant messages are broadcast for each alarm occurrence.

The ALOHA calculation assumes the following: a constant noise level, that each transmission is broadcast based on a ±25% dithered value of a standard interval, and that if two signals overlap then both are lost. The modified ALOHA equation is listed below and was derived from equations listed in [4]:

$$P_s = 1 - [1 - e^{-LNT}]^M \qquad (3)$$

where:
P_s = Probability of Success
L = 1/transmission time interval (seconds)
N = number of transmitters - 1
T = time duration of transmission (seconds)
M = Redundancy; the number of times the same message is rebroadcast (# redundant messages).

Redundancy is calculated by dividing the minimum required supervisory interval (as determined by the regulatory agency e.g., UL) by the number of transmissions which are actually transmitted in that interval. For example: If your system requirements dictate that a supervisory message must be received at least every 30 minutes and the transmitter is programmed to broadcast every 5 minutes, the redundancy is 30/5=6.

$$P_C = 1 - P_S \qquad (4)$$

where P_C = Probability of Collision.

You will need to determine the values of these variables based upon the requirements of your application.

The probability of success can be improved by a receiver algorithm which does not discard both signals during an overlap (i.e. time simultaneous) condition.

How frequently should the system receive supervisory/status messages from each transmitter? – The supervisory or status message consisting of transmitter identification and sensor status is typically broadcast on a dithered standard time interval in order to let the system controller know that the transmitter is still functional. Supplemental information within the supervisory message may include battery status and a transmission sequence number. The sequence number provides an additional level of security by allowing the system to determine how many messages have been missed from one received transmission to the next.

Currently, FCC requirements limit 400 MHz narrow band FM transmitters to 60 minute supervisory intervals while Part 15.247 spread spectrum transmitters have no minimum limit. In a theft or security system, a supervisory interval of 60 minutes is clearly non-optimal since a clever thief could theoretically shield or jam the transmitter's alarm bursts from the receiver. Since these systems are generally programmed to phone the monitoring agency only after two or three missed supervisories (to program a system to phone after only one missed supervisory would result in a high number of false alarms since signal collisions or sporadic interference can easily lead to one lost message), the thief could have up to three hours to fill his bags.

How attractive is the installed wireless system? – Form versus functionality is often a consideration where exterior antennas or large housings maybe considered too unsightly for home or commercial installations. Low visibility, low cost solutions such as efficient, small internal antennas and compact transmitter circuitry are available from a number of wireless system designers.

Cost Drivers

In today's competitive market, the ultimate factor which dictates the market success or failure of a new product relative to similar products is the full system cost with respect to the features and performance offered by that system. The wireless system is no different than any other system, so cost can be divided into four primary topics: manufacturing, installation, maintenance, and product lifetime.

What design analysis has been performed to ensure that the manufacturing drop-out will remain within acceptable limits? – To provide an indication as to real-world circuit performance, Monte Carlo calculations should be performed to show the circuit's performance with respect to component and manufacturing process variations. Like every model, Monte Carlo calculations illustrate performance over the bounds of the input terms most component manufacturers specify three sigma value tolerances. Consequently, the validity of greater than three sigma Monte Carlo calculations must be understood. Also, as the required standard deviation value increases, beware that a larger number of permutations will be required to yield the needed resolution from the calculations as shown in Table 2; this increased number will of course require additional time and/or computing horsepower to calculate.

The complete Monte Carlo calculation of a circuit for a relatively simple low cost transmitter can take up to one minute for each required individual calculation. Reasonableness must be maintained when specifying the desired resolution of Monte Carlo calculations, since a five sigma estimate requiring 100,000 individual calculations would take over two months at one calculation per minute.

What provisions are incorporated in the design for component second sourcing? – The use of single source components can of course greatly increase the risk and cost associated with any volume production run.

How are the receiver and transmitters tested and tuned after manufacture? – Ideally, an RF device would go immediately from the manufacturing floor to the field; unfortunately, the unit must first be tuned. The following questions are applicable to the tuning process:

- How many tunes are required?
- Is the tuning process iterative?
- How often is periodic re-tuning

Standard Deviation (σ)	Cumulative Percentage	# of calculations required to reach desired resolution:
3	99.73	10,000
4	99.99	10,000
5	99.996	100,000
6	99.99604	10,000,000

Table 2: Number of Monte Carlo calculations needed for a given σ to ensure manufacturing drop-out rate will remain within acceptable limits.

required?
- What is that procedure?
- What is the system performance if this re-tuning is not performed?

For high performance systems and as a general rule, the system designer should be wary when told that no tunes are required; especially when the unit is designed to operate over an extended temperature range.

What is the installed system cost? – Many engineers are pursuing wireless solutions to traditionally hard wired applications because rules, regulations, and restrictions put in place by federal or local regulatory agencies require extraordinary and expensive measures for compliance when routing connecting cables and wires.

When considering wireless system installation costs, the engineer must evaluate receiver/transmitter performance with respect to the number of receivers which are needed to support each transmitter. Since these receivers generally interface to the central control panel through traditional hardwiring, a high transmitter to receiver ratio is preferred.

A building or other environment which is outfitted with a wireless system consisting of low power transmitters and poor sensitivity receivers will require a higher number of associated receivers. The cost of hardwiring each receiver plus the cost of periodic battery replacement could ultimately be greater than a traditional hard wired system.

Why do some wireless systems perform so much better (or worse) during performance trials than they do in the real system installation? – There are several issues which can affect installed vs. tested performance.

Holding a transmitter in your hand during testing could result in greatly improved (or degraded) antenna radiation characteristics due to coupling between the antenna and the human body. It is therefore necessary to place each transmitter on a representative surface or location when determining comparative system performance.

Comparative performance tests are useful for determining relative system performance. However, because of the issues relating to sensitivity and selectivity, better performance by one radio in one location does not necessarily mean that it will perform better in all locations. A radio may have a -110 dBm sensitivity specification but with a front-end that is very vulnerable and overloads quite easily in the presence of in-band or out-of-band jamming signals. When evaluating any system, it is important to focus on the entire system architecture and design rather than just one parameter such as sensitivity.

What if the transmitter message length is increased in the future? – According to part 15.249 and 15.35(c), the FCC allows an averaging factor (based on 20 log of the transmitter duty cycle within a 100 mSec period) for application to, and reduction of, spurious emissions above 1 GHz. Designs which use the averaging factor to comply to restricted band emissions may not later support increased message lengths since the amount of averaging factor is reduced. If additional future products are foreseen by the system designer, it is important to ensure that the same transmitter configuration will meet FCC requirements if later firmware modifications are performed to increase the message content and length.

Summary

For best system performance, the wireless systems designer must clearly define the system with respect to many parameters which set the stage for performance, cost, and reliability. A good grasp of technical issues including process gain, sensitivity, message content, and battery life is necessary to find the best solution for specific system architectures. ***RF***

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About the Author

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(continued from page 20)

related services. Target markets for E.F. Johnson Services include the emerging personal communications service (PCS) industry, as well as cellular telephone providers and specialized mobile radio (SMR) operators.

New Office in Hong Kong

Andrew Corporation, a global supplier of communications systems equipment and services, has opened a regional headquarters in Hong Kong to better serve its customers in the Asia-Pacific region. The Hong Kong facility will incorporate sales, marketing, sales support and financial functions for the Asia-Pacific region. Andrew supplies terrestrial microwave antennas, satellite earth station antennas, Heliax coaxial cable, waveguide, and Radiax radiating cable to wireless communications customers. These include cellular, personal communications systems, land mobile radio networks and broadcast and public telephone company operators.

Contracts

Contract for Roamfree Gateway Awarded—Synacom Technology, Inc. announced that it has signed a contract to supply RoamFree Gateway systems to Nokia Telecommunication, for commercial service in the fourth quarter 1996. The RoamFree Gateway is designed to enable seamless roaming between DCS/PCS-1900 (the North American version or the GSM standard) networks and IS-41 networks. PCS operators in North America can use this product to broaden their roaming coverage with a dual-mode PCS phone.

Wireless Subassemblies Order Awarded—Watkins-Johnson Company announced it has received an order exceeding $11 million for converter subassemblies to be used in personal communication systems (PCS), being built by Lucent Technologies. Lucent Technologies is the new systems and technolgy company formed by AT&T as part of AT&T's restructuring.

ARPA Contract for MCM Design Software—The Advanced Research Projects Agency (APRA) was awarded a one-year, $1.2 million follow-on contract to Tanner Research, Inc., for the development of software technology which will enable affordable commercial software tools for the design and simulation of multi-chip modules (MCMs). The award, funded by ARPA's Application Specific Electronic Module (ASEM) initiative, calls for Tanner Research to develop advanced algorithms to enable performance-based and other custom routing, transient thermal analysis and MCM-L technology support. Under company funding, Tanner Research will produce the resulting technology by enhancing their existing commercial software suite—Tanner Tools MCM Pro—to attain power, integration and ease of use. *RF*

An Inexpensive Receiver Preselector

By Eric Kushnick
LTX Corporation

For many years I have had a desire to design my own HF receiver. The main goals of my receiver design project are reasonably high performance at low cost. One method of improving performance in the significant areas of intermodulation distortion and overload capability is to use a good preselector ahead of any active stages in the receiver. This paper describes the design of an inexpensive preselector designed to be placed between an antenna matching transformer and an RF amplifier.

Specifications

The preselector was designed to work in a 450 to 500 Ω environment, to be placed between a 1:3 turns ratio broadband transfer (50 Ω : 450 Ω) and an RF amplifier whose optimum source resistance for best noise figure is approximately 500 Ω. The preselector response was chosen to be that of a single tuned circuit with a Q of 5 to 10 at switch selected frequencies covering the range from 1.5 to 30 MHz. This response allows the frequency range to be covered with a reasonable number of switched inductors and capacitors, while still providing 18 to 20 dB of attenuation to signals near one half the selected frequency. (Signals near one half the desired frequency have the potential to cause 2nd order intermodulation products that fall within the bandwidth of the desired signal.) It was initially assumed that all the switches would be relays to avoid the generation of distortion products within the switches of the preselector itself. It was further assumed that with reasonably high Q inductors and capacitors, and relays as switches, that the insertion loss of the preselector would be no more than a couple of dB.

Design History

Figure 1 shows what was the initial design of the preselector. Four inductors with some initial parallel capacitance set the high end of four frequency ranges. Binary weighted capacitors are switched in parallel with the initial parallel resonant tank circuit to lower its resonant frequency in appropriately sized steps. The largest capacitors are not used on the higher frequency ranges, and the smallest capacitors need not be used on the lowest frequency ranges. All switches were inexpensive (about $1) reed relays with a DC resistance of less than 150 mΩ.

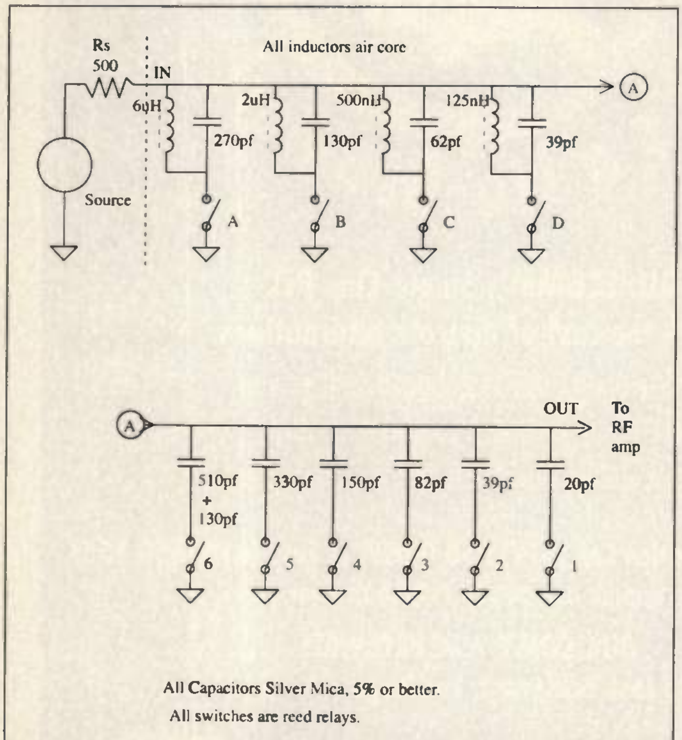

Figure 1. Initial preselector design using reed relays as switches. This design had unacceptable insertion loss above about 10 MHz.

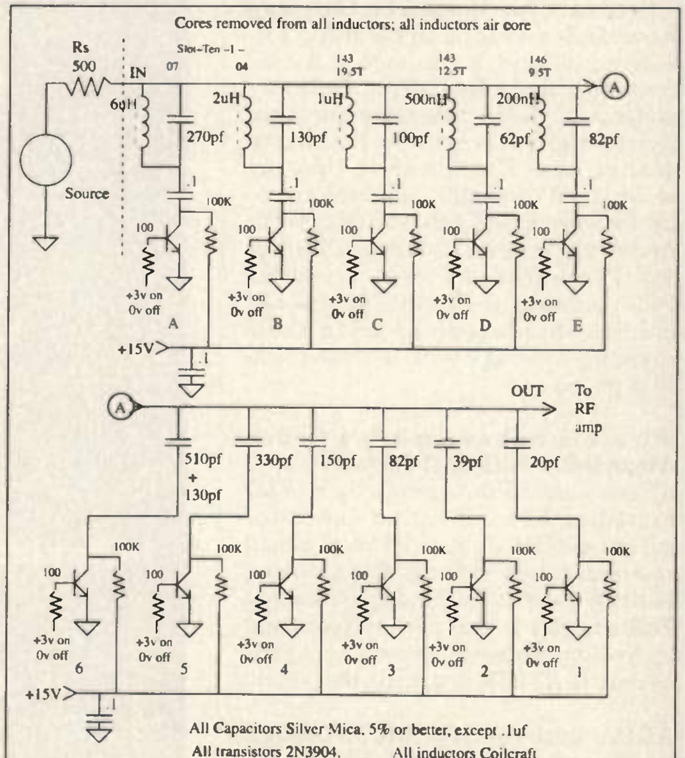

Figure 2. Final preselector design using 2N3904s for switching.

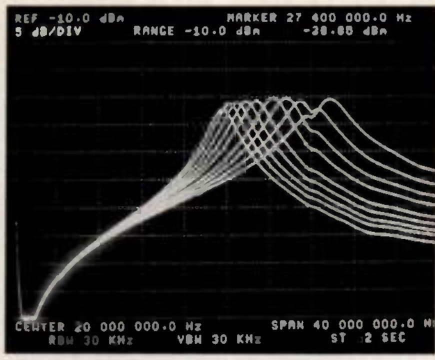

Figure 3. Preselector response on range E, 20 to 30 MHz. For this figure and figures 4 through 7 vertical resolution is 5 dB/division, horizontal range is DC to 40 MHz, and Input signal is –15 dBm.

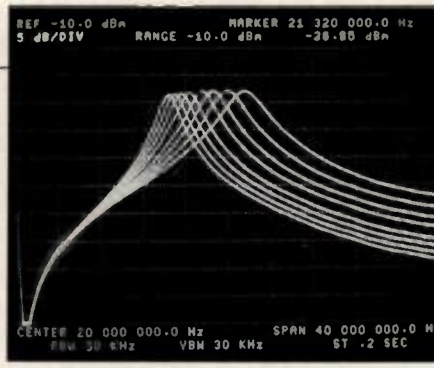

Figure 4. Preselector response on range D, 14 to 22 MHz.

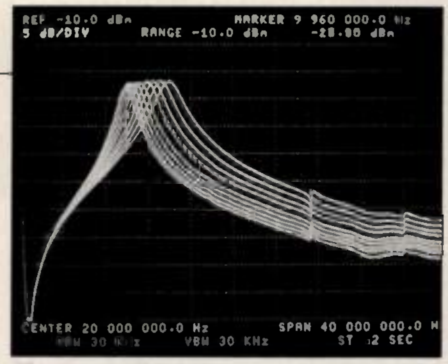

Figure 5. Preselector response on range C, 10 to 14 MHz.

Resonant frequency and Q of the circuit were calculated assuming lossless components, using the equations:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$X_L = 2\pi f_r L \tag{2}$$

$$Q = \frac{R_{source}}{X_L} \tag{3}$$

where L is the circuit inductance; C is the total capacitance in the circuit; f_r is the resonant frequency of the tank circuit; X_L is the inductive reactance of the inductor, L, at the resonant frequency; and R_{source} is the source resistance, in this case 500 Ω. It was expected that the insertion loss of the preselector would be no more than a couple of dB due to the losses in the inductors and in the switches.

Measurements with a spectrum analyzer showed the actual insertion loss of the preselector to be as much as 10 to 15 dB at the higher frequencies, which was totally unacceptable. The unloaded Q (Q_u) of each of the inductors was measured and each was above 40 at the frequencies of interest.

$$Q_u = \frac{X_L}{R_{series}} \tag{4}$$

where R_{series} is the equivalent series resistance of the inductor at the frequency of interest. With some manipulation of equations (3) and (4) and if $Q_u > 10$, the insertion loss can be shown to be:

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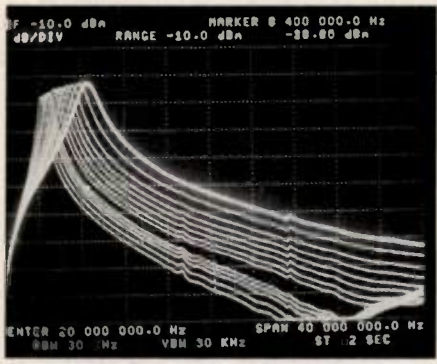


Figure 6. Preselector response on range B, 4 to 9.5 MHz.

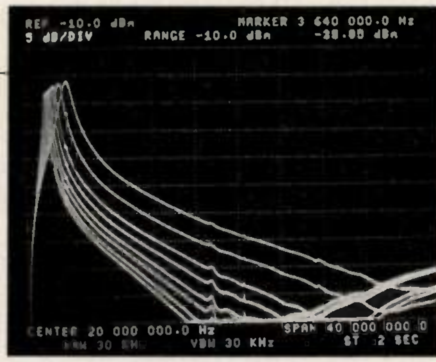


Figure 7. Preselector response on range A, 1.5 to 4.0 MHz.

