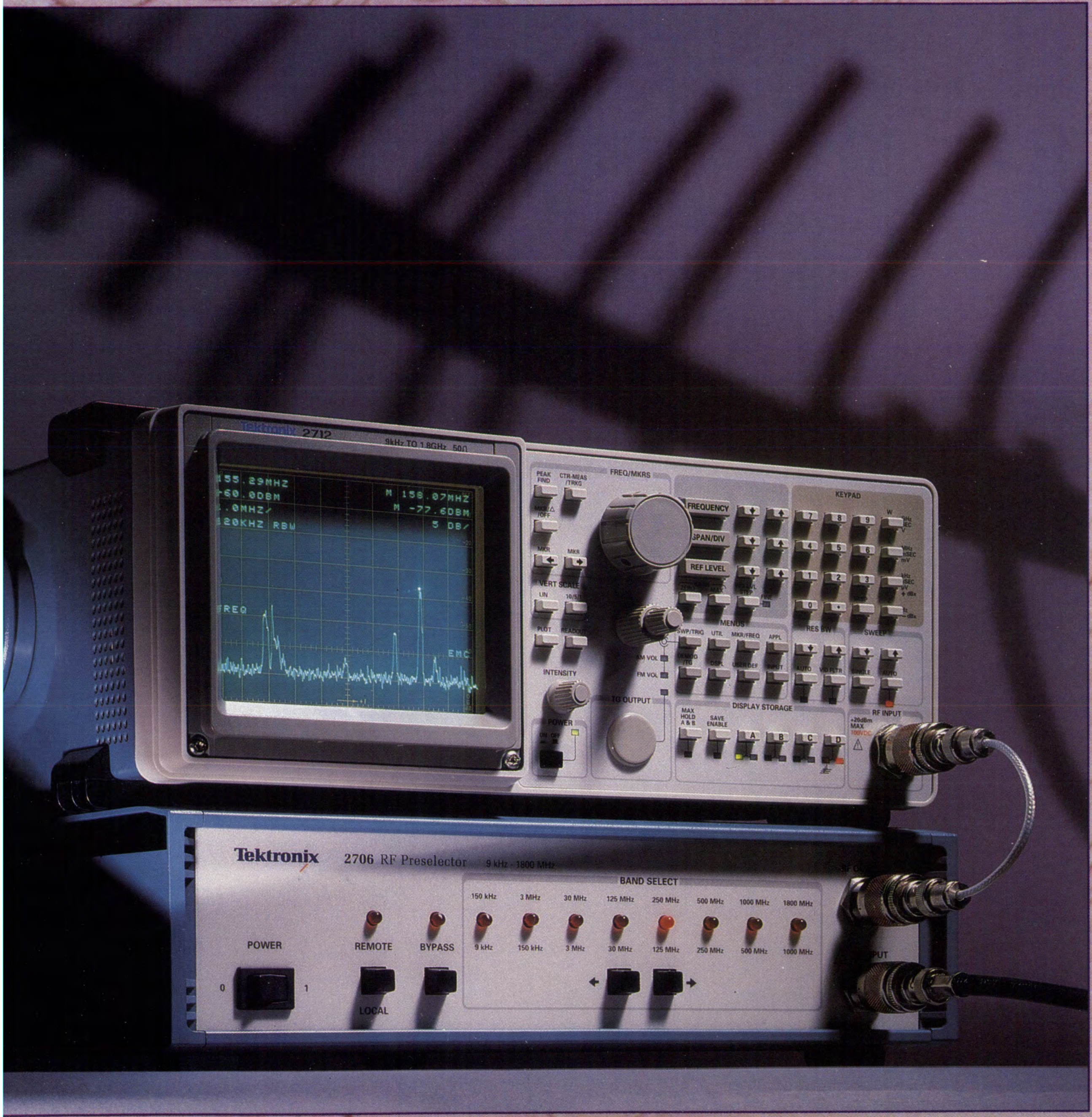
RF design

engineering principles and practices

August 1992



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2.00	8.00	4.5	29.0	1.20	15	DAMB6050
2.00	18.00	9.0	32.0	2.50	13	DAMB6063
2.20	2.40	2.3	18.5	0.50	10	DAML6073
4.00	8.00	3.0	30.0	1.00	15	DAML6023
5.90	6.40	2.0	30.0	0.50	10	DAML6084
6.00	12.00	5.0	23.0	1.00	22	DAMM6012
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INFO/CARD 3

AMPLIFIERS ATTENUATORS BIT DETECTORS COUPLERS MMICS MODULATORS PHASE SHIFTERS SWITCHES

RF design

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August 1992

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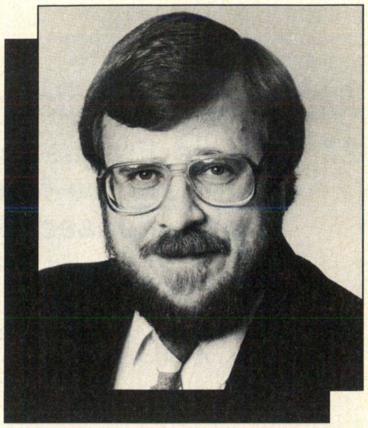
An EMC Wish List



By Gary A. Breed
Editor

This issue features electromagnetic compatibility, a key engineering factor in all RF products. With this subject in the forefront, here's my personal list of things that I hope can be done in the area of EMC:

Susceptibility standards — The FCC already has the authority to regulate the susceptibility of products to interference, but no regulations have been implemented. I think we need susceptibility standards because very few manufacturers are voluntarily paying attention to this aspect of performance. Yes, I am a ham operator, and fewer interference complaints would make my life easier, but too many complaints involve electronic gadgets that receive interference at extremely low RF field strengths.

A good example is inexpensive telephones. They are supposed to be purely audio products, yet many will rectify and amplify RF signals from nearby broadcast, amateur, CB and mobile radio services. Although some products like TVs and VCRs have been getting better, consumers are buying more electronic devices than ever, and they have a right to expect them to work reliably.

Frequency allocation — The past couple years have seen dozens of new uses for RF communications, from wireless computer networks to automatic toll collection. The revised FCC Part 15 rules can accommodate many of these new services, but certainly not all of them. Ideas like an improved cordless telephone system get my vote for quick action — my neighborhood has so many 46/49 MHz units that there isn't a channel that is totally interference-free! The sheer number of other proposed wireless applications requires some accommodation for the most promising of them.

In this regard, the FCC is wrestling with the problem of what to do with existing users of the spectrum around 2 GHz. I can appreciate the political difficulty in dealing with unhappy communications users who must move to another part of the spectrum to fit in new services. However, regulation of the radio spectrum is a dynamic process that must respond to markets and technologies.

Engineer awareness — I hope every engineer, his boss, and his boss's boss all understand how important it is to deal with unwanted electromagnetic effects early in the design process. Those RF designers who understand EMC tell me that even a few simple concepts can help with both radiation and susceptibility. Strategically-placed 2-cent bypass capacitors, minor changes in p.c. board layout or careful routing of cables can contribute many dB toward improved EMC performance. These practices result in a more reliable product in the customer's own environment, which has plenty of possible victims and sources of interference.

Ok, so I got on my soapbox — but these matters affect all of us in the RF industry, both professionally and as consumers. At a time when quality, productivity and competitiveness are high on the business agenda, ideas that make better products and happy customers should be taken seriously.

RF design

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Letters should be addressed to: Editor, *RF Design*, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Published letters may be edited for length or clarity.

Device Specification Comments

Editor:

These are comments on the tutorial articles, "Diode Detector Types and Specifications" and "RF Transistor Specifications" in the May and June issues of *RF Design*. The tutorial idea is good, and the need to keep reminding designers — especially the younger ones — about things to watch out for in device specifications is clear. The need for accuracy in all details may be arguable, but you may hear from a few sleeve-tuggers like me.

In the diode detector tutorial, you state, "the physics of its [Schottky barrier diode] operation are the same as the PN junction diode..." That is misleading, since the p-n diode depends on minority carriers for its operation. Those minority carriers produce the main limitation of the p-n diode in high-speed switching or RF detection applications. Charge is stored in the junction — in the form of minority carriers — during forward conduction. On reversal of the voltage across the diode, the stored charge must be swept out, and that may take nanoseconds, or even microseconds. The main advantage of the Schottky diode is not lower capacitance or lower series resistance, but is instead its essential freedom from minority carrier effects. There are, in fact, great differences in the physics of operation of these two diode types.

Regarding the tutorial on transistor specifications, I really must wave a red warning flag about "typical" characteristics. Every AC characteristic shown on the example data sheet is typical; nary a one is guaranteed. Without min/max guarantees there is no way to feel confident that the manufacturer is dedicated to offering a consistent product month after month and year after year. There is no way to test for compliance with a "typical" characteristic that has no min or max limit associated with it. I find myself repeatedly cautioning designers to avoid depending on those essentially meaningless "typical" numbers.

Larry Johnson
Materials Engineer, Semiconductors
Trimble Navigation

FilDes Corrections

A couple minor corrections are necessary for the article "FilDes: A Filter Design System for the RF Engineer" by Bob Lombardi in the June '92 issue. First, the statement after equation (7) should read: (3 dB BW specifications multiply this by $\cosh(\phi)$) — not $\cosh(b)$. Following equation (9), the expression for g[k] should be numbered as equation (10), and the comment after it should be corrected to read: (multiply by $\sqrt{\cosh(\phi^2)}$ for 3 dB BW).

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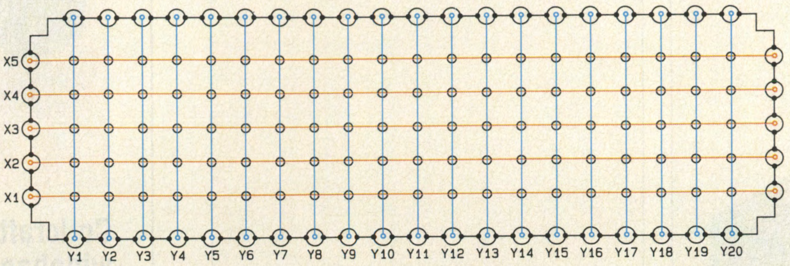

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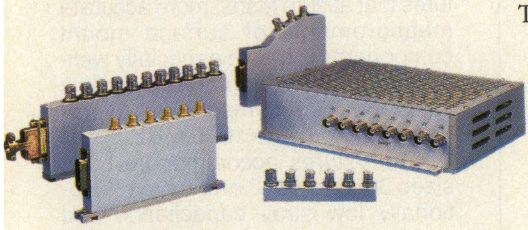

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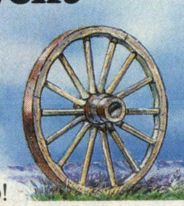

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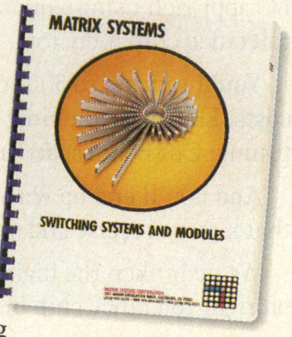

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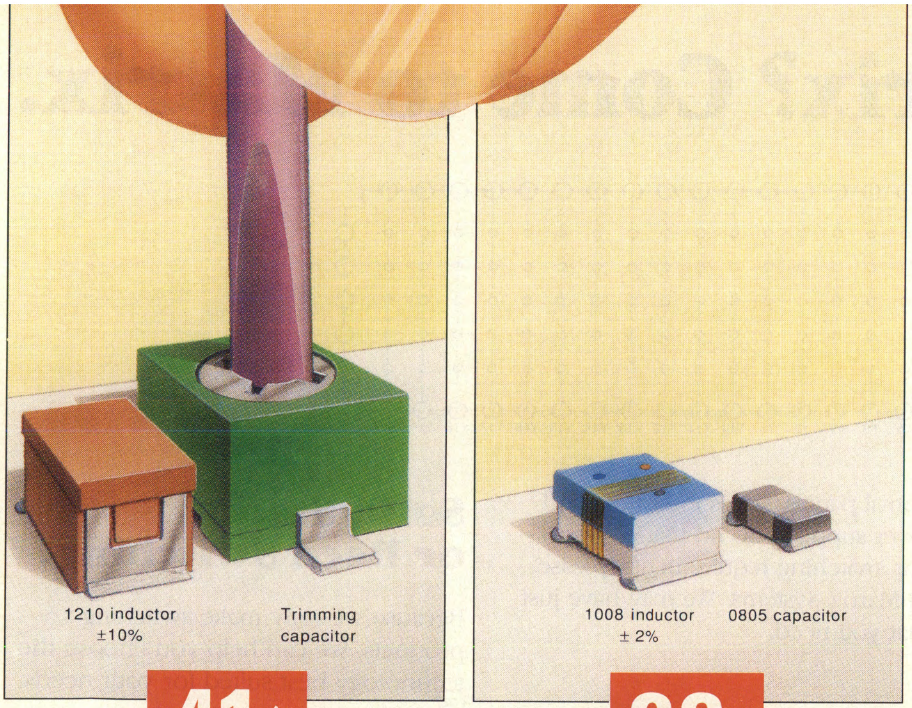

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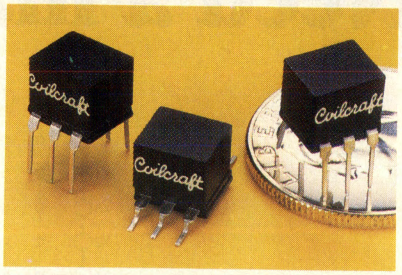

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INFO/CARD 12

RF calendar

August

18-20 **IEEE International Symposium on Electromagnetic Compatibility**
Anaheim, CA
Information: Oscar Crawford, Jr., Rockwell. Tel: (213) 922-4091.

24-26 **22nd European Microwave Conference**
Helsinki, Finland
Information: Microwave Exhibitions and Publishers, 90 Calverley Road, Tunbridge Wells, Kent TN1 1BR, England.

30-3 **Surface Mount International**
San Jose, CA
Information: EIA, 2001 Pennyslvania Avenue, NW, Washington, DC 20006-1813. Tel: (202) 457-4900. Fax: (202) 457-4985.

September

2-4 **International Mobile Communications Expo/Fall**
Atlanta, GA
Information: Cardiff Publishing, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600. Fax: (303) 770-0253.

9-12 **NAB Radio Show**
New Orleans, LA
Information: '92 NAB Radio Show Registration, 1771 N Street, NW, Washington, DC 20036-2891. Tel: (800) 342-2460. Fax: (202) 775-2146.

15-17 **The 14th Annual Piezoelectric Devices Conference and Exhibition**
Kansas City Westin Crown Center
Information: Peter J. Walsh, Staff Vice President, Components Group, Electronic Industries Association, 2001 Pennsylvania Avenue, N.W., Washington, DC 20006. Tel: (202) 457-4932.

21-24 **Eighth International Conference on Electromagnetic Compatibility**
Edinburgh Conference Centre, UK
Information: Conference Services, IEE, Savoy Place, London, WC2R 0BL, UK. Tel: (44) 071 240 1871. Fax: (44) 071 240 7735.

22-24 **RF Expo East**
Tampa, FL
Information: Barb Binge, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600, (800) 525-9154. Fax: (303) 773-9716.

29-2 **1st International Conference on Universal Personal Communications**
Dallas, TX
Information: ICUPC '92 Registration, c/o Bob McFadden, NEC America, Inc., 1525 Walnut Hill Lane, Irving, TX 75038. Tel: (214) 518-5341. Fax: (214) 518-5160.

Here's where the top industry professionals share their knowledge on today's most important topics:

TUESDAY, SEPTEMBER 22

Exhibit Hall Open 11am-6pm

Time	Session 1	Session 2	Session 3
8:30-11:30	**A-1: CAD Techniques I** Computer-Aided Design of RF Circuits by the Addition of New Components Practical Applications of Non-Linear Analysis, Simulation and Measurement Techniques Practical Object Oriented CAE for RF Engineers	**A-2: Medical and Scientific Applications** ATS-3: Celebrating 25 Years of Service in Space Signal Synthesis for Controlled Particle Extraction from High-Energy Accelerators Noncontacting Coal and Rock Thickness Measurement with a Vector Network Analyzer	**A-3: Wireless Communications Applications** A Rapid Acquisition Technique of Spread Spectrum Signals Embedded in an ASIC Costas Phase Locked Loop Field Strength Measurements for FCC Compliance Pulse Shaped PSK Modulators Using Direct Digital Synthesis
Also 8:30-11:30	**RECENTLY ADDED TO THIS YEAR'S PROGRAM: AN A/D Converter Tutorial "Understanding Data Converter Frequency Domain Specifications"**		
11:30-1:30	**Deli Luncheon**		
1:30-4:30	**B-1: CAD Techniques II** RF Design with the HP-48 Comparing Simulation Methods for RF Designs Measurement of RF Components in a Microstrip Environment	**B-2: Complex Modulation** A Network Theoretic Approach to the Reduction of Distortion in Quadrature Detectors The Vector Discriminator Third Generation Spread Spectrum S-Band Transponder	**B-3: Advanced Design Methods** Iterative Algorithms for the Design of Arbitrary Phase Finite Impulse Response Functions Image Compression Reduces Bandwidth Requirements The Role of High Temperature Superconductivity (HTS) in Electronics Warfare

WEDNESDAY, SEPTEMBER 23

Exhibit Hall Open 11am-6pm

Time	Session 1	Session 2	Session 3
8:30-11:30	**C-1: RF Systems I** Choosing the Optimum Synthesizer Architecture for your Receiver Application CW Rejection Optimizing Performance of Collocated UHF and VHF Ground to Air Radios	**C-2: Filter Design** IF Transversal Filtering Catalog of Rhodes Filter Transfer Functions and Element Values Synthesis of Low-Pass Filters Containing Quads of Zeros	**C-3: Oscillators and Synthesizers** Modern Methods of Frequency Control Self-Adaptive VCO A CAD and Optimization Program for Microwave Oscillators
11:30-1:30	**Open Lunch**		
1:30-4:30	**D-1: RF Systems II** A Simple Road Information Transmitter Waveguide and Coax Components for High Power Broadcasting An Image Improvement of Microwave Diffraction Tomography for 2-Dimensional Inhomogeneous Dielectric Cylinder Based on Projection Function	**D-2: Crystal and SAW Filters** Crystal Filters Having Superior In-Band and Out-of-Band Intermodulation Characteristics Extensions of the Holt & Gray Crystal Filter Design Technique Modular Implementation of the Coupling of Modes Analysis for Surface Acoustic Wave Resonators	**D-3: Components for New Applications** A Versatile Mixed-Signal Cell-Based Array for Wireless Receiver ASICs Multiple Modem Configurations Realizable With One Set of Off-The-Shelf Stanford Telecom ASICs Pushing Low Quiescent Power Op-amps to Greater Than 55dBm 2-Tone Intercept, and an Automated Very Wide Dynamic Range Measurement Approach to Assess These Exceptionally Low Spurious Levels

THURSDAY, SEPTEMBER 24

Exhibit Hall Open 9am-1pm

Time	Session 1	Session 2	Session 3
8:30-11:30	**E-1: High Power Applications** A 1kW RF Amplifier for UHF 470-860MHz Television Applications Design Considerations for Solid State High Power Amplifiers Used in Radar A Quasi-Complementary Class D Amplifier	**E-2: Small-Signal Design** An S-Parameter Based Amplifier Design Program Noise Measurement on Microwave Devices Using a Scalar Analyzer Predicting Noise Contributions in RF Circuits	**E-3: Test and Measurement** What Ever Happened to the Q Meter? Selecting the Right Frequency Domain Measuring Instrument Design and Optimization of Lumped-Element LCM Directional Couplers

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RF Circuit Design I: Fundamentals and Passive Circuits — September 22

The recently revised version of this highly popular course provides an introduction to RF circuit concepts, without an intimidating amount of complex mathematics. Switching from definitions based on voltages and currents, the course introduces power-flow concepts, transmission line fundamentals, scattering parameters, leading to graphical circuit manipulations through the Smith Chart. RF component models in their physical forms are examined, discussing parasitic effects and losses of "real-life" resonant circuits and filters. Impedance matching is reviewed by both analytical and graphical techniques, considering Q and bandwidth relationships. Interactive, video-projected CAE illustrations add to the understanding of the topics covered. Instructor: Les Besser, president, Besser Associates Inc.

RF Circuit Design II: Active Components and Circuits — September 23

A sequel to Part I, this course begins by reviewing PIN diode devices, switches and attenuators. Narrow- and broad-band, small-signal and low-noise amplifier design techniques are introduced via s-parameter techniques, including stability and bias network effects, leading to linear power amplifier performance considerations. Trade-offs of unilateral (assuming $s_{12} = 0$) and bilateral design are examined. Wide-band feedback amplifier design, its advantages and limitations are also discussed. Illustrative examples of linear and nonlinear amplifier performances are shown. Instructor: Les Besser, president, Besser Associates Inc.

Oscillator Design Principles — September 24

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Linear & Nonlinear System Analysis and Identification
September 15-17, 1992, Washington, DC
Modern Microwave Techniques
September 21-24, 1992, Del Mar, CA
Navstar/GPS: Design and Applications
October 14-16, 1992, Washington, DC
Information: University Consortium for Continuing Education. Tel: (818) 995-6335. Fax: (818) 995-2932.

RF Component Modeling
August 24-26, 1992, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (310) 825-1047. Fax: (310) 206-2815.

Personal and Mobile Radio Systems
September 6-11, 1992, Swansea, UK
Digital Signal Processing: Principles, Devices and Applications
September 27-October 2, 1992, Leicester, UK
Information: IEE, Savoy Place, London WC2R 0BL, United Kingdom.

Global Positioning System: Principles and Practice
September 9-11, 1992, Washington, DC
Introduction to Radar ECM and ECCM Systems
September 9-11, 1992, Washington, DC
Lightning Protection
September 10-11, 1992, Washington, DC
Modern Receiver Design
September 14-18, 1992, Washington, DC
October 26-30, 1992, Amsterdam, Netherlands
Microwave Radio Systems
September 16-18, 1992, Washington, DC
Communications Satellite Engineering
October 5-9, 1992, Washington, DC
Personal Communications Systems and Networks (PCS and PCN): A Telecommunications Revolution
October 7-9, 1992, Washington, DC
Mobile Cellular Telecommunications Systems
October 14-16, 1992, Washington, DC
Communications and Radar Signals: Detection, Estimation & Geolocation Techniques
October 14-16, 1992, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Merril A. Ferber. Tel: (202) 994-8522 or (800) 424-9773.

Electrostatic Discharge in Integrated Circuits
October 15-16, 1992, Burlingame, CA
Design of Superconductive Integrated Circuits
August 20-22, 1992, Chicago, IL
Information: Continuing Education in Engineering, University Extension, University of California, Berkeley. Tel: (510) 642-4151. Fax: (510) 643-8683.

Advanced Digital Communications
August 24-28, 1992, Anaheim, CA
Information: Technology Service Corporation, Lynda S. Epstein, Training Coordinator. Tel: (301) 565-2970. Fax: (301) 565-0673.

The EC Directive on EMC
August 17, 1992, Anaheim, CA
Information: Technology International, Inc. Tel: (804) 644-7735 or (800) 242-8399.

Satellite Communications and Broadcasting
August 24-29, 1992, Davos, Switzerland
Far-Field, Compact and Near-Field Antenna Measurement Techniques
August 31-September 4, 1992, Davos, Switzerland
Digital Receivers for Satellite and Mobile Communications
August 31-September 4, 1992, Davos, Switzerland
Digital Signal Processing in Modern Communication Systems
September 14-18, 1992, Davos, Switzerland
Adaptive Signal Processing
September 16-18, 1992, Davos, Switzerland
Personal Wireless Communications: Cellular Telephony, Portable Computing, and Broadband Wireless Networks
September 21-25, 1992, Davos, Switzerland
Information: CEI-Europe/Elsevier, Mrs. Tina Persson. Tel: (46) 122-175-70. Fax: (46) 122-143-47.

ISO 9000 Introduction and Company Registration
September 15-16, 1992, Danbury, CT
ISO 9000 Internal Auditor Course
September 17-18, 1992, Danbury, CT
Information: TUV Rheinland. Tel: (313) 464-8881.

Transient Immunity Tests According to IEC and CENELEC: Theory and Hands on Demonstrations
August 25, 1992, Woodland Hill, CA
August 27, 1992, Santa Clara, CA
Information: Dawne Fay, Haefely Test Systems, Inc. Tel: (703) 494-1900.

EMC Foundation Course
October 21, 1992, Harrogate, Yorkshire, UK
November 4, 1992, Guildford, Surrey, UK
Information: Surrey Conferences. Tel: (44) 0784 461393.

RF Component Modeling
August 24-26, 1992, Los Angeles, CA
Information: Besser Associates, Eva Koltai. Tel: (415) 949-3300. Fax: (415) 949-4400.

Electronic Design Techniques and Analysis Required to Meet Electromagnetic Compatibility Requirements
September 23-24, 1992, Novi, MI
Advanced EMC Printed Circuit Board Design
September 25, 1992, Novi, MI
Information: JASTECH. Tel: (313) 553-4734.

DSP Without Tears
August 17-19, 1992, Orlando, FL
September 2-4, 1992, San Jose, CA
September 9-11, 1992, Norcross, GA
Information: Z-Domain Technologies. Tel: (800) 967-5034. Fax: (404) 442-1210.

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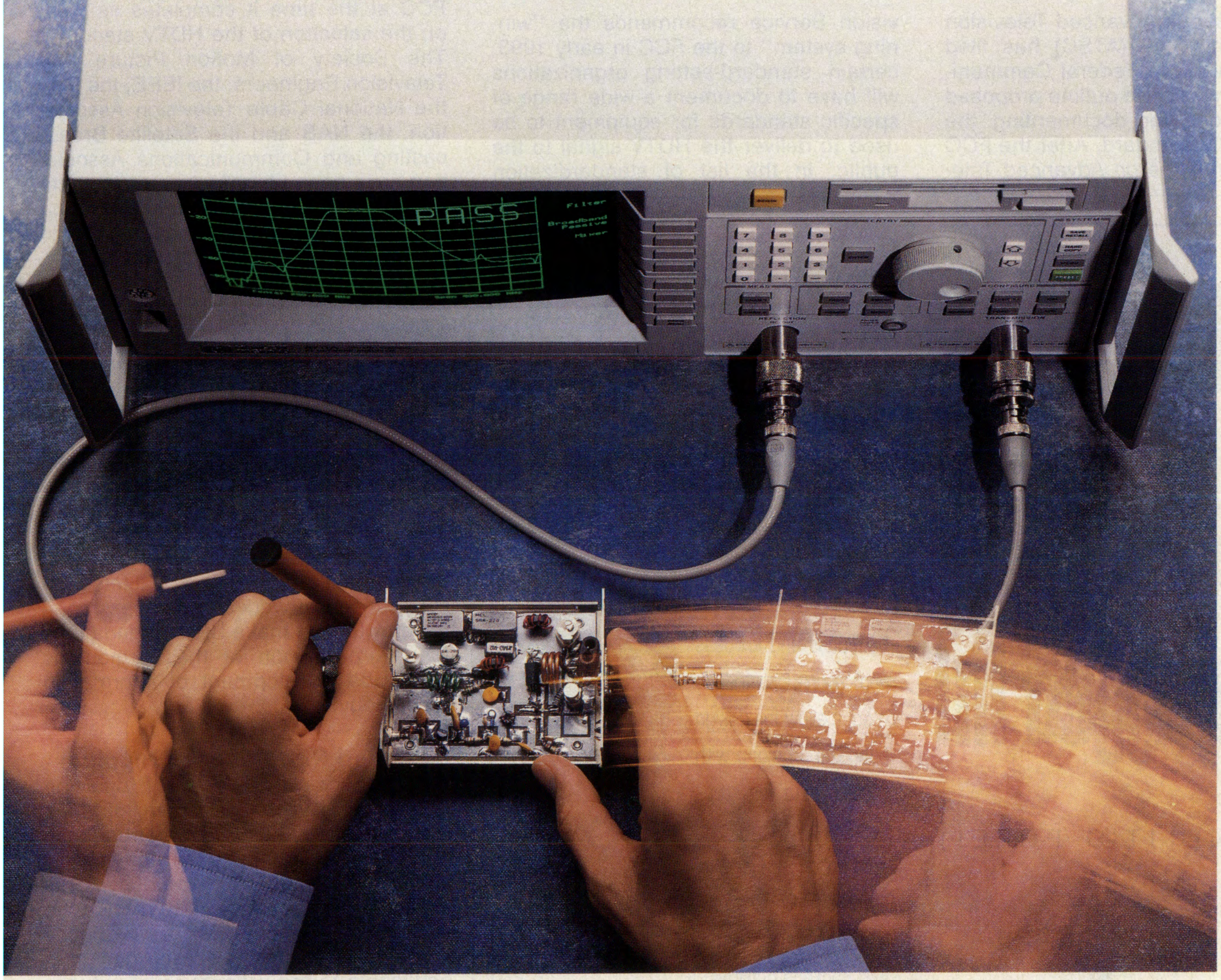