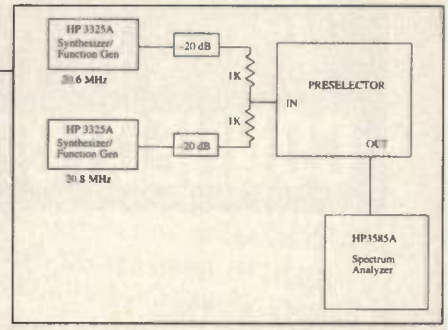


Figure 10. Test setup for measuring third-order input intercept point.

$$IL = -20 \log \frac{Q_u}{Q + Q_u} \qquad (5)$$

where IL is the insertion loss of the circuit in dB assuming the inductor losses are the dominant losses. To check if the inductor losses are dominant we can calculate the equivalent series resistance of the inductors and compare this value to other stray resistances in series with the circulating current of the tank circuit.

$$R_{series} = \frac{R_s}{Q \cdot Q_u} \qquad (6)$$

If $Q = 10$ and $Q_u = 40$ then $R_{series} = 1.25\ \Omega$ and we would expect the inductor losses to dominate. Then the insertion loss should be:

$$-20 \log \frac{40}{10 + 40} = 1.9 \text{ dB} \qquad (7)$$

Additional measurements showed the reed relays to be responsible for the large insertion losses. Table 1 shows the resistance and reactance measured through the closed contacts of a reed relay on an HP 4275A multi frequency LCR meter. For comparison, the resistance and reactance of a piece of #24 AWG wire the same length as the relay are also shown at 1 and 10 MHz.

A new switch was needed, preferably one that was inexpensive and did not introduce its own distortion products into the preselector output. There are relays that are very good at RF switching and do not have the problems exhibited by the reed relays, but they are not inexpensive, and many of them have very limited lifetimes (measured in number of operations) compared to the reed relays. More measurements with the multi-frequency LCR meter led to the idea of using the 2N3904 transistor as an RF switch. It is certainly inexpensive, and has a very long lifetime.

Figure 2 shows the schematic diagram of the final version of the preselector. Because the on resistance of the transistor is not as low as the on resistance of a good relay, the transistor cannot switch as large a capacitor in parallel with the tank circuit as a good relay could before the losses become excessive. Therefore the inductance values were rearranged and an additional range was added to allow the full 1.5 to 30 MHz frequency range to be covered. Also, because the stray capacitance of the transistors is much larger than that of a good relay, a significant portion of the tank circuit circulating current at high frequencies flows through the stray capacitance. Because these stray capacitances are lossy (transistor collector-base capacitances), insertion loss of the preselector at high frequencies is increased. The 100k resistors from the transistor collectors to +15 V bias the off transistors to reduce the stray capacitance, and to reduce the intermodulation products that are produced by signal voltage appearing across the collector-base capacitance which is a nonlinear function of collector-base voltage.

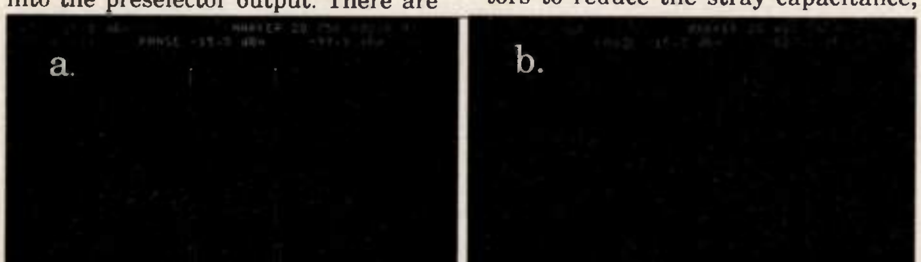


Figure 8a, 8b. a. Two-tone 3rd order IMD test. b. close-up of third-order product. Vertical resolution is 10 dB/div, center frequency is 20.7 MHz, span is 1 MHz. Measurement performed using a 20 dB attenuator probe.

Measured Results

Figures 3 through 7 show the measured response of multiple binary weighted steps on each of the ranges. In all cases the input signal was at the –15 dBm line on the spectrum analyzer, so insertion loss varies from –1 dB on certain of the lower frequency ranges to approximately 5 to 6 dB on the highest frequency range. As can be seen, the preselector does cover the 1.5 to 30 MHz range.

Figure 8 shows how clean a two tone test signal looks during a third order intermodulation product test. This measurement was taken through a 20 dB attenuation probe. The actual level of the two input tones at the measurement point is –0.4 dBm. Figure 9 shows a very narrow sweep used to see the third order product which is hidden in the noise in figure 8. The actual level of the 3rd order product is –87 dBm. The third order input intercept point at 20.7 MHz is +45 dBm. (43 dBm output intercept plus 2 dB insertion loss.) With signals at 10.0 MHz and 10.7 MHz, and the preselector tuned to 20.7 MHz, the second order intercept point was measured to be +82 dBm.

The total parts cost for the preselector can easily be under $3.00, depending on quantities. *RF*

About the Author

Eric Kushnick is a Staff Scientist at LTX Corporation. In 1976, he received his BS and MS degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology. He is currently enrolled in a Ph.D. EE program at Northeastern University. Eric can be reached at LTX Corp., University Ave., Westwood, MA 02090

Anritsu Wiltron's Site Master Drops Cell Site Maintenance Costs

By Ken Harvey
Anritsu Wiltron

PCS and Cellular installations are accelerating through record breaking pace in '96. As the new bandwidth comes on-line, inevitable pressure on air-time prices will challenge profit margins. As more cell sites are installed, cellular service operators must either a) shrink expense-per-base station or b) plan for lower earnings.

Rather than submit to the latter, service engineering managers must drastically reduce per cell expenses. It's not just a matter of doing more with less. It requires a different approach to the standard radio maintenance processes – a process that hasn't changed much in almost 30 years.

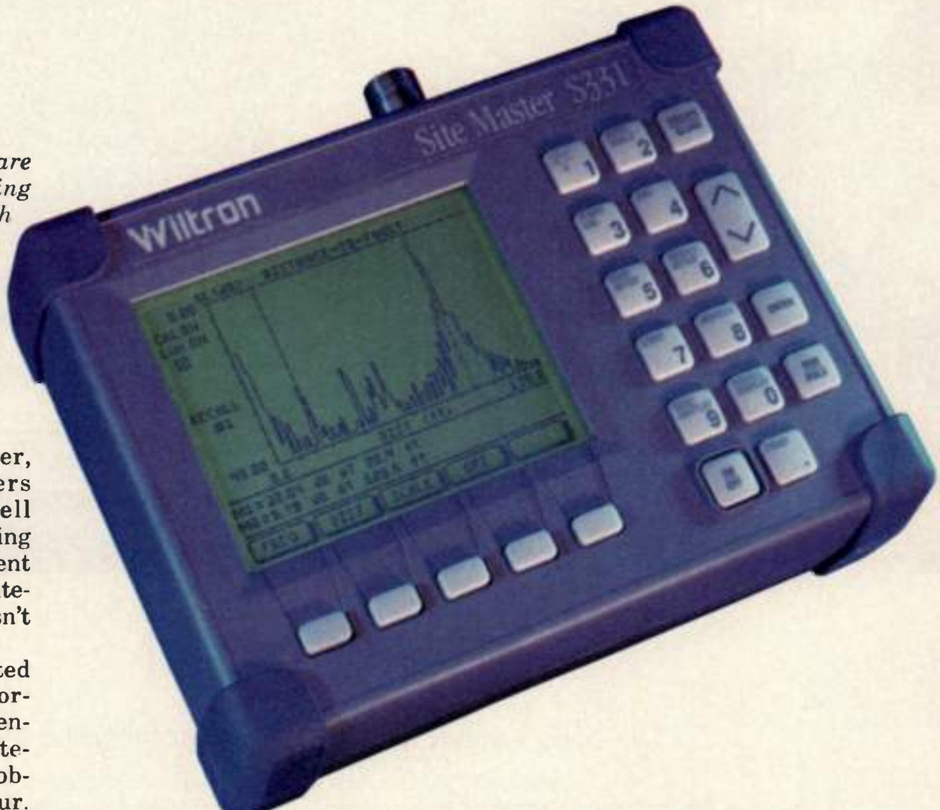
Historically, repairs are conducted on a fix-after-failure basis; performance problems are allowed to degenerate into failures. The new maintenance paradigm seeks out the problems before expensive failures occur. Thus, the failure prevention concept simultaneously reduces service costs and improves quality.

Much has been accomplished already through more reliable radio transceiver equipment. This article focuses on applying Site Master's Frequency Domain Reflectometry, FDR, to the antenna system. Sixty to eighty percent of the problems at a typical cell site are caused by the antenna system. As future antenna systems add more transmission line components, these ratios will increase unless prevention techniques are utilized.

Antenna Failure Prevention

The concept of cost savings through preventative maintenance isn't new; however, its application to routine antenna service is. How can transmission line problems be detected before they degenerate into failures?

Two basic changes are required. First, standard maintenance checks are performed regularly. Second, a change in test technology is required.



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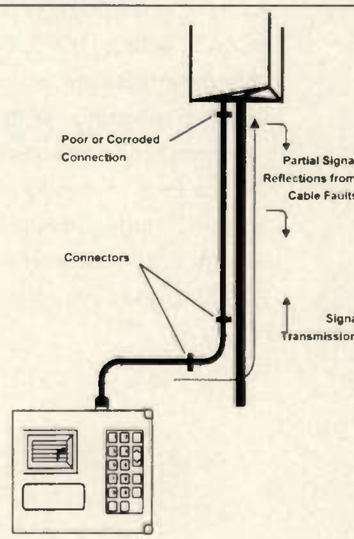

Figure 1: Common antenna system problems.

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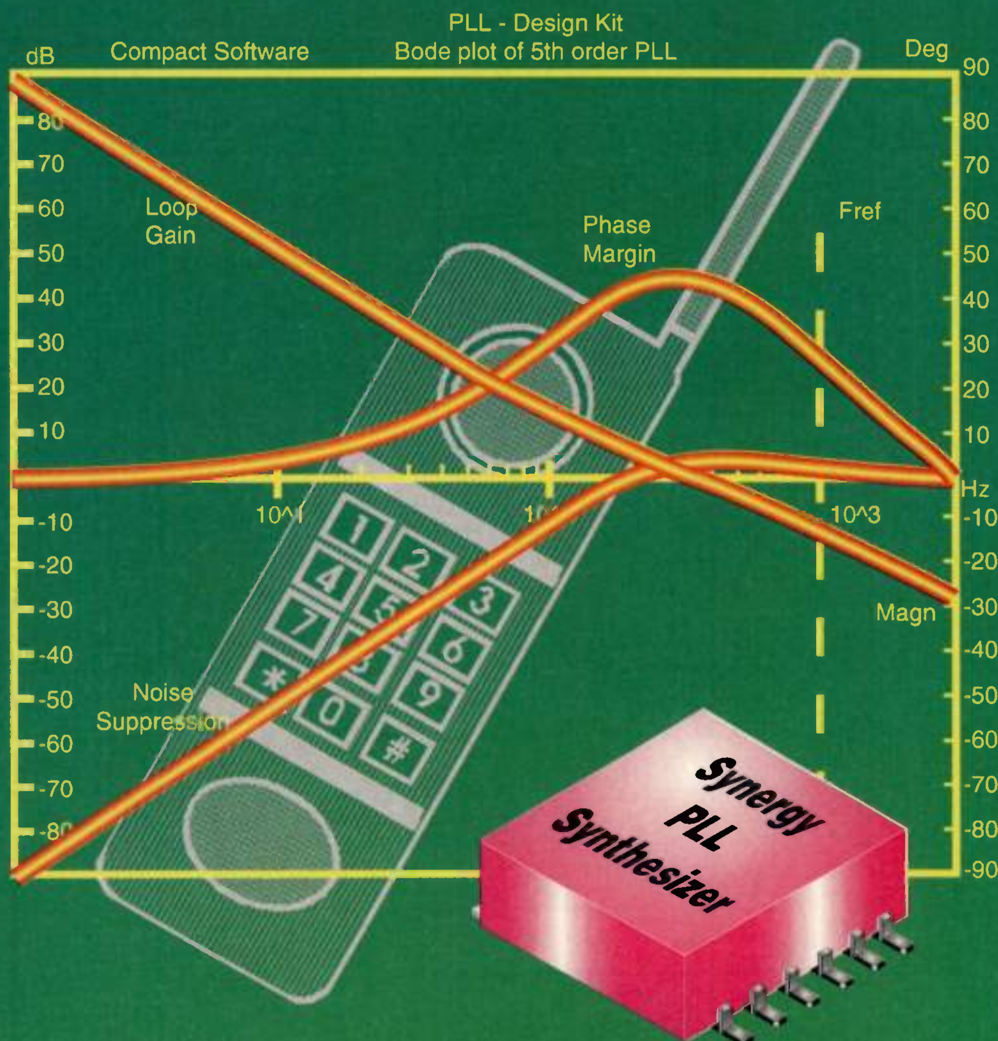

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The test equipment must diagnose problems clearly. Meaning, the accuracy and sensitivity must be adequate to identify small RF problems. Operational ease is an additional concern. Experienced RF technicians are in short supply today. If the equipment requires use of RF black magic techniques, learned after years of experience, neither cost savings nor quality improvements will be realized from investment in new test gear. The diagnosis must be actionable!

Smallish concerns, perhaps. But, this type of self-critical thinking initiated the technology behind Site Master's unusual capabilities.

Design Requirements

Site Master's unique combination of features allows preventative maintenance. The application of microwave technology developed for military use to the RF maintenance problem yielded a few obvious characteristics. For example, Site Master's frequency range covers a wide 5 MHz to 3300 MHz and allows a single Site Master model to test multiple antenna system types from television antennas to two-way radio and PCS systems. A Distance-To-Fault, DTF, analysis mode pinpoints problem locations.

The rationale behind Site Master's other characteristics are less obvious, a fact which helps explain why no other test instrument solves antenna test problems similarly. It also explains the historical absence of preventive maintenance applications for commercial antenna systems.

Re-thinking RF test equipment design requirements presented important challenges. First, measurement accuracy is paramount to achieving repeatable and verifiable results. Second, there must be a method of compensating for insertion loss through the antenna's cabling because the cable's loss will mask return loss problems of any component mounted up the tower. Third, high levels of RF interference must not degrade the quality of the measurement.

Fourth, sensitivity must be high enough to detect small dimensional changes within the antenna cabling. Fifth, some antennas and other tower mounted equipment can be either inconvenient or dangerous to remove; thus battery power and a small chassis are required.

Sixth, ruggedized construction must survive routine drop shock and miles of

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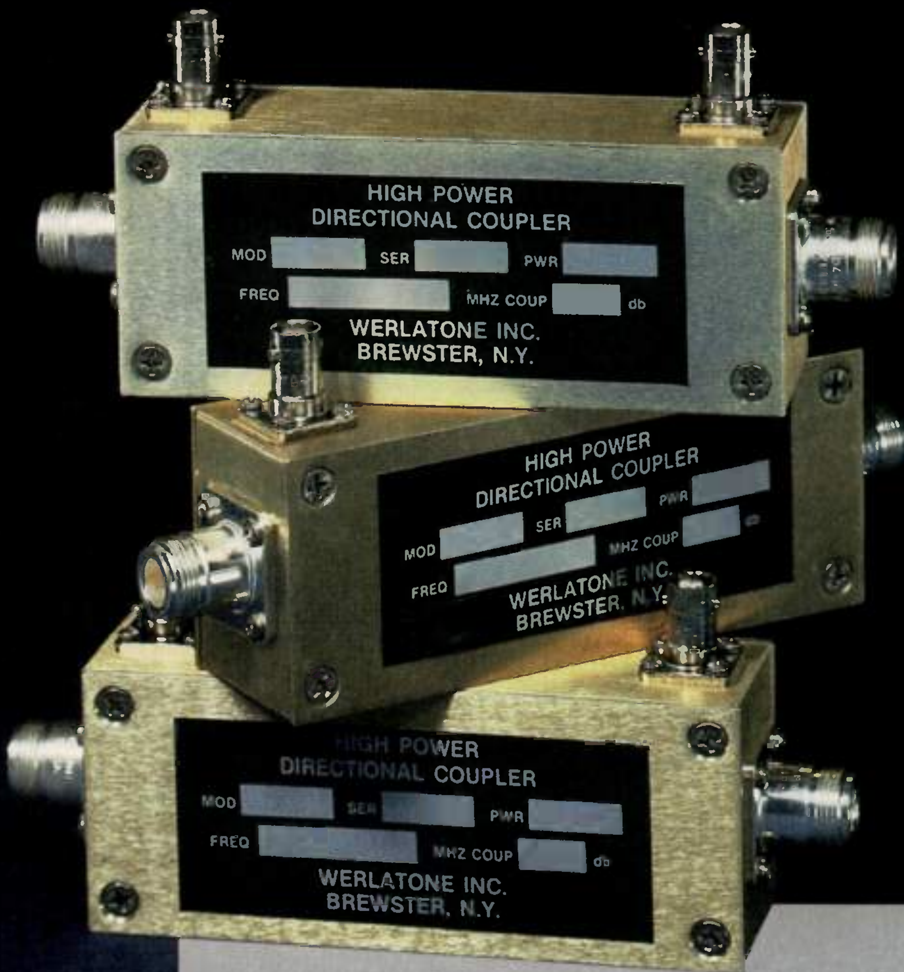

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Figure 2: Photo of technicians printing plot from Site Master. Technicians compare data to historical performance. Current SWR and DTF plots are stored or printed.

dirt roads in the back of a pickup truck. Seventh, the front panel controls must be focused on the specific task of antenna system test so that minimal training is required for site technicians.

Eighth, cost must be at least an order of magnitude lower than military style test gear. Ninth, a Windows based software program for down loading measurements must provide an on-line database for comparison to previous test data. And, when a PC isn't available, the operator must be able to print the test results. Finally, precision calibration components, ruggedized for field use, must provide the same accuracy and NIST traceability as a laboratory grade vector network analyzer.

Accuracy

How accurate are existing test methods? How will adapters and test port extension cables effect accuracy? Does measurement accuracy drive the quality plan or does instrumentation accuracy serve instead. Briefly, measurement accuracy includes such factors as test setup components, ambient temperature, and RF interference in addition to instrumentation accuracy. Even in this era of quality emphasis and ISO-9000 style principles, many test managers simply locate a suitably small looking number from a manufacturers data sheet as indicative of test quality. Rarely, however, does field work match the host of fine print requirements stated in data sheets. Further, instrumentation accuracy figures frequently refer to statistics such as distance or frequency stability that are not direct indicators of antenna system test quality. Namely, the ability to detect performance changes over time is not specified.