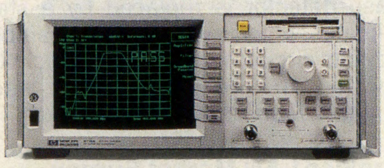

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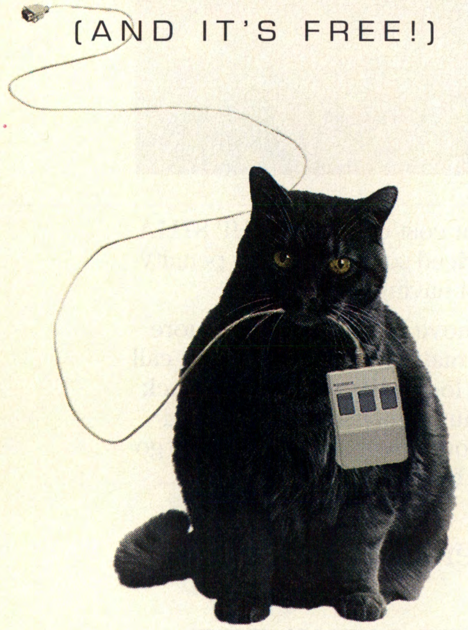
ATSC Proposes Industry Activities for Documenting HDTV Standard

The United States Advanced Television Systems Committee (ATSC) has filed information with the Federal Communications Commission to outline proposed industry actions for documenting the selected HDTV standard. After the FCC Advisory Committee on Advanced Television Service recommends the "winning system" to the FCC in early 1993, certain standard-setting organizations will have to document a wide range of specific standards for equipment to be used to deliver the HDTV signal to the public. In the list of standardization activities, the ATSC has been assigned responsibility for issues which must be resolved quickly for consideration by the FCC at the time it completes its work on the selection of the HDTV standard. The Society of Motion Picture and Television Engineers, the IEEE, the EIA, the National Cable Television Association, the NAB and the Satellite Broadcasting and Communications Association have been identified as appropriate organizations for the standardization work which will need to be done after the FCC selects the winning system.



World Telecommunications Advisory Council Established — Members of the International Telecommunication Union have agreed to create a World Telecommunications Advisory Council. The council will provide the ITU with strategic advice from the public and private sectors on the telecommunication environment and how the Union's principal activities could be carried out more effectively. The council will also consider the state of the global telecommunications network and services, monitor growth and make recommendations for the promotion of the harmonious worldwide development of information technology.

Improved PLL Reduces Ripple — Researchers at NASA's Jet Propulsion Laboratory have developed an improved phase locked loop for a frequency demodulator that uses a frequency-to-voltage converter which produces less ripple. Originally intended to reduce the noise in a receiver for a frequency modulated telemetry link, the design is applicable to the processing of virtually any received FM signal. In this PLL, the phase detector is replaced by a state estimator which uses a ramp/sample-and-hold circuit. This work was originally reported in the June 1992 issue of *NASA Tech Briefs*.

Wireless LAN Market Survey — A recently published report by Strategies Unlimited predicts that the U.S. wireless LAN market will reach $440 million by 1996. "The U.S. Market for Wireless Local Area Networks" reviews: the personal computer market, the mobile computing market, the FCC regulatory environment, the networking and connectivity environment, the competitive environment and the technical outlook. The report also provides a detailed market forecast as well as a component forecast for RF assemblies including GaAs, silicon, and passive components. For more information regarding this report contact Strategies Unlimited, 201 San Antonio Circle, Suite 205, Mountain View, CA 94040. Tel: (415) 941-3438.

QUALCOMM Awarded Digital Cellular Patent — QUALCOMM recently announced that it has been awarded a patent for its method of providing "soft" hand-off in a Code Division Multiple Access digital cellular telephone system. Benefits of this patent include reduced power consumption by a mobile unit and an increase in overall system capacity and reliability. The soft handoff utilizes a make before break approach when handling a call which reduces the chance of a break in communications.

Development Program for Wireless LANs — GEC Plessey Semiconductors has released functional prototypes of a 2.4 GHz frequency hopping wireless transceiver for the wireless LAN market. They conform to FCC Part 15 regulations and therefore do not require licenses for operation. The transceivers have low power consumption with up to 1 MB/sec. data rates.

Power Amplifier Patent Awarded — Motorola's Cellular Subscriber Group was recently granted a patent for a new power amplifier. Phones that incorporate the patent can provide dual mode cellular AMPS/TDMA telephone users with up to 30 percent improvement in AMPS mode talk time.

U.S. Markets for Power Amplifiers to Grow — U.S. markets for bipolar transistor power amplifiers are expected to grow 13 percent annually through 1994, according to a recently published report on the U.S. amplifier and discrete semiconductor markets. Other large growth areas include silicon power semiconductors and GaAs MMICs. Cellular and satellite communications, GPS and personal communication network testing are among the many products and services driving demand for amplifiers and their building blocks. The report "RF & Microwave, Power and Low Noise Amplifiers, 1991-1994 Analysis," is available from ABI, 793 Fort Salonga Road, Northport, NY 11768. Tel: (516) 754-0836.

Watkins-Johnson Wins Contract — Watkins-Johnson Company recently announced that it has been awarded a contract valued at $3.1 million by Raytheon Company. Under the contract, W-J will deliver continuous-wave acquisition and tracking receiver subsystems for shipboard use as part of the TARTAR missile fire-control system for the U.S. Navy. The contract includes an option for an additional $1.7 million.

Flam & Russell to Provide Instruments for Aircraft Test Facility —FFV Aerotech AB of Sweden has awarded a contract to Flam & Russell, Inc. for the supply of the test instrumentation for a new full-scale aircraft antenna test range. The range will permit the automated testing of a wide variety of antennas while mounted on a complete full-scale aircraft. In addition to conventional antenna pattern measurements over the 0.1 to 18 GHz band, the system is also designed to test ECCM techniques. This is accomplished by the provision of multiple jamming transmitters located at several points on the range. Jamming transmissions are controlled by the measurement system controller which is based on the Flam & Russell Model 959 Antenna Measurement Workstation.

Advanced Energy Licenses RF Power Amplifier Circuit — Advanced Energy Industries recently received from Design Automation, Inc. a license to manufacture and sell RF generators incorporating Design Automation's patented Class-E high-efficiency RF power amplifier circuit. Use of the Class E design in the drive circuits for the Advanced Energy proprietary power amplifiers contributes to the small size and light weight of the generators. License terms were not disclosed.

M/A-COM Antenna & Cable Division Named Sole Supplier — Boeing recently selected M/A-COM, Inc. Antenna & Cable Division as its sole source supplier of GPS antennas for Boeing's new line of 777 aircraft. M/A-COM will deliver initial production hardware later this year. Other terms of the contract were not released.

AEL Receives Modification Award — AEL Defense Corp and Lockheed Sanders have received a $38.2 million contract modification from the U.S. Army for eight electronic countermeasure engineering development models of the tactical communications jammer system. The contract, which includes associated hardware and software, adds a modular countermeasures (jamming) capability against modern modulation tactical radios and is used in conjunction with the TACJAM - an Electronic Warfare Support Measures subsystem.

Motorola Awarded Nationwide Cellular Mobile Data Network — Motorola, Inc., has announced an agreement with United Parcel Service to provide modems and telecommunications equipment for the country's first nationwide cellular mobile data network. The $150 million investment in cellular data technology will include the manufacture and support for an in-vehicle communications system, including more than 50,000 cellular telephone modems.

Giga-tronics Acquires Wavetek's Microwave Division — Giga-tronics Inc. recently announced the acquisition of the Microwave Division of Wavetek Corp. The acquisition is part of a strategy that Giga-tronics initiated two years ago for expansion into new product and market segments. Final terms of the deal were not released.

Cross Systems Division Wins Contract — The Cross Systems Division of AEL Defense Corp., has been awarded a contract for $3.0 million from Phoenix Air. The award is in support of the Contract Training Flight Services (CTFS) Program which provides air-to-air intercept training for fighter aircraft in a simulated enemy jamming environ-

ment. Cross Systems will provide the electronic warfare suite which contains many improvements over the previous CTFS configuration, and reflects recent improvements in threat self-protection pods.

Centel to Commercialize NAMPS Technology — Centel Cellular has announced that they will commercialize Motorola's Narrowband Advanced Mobile Phone Service technology. NAMPS is a digitally enhanced analog technology which will allow Centel Cellular to triple the capacity of its current analog system, offer its customers digital messaging services and ease the migration to a digital cellular network.

Sensormatic Signs Reseller Agreement — Sensormatic Electronics Corp. has announced that it has signed a reseller agreement with Texas Instruments to market TI's TIRIS™ RF identification technology in industrial security applications. TIRIS is an electronic, low-frequency radio ID technology. Sensormatic plans to use this system in a variety of applications such as asset management, and personnel and vehicle access control.

General Instrument to Purchase General Semiconductor's Operations in Ireland — The Power Semiconductor Division of General Instrument Corp. has signed an agreement with Square D Company, the parent of General Semiconductor Industries for the purchase of all of GSI's operations in County Cork, Ireland and certain other product lines which are currently in production in their Tempe, Arizona facility. The acquisition will expand PSD's position in the high growth transient suppression market. Terms of the acquisition were not announced.

Richardson Opens Division — Richardson Electronics has announced the opening of its Cetron Communications Division. The new division will offer service on all popular tube types, semiconductors and CCTV equipment. They can be reached at (800) 238-7661 or Fax (708) 208-3750.

Cable Systems Acquires Connector Technology Corp. — Cable Systems, Inc., has acquired Connector Technology Corporation from the Rockbestos Company. CTC joins the HVT Group which was formed earlier this year by Cable Systems and Dielectric Sciences. Terms of the acquisition were not released.

Krystinel Undergoes Name Change — Krystinel Corporation recently announced a name change to MMG-North America. The change in nomenclature highlights the company's affiliation with the MMG worldwide network of manufacturing and sales outlets.

Tecknit Purchases Electro-Kinetic Systems Division — Tecknit announced the purchase of the assets of the EKS Norland Division of Electro-Kinetic Systems. EKS-Norland was involved in the manufacture and sale of electrically conductive composite materials for EMI shielding.

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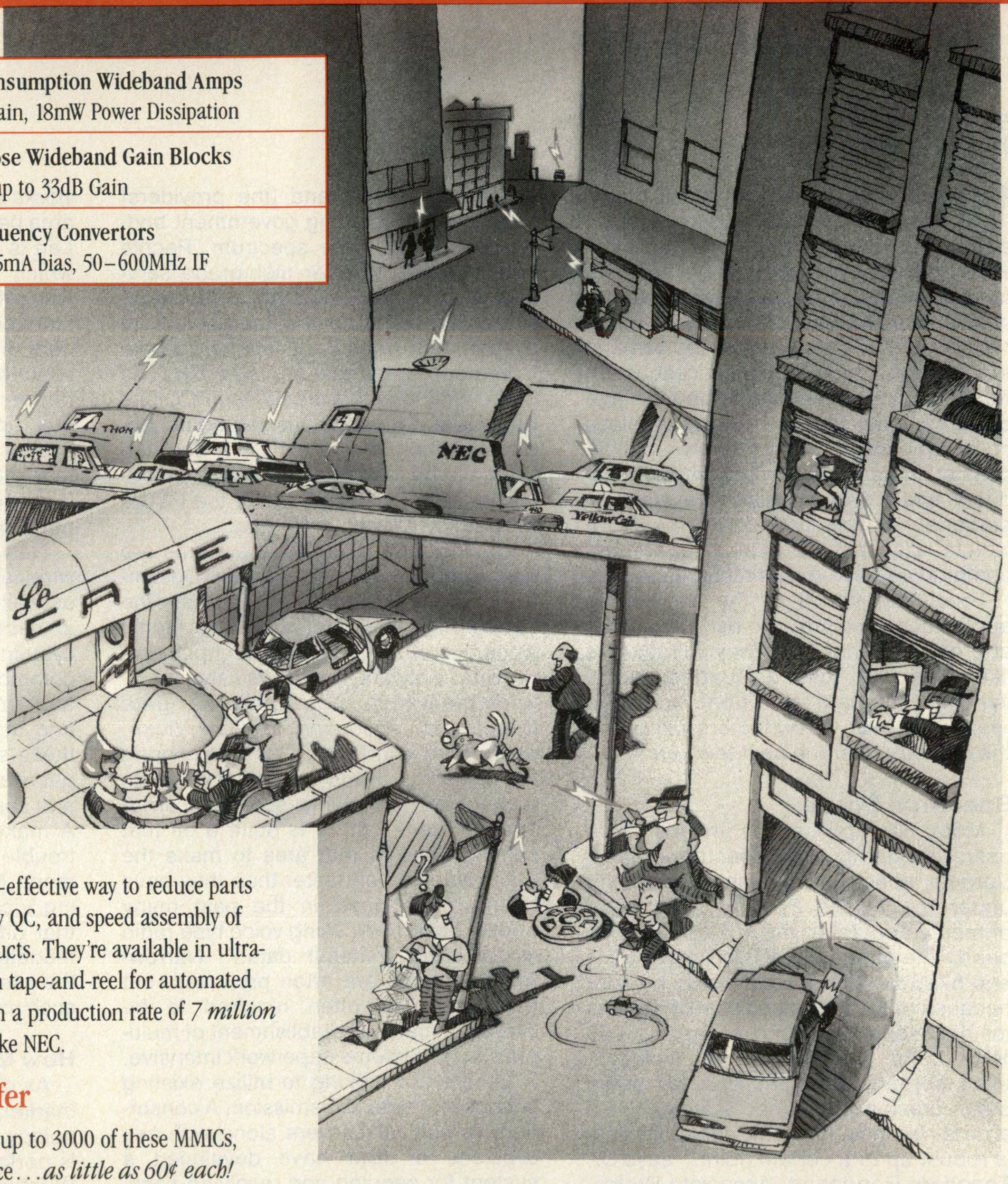

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INFO/CARD 21

Wireless Data Communications Try To Fit In

By Andy Kellett
Technical Editor

Wireless data communications are expected to be the next segment of the electronics industry to take off. This is not too surprising when you consider that laptop computers and mobile voice communications are segments that are booming now. All of these areas reflect the demand for mobility. A number of applications are ready to take advantage of the marriage between data processing and wireless communications: from narrow applications such as telemetry between a transducer and a data acquisition system, to personal communication systems (PCS) which will provide voice and data communications in a small handset.