Site conditions can make the task difficult. Comparisons to historical data must show if a connector has degraded from a 30 dB return loss (SWR = 1.07) to a 25 dB return loss (SWR = 1.12). A change of just a few dB in the antenna's return loss may indicate moisture and corrosion which will cause resonance and hence intermodulation distortion problems. Or, after a storm, the antenna may be out of position by a few degrees – thus changing the site's propagation pattern.

To solve these problems Site Master's measurement channel receiver is configured similarly to a vector network analyzer. On site and just prior to test execution, the operator performs three steps for calibration, each requiring connection of a different impedance standard. The standards are an open circuit, a short circuit and a precision load. The calibration requires about 60 seconds, and when completed, provides NIST traceable accuracy at the position where the standards were connected. Since a vector receiver is utilized, any in-line components such as adapters or extension cables are automatically compensated. Vector error correction removes the SWR response of these test setup items from the final data. Since the calibration is performed at ambient temperature, measurements results, performed at differing dates, at differing temperatures, are directly comparable. Thus, measurement data is directly comparable to the historical database. If a measurement shows a discrepancy to the site commissioning data, the cause can be investigated and repaired.

Cable Loss Compensation

Antenna cables have insertion loss. Without a compensation technique, problems up the tower can be impossible to diagnose. A spectrum analyzer with tracking generator can measure return loss, but it is difficult if not impossible to carry up the tower for measurement of components like antennas, jumpers, and duplexers.

Site Master's return loss display has the same problem. However, in Distance-To-Fault mode, Site Master uses Frequency Domain Reflectometry, FDR, to compensate for the cable's insertion loss. The display shows component return loss versus distance similarly to a time domain reflectome-

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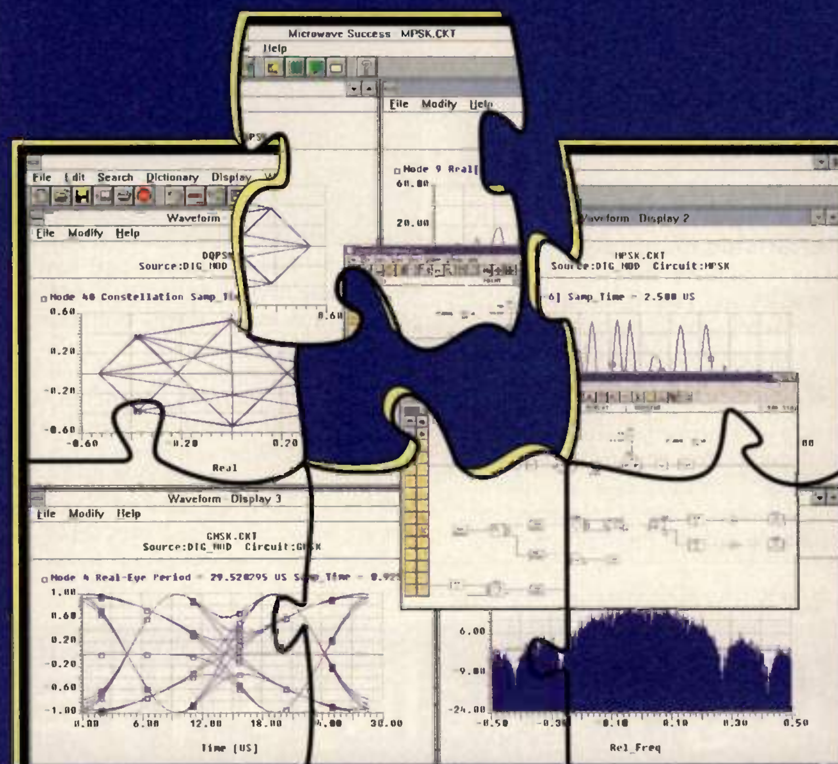

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- Spectrum Analysis
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ter, TDR. A basic difference between TDR and FDR technology is the test stimulus signal. FDR uses an RF frequency sweep instead of a DC pulse. Since the FDR method uses only the RF signal frequencies, test data can be compensated according to the cable's RF loss characteristics. This allows easy identification of problems up the tower, such as moisture collection or antennas damaged by lightning. The antenna's return loss performance is displayed accurately, even when the test is conducted at ground level.

RF Interference Immunity

Hot site tests have always concerned test technicians; previous test techniques required climbing the tower to retrieve the antenna and/or to attach a termination to the end of the feed cable. Today, service technicians are frequently prohibited from climbing the antenna tower due to insurance restrictions. Further, system operations dictate that a site's transmitters remain active during daylight. A competitor with a co-located site—an increasingly common situation, that helps, not hurts cellular signal quality—may not allow the down-time.

Figure 3: Two adjacent cell towers; co-location of competing cellular providers is increasingly common.

Existing test gear doesn't solve the problem. TDRs, for example, are useless at a hot site. Spectrum analyzers with tracking generators are marginal. And, at sites with higher ambient RF conditions, such as paging or television antennas, even the big, lab grade vector network analyzers are overloaded. A TDR can find an open or short circuit failure, but a preventive maintenance philosophy requires rejection of the interference and an accurate indication of RF performance.

Site Master measures RF performance under conditions unsuitable to traditional test technologies. The synthesized sweep source and novel phase tracking receiver technology reject ambient RF interference coming into the antenna. Spread spectrum technology helps to see through the interference. Site Master has the highest RF interference rejection of any RF instrument available, commercial or military. Immunity performance is enhanced in the 5 to 1200 MHz models. Thus, the cell site can continue operating, allowing day time testing. No one needs to climb the tower during maintenance checks.

Sensitivity

Frequency Domain Reflectometry (FDR) technology is used to identify very small changes in RF impedance versus distance. FDR sweeps the cable and antennas over the same RF frequencies as that used for normal operation. By measuring RF characteristics directly, FDR provides a clear performance indication.

FDR principles involve the vector addition of the source's output signal with reflected signals from faults and other reflective characteristics within the tested transmission line. The vector addition of the signals creates a ripple pattern versus frequency. The number of ripples is directly proportional to the distance of the reflective point on the transmission line. The measured signal is an interference pattern, the pattern of ripples in the return loss measurement. FDR software detects the relative magnitude variations versus frequency: the signal is well away from the effects of noise. Thus, the high sensitivity easily locates conditions such as corroded connection terminals, partially mated (untightened) connectors, dented cables, moisture, and damaged lightning arrestors.

The accuracy of the FDR distance indication matches the precision of the frequency synthesizer and the known value of the antenna cable's electrical propagation velocity. FDR techniques inherently detect electrical length and are accurate by virtue of the physics of RF propagation. By contrast, TDR based instruments are careful to cite distance accuracy limitations: the need to synchronize the TDR's internal DC pulse generator and the A/D sampler are inherently limited by the quality of the time base that time the relative arrivals of the DC pulse reflections.

Further, the TDR's DC pulses provide adequate sensitivity for DC conditions such as open and short circuits; however, sensitivity to RF frequency reflection is relatively poor. For example, the TDR's A/D sampler and time

Figure 4: Site Master with detector. The optional RF detector outputs signal power data in Watts or dBm.

base won't display the small return loss changes of a corroded connector. An antenna looks like an open circuit, whether the antenna is operating properly or damaged by lightning. For the purpose of preventive maintenance, the sensitivity of FDR technology is equal in importance to accuracy because it allows the accurate comparison of historical test data.

Up the Tower

Who wants to climb a 300 foot tower, remove a 50 pound panel antenna and, between wind gusts, lower it to the ground so a senior technician can test it with a network analyzer. And, since the site is now down, be careful up there because it's dark at night! Did the antenna fail because water froze inside? If so, remember to wear something warm.

And it may not be that simple. Large antennas such as those used for television and FM broadcasting can't be removed without a helicopter

Site Master's small size and battery power can save time and hazard pay. When someone must climb the tower, Site Master is small enough to be carried and it can be operated with one hand. An optional RF detector is available for use as a power meter for verification of antenna signal power.

Rugged Construction

Site Master's 2.2 pound weight is easily transported, and its ruggedized construction survives the trip. Simply put, people drop things, instruments included. If the instrument can't handle a drop to a concrete floor or a long bumpy ride in back of a pickup truck, it won't be useful at site.

To meet this challenge, Site Master is designed on a single PC board using as much surface mount technology as possible. The swept frequency synthesizer and phase tracking vector receiver are adjacent. The high frequency RF bridge is also implemented on the same circuit board. The circuitry, display mounting, and internal battery are securely mounted to the high impact plastic casework. Corner bumpers further improve shock survival. A protective soft carry case, included as standard, protects against more extreme drop hazards and provides a handy, waist-length strap for one-hand operation up the tower.

Operator Training

When investigating system problems, test technicians need to focus their mental energy on the antenna system, not on the operating procedures of the test gear.

Large, general purpose laboratory instruments are designed to cover many applications. Test equipment manufacturers, particularly the largest firms, have a profit motive to apply general purpose products to as many specific applications as possible. Frequently, field service managers are forced to purchase large, bench style analyzers, but only 10 percent of the instrument's functionality is actually used in the field. This one size fits all practice also makes the human inter-

Figure 5: Four coaxial components. Precision N and 7/16 connector components enhance accuracy.

face more complicated than necessary.

Site Master's front panel is easily deciphered because it's devoted to antenna systems test. Extra front panel keys and complicated engineering jargon are avoided. Not only does Site Master speak the technician's language, but it is also so much easier to use that it has improved the language of some technicians. Additional benefits to a less complicated front panel include smaller size and drastically lower cost.

Low Cost

Make no mistake: performing tests, maintaining equipment, and training technicians is very expensive. Not performing tests can be much more expensive. While defective equipment can be replaced, one can't replace customers who send their dollars elsewhere because of poor call quality. Compared to these concerns, the purchase price of any test gear is a small fraction of overall test expense.

Historically, TDR techniques have been popular for testing electrical cables. FDR based techniques have been available, but until now TDR instruments were about an order of magnitude lower cost than the available FDR products.

Today, however, all of the FDR analyzers in the Site Master line are priced lower than TDRs typically used by RF technicians. Most Site Master models also cost less than a spectrum analyzer's tracking generator option. For some, income from the excess equipment sale can pay for Site Master's purchase expense.

Software Tools

Preventative maintenance plans use return loss and FDR based Distance-To-Fault (DTF) measurements to create a performance history for each the cable/antenna. Baseline transmission line characteristics are measured during site installation and stored to a PC database. During subsequent maintenance efforts, performance is compared to the original baseline data.

That's the purpose of Site Master Software Tools, a copy of which accompanies each Site Master. The Software Tools contain built-in DTF software. The DTF display is calculated from Site Master's vector (magnitude and phase data is required) return loss data.

The DTF mode, like return loss measurements, is based upon signal reflection principles. No transmission line component is a perfect impedance match; each reflects some of the RF signal energy. Each cable/antenna tends to have a unique DTF Signature because differing cable electrical lengths, cable types, dielectric thickness variations, and the position of components such as connectors, adapters, and lightning arrestors will cause different reflections at differing positions in the transmission line.

Reflections from the transmission line's various components are vector signals which will add and subtract vectorially depending upon their relative phases. The relative phases are dependent upon 1) the individual characteristics of each device and 2) their relative physical position in the transmission line. When measuring at the end of a transmission line, addition and subtraction of the various reflections create an nearly random pattern of passband ripples on the return loss display. The net effect is that each transmission line has a signature or fingerprint.

Variations in the signature between maintenance intervals offers a good indication of damage or damage causing conditions. A large change indicates a problem. Small changes may indicate aging, ultra-violet exposure, or dimensional changes due to seasonal temperature conditions.

Precision Calibration Components

An instrument's measurements are only as good as the calibration that traces the data to accepted standards. For accurate data, Site Master, like any vector network analyzer, relies upon precision calibration components. These components support a typical 45 dB measurement directivity up to 3.3 GHz at a cost drastically lower than comparable network analyzer calibration kits.

Site Master's calibration components are designed for rough field handling. Drop shock from bench height is typically survivable to rated specification with the lone exception that the connector mating surfaces not be deformed. There are limits however; if a component is ever dropped from the top of a cell tower, plan on sending it back to the calibration lab.

Proof of Concept

Field trails have reiterated the benefits of preventive maintenance. The savings are surprising. Today, cables and antennas account for approximately 60 to 80 percent of base station problems. Service technicians have drastically reduced the material and service labor costs by fixing problems before they result in permanent damage. Extending the life of a typical transmission line by a multiple of 2 to 3 cuts replacement expenses by 67 to 50 percent. Contractors, who are hired to climb the tower and install the equipment, are used more efficiently. Their time can be scheduled and prioritized, avoiding costly overtime and emergency repair service. Further, the contractors are no longer needed for exploratory, please find the problem, work orders. For the first time, the typical site technician can identify problem's, prioritize the required response, and request necessary service.

RF performance also benefits. Equipment failure can be prevented. Down time is reduced. Transmitter performance is optimized. The cell site's coverage is more consistent, which reduces customer dissatisfaction.

PCS firms have been the first to adopt FDR based preventative maintenance procedures. Due to higher operating frequencies, extensive use of digital modulation standards, and, most importantly, the much higher number of required base stations, PCS firms are forced to implement new, cost saving maintenance procedures.

Cellular and two-way radio service firms have been slower to adopt the newer methods, a reasonable case considering that it is more difficult to change older, existing test procedures than to simply start from scratch with new methods. Existing service groups are also organized and budgeted around a certain historical level of maintenance, typically based upon percent of revenue. Buying the new equip-

Fix-After-Failure versus Failure Prevention – Practical Examples From the Field

Cell Site Commissioning

A service provider in Latin America reported a continuing problem with a recently installed base station. The manufacturer, contracted for both the equipment and the installation service, sent RF engineers to ensure that the system passed the manufacturers' standard TDR and SWR tests. The system passed, but problems persisted.

The TDR test didn't find the problem because the antenna always appears as a large reflection, an open circuit, on the TDR's display. The tracking generator and spectrum analyzer didn't find the problem because the cable's insertion loss masked the poor antenna return loss. The service provider continued reporting difficulty with intermodulation distortion and signal quality. Swapping radios and passive combiners didn't fix it.

Site Master's vector network analyzer based technology quickly pin pointed unusual return loss characteristics in four of the receive antennas. Investigation revealed water ingress. In an effort to modify the coverage pattern, the antennas had been tilted too far forward: the moisture weep-holes at the antenna's base could not expel the water.

What's the moral in this story? Focusing on the intermod "failure" wasted time, expense, and cell coverage quality. A preventive maintenance plan for the antennas easily would have found the problem early.

Cellular Service

Defective weather seals, all installed in the same, improper fashion, allowed moisture to corrode seven 250 foot cables. For over a year RF interference masked the problem from standard TDR and spectrum analyzer tests. The problem went undetected as several months of propagation analysis and installation of more sensitive receivers yielded marginal results.

Eventually, one of the worst feeds crossed the SWR spec of 1.5 dB and an outside contractor inspected one of the defective cables. Subsequent inspection of the other cables showed defects in seven of twelve. The contractor expense amounted three days at $1,500 per trouble call, and $51 per installed foot of new low loss cable.

The total repair cost of almost $100k sounds large, but it's only part of the total costs that went into engineering studies for propagation and the cost of lost customers. This ,horror story, is surprisingly common place. Site Master DTF mode finds these problems before the severe damage results.

PCS Installation

Since PCS operates at almost 2 GHz, Site Master is simply the easiest and least expensive way to measure the antenna's bandwidth. The FDR capability is an added benefit that promises to drastically reduce per cell maintenance expense below that of cellular service competitors.

Public Service Two-Way Radio

Few organizations rely on the performance of radio equipment so heavily, but so sorely lack knowledge of proper RF equipment maintenance. Lower operating frequencies and use of analog signals allow damaged transmission lines to operate on a marginal basis for a long period, only to fail at critical moments, particularly during storms.

An antenna, filled with water, can have bandwidth drift of 40 MHz or more. If the antenna or cables freeze during an unexpectedly cold night, communication quality to dispatch operators will be poor at best, and non-existent at worst. A damaged lightning arrestor will not protect radio dispatch equipment during a lightning strike. The operator would end up working from a vehicle radio - drastically reducing coverage and signal quality.

Less troubling concerns such as pinched cables and loose connectors simply reduce radio propagation coverage area. In strong winds, loose assemblies will vibrate against the antenna mast inducing static and further damage until the cable or connectors break. Each of these conditions are easily detected with FDR technology.

Television and Radio

A 600 foot antenna transmitting 50 kW should be maintained with the utmost care, particularly when the station doesn't have an adequate back-up antenna. Most stations don't, antennas are expensive. For a commercial broadcaster that means expense, something to be cut. But then, perhaps cut is an ugly word.

Ugly because it actually happened. The main power divider feeding an array of four transmit antenna elements was built with a defect. Four small pins that were supposed to hold the center conductor weren't installed. Over an eight month period arcing left conductive deposits on the surface of the center conductor until one day it failed, reflecting 50 kW straight back down the feed. It obliterated the impedance transformer and damage contaminated 400 feet of 6 inch transmission line before the amplifier shut down.

When the emergency repair consultants arrived at site, traditional sweep tests using network analyzers couldn't measure the antenna due to ambient interference. The analyzer was sending 10 dBm into the line and measuring 15 dBm coming back. At the request of a friend, Anritsu Wiltron shipped a Site Master for priority overnight delivery. Tests, performed with Site Master showed that the antennas were okay. The test technician, performing the tests at night, 700 feet up the tower, was particularly grateful for the small size and weight.

Site Master also helped find the bad power divider located 400 feet up the tower. After seven days of heroic efforts of the repair crew and an antenna parts manufacturer, the television station was back on the air. The problem wasn't visible to standard test procedures, but could have been diagnosed easily with Site Master's combination of high interference immunity and high, FDR based fault location sensitivity.

ment, selling off the old gear, and introducing new test/maintenance criteria are not perceived as priorities by maintenance supervisors who are already struggling to keep pace with network growth. Changing that infrastructure overnight is simply unrealistic. For many, the changes will only occur when revenue shortages and shrinking budgets leave no alternative.