Predicting which of the developing applications will prove to be truly useful, and exactly what form they will take, is like trying to toss a quarter into a vending machine slot from across a room. However, a few factors will shape the industry over the next few years.

Spectrum Space

More RF applications means more users, requiring more spectrum space. Spread spectrum systems operating under the FCC's Part 15 rules have primarily populated the 902 to 928 MHz band. The bands at 2400 to 2483.5 MHz and 5725 to 5850 MHz are less popular because of the increased cost of devices for the higher frequencies. As the 900 MHz band becomes more crowded, even spread spectrum systems could begin crashing. "Spread spectrum has an interference rejection capability that is robust up to a certain point." says Dr. Theodore Rappaport, Associate Professor of Electrical Engineering and Director of the Mobile and Portable Research Group at Virginia Polytechnic Institute and State University. "You have a soft degradation of performance as the number of users increases, however, once you hit a critical point in an uncoordinated way, the system may fail."

In addition, Part 15 devices are unprotected against interference from outside sources. Rappaport notes, "A lot of wireline type providers have been reticent to use the ISM bands because they are not protected and [the providers] have been pressuring government bodies to free up more spectrum. People cannot afford to offer high-grade services in a band that is not protected." Protected space for a spread spectrum system has been requested by Apple Computer and others around 2 GHz. As of the writing of this article, the FCC has not made any decisions regarding Apple's petition, but the FCC's decision will have been made by July 16 according to David Siddall, Chief of the FCC's Frequency Allocation Bureau.

Narrowband modulation systems are also vying for spectrum space. Designers of these systems work to retain the narrowband character of these systems while increasing data throughput. Improving network protocols and radio implementation can increase data throughput. According to Alan Victor, co-founder and Director of Engineering for Monicor, "From an implementation standpoint, switching speeds, carrier attack time — there is quite a bit that can be done in that area to make the data radios much faster than they have been in the past. In the past many people have been using voice type radio systems [to transmit data]." Narrowband systems are often protected, but they are also often required to be licensed, making establishment of multiple station systems paperwork intensive.

Others are looking to utilize existing services for data transmission. A consortium of cellular carriers along with two divisions of IBM have developed a system for sending and receiving packetized data via the current cellular telephone network. The system is called Cellular Digital Packet Data (CDPD), and it will move a subscriber's data via idle cellular telephone channels. One member of the consortium, McCaw Cellular Communications, along with the Oracle Corporation, has developed a data broadcasting system which will also utilize unused cellular telephone time.

Technical Standards

Compatibility with existing wired networks is the main issue for wireless local area networks (WLANs). Proxim's RangeLan is a spread spectrum LAN adapter which fits in a PC expansion slot. RangeLan is not sold as new, fantastic technology, says Paul Smith, Vice President of Marketing for Proxim, rather it is described as a LAN adapter which happens to have no cable. "When you buy any ETHERNET card today you expect that any network operating system you are using will run on it, and you have that same fulfillment when you buy our product," says Smith.

Network protocols are an issue for wireless wide area networks (WWANs) as well. A number of these systems are in place, some private (Federal Express' system, for example), some acting as common carriers (the RAM Mobile Data and Ardis systems). MMP, MDC, RDLAP and Mobitex are all protocols used in these systems. Some networks provide gateways which allow different protocols and some require a prescribed protocol. A maker of an RF modem might have trouble deciding which protocol to implement. Motorola's Data Division Marketing Vice President, Jeff Morris explains that different protocols can be accommodated in the same modem through the use of DSP circuits. Motorola makes such modems, as does Synetcom Digital.

How Much Wireless?

As demonstrated in the wireless LAN market, customers can appreciate technology, but what they ultimately require is performance, at an acceptable price. Wireless solutions are not being developed just for the sake of being wireless — they are a result of customer's needs which cannot be accommodated in existing wireline services. The future of wireless data communications depends primarily on its ability to integrate invisibly with existing systems, not on promotion of its technical capabilities. *RF*

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Radio Frequency Interference from Non-Licensed Devices

By Robert D. Weller, P.E.
Federal Communications Commission

Many regulatory agencies prescribe radiated and conducted emissions standards to minimize the potential for interference to susceptible electronic devices, particularly radio receivers. The FCC's Field Operations Bureau enforces these regulations and investigates interference problems in the United States. Compiled data on various cases of interference is presented so that designers and manufacturers will appreciate the effort expended in designing for EMC.

Control of the radio frequency (RF) radiation associated with electronic devices is a legal requirement in many countries. In the United States of America, the Federal Communications Commission (FCC) is statutorily responsible for the development of mandatory radiated and conducted emissions standards. Various devices, including digital devices (1) such as computers, with a demonstrated potential for radio frequency emissions, cannot be legally sold to the public in the U.S., without having first been tested for compliance with the emissions standards contained in Part 15 of the FCC's rules (2).

The FCC

The FCC was established in 1934 as an independent agency of the U.S. Government with responsibility for assuring that a rapid, efficient nation-wide wire and radio communication service exists in the U.S. (3). The agency has four licensing bureaus, each with a specific area of responsibility. These bureaus are:

Mass Media (MMB), with responsibility for the regulation of broadcast television, radio, cable television and their ancillary services.

Common Carrier (CCB), with responsibility for the regulation of both wireline and non-wireline telephone and related services.

Private Radio (PRB), with responsibility for the regulation of private, two-way radio services, including public safety, industrial (business), marine, aviation and amateur radio.

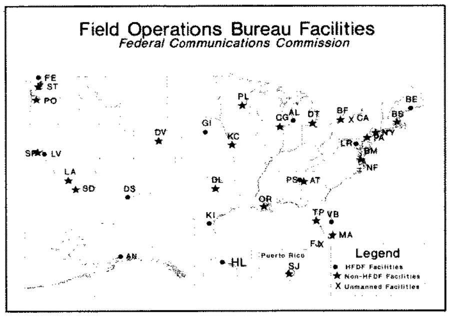

Figure 1. FCC Field Operations Bureau facilities.

Finally, the *Office of Engineering and Technology (OET)* regulates experimental uses of radio and devices which can be operated without specific authorization from the FCC. The latter category is commonly known as non-licensed devices (NLDs). NLDs are divided into two types: intentional radiators, such as cordless telephones, and unintentional radiators, such as computers.

There is a fifth FCC bureau, which does not issue station licenses. The *Field Operations Bureau (FOB)* is responsible for the field monitoring and enforcement of many of the licensing bureaus' regulations so that order may be maintained on the airwaves.

FOB

The Field Operations Bureau has 339 employees, spread over 36 locations.

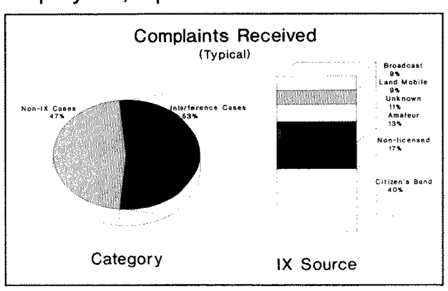

Figure 2. Statistical summary of complaints recieved by FOB's Denver Field Office.

Approximately 40 of these individuals are located at the headquarters office in Washington D.C. The remainder are located at various field installations throughout the United States, plus the territory of Puerto Rico.

FOB maintains two types of field facilities. "HFDF Offices", which have elaborate, netted direction-finding (DF) facilities for locating and identifying signals at high frequencies ("HF", i.e., 3 - 30 MHz). In order to facilitate this mission, these offices are generally located in rural areas, away from major population centers and their associated RF noise sources. In contrast, "Non-HFDF Offices" are located near or within some of the largest U.S. population centers. These offices are designed principally for the monitoring and enforcement of the spectrum above 30 MHz (i.e., VHF and above). In order to maximize the efficiency of this mission, such facilities have been located near the area of greatest radio use.

A map, showing the location of the various FOB facilities is presented in Figure 1.

Compliant Case Management

From its nascence, the FCC has kept records of complaints of interference to radio reception, referred to as "IX" within the agency. In 1989, this process was formalized somewhat with the introduction of a customized complaint database, called the Case Management System (CMS).

The author used data from the database maintained at each of the thirty-five field offices to determine the workload imposed by responding to the various categories of complaints received from the public. Nearly 100,000 cases were analyzed. Slightly less than half (47 percent) of the total volume of complaints related to non-interference matters, such as quality of cable television service or telephone billing. The remainder (53 percent) were complaints of RF interference (RFI) of some sort. Further analysis of the latter category of com-

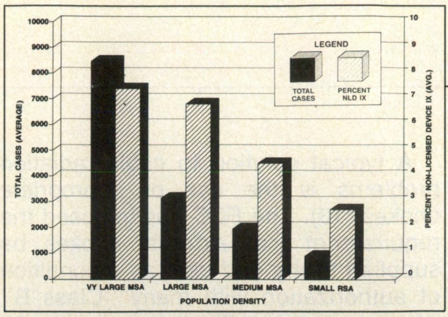

Figure 3. Total interference cases and percent NLD cases vs. population density.

plaints revealed that the majority of these cases involved interference from licensed transmitters, such as citizens band (CB) operators or broadcasters (see Figure 2).

NLDs as Sources of IX

A non-trivial number of cases (17 percent, or nearly 6800) involved interference from non-licensed devices regulated under Part 15 of the FCC Rules. Nearly all of these cases were of interference to some licensed service, such as TV broadcasting. Responding to such a large number of cases is time consuming. Hence, FOB seeks to minimize the number of on-scene responses required. Since the majority of NLDs causing interference are thought to comply with FCC radiation standards, the distance between the source and affected equipment is expected to be small, on the order of tens of meters or less.

The expected radius within which the interference source is located lies, in many cases, entirely within the complainant's property. In other words, the complainant is often found to be interfering with himself. In such circumstances, FOB encourages the complainant to isolate the source himself and provides only self-help information for assistance. In the more difficult, widespread, or insidious cases, FOB may dispatch an investigator to locate and close down the offending equipment. In either case, the owner of the radiating equipment is referred to the manufacturer for assistance.

NLDs as Receivers of IX

Users of licensed radio services are generally protected from interference from NLDs. Users of NLDs, however, are afforded no protection from interference (4). The FCC does not regulate susceptibility of equipment to EMI at this time (5).

The author's research shows that approximately two-thirds (nearly 32,000) of FOB's interference complaints involve interference to consumer electronics equipment, such as televisions, stereos and computers. Measurements made by FCC engineer Leo Cirbo and myself confirm calculations estimating the magnitude of the electric field from a 1 kW HF amateur radio transmitter at a neighbor's home. At about 30 meters distance, that field is on the order of 9 V/m. Further, the estimated voltage induced by the amateur signal on the neighbor's power mains, and conducted to his equipment, is on the order of 4.5 V (6).

Most present consumer electronics equipment designs are unable to reject signals of that magnitude, and interference to the consumer equipment results.

Priorities

In conformance with the International Rules and Regulations (7), the FCC recognizes certain frequencies as supporting operations preserving the safety of life and property. These frequencies include 121.5 MHz, the international VHF distress frequency, also used by the Search and Rescue Satellite (SARSAT) system to locate aircraft or marine vessels in distress; 156.8 MHz, the marine safety frequency; and the various frequencies used by aircraft, marine and public safety entities. The elimination of interference on these frequencies is the FOB's highest priority. In contrast, the resolution of interference to consumer electronics equipment is among the FOB's lowest priority of work.

Case Histories

In 1976, when the use of computers and microprocessors (digital devices to the FCC) was beginning to expand beyond laboratories and large business settings, the Nevada Highway Patrol began receiving interference to their primary operations frequency in the 40 MHz band. This interference was observed mostly in the vicinity of the casinos and bars in the Reno and Las Vegas, Nevada, areas and obstructed their communications, including those relating to safety of life. Investigation by FOB revealed that the source of this widespread interference was the first mass-produced, electronic video-game, "Pong".

Subsequent investigation by the FCC determined that the "Pong" radiation was due to a combination of design faults. When the FCC pointed this out, the manufacturer's response was to change the clock frequency. The designers, while literate in logic design, did not consider the EMI potential of their product. In response to a growing number of similar interference problems, the FCC incorporated the infamous "Subpart J" into its regulations concerning NLDs.

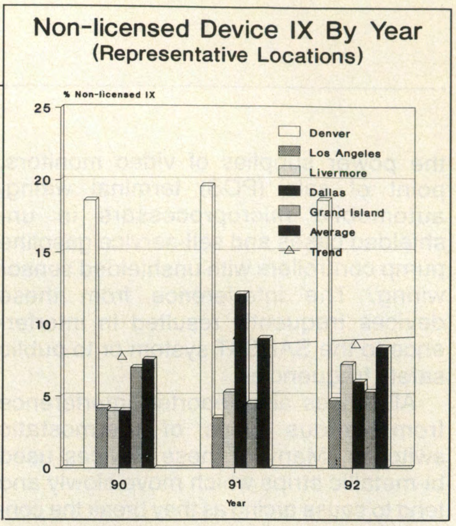

Figure 4. Percent of NLD IX cases for representative locations vs. time.

As the science of EMC has emerged from the secretive military industrial complex, and through the efforts of the FCC, most companies currently engaged in the production of digital devices have become sensitive to the EMI problem. Despite this, as previously cited statistics show, interference from NLDs is a continuing problem.

Some more recent cases follow:

In the Boston, MA area, a telephone company has installed central office digital switching equipment which is causing interference to a police department. The source of the radiation appears to be the cabling.

In the Atlanta area, another telephone company installed a digital switch for a cellular system which is causing interference to a metropolitan fire department.

Nearly every FOB office reported responding to interference generated by an ultrasonic rodent eliminator. This device used a VCO to drive a piezoelectric transducer, but every unit tested was found to be transmitting a swept RF signal in addition to the audio one. Stories about this device have found their way into the literature (8).

Nearly every office also reported interference from television booster amplifiers. These devices are high-gain, broadband RF amplifiers, designed to improve TV reception in fringe areas. They frequently oscillate when unterminated or exposed to extreme heat or cold.

All offices reported many cases of interference from computer systems. The causes included computer processor boards installed in unshielded cases, oscillating transformer laminations in the power supplies of video monitors, point of sale (POS) terminal wiring, automobile microprocessors in unshielded cases and self-service gasoline pump controllers with unshielded sensor wiring. The interference from these devices frequently resulted in interference to the SARSAT system or to public safety frequencies.

All offices also reported interference from various types of thermostatic switches. Many of these devices used bi-metallic strips which move slowly and tend to cause arcing as they break the connection. Use of contact material which tends to pit or break down during arcing made the problem worse. Interference has been documented from arcing thermostats on frequencies up to 6 GHz. Recent changes in the FCC Rules have permitted the expanded use of NLDs. Thus the problem is likely to increase.

Emissions Testing Methods

In many of the aforementioned cases, adequate attention was not focussed upon the properties of the installed device. External connections and environmental factors severely impact the radiation from a device. Equipment which complies with FCC standards in the laboratory may not comply in-situ.

Ideally, it would be desirable to conduct system-level EMI testing on installed equipment. There have been proposals to construct the necessary simulators to do just that (9). The expense involved with such testing cannot be justified, except perhaps on very large, EMI critical systems, such as military C^3 systems. Thus, it is important to anticipate the potential sources of EMI in an installed system and take the necessary steps to minimize it. The FOB and others (10, 11, 12) have found that the common-mode currents on interconnection cables are a major, if not dominant, contributor to system EMI. System re-engineering, or at least cable replacement, may be required on systems which cause interference, largely because they have not been adequately tested in a realistic "in-service" environment or the manufacturer did not consider the in-situ environment during the product's design.

A typical solution to cable radiation problems is the use of appropriate chokes (13). The FCC has imposed the requirement that external chokes be supplied to the end user as a condition of authorization with many "Class B" computers. It is difficult to imagine why these inexpensive and effective devices are not routinely installed internally.

It is also desirable to conduct EMI testing under environmental conditions other than the ambient, to assure that device performance is robust under all reasonable operating conditions. As previously mentioned, otherwise well-behaved devices, such as television booster amplifiers, can become high-level oscillators under conditions of extreme heat or cold.

Devices which use mechanical switches, especially thermostatic switches, can fail in rather spectacular bursts of RFI. One apartment building, with nearly 500 units was found to be using a particular type of thermostatic zone switch. Nearly one-third of the 500 installed switches were found to be failing and producing interference to a nearby earth station operating near 4 GHz.

As EMC becomes more prominent and better understood, it behooves manufacturers to take the time to analyze their products for both obvious radiation sources and the not-so-obvious potential sources, such as peripheral devices, cabling, failure modes and changing environmental conditions.

EMI and Susceptibility

EMI susceptibility involves the functional upset of a device when exposed to an adverse electromagnetic environment. As previously mentioned, the FCC does not presently mandate susceptibility criteria. This is despite the fact that the U.S. Congress specifically authorized the FCC to do so (14). One reason that the FCC has elected not to impose susceptibility requirements on equipment manufacturers is because the Electronics Industry Association (EIA) has developed various voluntary standards covering certain consumer electronics equipment as an alternative to additional governmental regulation (15, 16). A nominal 1 V/m standard for E-field immunity at HF is suggested by the EIA standards.

If the goal is to reduce interference from neighborhood amateur operators, the EIA-recommended susceptibility standard may be insufficient.

EMC Design Goals

By designing equipment with the susceptibility aspect of EMC in mind and adopting reasonable standards for such susceptibility, FCC emissions requirements would likely be easily met (17). Designing for EMC would also reduce unscheduled maintenance calls and customer complaints. Since EMI susceptibility protection also provides some de facto protection from lightning (ESD) transients, a more robust system would result. Thus, a product that is produced with EMC as a design goal will have improved reliability in the field.

A more robust system would be desirable to many customers. They would be willing to pay for the value of added EMC/ESD protection. Many computer owners have purchased at least one external transient suppressor. Some have purchased an uninterruptible power source (UPS). Both of these devices are intended to reduce the likelihood of conducted transients causing damage to their valuable equipment and data.

FCC "Encouragement"

The principal tool used by the FCC to encourage manufacturers to comply with its rules is education. Most manufacturers and sellers voluntarily comply with the FCC requirements. There are a few unscrupulous manufacturers and dealers who avoid the FCC certification process by use of "lab queen" equipment, rather than true production samples, or counterfeit certification stickers. The FCC's Equipment Authorization Branch (OET) receives approximately 100,000 applications for equipment authorization annually. FOB receives about 600,000 notices of importation annually. It is impossible to fully review such a large number of applications.

FOB has an ongoing inspection program which concentrates on end-user sales. Sanction actions, such as fines, may be imposed against manufacturers, distributors or sellers of uncertified equip-

ment. Presently, a fine of $7000 per day is typically imposed upon manufacturers and sellers of uncertified equipment (18). A greater amount is imposed for egregious offenses, such as misrepresenting the equipment as FCC-certified. The maximum penalty is $75,000. This penalty is above and beyond the cost of removing uncertified equipment from market, "make goods" and potential redesign costs.

Non-licensed equipment, including that for which an FCC equipment authorization is not required, which causes interference may be required to shut down, raising the ire of the end user and resulting in equipment returns and complaints to the manufacturer.

Conclusion

The FCC expends a large amount of its resources on responding to complaints of interference to and from non-licensed equipment. End users of such equipment are required to cease operations and are referred to the manufacturer for assistance in eliminating the EMI. Manufacturers should market products that do not create an adverse electromagnetic environment for other systems.

A large number of consumers experience problems with interference to their electronics equipment, due to high susceptibility to electromagnetic fields.

Equipment designed to reduce susceptibility to EMI and ESD would likely provide near-compliance with the FCC's emission limits as a no-cost bonus. Consumers presently pay for external devices to provide ESD protection. The cost paid by consumers for these extras, added to the cost of designing equipment for compliance with existing FCC emissions standards, could possibly equal the incremental cost of adding ESD (and hence EMI susceptibility) protection to the equipment at the factory. In order to minimize the cost of getting the improved product to market, the EMC engineer should consult with design teams throughout the design and production of the product.

A product that is produced with both compliance with FCC regulations and a reasonable limit on susceptibility stands a greater chance of being reliable in the marketplace.

Acknowledgements and Disclaimer

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The views expressed are those of the author and do not necessarily reflect the views of the Commission. (47 CFR 19.735-203(c))

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RF

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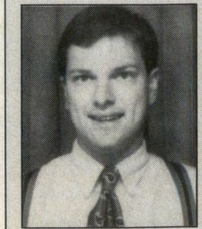
About the Author



Robert Weller is presently the Engineer in Charge at the FCC's Denver, CO field office. He is a 1984 graduate of the College of Engineering at the University of California, Berkeley and a Registered Professional Engineer. He can be reached at 165 South Union Blvd., Suite 860, Lakewood, CO 80228. Or by phone at (303) 969-6497.

New EMI/EMC Test Capabilities Lead the Way to Compliance

With the introduction of the new 2706 Stepping RF Preselector, Tektronix continues its role as a major supplier for applications in electromagnetic interference (EMI) and electromagnetic compatibility (EMC). Combined with last year's introduction of the 2712 Spectrum Analyzer with EMC prequalification testing capabilities, these instruments provide engineers with the ability to verify EMC performance of the products they are developing. Tektronix' experience with its own design, manufacturing and EMC compliance requirements are reflected in products designed for this aspect of engineering.

Regulatory trends in the world market are catapulting EMI and EMC into the spotlight of major concerns for electrical, electronics, and other industries. The new European trade alliance is one major catalyst for this trend, as is the new FCC Part 15 Subpart B. Subpart B, replaces the familiar Subpart J, and will increase testing for many products. Companies are scrambling to establish product performance and testing requirements for these new requirements.

What are EMI, EMC and EMS?

All electrical currents create electromagnetic fields. At low frequencies, they may be unimportant, but as the currents that generate these fields change at faster rates, they generate electromagnetic waves that can propagate through space as a radiated signal, or through wires as a conducted signal.

In many instances, these waves are intentional. A radio transmitter, for example, is specifically designed to radiate RF energy from an antenna. But even a radio transmitter might radiate unintentional signals due to poor design, poor maintenance, or failed components. Similarly, there are other products not intended to emit RF energy, but they may do so. The signals that travel through the circuits inside a personal computer, for example, can be radiated or conducted outside the unit.

When these unintended signals cause interference to other electronic equipment, or have the potential to do so, this phenomenon is call electromagnetic interference (EMI).

At the other end of an electromagnetic wave's travel is electronic equipment that can be the victim of EMI. The degree of sensitivity that equipment exhibits to outside disturbances is called electromagnetic susceptibility (EMS).

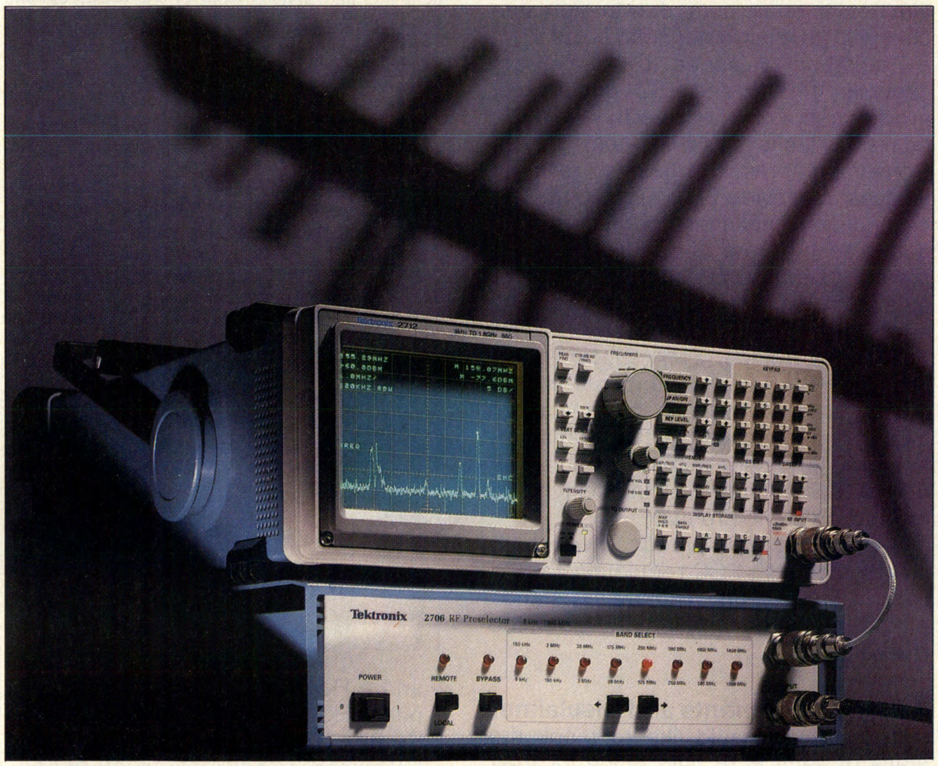
EMI and EMS are controlled primarily through good design practice. Radiated emissions can be reduced through shielding of critical components or subsystems. Decoupling capacitors and line filters are means of controlling conducted emissions. When EMI and EMS are sufficiently controlled such that one piece of equipment can operate in the presence of another, electromagnetic compatibility (EMC) is achieved.

To assure EMC, agencies throughout the world have established various standards for EMI and EMS. EMC compliance is the ability of equipment to meet those standards. EMC certification is authorization by the regulatory agency to operate the device or equipment, based on measurements of EMI and EMS performance.

EMC Regulations

EMC regulations are designed primarily to reduce interference between pieces of equipment. Regulations exist for both consumer and industrial (commercial) equipment. In the United States, the limits for radiated and power-line-conducted EMI are defined by the FCC in Part 15 of their Rules and Regulations. Further requirements for unintentional radiators which have emissions of 9 kHz or greater are contained in Subpart B of Part 15.

Subpart B extends the maximum test frequencies above 1 GHz, which was the maximum stated in Subpart J. Under Subpart B, the maximum test frequen-



Tektronix offers products for EMC testing in design and prequalification phases of product development.

Gain-Bandwidth Product Tests to Cut Production Costs

Economic solutions for production testing should reduce test time, equipment cost, documentation, and operator skills. Gain-bandwidth product testing using white noise is a new method that can produce all of these results.