Conclusion

Site Master identifies the health of installed transmission lines, even in the presence of external RF interference. As a trouble shooting tool, FDR techniques pinpoint problems and impending failure conditions. Service professionals are able to implement preventative maintenance plans and reduce per-cell service expense.

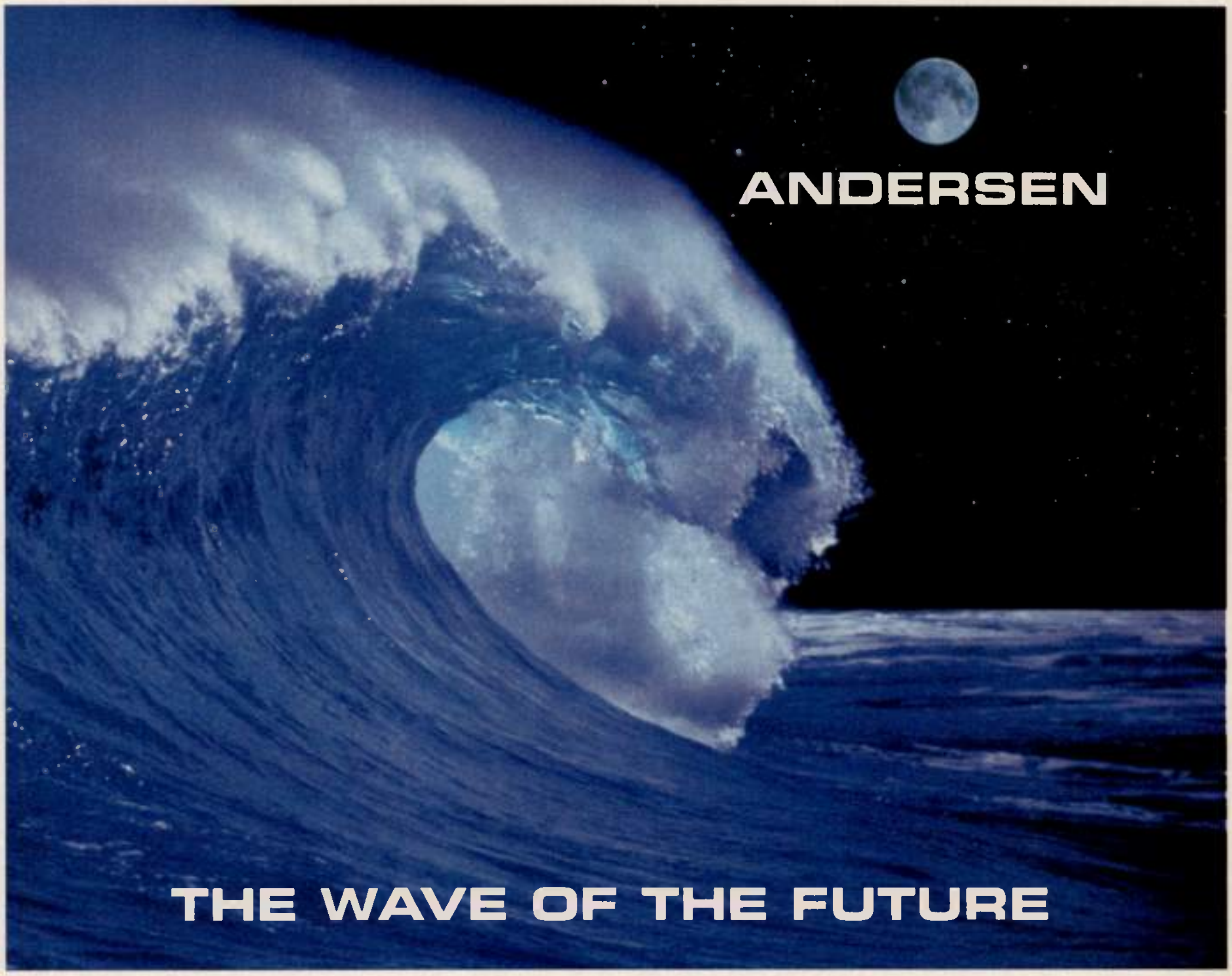
DTF and return loss are key indicators of an antenna system's performance. When these two characteristics are stable over time, other key characteristics such as insertion loss and third order intermodulation also tend to remain stable. Thus, maintenance tests can be limited to the DTF and return loss tests, a subset of the complete site commissioning RF tests. The on-line database provided by the Site Master Software Tools maintains both the site history and the data analysis in one convenient place. Since the software is Windows based, graphs and other data can be copied and pasted into report documents.

Site Master models start at $4,900 and are available for immediate delivery. Contact your local representative or call (408) 778-2000for more information. Technical questions or comments can be directed to the Technical Hotline at (210) 227-8999. ***RF***

You can also get more information about the Site Master series by circling INFO/CARD #250.

About the Author

Ken Harvey is a Product Marketing Manager and Development Program Manager for broadband and poratble RF/Microwave instruments at Anritsu Wiltron's Microwave Measurements Division. He received an M.B.A. from Santa Clara University and his BSEE from the University of Akron. Ken's professional interests are focused upon enhancing the productivity and performance quality of RF test processes.



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INFO/CARD 65

SAW-Based Frequency Control Products for Modern Telecommunication Systems

By: C.S. Lam, D.S. Stevens, and D.J. Lane
Vectron Technologies

It is confident to assert that we will enjoy more services using different wireless technologies as we enter the next century. These wireless services will continue to rely on the wired lines (high speed optical transmission) which serve as the backbone to carry and distribute the information. We will see explosive growth of both wired and wireless equipment worldwide.

In this article, we present several US made SAW-based frequency control products which find applications in modern telecommunication systems like Synchronous Optical Network (SONET), Synchronous Digital Hierarchy (SDH), and Asynchronous Transfer Mode (ATM). These products include timing recovery SAW filters, SAW-based timing recovery units, and SAW-based voltage-controlled oscillators (VCSOs). They play the important role of frequency synthesis, frequency translation, data and clock recovery, and clock signal distribution to ensure low bit error rate transport of signals in high frequency optical telecommunication equipment up to 2.5 GHz.

SAW-Based Timing Recovery Unit

The SAW-based timing recovery unit (TRU600) regenerates data and clock signals from corrupted NRZ digital data streams, such as those encountered in fiberoptic data link and telecommunication applications. Although there are many suppliers providing discrete SAW filters for timing recovery applications, the TRU600 allows an easy drop-in solution for customers. There are also many suppliers of PLL-based modules and transceiver chip sets with built-in clock & data recovery functions. SAW-based timing recovery scheme offers the best jitter performance in many situations. One example is in an ATM/SONET/SDH network interface card application situation as shown in Figure 1.

The TRU600 features a high-speed bipolar ASIC and a SAW filter in a hermetically sealed, 28-lead ceramic surface-mount package ($18.5 \times 10.5 \times 3.4$ mm^3). To extract a clock signal from the input data, the data is first passed through a prefilter and frequency doubler stage. This generates pulses containing significant spectral energy at the input data rate. A precision narrow-band SAW filter, centered at the clock frequency, substantially suppresses jitter by rejecting other frequencies. The extracted clock is then accurately aligned with the incoming data signal at the input of a decision circuit which then retimes the data (Figure 2). In addition to producing outputs with very low jitter, the TRU600 has excellent stability, fast acquisition time, and robust operation. It is available with standard SONET/SDH/ATM frequencies at 155.52, 311.04, and 622.08 MHz. Additional frequencies (124.416, 125, 139.264, 200, 265.625, and 278.528 MHz) for FDDI, ESCON, Fiber Channel, ISDN (CEPT 4), and other applications are also available.

A summary of the specification is shown in table 1.

To prepare for the increasing capacity demand in the tele/data communication market, a similar device which works up to the STS-48/STM-16 rate (2488.32 MHz) is desirable. Such a SAW-based clock and data recovery module is preferred in the emerging high speed optical communication receiver applications.

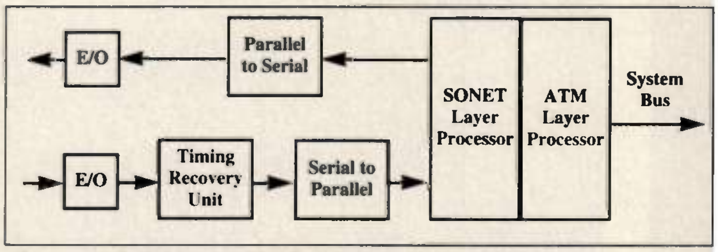

Figure 1. SONET/ATM Network Interface Card.

Nominal Output Frequency	100 to 700 MHz
Supply Voltage	5 V
Acquisition Time	< 2μs
Output Clock Random Jitter	10 ps rms
Power Consumption	325 mW
Operating Temp. Range	–40 to 85 °C

Table 1. Specifications for the SAW-based timing recovery unit.

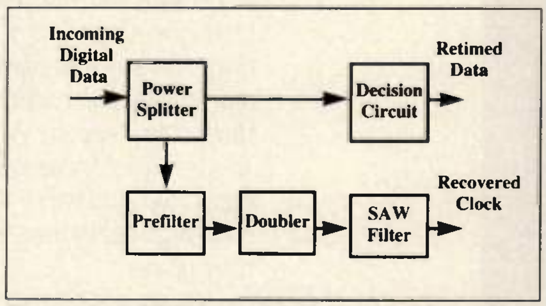

Figure 2. A SAW-based timing recovery unit.

Discrete SAW Filters for Timing Recovery

For customers who prefer to build their own timing recovery path on their SONET/SDH/ATM boards, we offer discrete SAW filters to perform the clock extraction function. They are available at 155.52 (18-type), 622.08 (17-type), and 2488.32 (19-type) MHz. A summary of the specification is shown in table 2.

The 155.52 MHz SAW filter is available in a standard 14-pin, metal dual-in-line package (20.3x12.7x7.4 mm3).

	(18-type)	(17-type)	(19-type)
Frequency (MHz)	155.52	622.08	2488.32
Insertion Loss (dB)	17	15.5	19.5
3-dB Q	420	800	750
Phase Slope (°/KHz)	–0.72	–0.33	–0.07

Table 2. Specifications for the discrete SAW filter for timing recovery.

Center Frequency	100 to 700 MHz
Absolute Pull Range	±50 ppm
Supply Voltage	-5 V
Control Voltage	-0.5 to -4.5 V
Linearity	±3%
Spurious Output Suppression	-60 dB
Operating Temp. Range	-40 to 85°C

Table 3. Specifications for the SAW-based voltage controlled oscillator.

The 622.08 MHz SAW filter is available in a low-profile, 22-pin, metal surface-mount package (15.9x13.6x3.2 mm3). The 2488.32 MHz SAW filter is available in a compact, surface-mount microwave package (11.4x10.7x2.1 mm3).

The SAW-Based Voltage-Controlled Oscillator

The SAW-based voltage-controlled oscillator (VC0600) is a highly integrated device which uses an ASIC with an on-chip phase shifter for frequency pulling and a SAW delay line with a typical 3-dB Q of 400. The VCO600 has an ECL output and is available with standard SONET/SDH/ATM frequencies at 155.52, 311.04, and 622.08 MHz. Additional frequencies at 278.528 and 368.64 MHz are also available.

Picture 1. VTI's VCO 600A.

The VCO600 is housed in a hermetically sealed, 28-lead ceramic surface-mount package (18.5x10.5x3.4 mm3, similar to the TRU600 package). Typical applications are data retiming and synchronization as part of a PLL, as well as frequency synthesis and frequency translation .

The VCO600A also has a unique output disable and clock through feature which improves board-level testing. A summary of the specification is shown in table 3. *RF*

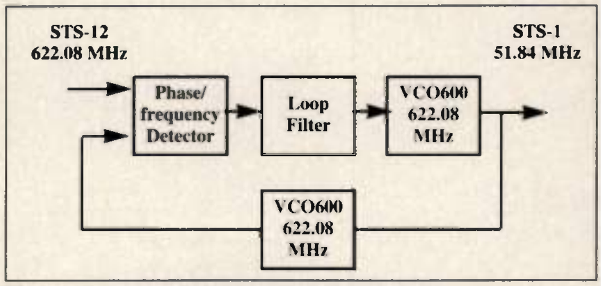

Figure 3. The SAW-based voltage-controlled oscillator.

For more information

Contact Vectron Technologies at 267 Lowell Road, Hudson, N.H. 03051, or call them at (603) 598-0070.

The Pull-Out Range and Noise Bandwidth of Third Order PLL

By Fu-Nian Ku

My previous article on PLLs [RF Design, April 1996] makes calculating the pull-out range and noise bandwidth possible. The pull-out range is a limitation regarding the transient processing speed of a PLL. If the frequency (or frequency changing rate) of a reference source is within this range, the transient process will quickly reach steady state. Otherwise, the process will be delayed and possibly never reach steady state. Thus, the pull-out range is an important factor when designing a PLL.

However, the pull-out range is dependent on the behavior of the phase detector (PD). In general, there are two kinds of PDs, analog and digital. An analog PD has its output proportional to sin (θ), where θ is the phase difference of two input waves. A digital PD has its output proportional to θ, when $|\theta| \leq 180°$. When $\theta > 180°$, sin (θ) changes its sign and reverses its feedback voltage. Using a digital PD, at $\theta > 180°$, the output voltage may not change signs, but it cannot keep the increasing trend and slow the tracking process. For example, MCH12140 is a typical digital phase detector. In this paper, we will assume $\theta = 180°$. Nowadays, most PLLs use a digital PD. However, at a frequency above several hundred MHz, the digital circuit can not offer the same self-assurance as the analog PD, so the analog PD remains.

Because most users employ a fixed frequency reference source, we will only deal with a pull-out range which uses an instantly connecting constant frequency source. This is equivalent to Case (2) of the preceeding paper [1].

The noise bandwidth of a PLL is defined as the integral:

$$\frac{1}{2\pi}\int_0^{\infty}\left(\left|H(j\omega)\right|\right)^2 d\omega \quad (1)$$

where $H(j\omega)$ is the closed loop transfer function (equations (1a) and (15) in the preceeding paper [1]).

If the applied noise to the loop is white, the noise power is calculated simply by multiplying the noise power spectral density and the noise bandwidth.

Analog PD

The tracking process is described by a non-linear differential equation. When the phase difference θ is small, $\sin(\theta) \cong 0$, it becomes linear and its solution is approximated by the digital PD solution. However, when θ is closer to 180°, its behavior becomes very critical. This means if the input frequency is large, maximum phase difference θ is near 180°, a small increase in input frequency can push the PLL out of lock. Be advised never to use a frequency near the pull-out range as only 90 percent of the range may be reliable.

Solution of the non-linear differential equation cannot be expressed explicitly. All the data is therefore obtained numerically by computer simulation.

Although the preceeding paper [1] is oriented to a digital PD, many basic concepts can be used with the analog PD.

Type 2, Third Order – The non-linear equation which governs PLL is:

$$\frac{d^3}{dt^3}\theta(t)+\frac{1}{T_3}\frac{d^2}{dt^2}\theta(t)+\frac{KT_2}{T_1T_3}\cos(\theta(t))\frac{d}{dt}\theta(t)+ \quad (2)$$

$$\frac{K}{T_1T_3}\sin(\theta(t))=\frac{1}{T_3}\frac{d^2}{dt^2}\theta_i(t)+\frac{d^3}{dt^3}\theta_i(t)$$

where θ_i, the initial phase difference, is assumed to be zero. When the input is a fixed frequency source, the right side of the above equation equals zero.

We use the same restriction on T_1, T_2 and T_3 as in the preceeding paper [1] and define:

$$T_3' = \frac{T_3}{T_s},\ T_2' = \frac{T_2}{T_s},\ \text{then } k = \frac{KT_s}{T_1} \quad (3)$$

resulting in:

$$\beta(\phi) = \left(\frac{\cos(\phi)}{1-\sin(\phi)}\right)^2 \quad (4)$$

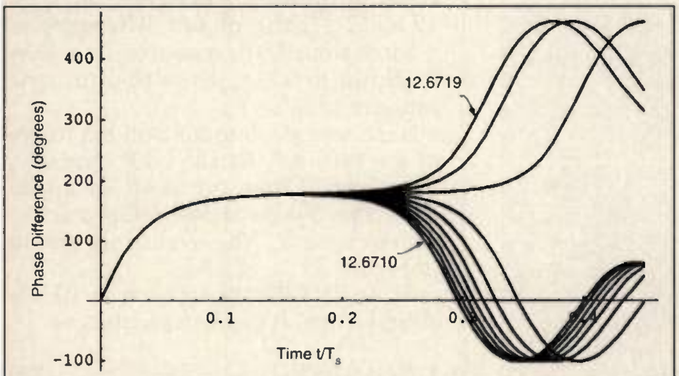

Figure 1. θ_e from equation 8 calculated for ten different values of f_0T_s.

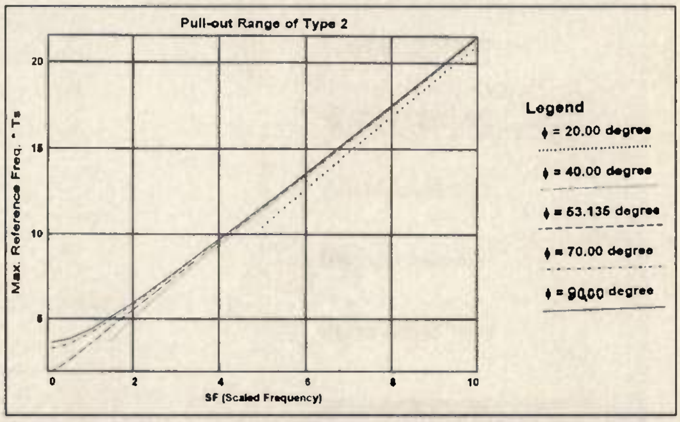

Figure 2. Pull-out range of Type 2 analog phase detector.

$$\alpha'(SF,\phi)=\frac{\pi}{2}\left[\left[\left(1+SF^2\right)\left(\beta(\phi)-1\right)-4\right]+\sqrt{\left[\left(1+SF^2\right)\left(1-\beta(\phi)\right)+4\right]^2-16\left(1+SF^2\right)}\right] \quad (5)$$

$$T_3'(SF,\phi)=\frac{1}{\alpha'(SF,\phi)+4\pi} \quad (6)$$

$$T_2'(SF,\phi)=T_3'(SF,\phi)\beta(\phi) \quad (7)$$

$$k(SF,\phi)= T_3'(SF,\phi)\alpha'(SF,\phi)4\pi^2\left(1+SF^2\right) \quad (8)$$

The non-linear equation is then converted to the following equation by using the above substitutions:

$$\frac{d^3}{d\tau^3}\theta_e(\tau)+\frac{1}{T_3'(SF,\phi)}\frac{d^2}{d\tau^2}\theta_e(\tau)+\frac{K(SF,\phi)}{T_3'(SF,\phi)}T_2'(SF,\phi)\cos\left(\theta_e(\tau)\right)\frac{d}{d\tau}\theta_e(\tau)+\frac{K(SF,\phi)}{T_3'(SF,\phi)}\sin\left(\theta_e(\tau)\right)=0 \quad (9)$$

where SF and ϕ are the two parameters and τ is time t in unit of T_s.