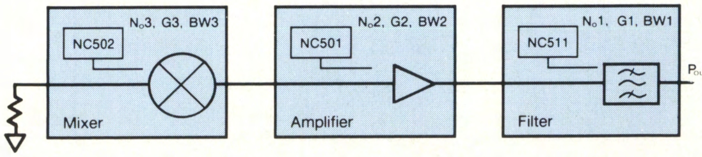
The gain-bandwidth product of a device under test can be tested by measuring the output power of the device and knowing the input noise spectral density. Variations in either gain or bandwidth will result in a reading different than normal or a fault indication.

The required test is a power measurement using a power meter, and the needed skills are the capability of reading a meter or a go/no-go indication.

The concept of the test is to measure the gain-bandwidth product of the components. The gain-bandwidth product is related to the injected noise power density and the total output power as follows:

$N_o \times GBW = P_{out}$

Noise sources are built into each subsystem block as shown in Figure 1. The subsystem block can be either a printed circuit board assembly or RF or microwave component. The noise sources are selected for each subsystem block so that the output power of the last block remains constant when the blocks are cascaded. Inexpensive noise sources are available from Noise Com with a wide range of noise power densities, N_o.



$P_{out}1 = N_o1 \times G1 \times BW1$
$P_{out}2 = N_o2 \times G2 \times G1 \times BW$(cascaded of 1 and 2)
$P_{out}3 = N_o3 \times G3 \times G2 \times G1 \times BW$(cascaded of 1, 2 and 3)

Figure 1. Gain Bandwidth Test Concept Block Diagram.

It is therefore possible to select the noise power density so that fixed go/no-go limits can be used on the power meter display. This simplifies electrical tests so that anyone can perform them. Statistic quality controls can conveniently be made by defining a nominal output power (P_{out}) and variation allowance for each component.

Each component manufacturer can integrate the noise source into the component during the production process. It will result in only a very small additional cost for each component and the noise source provides a means of production screening by the component manufacturer as well.

The noise sources give the final product added value, because it now includes simple, inexpensive built-in testing and fault isolation testing to the component or subsystem level. This means easier service, reduced MTTR, inexpensive instrumentation for maintenance by the end-user, less complex maintenance guides and incoming inspection documentation in addition to the savings in production testing.

By standardizing on a gain-bandwidth product test philosophy, intra-industry and intra-military commonality of system and component test stations could be increased. Automatic test equipment could measure gain, noise figure (sensitivity), and bandwidth by using the built-in noise sources. The only requirements to make these as well as the gain-bandwidth product measurement are knowledge of the noise power density, a calibrated filter before the power meter, and some simple computation.

Applicable Noise Com products include diodes, and noise sources housed in TO-8, dual-in-line and surface mount packages, as well as modules with connectors.

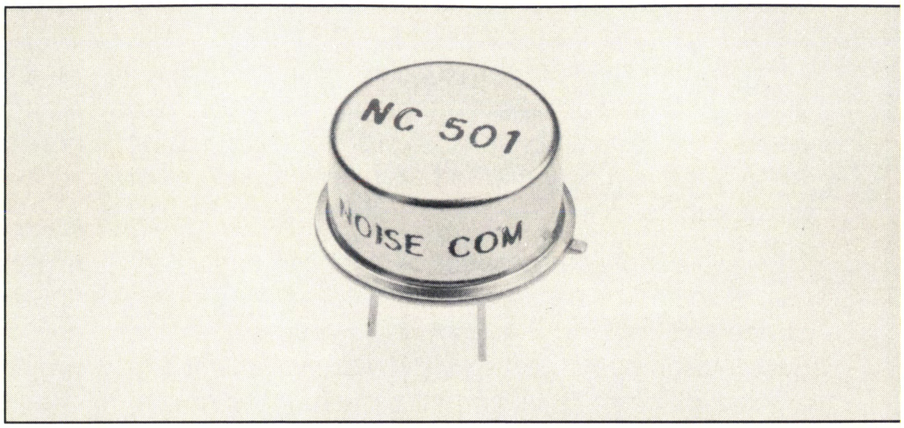
Specifications for applicable TO-8 packaged noise sources, which are available with higher output power or built-in directional couplers as options, can be found on the next page.

Turn the page for related products . . .

NOISE/COM
E. 49 Midland Avenue, Paramus, New Jersey 07652
(201) 261-8797 • FAX (201) 261-8339

Drop-in Noise Modules for BITE

NC 500 Series
200 kHz to 5 GHz



Features

- Economical solution to BITE
- Drop-in TO-8 packages
- 31 dB or 51 dB ENR output
- Minimum crest factor 5:1
- Operating temperature −55 to +85°C
- Storage temperature −65 to +150°C
- Temperature coefficient 0.01 dB/°C
- Noise output rise and fall times less than 0.5 ms

The NC 500 Series drop-in noise modules are an economical solution for built-in test requirements. They contain complete energizing circuits and need no external peripheral devices.

The NC 500 Series modules are housed in a TO-8 metal can, and require +15 VDC at 0.2 to 5 mA. The modules produce 31 dB ENR of white noise with a Gaussian distribution, and are available from stock in ranges to 5 GHz. Like all Noise Com products, they contain a fully characterized noise diode that has been burned-in for 168 hr.

The examples listed are representative of NC 500 Series units for typical applications. Noise Com can optimize frequency range, voltage, and output level of the NC 500 Series for specific applications.

Options:

1. Military version in compliance with MIL-E-5400T Class 2. (Add suffix M.)

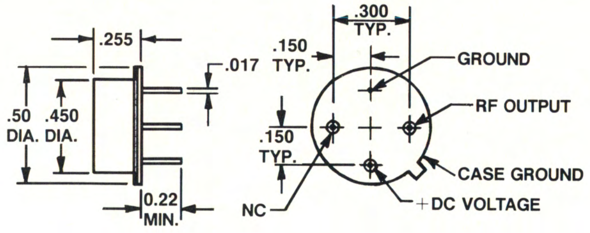
NC 500 Series

MODEL FOR +15 V SUPPLY	MODEL FOR +28 V SUPPLY	FREQUENCY RANGE (MHz)	MINIMUM OUTPUT		FLATNESS @ 25°C (dB)
			ENR (dB)	@ R_L (Ω)	
NC 501/15	NC 501	0.2– 500	31	50	±0.5
NC 502/15	NC 502	0.2–1000	31	50	±1.0
NC 503/15	NC 503	0.2–2000	31	50	±1.5
NC 504/15	NC 504	0.2–3000	31	50	±1.5
NC 505/15	NC 505	0.2–4000	31	50	±2.0
NC 506/15	NC 506	0.2–5000	31	50	±2.5

NC 510 Series*

MODEL	FREQUENCY RANGE (MHz)	MINIMUM OUTPUT		FLATNESS @ 25°C (dB)
		ENR (dB)	@ R_L (Ω)	
NC 511/15	0.2–500	51	50	±2.0

*Requires 30 mA. Commercial version only.



NOISE/COM
E. 49 Midland Avenue, Paramus, New Jersey 07652
(201) 261-8797 • FAX (201) 261-8339

Using the New 2706 Preselector for EMI Measurements

A preselector is a filter that is placed before the input of a spectrum analyzer to pass signals on the desired measurement frequency, and reject signals that lie beyond the frequency of interest. Its principal function is to prevent strong signals from generating spurious responses within the analyzer circuitry which can contribute to erroneous measurements, or restrict the dynamic range of a spectrum analyzer measurement.

Unlike a preselector that simply eliminates mixer image frequencies, an EMC preselector needs a relatively narrow bandwidth. Ideally, this bandwidth is just a bit wider than the specified analyzer resolution bandwidth. The 2706 uses eight calibrated stepped bandpass filters, packaged with their associated selection switches in a GPIB-controlled system. Advanced versions of the Tektronix S26EM12 Commercial EMI Test Software incorporate commands that integrate operation of the preselector into the test system.

The compromise of using eight filters instead of a more complex 10 percent bandwidth swept filter is cost. For one-fifth the cost, approximately 80 percent of the necessary preselection tasks can be accomplished. Bands selected correspond to CISPR band requirements, plus expected EMI signal intensity expectations. These bands are:

- 9 kHz - 150 kHz
- 150 kHz - 3 MHz
- 3 MHz - 30 MHz
- 30 MHz - 125 MHz
- 125 MHz - 250 MHz
- 250 MHz - 500 MHz
- 500 MHz - 1000 MHz
- 1000 MHz Highpass

The Tektronix 2706 Stepping RF Preselector is priced at $4,450 each; reduced to $4,250 when purchased with a Tektronix 2711 or 2712 Spectrum Analyzer. For more information, call (800) 426-2200 or circle Info/Card #182.

cies are determined by the highest operating frequency of the equipment, as follows:

- Testing to 30 MHz for equipment operating below 1.705 MHz.
- Testing to 1 GHz for equipment operating from 1.705 to 108 MHz.
- Testing to 2 GHz for equipment operating from 500 MHz to 1 GHz.
- Testing to at least 40 GHz, or to the fifth harmonic of highest operating frequency, for equipment operating above 1 GHz.

Regulations vary for equipment intended to be sold in other countries. The regulating agency in each country establishes the specific regulations that apply to all equipment that will be used in that country.

EMI/EMC Testing

There are four phases to successfully meeting EMC compliance requirements:

- Design
- Pre-Certification Testing
- Final Certification
- Maintaining Compliance

The design phase may be the most important part of the process. Any compliance problems that are a result of poor design must be re-designed and re-tested for compliance. Simple EMI diagnostics can done using the Tektronix 2712 Spectrum Analyzer, along with near-field RF probes. A shielded room is highly desirable, so testing can be done in a "quieter" environment. Leakage and EMI hot spots in prototype subsystems can be fixed more easily in this early phase of product development.

Pre-certification testing should approximate the results of full-scale certification testing, but with greater speed and lower cost. The majority of EMI problems should be resolved in the design phase, but pre-certification testing will reveal any remaining problems before committing to final certification testing.

Tools for pre-certification testing include a spectrum analyzer with EMC test capabilities such as quasi-peak detection, and appropriate filters, such as the Tektronix 2712. A preselector , such as the new 2706 Stepping RF Preselector can significantly improve measurement accuracy by removing most high-level signals outside the current frequency of interest, which might overload or reduce the dynamic range of the spectrum analyzer. The specified test antennas, Line Impedance Stabilization Network (LISN), and

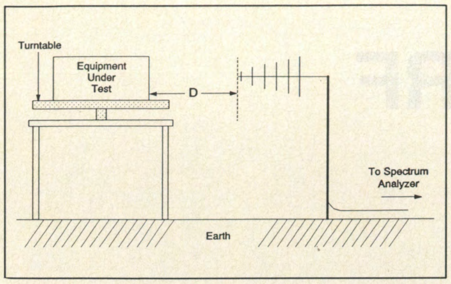


Figure 1. The basic setup for prequalification testing for radiated emissions. Tests use various antennas, test distances and equipment positions.

mechanical components are also required.

Automated testing is a tremendous time saver. Use of the Tektronix S26EM12 EMI Test Software can make radiated and conducted emissions tests go much faster, with greater data collection accuracy. The S26EM12 package runs on an MS-DOS personal computer and provides automatic setup, including accommodations for cable loss, antenna factor, and other corrections.

The main limitation of cost-effective pre-certification testing is the site. A calibrated open-area test site (OATS) or a certified anechoic chamber can be expensive to construct and maintain. A shielded room is one alternative, as is a small anechoic chamber. Variations in measurements between pre-certification and final certification should be noted to better correlate future measurements.

Final certification represents proof of compliance with the governing EMC standards. This phase is easiest if design and pre-certification are done competently.

Maintaining compliance is a requirement. A continuous follow-up program must be maintained to assure continued compliance with regulations. Remember, the FCC has the authority to randomly test product samples as an audit of a manufacturer's claim of compliance. Self audits will virtually eliminate future problems. Two methods are recommended: EMC checkpoints in the manufacturing process, and testing of product samples from inventory. Checkpoint testing will not only show developing areas of non-compliance, but will locate what part of the process is involved. Selecting random samples and applying the same rigorous testing as the pre-qualification phase mimics the process used by FCC to assure continued compliance.

Summary

EMC is a key market concern for manufacturers and importers of electronic equipment. Moreover, with the proliferation of electronic products and electronic subassemblies in many other products, the possibility for EMI and EMS problems increases. Regulating agencies are continuously evaluating the potential for EMI problems are issue new standards as necessary.

Tektronix, out of necessity in marketing numerous products worldwide, stays abreast of the latest regulations, and will continue to offer cost-effective EMC test equipment, accessories and software to the industry. ***RF***

RF Design — A Suite of RF Problem Solvers

By Herman A. Kruse
Scientific Atlanta

This program was a runner up in the second RF Design Awards PC Software Contest. This menu-driven collection of small programs covers a wide range of RF design problems, from filter design to bipolar transistor biasing.

The RF Design program consists of two dozen RF related programs that have been linked to a master menu program, thereby presenting single program operation to the user. All subprograms are independent but for ease of operation, they all return to the main menu when terminated. The programs were written in GW Basic and compiled in QuickBasic.

It is highly recommended that the help section be reviewed before attempting to use the program. Help sections covering the major design categories are provided and include circuit diagrams, circuit descriptions and program operating details.

The program has five major divisions: filters, frequency equalization, RF network analysis, transmission lines and miscellaneous. Under each major division are three to six choices; selecting one of these items begins an actual design operation. Input is via interactive prompting (Figure 1). Output can take the form of tables, frequency response curves, circuit files or combinations thereof. Simply pressing the "PRT SCR" key will produce printouts of the generated tables. Response curves can be produced in the same way if the MS-DOS program "GRAPHICS" (or equivalent) is run prior to starting RF Design.

Network Analysis

Because forms of this routine appear in the other main menu selections, the network analysis subprogram will be discussed first. The analysis program evaluates performance characteristics of passive RLC AC networks. The program recognizes megahertz, picofarads and nanohenries as the data input format. Lower frequencies are handled as fractional MHz. A circuit description can come from a previously produced circuit file or the user can manually enter the description in the form of component and connection codes. When the user selects the run option, the program steps through a frequency range for analysis and plots a frequency response curve. A typical example is shown in Figure 2.