Solve the above equation for different SF and ϕ. The 10 curves of θ_e in Fig. 1 is calculated at ϕ=20° and SF = 6.0, where the input frequency f_0T_s = 12.6710,12.6711, ...12.6709 respectively. When $f_0T_s \le 12.6716$, θ_e curves have maximum value 180° and converge to zero. The other three θ_e curves, $f_0T_s \ge$ 12,6717, have maximums bigger than 180° (it should be 3 × 180°) and may converge tremendously later.

From Figure 1, we can conclude that for an input reference frequency $f_0 < 12.6716/T_s$, the phase difference θ_e is not larger than 180° during the entire tracking process. However, for $f_0 > 12.6717/T_s$, the phase difference is greater than 180°, resulting in a slow tracking process. Thus the pull-out range is $12.6716/T_s$.

Next, we calculate the pull-out range at ϕ = 20°, 40°, 53.135°, 70°, and 90°. SF is varied from 0.1 to 10 on the X-axis. The Y-axis is the reference frequency time T_s. The results are shown in Figure 2.

At ϕ=53.135°, the curve is like a straight line. It can be described as:

$$1.7 + 1.95(SF) \quad (10)$$

For a better approximation, the same curve can be described as:

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SPDT	DC-2.5	.5	39	Terminated internally	SW-338

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4 Bit Digital	DC- 2.0	2,4,8,16	1.6		AT-220
3 Bit Digital	DC- 2.0	4,8,16	1.6		AT-230

*Typical parameters at 1GHz.

VOLTAGE VARIABLE ATTENUATORS

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VVA	.5 - 2.0	0 - 35	3.2	Best linearity, single positive control	AT-108
VVA	DC- 2.0	0 - 35	7.2	18 dBm IP3	AT-635
VVA	DC- 2.0	0 - 15	3.2	Economical; small size (50T-14B)	AT-259

*Typical parameters at 1GHz.

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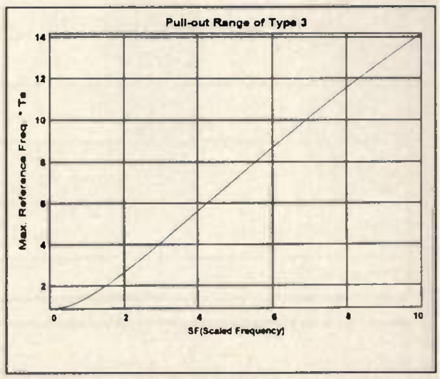


Figure 3. Pull-out range of Type 3 analog phase detector .

$$1.57 + 1.983(SF) + 0.39e^{-10SF} \tag{11}$$

At $\phi = 90°$, 3rd order degenerates to 2nd order and we can assume the following approximations:

$$1.55+1.99(SF)+2.26e^{-SF^{0.75}} \tag{12}$$

$$3 + 2(SF) \tag{13}$$

The pull-out range of a 2nd order is [2]:

$$1.8\omega n(1 + \zeta) \tag{14}$$

It is also the result of a computer simulation. With our symbol, it is equivalent to:

$$1.8\left(1+\sqrt{1+SF^2}\right) \tag{15}$$

Type-3, Third Order – The non-linear differential equation is:

$$\frac{d^3}{dt^3}\theta(t)+K_3\left[T_2^2\cos(\theta(t))\frac{d^2}{dt^2}\theta(t)+\left(2T_2\cos(\theta(t))-\left[T_2^2\sin(\theta(t))\frac{d}{dt}\theta(t)\right)\frac{d}{dt}\theta(t)+\sin(\theta(t))\right]=\frac{d^3}{dt^3}\theta_i(t) \tag{16}$$

where θ_i, the initial phase difference, is assumed to be zero. With:

$$K_3 = K/T_1^2 \tag{17}$$

we take:

$$t_1=\frac{T_1}{\sqrt{K}(T_s)^{1.5}} \quad \text{and} \quad t_2=\frac{T_2}{T_s} \tag{18}$$

Making the same transformation as in the preceeding paper [1], we get:

$$t_1(SF)=\frac{\sqrt{2}}{(2\pi)^{1.5}}\frac{\sqrt{1+\sqrt{1+SF^2}}}{1+SF^2} \tag{19}$$

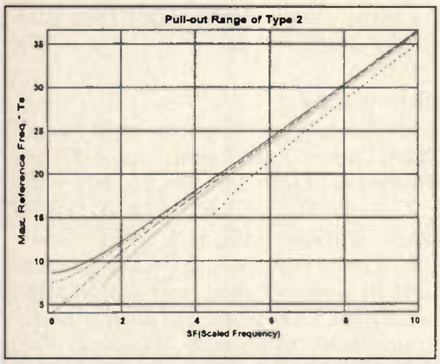


Figure 4. Pull-out range of Type 2 digital phase detector.

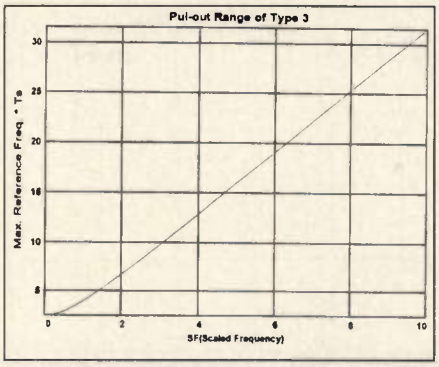


Figure 5. Pull-out range of Type 3 digital phase detector.

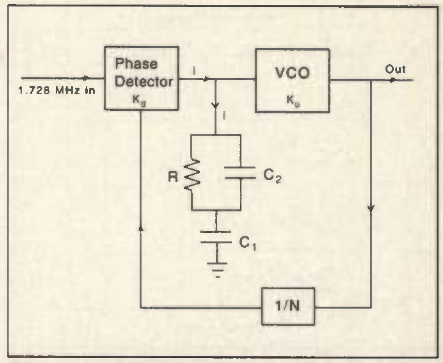


Figure 6. Block diagram for example phase-locked loop.

$$t_2(SF)=\frac{1}{2\pi}\left(\frac{2}{1+SF^2}+\frac{1}{\sqrt{1+SF^2}}\right) \quad (20)$$

with the resulting non-linear differential equation being:

$$\frac{d^3}{d\tau^3}\theta(\tau)+\frac{t_2(SF)^2}{t_1(SF)^2}\cos(\theta(\tau))\frac{d^2}{d\tau^2}\theta(\tau)+\left(2\frac{t_2(SF)}{t_1(SF)^2}\cos\theta(\tau)-\frac{t_2(SF)^2}{t_1(SF)^2}\sin(\theta(\tau))\frac{d}{d\tau}\theta(\tau)\right)\frac{d}{d\tau}\theta(\tau)+\frac{1}{t_1(SF)^2}\sin(\theta)=0 \quad (21)$$

where SF is the only parameter and variable τ is time t in unit of T_s.

We can find a solution θ for every SF when a reference fixed frequency f is applied. We can then find the threshold of f that can make $\theta > 180°$ at the tracking process. Figure 3 is the result and is defined by the equation:

$$-0.47 + 1.5(SF) + 1.3e^{-1.2SF} \quad (22)$$

When SF > 1, the curve resembles a straight line. Thus we can simulate this part of the curve as:

$$-0.1 + 1.42(SF) \quad (23)$$

with SF between 1 and 10

Digital PD

The output of a PD is proportional to the input phase difference θ. It can be depicted with a linear differential equation of θ, and solved using the Laplace transform. The solution is shown by equation (a1) in the appendix of the preceeding paper [1].

When $|\theta| > 180°$, the output of the PD does not change signs. The resultant change at $\theta = 180°$ is not as big as with the analog PD. We can full use of the pull-out, if necessary.

To locate the pull-out range, we must find the threshold of input reference frequency f, at which the maximum deviation during the tracking process of θ is 180°. Because the solution is linear to input f, when we know one value of maximum θ at respective input f_0, the pull-out range is defined as $f_0 180°/\theta$.

Type-2, Third Order – Figure 4 shows the result. At $\phi = 53.135°$, the curve resembles a straight line. It can be depicted as:

$$3.7 + 3.41(SF) \quad (24)$$

or

$$5.3 + 3.2(SF) - 1.7e^{-0.3SF} \quad (25)$$

At $\phi = 90°$, 3rd order degenerates to 2nd order. The second order has an exact solution for pull-out range [2]. With our symbol it is equivalent to:

$$\text{Pull-out Range} = n\sqrt{1+SF^2}\,e^{\frac{\arctan(SF)}{SF}} \quad (26)$$

Checking with our data, the above equation gives exactly the same value with no error. This proves the above curves are correct. However, you may believe the above equation is too complex to evaluate.

I suggest using an approximation formula that is composed of only three terms:

$$A + B(SF) + Ce^{-Dx} \quad (27)$$

The equation then becomes easy to calculate with a tolerable error.

Type-3, Third Order – Figure 5 shows the result. I suggest using the following formula to approximate the above curve:

$$0.24 + 3.14(SF) + 2.27e^{-1.5SF} \quad (28)$$

Example

Figure six is taken from the recent literature [3] and shows the block diagram for a PLL used in a DECT application. The output of the digital PD is a current which produces voltage at the shunt, R, C branch. Converting his notations to our symbols, we get:

c_1 is symbol T_1 (29a)
$t_1 = r(c_1+c_2)$ is symbol T_2 (29b)
$t_2 = rc_2$ is symbol T_3 (29c)
K_v is K_o (29d)

$K_d = 270.56 \times 10^{-6}$ A/rad (29e)
$K_v = 1.256637 \times 10^{8}$ rad/s/V (29f)
$N = 1025$ (29g)

$$K=\frac{K_d K_a K_o}{N}=\frac{K_d K_v}{N}=33.17 \quad (30)$$

Assuming SF=1, ϕ=45° and T_s = 0.0002135 sec, and using either the graphs or formulas from the preceeding paper [1], we get:

$T_1 = 4.623 \times 10^{-8}$ sec (31a)
$T_2 = 5.800 \times 10^{-5}$ sec (31b)
$T_3 = 9.952 \times 10^{-6}$ sec (31c)

with the phase margin being 45°. These results are the same as those in the example paper.

This illustrates that my structured design is correct and provides more freedom than any other method.

Noise Bandwidth

As mentioned before, we need to calculate a complex integral. The integrand is the square of the close loop transfer function. This function is transformed with parameters SF and ϕ for type 2, and only SF for type 3.

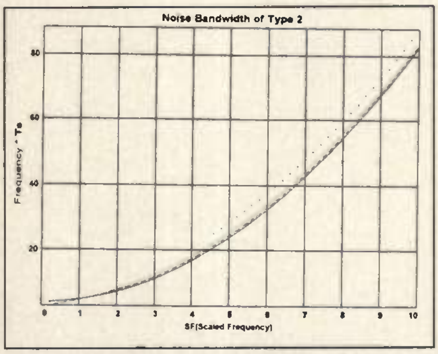


Figure 7. Noise bandwidth of Type 2 phase-locked loop.

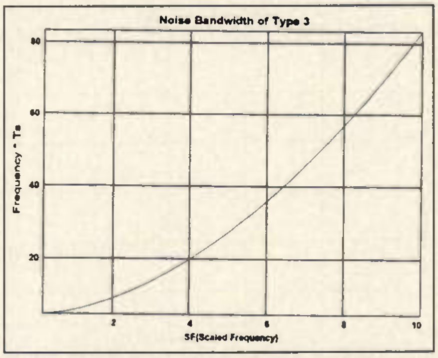


Figure 8. Noise bandwidth of Type 3 phase-locked loop.

We can separate T_s from the integral by making it a divider.

Type 2, Third Order – Figure 7 is the result. When ϕ = 90°, the 3rd order degenerates to the 2nd order. The noise bandwidth of the 2nd order has a distinct formula [3], which is:

$$\text{Noise Bandwidth} = 2\pi\left(0.5 + \frac{1+SF^2}{8}\right) \quad (32)$$

in our notation. Checking the corresponding curve in Figure 8, we discover it agrees with the above formula.

Type 3, Third Order – The result is Figure 8. The above curve can be approximated by the following formula:

$$\text{Noise Bandwidth} = 2.96 + 1.7e^{-SF} + 1.68(SF) + 0.63(SF^2) \quad (33)$$

I hope these curves and formulas wiil be useful to you. *RF*

References

1. Ku, Fu-Nian, "Structured Design of Third-Order, Type-2 and Type-3 PLLs," *RF Design*, April 1996, pp. 95 -101.
2. Best, Roland E., *Phase-locked Loops*, McGraw Hill, Inc., 1984
3. Franceschino, Albert, "Phase Locked Loop Primer and Application to Digital European Cordless Phone" *Applied Microwave & Wireless*, Fall 1994, pp. 65-84.

About The Author

Fu Nian Ku is currently working as a consultant at Mitsubishi's Advanced TV Lab. Previously, he worked at ADEMCO. He received his BSEE and Ph.D from Tsinghua and Peking Universities, respectively. He can be reached at 35 Violet Avenue, Mineola, NY 11501.

ENGINEER'S NOTEBOOK

Controlled Bypassing Sets Limiter Threshold

Gary A. Breed
Consulting Editor

Limiting IF amplifiers are commonly available from integrated circuit manufacturers as stand-alone ICs, or combined with various mixers, detectors and other ancillary functions. Some applications may benefit from control of the limiting threshold — to maximize dynamic range, reduce noise sensitivity, or to provide additional linear gain before limiting occurs. This note demonstrates a simple technique for controlling the limiting threshold over a range that can be as large as 40 dB, depending on the device used.

Figure 1 shows the diagram of a typical integrated circuit limiting IF amplifier. The circuit consists of a cascade of differential amplifiers, with feedback resistors around the entire chain. The input is normally applied single-ended to one of two differential inputs, with the other input bypassed. A low impedance bypass capacitor effectively grounds that connection at the signal frequency to allow a single-ended input.

If that terminal is left unbypassed, the gain of the IF chain is reduced, since the unused input is referenced to the output, not to ground. This gain reduction can be as much as 40 dB (observed with the Motorola MC3362 and MC3363 family of receiver ICs). If the impedance of the bypass network can be varied from an AC short-circuit to an open circuit, the gain of the IF can be controlled over a 40 dB range. In Figure 1, the resistor/capacitor bypass option represents this kind of variable impedance. The graph in Figure 2 shows the effect of controlling amplifier gain, and therefore, limiting threshold.

My first application of this technique was to get as much linear range as possible in a CW/SSB receiver application. 40 dB of linear IF gain was acceptable, and the onset of limiting served to protect following circuits (and ears!) from excessive signal levels, acting as a rudimentary AGC. In a minimum-component design without critical performance specifications, this arrangement worked well.

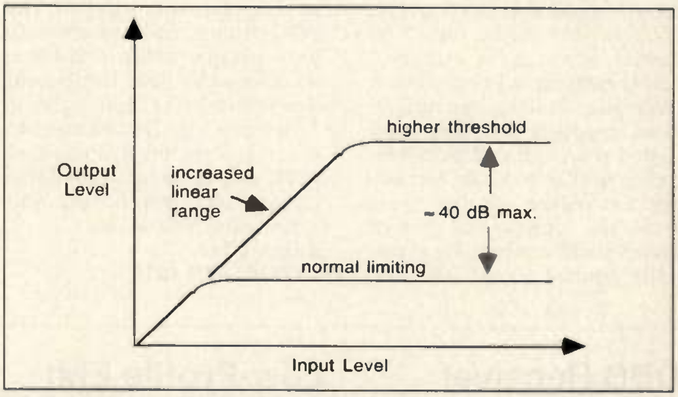


Figure 2. Increased linear range delays the onset of limiting to a higher input signal level.

Another application where this technique has been used in in a cable-based data transmission system. Again, a minimum-component design was implemented, with an FM receiver IC used for FSK demodulation. The full 100 dB of limiting IF gain was not needed, given the constant signal levels of a closed-circuit system. The gain was reduced for better noise rejection by actually *eliminating* a part (the bypass capacitor) from the standard receiver configuration.

In summary, this technique allows you to control the limiting threshold, or get maximum linear amplification range, from a common FM IF amplifier. This control is achieved by modifying the bypass configuration of the unused input, requiring no more than one additional component. *RF*

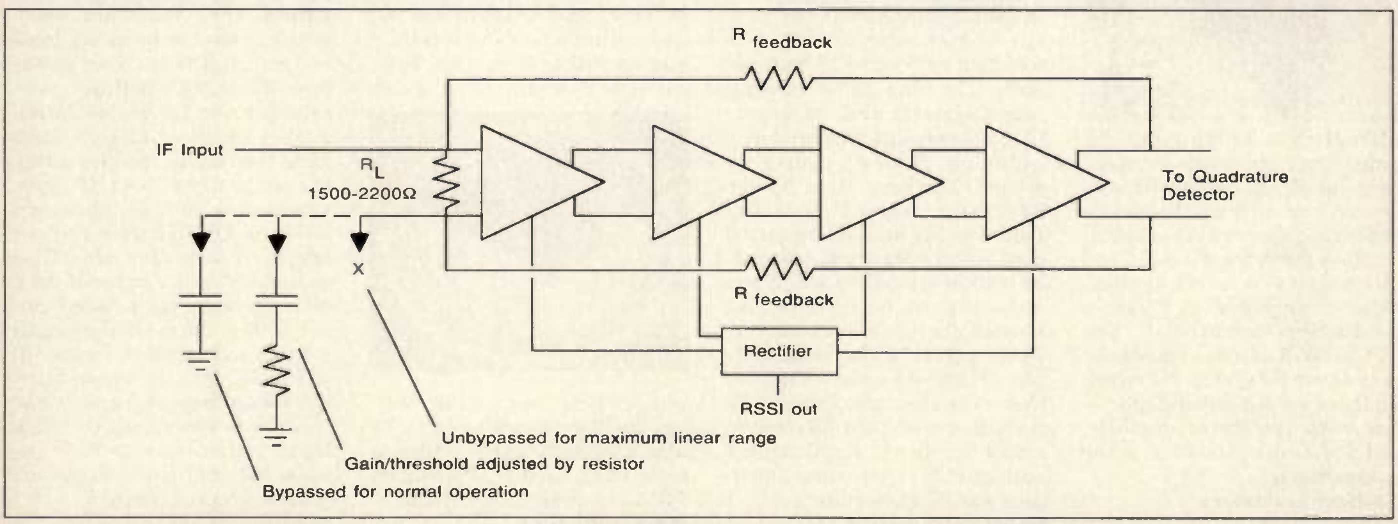


Figure 1. Typical IC limiting IF amplifier. Controlled bypassing of the unused input is used to adjust the limiting threshold.