Filters

The first selection on RF Design's main menu is "Filters." Under this main selection are three options: a Chebyshev filter design routine (including LP, HP, C-coupled BP and L-coupled BP), a C-coupled series resonant Chebyshev BP designer, and a routine which designs C-coupled BP filters for high Z match to collectors, etc. All routines except the last one produce circuit files. A version of the previously discussed network analysis subprogram is included for immediate evaluation of designs.

Frequency Equalization

The second main menu item is a set of frequency equalization routines. Four options appear under this main selection: a bridge T cable equalizer network designer, a bridge T cable simulator, a set of frequency response trims for different circuit configurations, and a set of special purpose equalizing circuits. Frequency response curves are produced by a version of the network analysis subprogram.

Attenuators

A set of attenuator design and conversion routines are included in the third main menu selection. Included are a

```
                         SELECT FILTER TYPE

                         LOW PASS L INPUT = 1
                         LOW PASS C INPUT = 2
                         HI  PASS L INPUT = 3
                         HI  PASS C INPUT = 4
                         BPF C COUPLED    = 5
                         BPF L/C COUPLED  = 6

                            SELECT TYPE  ? 1
RIPPLE DB=? .005
ORDER N=? 5
FREQUENCY-RIPPLE CUTOFF=? 1.12
Z=? 50
L( 1 )= 4832.47
C( 2 )= 3567.8
L( 3 )= 10585.64
C( 4 )= 3567.79
L( 5 )= 4832.38
F3DB= 1.513227

          1  SELECT ANOTHER FILTER    2  MAIN MENU -PLOT    3  END
                        MAKE SELECTION ?
```

Figure 1. Typical input screen.

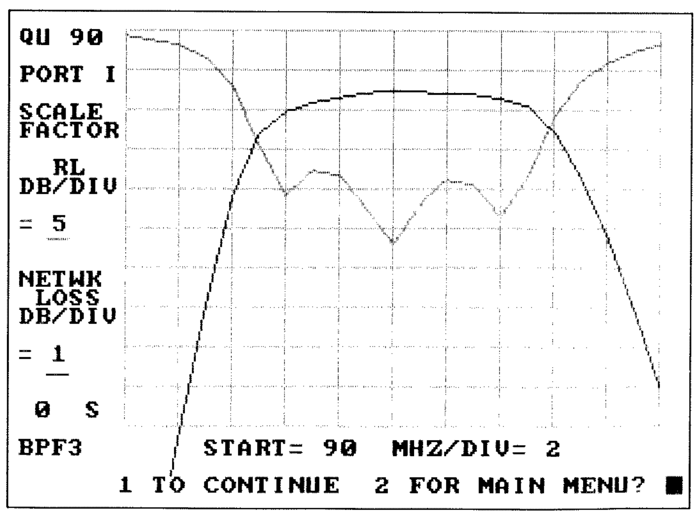


Figure 2. Typical frequency response graph.

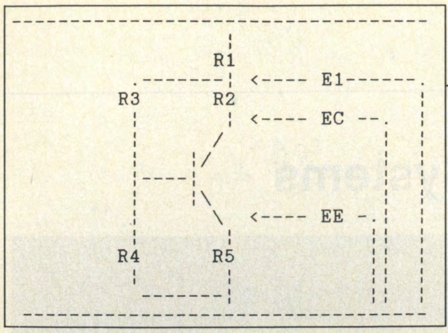


Figure 3. Transistor bias circuit.

bridge T attenuator, pi attenuator and T attenuator designer routines, along with a pi to T or T to pi conversion program.

RF Networks

The fourth selection from the main menu is a series of RF network related programs. The first item is the previously discussed network analysis routine. The next two items are special versions of the Chebyshev lowpass filter design program. These routines produce LP networks which absorb stray capacitance or inductance. A table of lowpass filters is calculated starting at or near the upper end of the band of interest. The filter which absorbs strays most efficiently can be selected from this table.

The next item designs multi-section, broadband matching networks. This program incorporates a circuit file generator so that the circuit can be conveniently evaluated by the network analysis program. The last RF network item is an impedance matching network designer. This program, based on a TI program published in *RF Design* magazine several years ago (1), provides a set of 14 LP and HP circuit topologies for the user to choose from. The program returns a set of component design reactances, component values and insertion loss for a specified unloaded Q.

Transmission Lines

The properties of different types of transmission lines are calculated in the next main menu selection. The first two options evaluate dimensional data and derive transmission line impedances for microstrip and coplanar lines. The routines can also be used to obtain dimensions for a required impedance. However, their primary purpose is to evaluate structural tolerance effects on line impedance. The third option generates a table of cable attenuation data that is useful when designing systems and equipment that must function with relatively long lengths of cable exhibiting considerable loss. The loss is evaluated relative to a maximum loss specified at the high end of a particular frequency range of interest.

Miscellaneous

This selection contains programs for a variety of small problems. The first item is a single layer inductor designer. This routine will produce a table of N inductance values for inductors of given wire diameter and turn radius and up to N turns. The next item is useful for the design and evaluation of bipolar transistor biasing circuits. The circuit shown in Figure 3 shows one of the two most common biasing circuits. The other common biasing configuration can be achieved by setting E1 equal to a value that is slightly less than VDC, forcing R1 virtually to zero. The last item is a collection of programs that performs such functions as calculation of resonant frequencies and return loss calculations.

Help

Item 7 on the main menu is the "Help" section. Help for each of the main menu selections (except for "Help" itself) is here. However, these help entries are not accessible while using a routine, so a hardcopy of "Help" is a valuable companion to the program user.

Summary

The RF Design program provides solutions to a wide variety of RF design problems. The integration of smaller programs into a single larger program makes location of specific programs easier.

This program is available on disk from the RF Design Software Service. See page 64 for ordering information. **RF**

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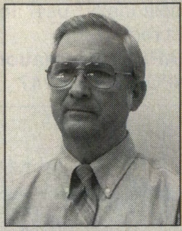
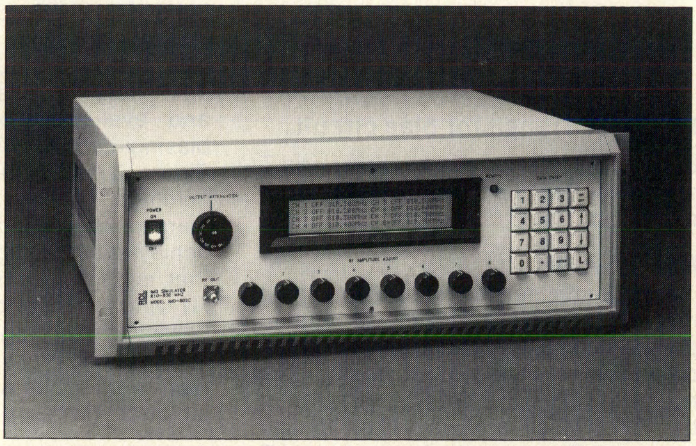
1. Burwasser, Alex J., "TI-59 Program Computes Values For 14 Matching Networks", *RF Design*, November/December 1983, pp. 12-31.

About the Author



Herman A. Kruse received his BSEE degree from Mississippi State in 1954 and has spent most of his engineering career as an RF design engineer. He is a Senior Staff Engineer at Scientific Atlanta, where he has been employed for 10 years. He can be reached at RT 3 Box 338-B, Winder, GA 30680, or by phone at (404) 903-5666.

Intermodulation Simulator Tests Cellular Systems



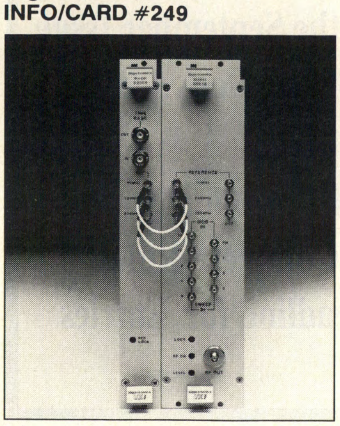
Eight synthesized RF sources are included within one box in RDL's line of IMD simulators. Each source is phase locked to a common reference to give a single coherent RF output. The frequency and on/off state of each module is controlled either by an external GPIB control bus or by a front panel key pad. Power output is controlled entirely by front panel controls; a 70 dB variable attenuator controls the combined output of all synthesizers; individual controls regulate output power of individual sources to within ± 1 dB. A reference output is provided to allow the linking of two units, resulting in 16 phase locked tones. Intermodulation products are ⩽ −80dB, spurs are −75 dBc max., and phase noise is −100 dBc/Hz at 25 kHz offset. Internal and external modulation capabilities are optional. The unit comes in standard rack mount configuration (19 × 7 × 16.5 inches). Model 803 covers the US cellular band, model 802 covers the Japanese cellular band while model 910 covers the European cellular band. Other frequencies are available on request.

RDL, Inc.
INFO/CARD #250

VXIbus Based Synthesizer

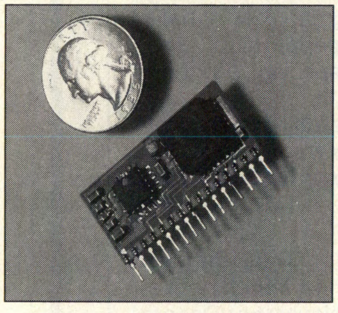
Giga-tronics announces the introduction of a synthesized microwave signal generation system conforming to the VXIbus architecture. The initial product offering consists of three C-sized modules. The Model 52000 Control Module uses the VXIbus word serial protocol and can drive up to eight additional Giga-tronics modules. The Series 50000 Synthesizer Modules are available in 6 different frequency ranges. Each synthesizer contains a YIG-tuned output oscillator. The Model 55510 Downconverter Adapter Module extends the frequency range of the 2 to 8, 2 to 12 or 2 to 18 GHz synthesizer modules down to 10 MHz. US list price for the model 52000 and model 55510 are $2,000 and $13,000 respectively. US list price for the model 50000 series ranges from $21,000 to $28,000 depending on frequency range.

Giga-tronics, Inc.
INFO/CARD #249



SIP DDS

Stanford Telecom's STEL-1479 is a complete direct digital frequency synthesizer in a single SIP package measuring 1.3 × 0.8 × 0.35 inches. The STEL-1479 is a ceramic thick film hybrid unit using the STEL-1179 modulated numerically controlled oscillator (MNCO) chip driving a high-speed 8-bit DAC to generate an analog output signal. The



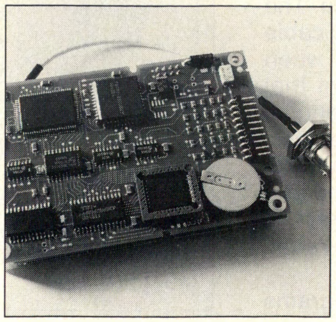
device is guaranteed to operate at clock frequencies up to 25 MHz over the temperature range of 0-70 degrees Celsius, giving an output frequency range up to 10 MHz, with frequency resolution of 1.49 Hz. In addition, the device features phase modulation capabilities at extremely high modulation rates — up to 50 percent of the clock frequency. The phase modulation capability allows BPSK, QPSK or 8-PSK modulation implementation. The 3-pin serial frequency loading scheme allows easy device control from any microcontroller or microprocessor. In quantities of 1000, the unit sells for $20 each.

Stanford Telecom
INFO/CARD #248

GPS Sensor Board Set

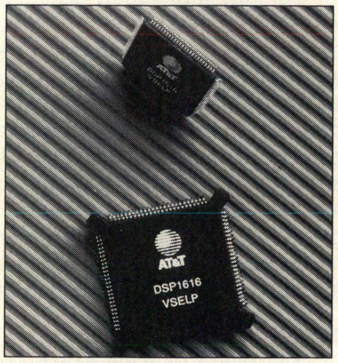
GARMIN International has introduced the GPS 10 Sensor Board Set. This board set is designed to be integrated into a wide variety of GPS systems. The GPS 10 is based on GARMIN's proprietary MultiTrac™ technology, which tracks and uses up to 8 satellites for accurate positioning. It provides fast first-fix, one-second updates and low power consumption. The GPS 10 with MultiTrac provides the sensitivity and performance needed for land and marine navigation and meets the dynamics requirements of high-performance aircraft. The GPS 10 weighs only 4 ounces (113.4 grams) and is 4.00 × 2.65 × 0.75 inches (101.6 × 67.3 × 19.05 mm) in size. The board set has two communication channels and user-selectable baud rates along with user selectable 2-D or 3-D navigation modes. The GPS 10 provides highly accurate 1-PPS output for precise timing; additionally, user initialization is not required.

GARMIN International
INFO/CARD #247



Speech Encoder/ Decoders

Designed specifically for application in digital cellular systems, AT&T Microelectronics' WE DSP1610 and WE DSP1616 VSELP are signal coding DSPs which can be programmed to



perform a wide variety of fixed-point signal processing functions. These devices are based on AT&T's DSP1600 fixed-point core with a bit manipulation architecture expansion for enhanced signal coding efficiency. The memory configuration and mix of I/O peripherals available on the DSP1610/1616 provide solutions specific to base station and mobile terminal system designs, respectively. Instruction cycle times are 33 and 25 ns (30 MIP and 40 MIP). These devices operate from a 5V supply and feature a low-power 0.9 micron CMOS technology. Power consumption is also reduced with a fully static design and a sleep/powerdown mode.