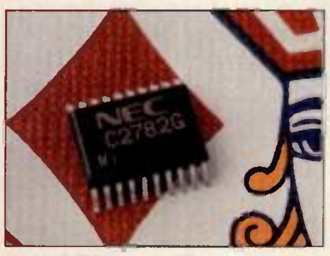
Synthesized Signal Generator

Telulex's SG-100 synthesized signal generator is based on Direct Digital Synthesis (DDS) technology, generating a variety of complex waveforms at precise frequencies from DC to 20 MHz with 0.1 Hz resolution. A Digital Signal Processor (DSP) has direct control over every aspect of the SG-100 DDS system. Frequency, phase, level, and the I and Q rails are all controlled in the digital domain, resulting in clean, precisely controlled modulated waveforms. This combination of DSP and DDS technology also makes possible signal analysis functions which process and analyze an externally applied signal. The SG-100 offers Linear/Log sweep, AM, FM, PM, SSB, BPSK, FSK, Burst, DTMF generation, DTMF detection and power level measurement. For each modulation mode, the user may select a modulating waveform that is either internally generated or externally supplied. The SG-100 uses flash memory to hold its operating software, enabling the unit to be field upgradable for adding new functions. An RS232 remote control is included. Priced at $795 with discounts available for quantity purchasers and educational institutions.

Telulex Inc.
INFO/CARD #210

DBS Receiver Downconverter

California Eastern Laboratories has added another NEC MMIC device to its wireless IC family. The UPC2782GR silicon MMIC downconverter combines a Gilbert cell mixer, two stages of LO buffering, local oscillator, external filter port, a high-output, variable-gain IF amplifier, and a temperature compensation circuit in a single 20 pin SSOP20 package. Performance features include a frequency range of 900-



2500 MHz, a 3 dBm input 3rd order intercept point, an AGC range of 25 dB, and an RF conversion gain of 10 dB. The device is designed specifically for digital satellite receivers, WLANs, and other digital receiver applications. It is priced at $1.50 in production quantities. The UPC2782GR is also available as part of an NEC chip set which includes an IQ demodulator, a low noise broadband amplifier, and a prescaler in addition to the downconverter.

California Eastern Laboratories
INFO/CARD #211

Low-Profile EMI Filter Plate

Spectrum Control Inc. introduces the Easy Mate Jr.™, a line of low profile, easy to install EMI filter plates that provide EMI filtering through 18 GHz. Easy Mate Jr. features a 0.260"

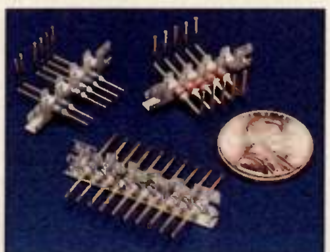


plate height, are available in either 0.990" or 1.240" plate lengths, in standard 0.100" density or high 2mm density centers, and with up to 10 lines per plate. The filter plates incorporate staggered, dimpled fingers that deliver high contact force, reducing RF impedance to ground. The Easy Mate Jr. line addresses varied filtering requirements by allowing mixed capacitance values and schematics within a single plate. Filter elements can be specified for straight-through connections, right angle or double bend. They are designed to snap into the chassis of electronic systems for installing feed-thru filters into small hardware applications such as PCS linear power amplifiers and RF transmitters.

Spectrum Control
INFO/CARD #212

High Accuracy VCXO

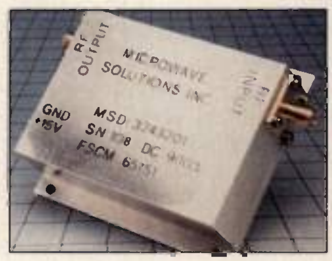
MF Electronics introduces VCXOs guaranteed to have less than 25 ppm deviation from the specified mid-point frequency. Models M2031, M2032, and M2033 provide frequency capture ranges of 75, 100, and 150 ppm, respectively, provided by ±2 V control voltage variation around 2.5 V. The oscillators are available for center frequencies from 1 to 175 MHz and are manufactured in dual inline packages. They are available in ECL and HCMOS logic families. Designed for 4.5-5.5 DC supply voltage, they provide full scale capture with 0.5-4.5 V control voltage, and draw 30-60 mA depending upon logic family and operating frequency. Typical jitter is less than 40 ps

peak-to-peak, and control voltage bandwidth extends to 75 kHz. Oscillator startup time is less than 5 ms. Priced at $14.75 in quantities of 1000.

MF Electronics
INFO/CARD #213

Connectorized GPS LNA Amps

Microwave Solutions' wide dynamic range, low noise amplifiers (LNA's) are unconditionally stable and are designed for GPS applications. Using a balanced



input utilizing quadrature couplers to improve VSWR performance, they maintain noise match across the frequency band and provide RF open/short protection. The LNA's feature a low noise figure of 1.2 dB over the frequency range of 1200 to 1600 MHz. Gain can be specified within the range of 14 to 43 dB, gain variation is ±0.5 dB. Minimum VSWR is 1.8:1. Minimum output power is 7 to 15 dBm min, IP3 is guaranteed 10 dB higher of the 1 dB compression point, typical current is 60 to 180 mA dependent on the gain and output power specification. All units include an internal voltage regulator and can be specified to operate with a single input voltage of 8 to 28 V DC while providing over-voltage and reverse-polarity protection.

Microwave Solutions
INFO/CARD #214

NEW!

J-LEAD

J MIXERS UNPRECEDENTED IN VALUE.

All Ceramic 2 to 1900MHz from $4.25 (qty. 10-49)

JMS mixers mean unparalleled performance and reliability. Solder plated J leads provide improved reliability of the solder connection while significantly reducing thermal stress and leaching. All-welded internal construction withstands reflow temperatures up to 240°C for 5 minutes, and rugged construction enables JMS mixers to pass tough MIL-M-28837 shock and vibration tests. Additionally, the all-ceramic surface mount package has a cover pull strength of 20 pounds! Other quality features include 4.5 sigma repeatability unit-to unit, automated assembly for low-cost and fast, guaranteed 1 week shipment, tape and reel availability plus a 5 year Ultra-Rel™ guarantee. If value is a must...specify JMS mixers from Mini-Circuits.

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

SPECIFICATIONS

MODEL	LO (dBm)	FREQUENCY (MHz) LO/RF	I F	MIDBAND (dB, typ.) Conv. Loss	Isolation L-R	L-I	$ea. (qty. 1-9)
JMS-1	+7	2-500	DC-500	5.75	45	45	4.95
JMS-1LH	+10	2-500	DC-500	5.75	55	45	8.45
JMS-1MH	+13	2-500	DC-500	5.75	60	45	9.45
JMS-1H	+17	2-500	DC-500	5.90	50	50	11.45
JMS-2L	+3	800-1000	DC-200	7.0	24	20	7.45
JMS-2	+7	20-1000	DC-1000	7.0	50	47	7.45
JMS-2LH	+10	20-1000	DC-1000	6.5	48	35	9.45
JMS-2MH	+13	20-1000	DC-1000	7.0	50	47	10.45
JMS-2H	+17	20-1000	DC-1000	7.0	50	47	12.45
JMS-2W	+7	5-1200	DC-500	6.8	60	48	7.95
JMS-11X	+7	5-1900	5-1000	6.7	35	37	4.25*

Note: *10-49 qty.

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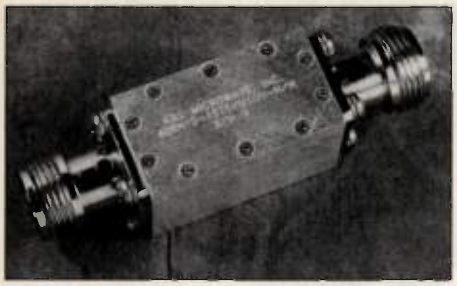
SIGNAL PROCESSING COMPONENTS

GPS Notch Filter

K&L Microwave Inc. has introduced model number 4DRN10-1575/U100-N/N, a ceramic



GPS notch filter at 1575 MHz with four section response. The 1 dB bandwidth is less than 100 MHz and the 40 dB bandwidth is greater than 20 MHz. The package includes N-connectors.
K&L Microwave
INFO/CARD #219

Variable Attenuators

Piher International Corporation has announced a line of variable attenuators. The AA type, 3 turn variable attenuator is particularly suited to applications where variable attenuation at constant impedance is needed. The attenuators are offered with attenuations of 10 dB and 20 dB and impedences of 50, 75, and 150Ω. The attenuators are provided in dust-proof enclosures.
Piher International
INFO/CARD #220

Dual Directional Coupler

Merrimac Industries Inc. has introduced model CGN-30-1.8G, a 500W dual directional coupler designed to monitor both forward and reflected power on a PCS radio base station antenna feed. Specifically developed for placement between final transmitting amplifier and the antenna, it comprises two opposed 30 dB directional couplers on each side of the main line. Insertion loss is 0.05 dB with VSWR better than 1.02:1 on either main line port.
Merrimac Industries
INFO/CARD #221

Surface Mount Filter

Lark Engineering Company has introduced model MS1333-106-3CC, a 3 pole lumped element filter measuring 0.5x0.5x0.3 inches. This filter has a center frequency of 1333 MHz with a minimum 3 dB bandwidth of 106 MHz. Minimum rejection is 26 dB at 1093 and 1573 MHz, and VSWR is 1.5:1 over the center 50 MHz of the passband. Center frequency insertion loss is less than 1.8 dB. Other designs are available with center frequencies ranging form 1 to 2000 MHz and bandwidths from 3 to 100%.
Lark Engineering
INFO/CARD #222

Harmonic Generator Switchable Filters

KW Microwave introduces a new series of integrated harmonic generator switchable filters covering a frequency range from 160 to 1600 MHz. They consist of a 160 MHz harmonic generator and a four-channel switch filter selecting frequencies in the range of 320 to 800 MHz with 160 MHz frequency step and two outputs at 800 and 1600 MHz. It utilizes GaAs FET switches and a SRD harmonic generator. The maximum switching speed is 200 ns, an ultimate rejection of 70 dBc up to 2.0 GHz and 40 dBc up to 3.0 GHz, and a typical size of 3.25"x2.25"x0.60". The filter is designed to meet or exceed the requirements of MIL-STD-202F.
KW Microwave Corp.
INFO/CARD #223

AMPLIFIERS

100 Watt VHF Amplifier

LCF Enterprises model number 100-30-100-35-A3 has an output power level of 100 watts CW from 30-100 MHz. The power amplifier measures 6.0"x2.0"x1.0" (for 35 dB gain) and achieves 50% to 70% efficiency depending on power. The amplifier is also available as a full rack-mount system with power supply, meters, cooling, and additional gain.
LCF Enterprises
INFO/CARD #224

GaAs Power Amplifier

Motorola has announced the addition of the MHW9014, a GaAs FET power amplifier, to its RF device portfolio. The MHW9014 power amplifier offers new biasing and control techniques that provide dynamic range and control circuit bandwidth ideal for PCN applications. The device operates from a 6 volt supply in the 1710-1785 MHz frequency range and requires only 1.0 mW of RF input power. It is priced at $64.35.
Motorola Semiconductor
INFO/CARD #225

TEST EQUIPMENT

Spectrum Analyzers

B+K Precision introduces four new spectrum analyzer models. Models 2615 and 2620 are ideal for applications up to 500 MHz. Both models include a scanwidth selector that can adjust the frequency display width from 50 kHz to 50 MHz per division and a four digit numeric LED readout that can selectively display either the center or marker frequency. Models 2625 and 26[illegible] have AM and FM demodulation to allow t[illegible] user to listen to and identify RF signal[illegible] These models enable frequency-domain me[illegible] surements from 100 kHz to 100 MHz p[illegible] division and include a 4-1/2 digit numer[illegible] LED readout. These models are guarante[illegible] to drift less than 0.150 MHz per hour. T[illegible] family is priced at $1795 (2615), $21[illegible] (2620), $2595 (2625), and $3395 (2630).
B+K Precision
INFO/CARD #226

High Density VXIbus Switch Card

Racal Instruments has introduced t[illegible] 1260-45 high density switch card. The 126[illegible] 45 is configurable as eleven different mat[illegible] ces from four 4x16 two-wire to one 16x[illegible] two-wire. It offers a high-density switchi[illegible] matrix in a single-slot C-size VXI module. [illegible] 3 dB bandwidth is 25 MHz, crosstalk [illegible] –50dB at 1 MHz and path resistance is le[illegible] than 0.5 ohms. The 1260-45 is part of t[illegible] 1260 series of switching systems, whi[illegible] offers modules in configurations from mat[illegible] ces to multiplexers, and frequencies from [illegible] to 26.5 GHz. It is priced at $4075.
Racal Instruments
INFO/CARD #227

mm-Wave Fixtures for Dielectric Constant Measurements

Damaskos, Inc. has introduced precisi[illegible] mm-wave fixtures for measurement of ε of [illegible] and U materials from 26-110 GHz. The fi[illegible] tures feature clam shell holders for go[illegible] sample contact and easy placement. Comp[illegible] nents include TRL/LRL standards and re[illegible] tangular cavities. They are available wi[illegible] software for instrument control and data pr[illegible] cessing for common vector and scalar ne[illegible] work analyzers. In addition to solids, po[illegible] ders may be measured with the aid of a co[illegible] pacting ram.
Damaskos
INFO/CARD #228

Real-Time, DSP-Based Data Acquisition Boards

Analog Devices' newest PC-based (IS[illegible] bus) data acquisition board family provides [illegible] complete, state-of-the-art integrated har[illegible] ware/software solution at an affordable pric[illegible] The RTI-2100 offers on-board simultaneo[illegible] sample and hold, along with programmab[illegible] gain amplifiers on each input channel. T[illegible] RTI-2100 Series provides sampling range[illegible] from 500 kHz to 1 MHz at 12-bit resolutio[illegible] plus programmable gain amplification f[illegible] accomodating full scale signal ranges fro[illegible] millivolts to ±5 volts. Other features inclu[illegible] 12- and 16-bit digital-to-analog (D/A) cha[illegible] nels and 24-bit digital I/O lines. The board [illegible] priced from $1260.
Analog Devices
INFO/CARD #229

SIGNAL SOURCES

Voltage Controlled Oscillator

Mini-Circuits has introduced the new JCOS-1100LN voltage controlled oscillator for cellular base stations in the 1079 to 1114 MHz frequency range. This VCO provides linear tuning, -150 dBc/Hz phase noise at 1 MHz offset, typical harmonics of -16 dBc and operates from a 5V supply. It is priced at $49.95.
Mini-Circuits
INFO/CARD #230

Programmable Master Clock Oscillator

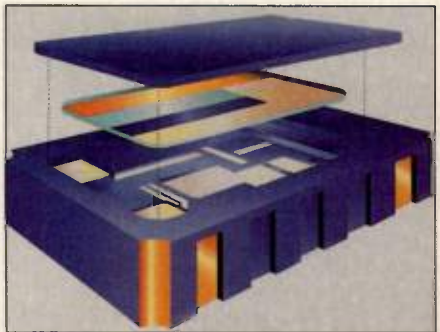
Microelectronics manufacturer Micro Networks has introduced the industry's first digitally parallel-programmed master clock oscillator with a range of 40 MHz to 1 GHz. In addition to programmability, the M115 series features less than 5 psec (rms) typical output jitter, 35 ppm stability, and 0-70°C operation, with extended temperature ranges and even greater stability available to customer specs. Standard M115 devices are packaged in 24-pin, double-wide, ceramic DIP packages. The different models feature progammable frequency ranges from 40 to 1000 MHz with resolutions ranging from 100 to 200 kHz. The clocks are designed for high performance computer, telecommunications, ATE, and data communications systems. The M115 series is priced at $155 in sample quantities and under $100 for OEM.
Micro Networks
INFO/CARD #231

Voltage Control Oscillators

Connor-Winfield announces the P8R and PL14R families of voltage control oscillators covering a frequency range of 100 kHz to 1.2 GHz. The product line is available with either HTC, PECL, or sinewave outputs. The oscillators are designed for use in phase loop applications such as telecommunications, video imaging, and frequency synthesis applications.
Connor-Winfield Corporation
INFO/CARD #232

Surface Mount Oscillator

Ecliptek Corporation announces its EC2500 and EC2600 sub-miniature ceramic oscillators. Available in 3.3 or 5.0 V, they measure



7.5x5x1.8mm. They have a frequency range of 1.5 to 66.667 MHz. Applications include PCMCIA cards, disc drives, PDAs, and laptops.
Ecliptek Corporation
INFO/CARD #233

Fast-Switching Synthesizer to 15 GHz

MITEQ's SLS series synthesizers utilize a fast-tuning phase-locked loop architecture to provide a balanced combination of exceptionally low phase noise and tuning speed. They are ideal for wireless and satcom applications over the frequency range of 1-15 GHz, with tuning bandwidth of up

to half octave and step sizes down to 200 kHz. These synthesizers have been ruggedized for guaranteed spurious performance over shock and vibration.
MITEQ
INFO/CARD #234

Ultra Low Noise Synthesizer

RF Prototype Systems introduces an ultra low noise synthesizer. This synthesizer offers a frequency range of 825 to 1025 MHz. The phase noise is better than -102 dBc/Hz at 1 kHz offset and -110 dBc at 10 kHz offset. It has its own internal reference oscillator and will accept an external reference as well.
RF Prototype Systems
INFO/CARD #235

DISCRETE COMPONENTS

Air Core Inductors

The Develan Division of American Precision Industries has introduced a family of air core inductors with values ranging from 2.5 to 43.0 nH and an average Q of 100+. The inductors feature a small footprint to conserve board space, and a cap for automated pick and place assembly. Custom configurations are available upon request.
API/Develan
INFO/CARD #236

GPS Receiver Crystals

Bliley Electric Company has introduced their BK3 series of quartz crystals for GPS receivers and navigational guidance systems. Available in both standard and specially designed versions, the standard series specifications include a frequency of 16.368327 MHz and an initial accuracy of +5/-10 ppm at 25°C.
Bliley Electric Company
INFO/CARD #237

SEMICONDUCTORS

Integrated Digital Video Encoders

Analog Devices has introduced models ADV7175 and ADV7176, integrated digital video encoders which include four 10-bit video DACs and convert digital YUV component video data into standard analog NTSC and PAL signals. Housed in 44-pin packages, the models provide 10-bit resolution for encoded video channels, programmable NTSC/PAL digital filters with low-pass/notch characteristics, and complete on-chip timing generation. The encoders can also drive RGB, S-video (Y/C), and YUV analog video signals. It is priced at $9.92 in quantities of 1,000.
Analog Devices Incorporated
INFO/CARD #238

10-Bit Triple Video Digital-To-Analog Converter

Signal Processing Technologies introduces SPT5230, a 10-bit video DAC which supports conversion rates of 50 million words per second (MWPS) with power dissipation of 280 mW. The DAC also features -49 dB chann to-channel crosstalk isolation and ±1 LS differential linearity in a package measuri 10x10 mm. The SPT5230 is designed f high-speed DAC, high-resolution color grap ics monitors, high-performance desktop vid processing and digital TV applications and priced at $23.80 in quantities of 1000.
Signal Processing Technologies Inc.
INFO/CARD #239

Monolithic Bias-Generating System

Linear Technology Corporation has dev oped model LT1166, a monolithic bias-genera ing system used for controlling the bias Class AB high-power amplifiers. The LT1166 a unique product with no equivalent functi available on the market today and is suited t driving power devices because it eliminat quiescent current adjustments and the need match FETs in the output stage. The LT11 corrects for device mismatches automatically no adjustments to the amplifier bias netwo are required. In addition, the LT1166 delive the benefits of reduced component count, si plified layout, and short-circuit protectio Priced at $2.35 in quantities of 1000.
Linear Technology Corporation
INFO/CARD #240

One-Chip Digital Satellite Receiver Front End

SGS-THOMSON Microelectroni announced its STV0196 digital satelli receiver front end. The chip integrates all t functions needed to demodulate incomi digital satellite TV signals from the tune including Nyquist filters, a QPSK demodul

Product Focus - Mixers

Wide Band 3.7 to 10 GHz Mixer

Mini-Circuits introduces the new ZMX-10G, a wide band 3.7 to 10 GHz microwave mixer with 5 dB conversion loss. The mixer features a LO-RF and LO-IF isolation of 37 dB and 17 dB, respectively and an IP3 of 11 dBm. Equipped with SMA connectors, it measures 1.0″x0.75″x0.58″ and uses a shielded metal case. Ideal for use in satellite up/down converters, line-of-sight links, and radar. Priced at $81.95.
Mini-Circuits
INFO/CARD #215

Double Balanced Mixer

Merrimac Industries, Inc. introduces a double balanced mixer to minimize intermodulation products falling in adjacent channels, as required in cellular radio systems. The DMH-4R-1000 Double Balanced Mixer operates at drive levels from 7 to 17 dBm. The half relay package used may be mounted directly to the PCB or the leads may be conformably formed to be in the same plane as the header.
Merrimac Industries, Inc.
INFO/CARD #216

Mixers from 2 to 18 GHz

Device Technology has developed a mixer product line featuring double balanced mixers, triple balanced mixers, and frequency doublers available in the 2 to 18 GHz range. These mixers operate at drive levels from 7 to 20 dBm and are available in multiple package styles.
Device Technology
INFO/CARD #217

GaAs Double Balanced Mixer-Oscillator

Richardson Electronics, has announced the availability of a new 0.5 to 3.0 GHz GaAs double balanced mixer-oscillator manufactured by Philips Microwave Limeil. The MXO-052A is a mixer-oscillator IC comprising a RF splitter amplifier, double balanced mixer, dual phase oscillator and an IF combiner. The IC operates with single-ended RF inputs and IF outputs and requires only a single, positive supply voltage. It is designed for use in satellite TV tuners and 2.4 GHz wireless LANs. The MXO-052A is priced at $4.80 in 10,000 piece quantities.
Richardson Electronics, Ltd.
INFO/CARD #218

tor, a signal power estimator, automatic gain control, a Viterbi detector, a de-interleaver, and a Reed-Solomon decoder and energy dispersal descrambler. Designed for the DBS digital TV receiver market, it is packaged in a standard PQFP 64 package.
SGS-THOMSON Microelectronics
INFO/CARD #241

Complete Chip Set for Analog Cellular Telephones

GEC Plessey Semiconductors introduces the ACE chip set which integrates the functions of up to 10 integrated circuit devices required for designing an analog cellular telephone. Components in the ACE chip set include an RF front end with VCO, receiver and transmitter interface, radio interface and twin synthesizer, audio processor, and combined system controller with data modem. The only additional ICs needed with the ACE are external memory, an IF amplifier, and a power amplifier. The chip set is priced at $28.00 in quantities of 100,000.
GEC Plessey Semiconductors
INFO/CARD #242

SUBSYSTEMS

Remote Data Control

The Skyline-RTU from RF Neulink is a Supervisory Control and Data Acquisition device comprising a UHF radio transceiver, RS-232 modem interface, and a digital/analog I/O board, all in a 3″x3″x2.5″ stainless steel enclosure. The standard device allows for eight opto-isolated digital inputs/outputs, and two analog to digital converter terminals. The I/O modules are stackable up to 8 units, providing the capabilities of up to 64 digital I/O and 16 A/D terminals. The radio modem platform is the Neulink 9600, a 9.6 kbps transceiver modem that allows up to 64 RF channels to be programmed into internal memory and can be configured for point to point and point to multi-point networks.
RF Neulink
INFO/CARD #243

Digital Video Compression Command Center

The PowerVu command center, offered by Scientific-Atlanta, provides network management, security, and subscriber management for digital video compression systems. The PowerVu command center allows the user to set up or change parameter values such as video, audio, and utility data rates as well as sampling rates with the click of a mouse. The network monitoring feature provides for automatic redundancy switching in the event of component failure. Security is controlled with B-MAC encryption systems which allows scrambling to be controlled globally or on a per service basis. Subscriber management capabilities include the ability to authorize subscribers on a individual, group, or global basis. The PowerVu command center is available in different models depending on number of subscribers.
Scientific-Atlanta
INFO/CARD #244

Hybrid PWM Amplifier

Apex Microtechnology has developed the industry's first product line of hybrid PWM amplifiers – the SA01, SA50, and SA51. All three amplifiers require two square-inches of board space and are 97% efficient. The SA01 is capable of 20A of continuous output on a 16-100 V single supply, switches at 42 kHz, and has a maximum power dissipation of 200 W. The SA50 and SA51 are both capable of 5 A of continuous output on a 16-80 V single supply and maximum power dissipation of 120 W. The SA50's switching frequency is at 45 kHz. The SA51 requires an external signal be provided but can produce a maximum switching frequency of 500 kHz. The PWM amplifiers are priced at $85 for the SA51, $95 for SA50, and $250 for the SA01 in 100s.
Apex Microtechnology
INFO/CARD #245

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

2.3 GHz CRO

Editor

A note to the article of Mr. Polidi (page 66 of RFD-Oct. 95). He claims for a 2.3 GHZ CRO with a bandwidth of 1.5% and a phase noise of -86 dBc @ 10 KHz.

The author seems very satisfied; but really these are poor results if one considers that Mizar Microwaves has produced in the last 3 years over 60,000 2.5 GHs CRO with 5% BW, -95 dBc @ 10Khz, second harmonic @ -35 dBc, the same power output and the same substrate size.

Our solution is cheaper because it utilizes less and less expensive parts (I. E. the transistors are SOT-23), uses a PCB substrate rather than an alumina substrate and does not require adjustments on the assembly line.

Roberto Tosini, Sr. Eng.
Italy

High-Frequency Active Auroral Research Program (HAARP)

Editor:

The HAARP's "Ionospheric Research Instrument (RI) ... will include 360 antennas (and) is designed to temporarily modify a 30 mile diameter patches of the upper atmosphere by exciting or heating their...electrons and ions." "The local heating effect of the HAARP transmitter is expected to raise the electron temperature by 40 (degrees) F, according to the Air Force, and to endure as long as three months." A "bank of six 2.5-megawatt ...generators" operate the full scale IRI, with a 2.8-10 MHz radio band. The IRI will beam 1.7 billion watts, gigawatts effective radiated power 3000 times more powerful than the biggest commercial AM broadcast radio transmitters."

The information was extracted from "MYSTERY IN ALASKA," Popular Science (PS) magazine, Sept. 1995, p. 20. It is reported the research program started in 1990, spending about $58 million to FY-95's end. The spending is projected to reach about "$200 million by FY-1999's end. The spending rate was $9.7 M/yr., for six years, and will jump to about $36 M/yr. in the next four years.

The program management office (PMO) for the research, is the USAF's Phillips Lab., Hanscom AFB, MA. The USAF has been in the forefront, the crusade to develop practical electromagnetic (EM) beam weapons. The program lead of the Strategic Defense Initiative (SDI), the Star Wars knights, and the present Ballistic Missile Defense Organization, the renamed SDI, is the USAF. It sounds like beautiful scenario of the beam weapon knights.

The power generators of the IRI, can supply 15 megawatts (MW) of AC-power powers. With 15 million watts AC input, it is impossible to output 1.7 billion watts of EM power. Assuming excellent AC-to-DC and DC-to-EM conversion efficiency, low losses to the

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antenna, very good antenna efficiency; the IRI could output 4 MW of average EM power. The IRI's "power P.R.," 1.7 gigawatts (GW), is virtual power.

Assume each of the IRI's 360 phased array antenna elements, after all losses, have gain of 1.2 (relative to an isotropic radiator). When well done, 360 elements have a net gain of 1.2 x 360 = 432. When supplied 4 MW average power, the array's effective radiated power is (432 x 4 MW) = 1,720 MW, or 1.7 GW. The P.R. power is referenced to a virtual antenna, its the power which is virtual. In commercial AM-radio station transmitters the key power specification is its average power; the 3000:1 [3000 or 8000 please look in story] IRI comparison is spurious.

The target of the HARRP is the F2-layer of the ionosphere. It has a virtual altitude of 200 mi, day and night. With a 30 mi patch diameter, a circular IRI beam spot must be about 200 mi overhead; the beam's angle width is about 8.5(degrees), indicating the IRI's gain slightly less than 432. The area of the beam spot is about 2x10(9th) square-meters (m2). Spreading the 1.7 GW effective power across that area; the HAARP could attack with only 0.85 watt/m2 (85 μW/cm2) power density.

The upper atmosphere has been holed by man's stupidity, and the power P.R. of the IRI has set off the alarms of environmentalist. They are fearful a 1.7 GW beam will violate Mother Nature's delicate skin. But, the Sun rains down many kilowatt per square-meter, and the IRI's radiation is not worth consideration. The concern should be, that US taxpayers are paying for overstated, big science research project.

The Sun makes ions, and the excited ions migrate to higher altitude, forming 10 miles or more thick layers (D, E, F1 and F2) in the ionosphere. The D-layer contains many ions, and very little of the IRI's radiation goes beyond 55 mi altitude during the day. The surviving radiation is absorbed by the E-layer (65-75 mi). About three hours after the Sun passes overhead, ion production fall at a high rate, and the D through F1 layers start to vanish. About eight hours after local midday, the F2-layer approach minimum ionization, the D through F1 layers disappeared hours before. In a few more hours, the Sun comes around again, and starts another heating cycle.

The IRI is "expected to raise electron temperatures by 40(degrees)F (22 degrees C), according to the Air Force, (for) as long as three months." That is a beautiful science beautiful scenario (BS2). The Sun's multi-thousand times stronger radiation, makes and redistributes ions about 12/24th of every day. How do the HAARP players expect to isolate their warm electrons from the rest, and track their survivors for up to three months? If they did, does this knowledge have $200-million payback?

The U.S. military's beam weapon quest cost exceeds $40-billion, and for over a quarter century a practical beam weapon has not been developed. Why go on? The typical, high power or high energy EM big science quest is for paychecks.

RF software

High-Frequency Design Software

High-frequency circuit designers now can create simple, efficient designs on personal computers (PCs) with the full circuit-simulation power of HP Series IV/PC electronic design automation (EDA) software. The software provides a fully integrated schematic editor, multiple circuit simulator, component libraries, analysis presentations and physical design tools for RF- and microwave-circuit designers who do high-frequency circuit design for commercial wireless and defense applications on a personal computer. HP Series IV/PC is supported on the new 32-bit multitasking Microsoft® Windows 95 and Windows NT Version 3.51 operating systems.

Hewlett-Packard Company
INFO/CARD #246

Electromagnetic Analysis Software

Version 4.0 of their industry standard electromagnetic analysis software is available from Sonnet. New features include automated optimizations, embedded netlist analysis (using a familiar netlist format), dielectric brick analysis and completely de-embedded internal ports. The automatic optimizer takes a given circuit geometry and automatically tunes dimensions to yield a design which meets the user's requirements. The netlist capability allows the user to include lumped element networks and measured data within an electromagnetic analysis. Automatic interconnection of the results of separate electromagnetic analysis is also provided. With dielectric bricks the user can specify regions of different dielectric constant within a given layer.

Sonnet Software, Inc.
INFO/CARD #247

Testing Software

New from Amplifier Research, SW1000 testing software permits computer-control of AR power amplifiers, signal generators and other equipment for a broad range of immunity testing requirements, including IEC-1000-4-3. The software utilizes an IEEE-488 communications link with a power meter or field monitoring system to level by power or field strength. The software also permits extensive monitoring of the EUT and testing to IEC-1000-4-3 requirements, in the method called for leveling by output power from the amplifier. The software permits an AR-powered system to automatically perform the 16-point field calibration, immunity test sequencing, data collection, and report preparation for IEC-1000-4-3 testing, and for a variety ofuser-specified procedures. The SW1000 software package is available as a standalone program under Windows 3.1 and 95.

Amplifier Research
INFO/CARD #248

RF literature

Updated Products Selector Guide

The RF Selector Guide has been updated to reflect new and current products of Motorola, Phoenix, Toulouse (France) and Hong Kong. It is separated into major categories such as power Fetes, power bipolar, small signal, monolithic integrated circuits, and low and high power amplifiers. Also provided are a listing of application literature and case dimension information. The new RF Device Data book is contained in one volume. All data sheets for low and high power discrete transistors, hybrid circuits for power amplifiers, linear amplifiers and monolithic integrated circuits have been combined into one section and are in alphanumeric order. Revision 7 features changes including the addition of new products introduced since the last printing. Case dimensions and a cross-reference are also provided in the data book.

Motorola, Inc.
INFO/CARD #249

ClockChip® Oscillator-Building ASIC

A new four page brochure describes MF Electronics' 0.046" x 0.035" x 0.02" ClockChip® ASIC for building time/frequency reference sources. Used with customer's own crystal, ClockChips® create precision 1.5 MHz - 66.6 MHz surface mount clock oscillators. Features include two built-in frequency dividers (f/2 and f/4), plus tri-state logic for ATE bed-of-nails testing. ClockChip® ASICs operate from 2.8V to 5.5V DC, provide 48/52 waveform symmetry and are compatible with TTL and CMOS logic families. The ASICs are available in MSOP, SOIC, and Waffle packages, as well as 4-inch wafers. Prices range from $ 0.29 to $ 0.69. Built-in frequency divider enables the user to select one of three (f, f/2, f/4) output frequencies for a given crystal. This freedom lets users stock fewer crystals for a given frequency range. The divider also gives users and alternative to hard-to-get crystals. Substitute a 20 MHz crystal, if 10 MHz or 5 MHz crystals are costly or unavailable. Another divider benefit: its output waveform has 50/50 symmetry.

MF Electronics Corp.
INFO/CARD #250

Wireless Communications Products Brochure

Look Who's Big in Wireless is the first brochure to integrate Philips Semiconductors' entire wireless product portfolio into a single document and showcase Their core competency in wireless communications. The brochure begins with a four-page product design tree which displays our broad product offering, from discrete transistors to integrated circuits and hybrid power amplifier modules. The design tree also references our integrated chip sets for major cellular, cordless and paging standards. The brochure includes key feature and benefit summaries for Philips RF front ends, IF receivers, frequency synthesizers, power amplifiers, compandors, baseband processors and cellular/cordless/paging chip sets.

Philips Semiconductors
INFO/CARD #251

New Edition of EMC Guide

EMC for Product Designers, Second Edition is the new EMC (Electro Magnetic Compatibility) reference guide from Butterworth-Heinemann. The second edition, authored by Tim Williams provides all the information necessary to meet the requirements of the EMC Directive. Most importantly, it shows how to incorporate EMC design principles into products, avoid cost and performance penalties, and meet the needs of specific standards; resulting in a better overall product. This new edition includes the latest developments which are essential for anyone complying to the regulation. In particular new basic, generic and product-specific test standards, new standards on measurement methods and revisions to existing standards, and changes to the standards generating process are covered. New measurement techniques are also described.

Butterworth-Heinemann
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Matched-Impedance Coaxial Connectors Brochure

Applied Engineering Products has developed a number of innovative subminiature coaxial connectors which not only match the 75-ohm impedance requirement, but fit in confined spaces as well. A four-page brochure has been released which features new products in this category, including: A series of SMB connectors and adapters which use an air-dielectric interface to produce a 75-ohm characteristic impedance while retaining the SMB series' small and convenient snap-on mating. A companion series of 75-ohm SMB connectors for use in applications which require a more robust interface, such as repeated mating and unmating of connector pairs. This series features telescoping insulators to support the inner contacts and guide them together during the mating process. The red Teflon insulators of these connectors allow easy identification after installation. Precision type F plugs for systems which require this interface, but need better electrical and mechanical performance than commodity-grade type F connectors, as well as adapters from type F to standard 75-ohm snap-on connectors. Complete cable assemblies to customer specifications using these connectors and matching coaxial cables. Applied Engineering Products is ISO-9001 verified as well as qualified to MIL-C-39012.

Applied Engineering Products
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RF Literature/Product Showcase

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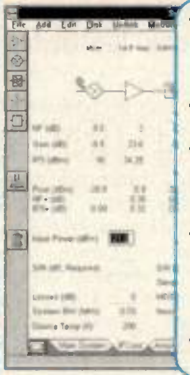

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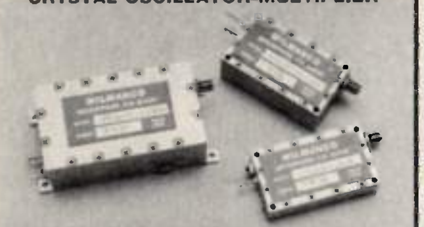

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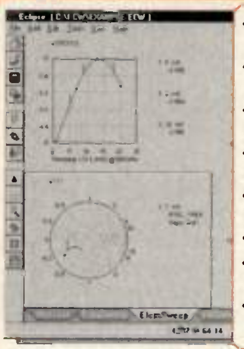

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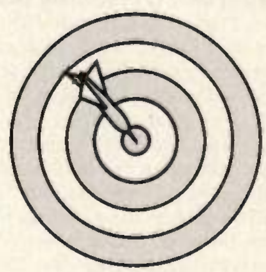

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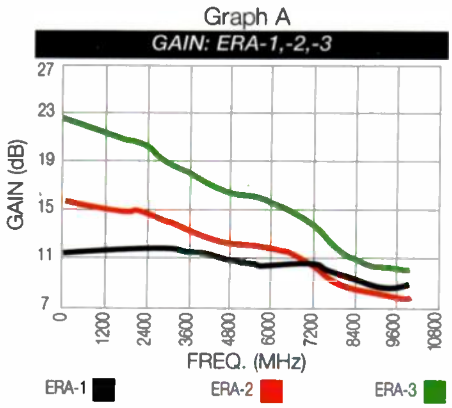
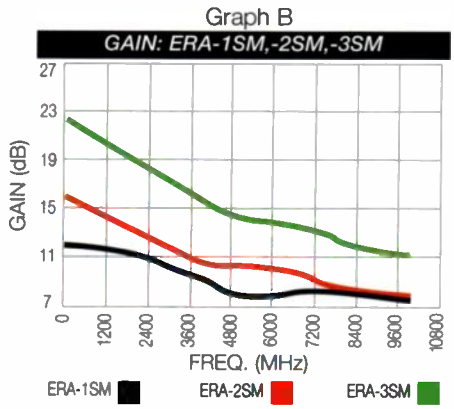
"Microwaves & RF" January 1996

Drop-In And SM MMIC Amplifiers Boost Signals Past 8 GHz

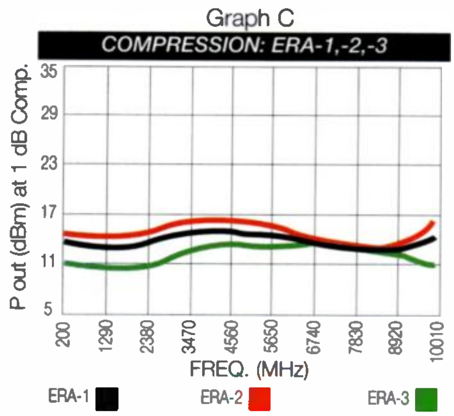
INEXPENSIVE signal gain is often required by system designers tc overcome losses from passive circuit elements and components. The ERA line of monolithic-microwave-integrated-circuit (MMIC, amplifiers from Mini-Circuits (Brooklyn, NY, provides generous levels of gain past 2 GHz (and usable pas 8 GHz) in drop-in and surface-mount packages.

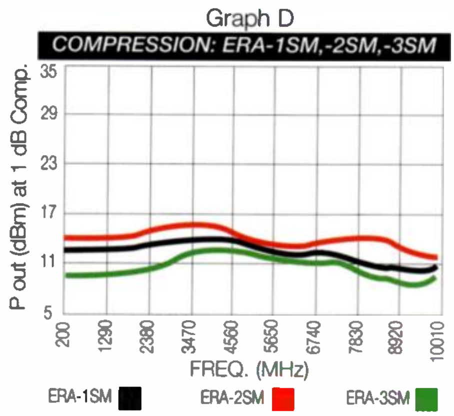
Based on heterojunction-bipolar-transistor (HBT) technology, the ERA amplifier line includes models ERA-1, ERA-2, and ERA-3 with 11.6, 15.0, and 20.0 dB typical gain levels, respectively, at 2 GHz. At frequencies as high as 10 GHz, the gain of the three amplifiers is still usable at respective levels of typically 9, 8, and 10 dB (Graphs A and B).





The gain of the ERA's extend to frequencies as high as 10 GHz.





The ERA-1's output power at 1 dB compression extends to better than +10 dBm at frequencies through 10 GHz.

Amplifier dynamic range-the differenc between the highest and the lowest possibl signal levels-is characterized by a component's noise figure for low-leve signals and its output power (at 1 dE compression) and third-order intercep point for high-level signals. In the case o the ERA-1, the noise figure is a moderate 7 dB at 2 GHz, while compressed outpu power is +13 dBm and third-order intercep point is +26 dBm at 2 GHz. The ERA-2 sports a slightly better noise figure of 6 dE at 2 GHz, with +14 dBm compressed output power and +27 dBm third-order intercept point at 2 GHz.

> *"...these low-cost MMIC amplifiers can provide performance comparable to higher-priced hybrid amplifiers..."*

The ERA-3 amplifier achieves an even better noise figure of 4.5 dB, with somewhat reduced output-power capabilities of +11 dBm compressed output powe and +23 dBm third-order intercept point (Graphs C and D). Note that the third-order intercept point of these amplifiers is about 13 dB higher than the 1 dB compression point, or about 3 dB better than comparable lumped-element or hybrid amplifiers. As a result, these low-noise MMIC amplifiers can provide performance comparable to higher-priced hybrid amplifiers, especially in multicarrier applications requiring wide-dynamic-range capability.

Broadband Matching

The ERA series amplifiers feature good broadband internal impedance matching to 50 Ω source and load connections. The typical input and output VSWR for the amplifiers is 1.80:1 for frequencies to 2 GHz and 2.00:1 for frequencies to 8 GHz. Such effective broadband impedance matching allows easy cascading and interface with other circuits without the need for additional elaborate matching networks.

VSWR: ERA PLUG-IN AND SURFACE MOUNT MODELS

Freq. (MHz)	ERA-1 In	ERA-1 Out	ERA-1SM In	ERA-1SM Out
100.00	1.67	1.48	1.71	1.54
2363.20	1.48	1.39	2.06	2.80
3494.80	1.55	1.48	1.97	1.80
4060.60	1.62	1.62	2.19	2.12
5758.00	1.62	1.80	2.35	2.31
6889.60	1.91	1.96	2.09	2.10
7455.40	2.12	2.16	1.98	1.97
8021.20	2.52	2.32	2.27	2.03
9152.80	2.98	2.35	2.44	2.44
10284.40	3.23	2.21	2.19	1.77

Freq. (MHz)	ERA-2 In	ERA-2 Out	ERA-2SM In	ERA-2SM Out
100.00	1.56	1.40	1.62	1.45
2207.50	1.43	1.41	2.00	1.91
3050.50	1.57	1.57	1.97	2.00
4315.00	1.55	1.58	1.90	2.03
5158.00	1.50	2.03	1.45	1.41
6857.40	1.77	2.65	1.81	1.70
7714.80	2.22	3.06	2.09	1.73
8143.50	2.52	3.03	2.77	1.77
9000.90	3.26	3.23	3.13	1.74
10287.00	4.26	3.60	5.59	2.36

Freq. (MHz)	ERA-3 In	ERA-3 Out	ERA-3SM In	ERA-3SM Out
100.00	1.79	1.96	1.98	1.95
2000.00	1.60	1.80	1.74	1.78
3263.60	1.48	1.64	1.64	1.89
4106.00	1.21	1.66	1.44	2.11
5369.60	1.11	1.64	1.46	1.98
6212.00	1.18	1.67	1.49	1.89
7054.40	1.36	1.73	1.27	1.61
8318.00	2.20	1.92	1.66	1.60
9160.40	2.57	1.72	2.10	1.70
10002.80	2.68	1.55	4.61	1.41

In a typical biasing configuration, DC blocking capacitors are added to the input and output ports (Fig.1). This configuration features common output and bias terminals, so an RF choke is added in series with a biasing resistor at the output port. Common values for these resistors span a broad range (Fig. 2). Additional bias resistor values can be calculated from:

$$R_{bias} = 1000\,(V_{cc} - V_d)/I_{bias} \quad (1)$$

where:

V_{cc} ***= the supply voltage,***

V_d ***= the device voltage (typically +3.8 VDC), and***

I_{bias} ***= the bias, current (in mA).***

The bias resistor appears in parallel with the 50 Ω output load. For example, with a +5 VDC supply, the bias resistor is 24 Ω for the ERA-1 and ERA-2 amplifiers. The RF current through the resistor is twice that of the RF output power. An RF choke can be added in series with the biasing resistor in order to minimize the effects of the resistor on the loss of gain and output power as well as on the output VSWR. The RF choke should have a reactance that is at least 10 times that of the load impedance (or at least 500 Ω) at the lowest operating frequency and it should be free of resonances up to the highest operating frequency.

Reliable Performers

The ERA amplifiers are designed for long-term, trouble-free operation. Their reliability is determined by the maximum junction temperature of the MMIC devices, which is in turn determined by the maximum operating temperature. The following formula is used for calculating junction temperatures:

$$T_j = T_{amb} + (P_d \times \theta_{jc}) \quad (2)$$

where:

T_j ***= the junction temperature (°C),***

P_d ***= the power dissipated in the amplifier (in W), and***

θ_{jc} ***= the thermal resistance from the junction to the case (in °C/W).***

For example, for the ERA-1 amplifier:

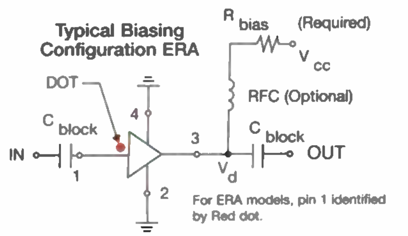
$$P_d = 3.8 \times 0.05 = 0.19W;$$

$$\theta_{jc} = 531°C/W \text{ at } +25°C \quad (3)$$

$$T_j = 25 + (0.19 \times 531) = +125\ °C \quad (4)$$

Fig. 1

TYPICAL BIASING CONFIGURATION



In this typical biasing configuration, DC blocking capacitors are added to the input port (pin number 1 on the packaged amplifier) and the output port.

An ambient temperature of +85°C results in a junction temperature of +185°C, which translates into a mean time to failure (MTTF) of more than 10 years. A junction temperature of just 5°C less results in a factor of four improvement in MTTF, while an increase of 15°C in junction temperature (over +185°C) drops MTTF to just 5 years (Graph E). As is obvious from these results, the MMIC amplifiers should provide long-term performance under normal operating temperatures.

The ERA series amplifiers are available in both drop-in and surface mount packages for ease of installation in most commercial systems. At +3.8 VDC, the ERA-1 and ERA-2 typically draw about 50 mA current while the ERA-3 draws about 35 mA current. All of the amplifiers are rated for operating temperatures from -25°C to +85°C.

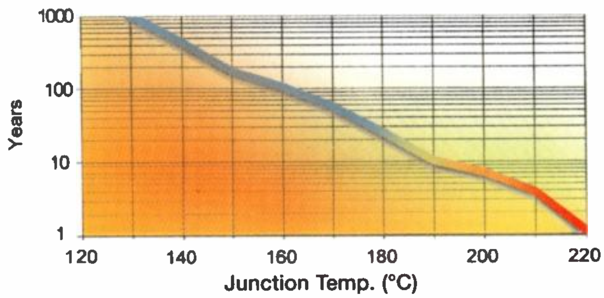
Fig. 2

ERA Resistor Values At Different Bias Voltages

	Supply Voltage			
Model	+5 VDC	+9 VDC	+12 VDC	+20 VDC
ERA-1	24Ω	104Ω	164Ω	324Ω
ERA-2	24Ω	104Ω	164Ω	324Ω
ERA-3	34Ω	149Ω	234Ω	463Ω

Graph E

MTTF vs. Junction Temperature



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All Specifications at 25°C

MODEL NO.	Δ FREQ. GHz f_l - f_u	GAIN, dB Typical over frequency, GHz 0.1	2	3	6	8	Min. @ 2 GHz	Flatness DC-2 GHz	MAXIMUM POWER, dBm at 2 GHz Output (1 dB Comp.) Typ.	Min.	Input (no damage)	DYNAMIC RANGE at 2 GHz NF dB Typ.	IP3 dBm Typ.	VSWR Typ. In* DC-3 GHz	In* 3-8 GHz	Out* DC-3 GHz	Out* 3-8 GHz	MAXIMUM RATING (25 °C) I (mA)	P (mW)	DC POWER at Pin 3 Current (mA)	Volt Typ.	THERMAL RESIS-TANCE θjc, typ. °C/W	Price $ (Qty 30)
ERA-1	DC-8	11.8	11.6	11.2	10.5	9.6	9	±0.15	13	11	15	7	26	1.6:1	2.2:1	1.5:1	2.1:1	75	330	50	3.8	531	1.37
ERA-2	DC-6	16.0	14.9	13.9	11.8	—	12	±0.6	14	12	15	6	27	1.5:1	1.5:1	1.5:1	2.0:1	75	330	50	3.8	531	1.52
ERA-3	DC-3	22.2	20.2	18.2	—	—	17	±1.1	11	8	13	4.5	23	1.7:1	—	1.8:1	—	75	330	35	3.8	432	1.67
ERA-1SM	DC-8	11.8	11.0	10.5	8.8	8.2	8.4	±0.5	13	11	15	7	26	1.8:1	2.2:1	1.7:1	2.2:1	75	330	50	3.8	536	1.42
ERA-2SM	DC-6	15.6	13.1	11.8	10.0	—	10.2	±0.9	13	12	15	6	27	1.8:1	1.7:1	1.7:1	1.9:1	75	330	50	3.8	536	1.57
ERA-3SM	DC-3	22.1	19.4	17.3	—	—	16.2	±1.5	11	8	13	4.5	23	1.8:1	—	1.9:1	—	75	330	35	3.8	437	1.72

Features

- *Miniature microwave amplifier*
- *Available in drop-in & surface mount (sm) versions*
- *Frequency range, DC to 8 GHz, usable to 10 GHz*
- *Excellent match 1.6:1 typ. below 3 GHz*

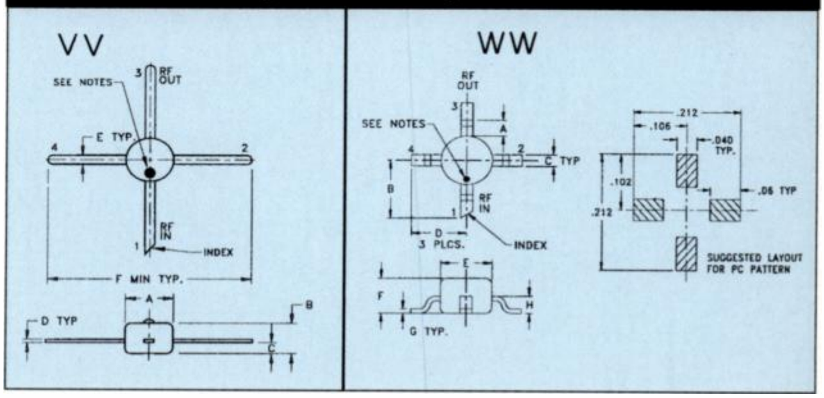
Absolute maximum ratings

Operating temperature: -25° to 85°C.
Storage temperature: -65° to 150°C.
Device voltage: 3.2 V min. & 4.4 V max.
Maximum case temperature: 200°C (for continuous operation).

Notes:

* *Up to 6 GHz for ERA-2 & ERA-2SM*
Δ *Low frequency cutoff determined by external coupling capacitors.*
A. *Units are non-hermetic unless otherwise noted.*
B. *Prices and Specifications subject to change without notice.*
① *Model number designated by alphanumeric code marking.*
2. *ERA-SM models available on tape & reel.*
3. *RF Input lead (1) identified by diagonally cut lead and orientation dot.. Model dash number identification by alphanumeric code.*

Case Style Outline Drawings And Dimensions



Case		A	B	C	D	E	F	G	H	WT. Grams.
VV 105	inch	.085	.060	.020	.008	.020	.256			.015
	mm	2.16	1.52	.51	.20	.51	6.50			
WW 107	inch	.020	.10	.020	.092	.085	.060	.008	.026	.015
	mm	.51	2.54	.51	2.34	2.16	1.52	.20	.66	

Pin Connections & Port:	RF In	RF Out	DC	Gnd Ext
	1	3	3	2,4

Marking ID: Model	ERA-1,-1SM	ERA-2,-2SM	ERA-3,-3SM
① Alphanumeric Code	E1	E2	E3

Designer's Kits Available

Kit No.	Model Type	No. of Units In Kit	Description	Price $ Per Kit
K1-ERA	ERA	30	10 of ea. ERA-1, -2, -3	49.95
K1-ERASM	ERA-SM	30	10 of ea. ERA-1SM, -2SM, -3SM	49.95

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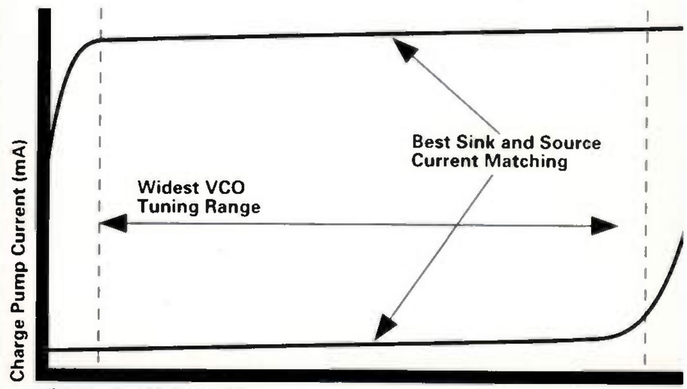

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