AT&T Microelectronics
INFO/CARD #246

MANUFACTURING, TOOLS AND MATERIALS

Cable Prep Tool

A new member of Andrew's EASIAX® line of cable prep tools cuts 7/8 inch HELIAX® foam dielectric coaxial cable. Like the other EASIAX tools, the new tool cuts both outer and inner conductors with one blade while another scores the jacket at the exact dimension needed for all LDF5 connectors.
Andrew Corporation
INFO/CARD #245

Ferrite Cores

The Delevan Division of American Precision Industries announces a new line of ferrite rods and cores. These coil forms use Mn-Zn and Ni-Zn ferrite materials and are available as rods, cups, pots, drums, toroids and other mechanical forms. They are available as leaded and unleaded forms, in standard shapes, or as custom manufactured units.
American Precision Industries, Delevan Division
INFO/CARD #244

Thick Film Materials

Minico, Inc. offers a wide range of polymer-based resistive, dielectric, conductive and solderable conductive polymer thick film inks. Technical literature detailing key features and specifications is available for all Minico polymer thick film inks.
Minico, Inc.
INFO/CARD #243

Easy Access Shielded Modules

A new line of shielded modules, (QBOARDMOD™ -1,-2,-3) from RF Prototype Systems allows the user to remove and reinstall a QUICK BOARD amplifier board without removing connectors. RFPS end launch connectors are soldered directly to a QUICK BOARD such as the GB1

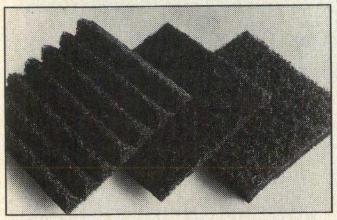
or GB2 and installed into a QBOARDMOD. The connector flange becomes part of the module enclosure.
RF Prototype Systems
INFO/CARD #242

Iron Powder

International Specialty Products' line of carbonyl iron powders find application in radar absorbing, electronic component and EMI/RFI shielding applications. These powders are produced using the carbonyl decomposition process and range in size from 2 to 10 microns. The iron powders are magnetically soft, exhibit low magnetic remanence and have excellent saturation characteristics.
International Specialty Products, Inc.
INFO/CARD #241

Microwave Absorber Sheets

Ultra wideband microwave absorber sheets for applications from 27 MHz to 40 GHz are now available from Mitsubishi Cable America, Inc. The sheets are



manufactured for the frequency bands of: 8-40 GHz, 6-40 GHz, 3-40 GHz and 0.03-2 GHz. An increasing fiber density allows these sheets to have a reflection loss of 20 dB with thicknesses of 0.5 to 2 inches.
Mitsubishi Cable America, Inc.
INFO/CARD #240

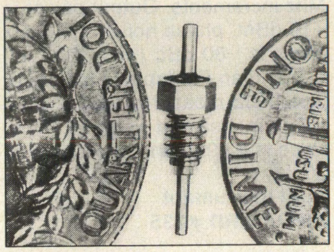
DISCRETE COMPONENTS

New Inductor Line

MagneTek offers four lines of standard magnetics and two lines of custom magnetics, all of them new. The standard magnetics include common mode EMI suppression inductors (E-core and toroidal construction), gate drive transformers, current sense inductors and output filter inductors. Design kits are offered for all of the standard magnetic lines. Custom magnetics include converter power transformers and mag amp inductors.
MagneTek
INFO/CARD #239

Miniature EMI Capacitor

The 4-40 EMI feed-through filter capacitor is located within the 0.125 inch head of a threaded bushing. Its leads are fed through



a full high temp solder seal and a quality hard epoxy. The filter passes gross leak tests and survives aggressive lead bending and subsequent solder operations.
EMI Filter Co.
INFO/CARD #238

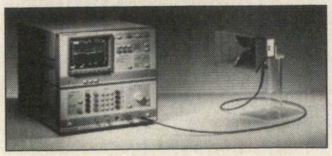
Fixed Attenuator Pads

Alpha Industries' new line of fixed attenuator pads are fabricated on a 7 mil substrate for efficient heat transfer. The resistor film is thermally stable and the coplanar symmetrical "T" design allows exceptionally flat performance up to 40 GHz. The bottom side of the chip is a bare substrate with Au/Ge backing available. Gold plated input/output pads allow for standard thermo-compression bonding techniques.
Alpha Industries, Inc.
INFO/CARD #237

TEST EQUIPMENT

EMI Test Receiver

With the EMI test receiver ESBI, Rhode & Schwarz is extending the upper frequency limit of their EMI test receivers for EMC testing to 5 GHz. The ESBI combines the top features of Rhode & Schwarz spectrum analyzers with those of their conven-



RF products *continued*

tional EMI test receivers. The test receiver includes integral measurement and analysis functions.
Rhode & Schwarz
INFO/CARD #236

2-10 GHz Signal Generator

The model 8002 from April Instrument is a handheld, programmable, microwave signal generator covering 2 to 10 GHz in 1 Mhz increments. Output power is +10 dBm, phase noise at 20 kHz offset is −80 dBc (−90 dBc typical) and an FM input is included. The 8002 measures 2.52 × 5.57 × 7.45 inches and weighs 2.6 lbs. Price is $3,995 and availability is 30 days.
April Instrument
INFO/CARD #235

Microwave Spectrum Analyzer

High input sensitivity and low intrinsic noise level make the Wandel & Goltermann SNA-7A microwave spectrum analyzer a suitable choice for monitoring digital satellite links. In the 4/6 GHz band, the intrinsic noise level is <−88 dBm with 100 kHz resolution bandwidth (RBW) and <−140 dBm with 3 Hz RBW. In the 20 GHz band the intrinsic noise level is −127 dBm with 3 Hz RBW.
Wandel & Goltermann
INFO/CARD #234

2.7 GHz Signal Generator

The model 3221 from Leader Instruments Corporation is a synthesized signal generator covering the range of 100 kHz to 2.7 GHz with 10 Hz resolution (20 Hz above 1.35 GHz). Modulation capabilities include seven modes, fourteen combination modulation modes and a GaAs FET modulator for pulse work. RF output levels range from +13 to −133 in either dBm or dBu units. The price is $12,300, and units are available from stock.
Leader Instruments Corp.
INFO/CARD #233

Noise Figure Meter

With a frequency range extending from 10 to 2047 MHz, the HP 8970B Option 020 noise figure meter can perform high-accuracy noise-figure measurements on components for direct broadcast satellites to 2047 MHz and European and Japanese digital cellular systems in the 1900 MHz band, all without the need for a downconverter. Option 020 includes major features of the standard HP8970B. US list price is $15,500 with delivery at six weeks ARO.

Hewlett-Packard Co.
INFO/CARD #232

CABLES AND CONNECTORS

SMA Right Angle Connectors

A mitred outer body is combined with the internal swept radius construction usually found in "cast" or "bent" assemblies in the COAXICOM SMITRE low-loss, SMA, right-angle adapter. The use of a one-piece, bent, center connector results in lower VSWR, lower insertion loss and lower unit price. Interface dimensions are in accordance with MIL-C-39012/SMA. The male to female adapter, COAXICOM model 3219A-9 is priced at $19.50 each for 10 pcs.

Coaxial Components Corp.
INFO/CARD #231

Broad Line of RF Connectors

A broad line of cost-effective, industry-standard RF connectors is available from Molex. The series includes BNC, TNC, Twinax, N, UHF, Mini-UHF, F-Style and between series adapters. Mounting styles include bulkhead, panel and PCB; termination options are crimp/crimp, clamp/solder and screw-on. Plating types include nickel, silver, gold, and black chromate.

Molex, Inc.
INFO/CARD #230

SEMI-CONDUCTORS

Monolithic Crossover Ring Quad

A new monolithic beam-lead crossover ring quad with capacitance of 0.08 dB has been introduced by FEI Microwave. The F81XA-B50 is a low barrier Schottky device with a noise figure less than 8 dB. Designed for use in planar circuits, the crossover topology allows direct access to LO and RF ports without additional jumpers. The device's small area reduces inductance and allows operation above 26 GHz.

FEI Microwave, Inc.
INFO/CARD #229

Wideband Switched Input Op-Amp

Burr-Brown's OPA678 provides wide 200 MHz bandwidth and two independent differential inputs. The SWOP AMP® accepts either TTL or ECL switching signals and provides input selection speed of 4 ns. The OPA678 has 11 ns settling time, ± 380 uV offset voltage and a 350V/us slew rate. US OEM price in quantities of 100s is $5.95.

Burr-Brown Corp
INFO/CARD #228

Wideband, Robust VCO

Qualcomm's Q3500 VCO series offers low loop phase noise sensitivity when used in PLLs; tunability over an octave or nearly an octave; lack of moding, dropout and subharmonic pumping; and moderate price. The Q3500 family covers three frequency ranges: 650 to 1300 MHz (Q3500-0613T), 900 to 1600 MHz (Q3500C-0916T), and 1350 to 2500 MHz (Q3500C-1325T). Pricing is as low as $27.50 each in quantities of 10,000.

Qualcomm, Inc.
INFO/CARD #227

1.5 Gigabit/Sec Chipset

Hewlett-Packard's HDMP-1000 Gigabit-Link (G-Link) chipset has selectable data rates and selectable ECL bus options which give the serial transmitter/receiver pair the ability to implement the Serial HIPPI standard, SCI-FI standard P1596 or a number of non-standard alternatives. In quantities of 1 to 9 units the US list price for the chipset is $710; the transmitter or receiver alone (HDMP-1002 and HDMP-1004, respectively) are $355.

Hewlett-Packard Co.
INFO/CARD #226

PCM Chips

A new family of CMOS chips from GEC Plessey provides a number of functions for use in CCITT recommended 2 Mbit PCM links. Heading up the family is the MV1403, containing all the data-link control necessary to make it a PCM terminal on a chip. Among the other chips are a variety of dual function chips. An evaluation board is available for the MV1403. The 1000 piece price ranges from $13.50 for the MV1403 to below $10.74 for the dual function devices.

GEC Plessey Semiconductors
INFO/CARD #225

GaAs MMICs for PCN Products

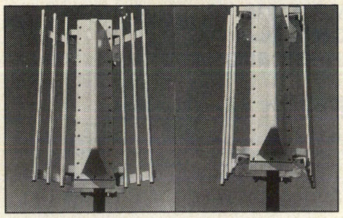
The Mitsubishi MGF7121 is a three-stage amplifier IC for use in the output section of PCN device transmitters. The MMIC operates from 4.6 volts and provides +22 dBm output power, 37 dB power gain and 30 percent typical efficiency. The MGF7051 is a SPDT switch intended for use as a diplexer in the transmit/receive section of PCN equipment. Switching speed is 100 ns, with isolation of 30 dB.

Electronic Device Group, Mitsubishi Electronics America, Inc.
INFO/CARD #224

SUBSYSTEMS

Variable Pattern Antenna

The AG-944W is a pattern adjustable antenna featuring a reflector setting with clearly marked beam widths at 60, 83, 105, 135 and 140 degrees. A companion tilt mount can mechanically tilt the antenna down 45 degrees.



The antenna covers the complete cellular band from 820 to 925 MHz, with mid-band gains of 11.2 dBd for a 60 degree beam width to 7.9 dBd for 140 degree beam width.
Radiation Systems, Inc., Mark Antennas Div.
INFO/CARD #223

Low-Profile GPS Antenna

M/A-COM's ANDX-C-717 L1, L2 and ANDX-C-718 L1 have a size and shape that allows them to be used anywhere L1 and L1/L2 performance is needed. Gain and pattern allow for excellent link margin which assures continuous communication even when a satellite is very close to the horizon. Low component count makes these antennas affordable.
M/A-COM, Inc., Antenna & Cable Div.
INFO/CARD #222

Flush Mounted Airborne Antenna

Model ADM-C10 is an extremely low weight flush mounted, wrap around airborne microstrip patch antenna array designed to operate over the frequency range of 2.2 to 2.3 GHz with greater than 10 MHz bandwidth from any given operating frequency. The antenna is designed to transmit a minimum of 10 watts of CW power. The antenna has minimum VSWR of 2:1.
Antenna Design & Manufacturing Corp.
INFO/CARD #221

SIGNAL SOURCES

Crystal Oscillator

Vectron Laboratories' crystal oscillator, the C0-287W, is available at any fixed frequency from 1.31 GHz to 2.6 GHz. Package size is 2 × 2.5 × 0.5 inches. Temperature stability is ±25 ppm over 0 to 75 degrees C, ±5 ppm over 0 to 50 degrees C. Price is $685 each in quantities of 100 for the 2.6 GHz version with delivery of 10-12 weeks ARO, and 6-7 weeks if needed.
Vectron Laboratories, Inc.
INFO/CARD #220

HCMOS SMT Oscillator

M-tron Industries' MM series quartz crystal oscillators offer HCMOS technology and an AT strip crystal in a miniature ceramic surface mount package. Output is TTL/HCMOS compatible from 1.5 to 40.0 MHz ("A" version), or HCMOS compatible from 40.1 to 60.0 MHz ("G" version). The package has lateral dimensions of .276 × .197 inches and a height of .091 inches.
M-tron Industries, Inc.
INFO/CARD #219

Low Phase Noise Oscillator

Piezo Crystal Company announces the availability of Model 2890080. This low profile, ovenized crystal oscillator is available in frequencies from 30 to 110 MHz. The unit utilizes Piezo's "SC" cut crystals and has typical phase noise of −95 dBc/Hz at 10 Hz offset from 100 MHz. Frequency stability is ± 5×10^{-8} over −40 to +70 degrees C. The approximate price for the Model 2890080 is $500 to $600 in quantities of 500.
Piezo Crystal Company
INFO/CARD #218

3.3 Volt HCMOS Oscillator

Fox's F4000 is a surface mounted, ceramic, HCMOS clock oscillator with tri-state enable/disable. Use of a 3.3 V system reduces power consumption, heat generation and EMI generation. The F4000 measures 5.0 × 7.5 × 2.0 mm.
Fox Electronics
INFO/CARD #217

Low Cost, Surface Mount VCO

The Series 190 oscillators from EMF Systems are low phase noise units using hyper-abrupt tuning diodes for linear tuning over wide bandwidths.

Tuning voltage is typically 0 to +12 V, and power output is typically +13 dBm. Models 190001, 190002, 190003, 190004 cover 800-1400, 1300-1900, 1800-2500, 2200-2800 MHz respectively.
EMF Systems, Inc.
INFO/CARD #216

AMPLIFIERS

50 W Power Amplifier

The EM Research Engineering model 810960-50 class AB linear power amp operates over the frequency range from 806 to 960 MHz. Output power is 50 Watts with 0 dBm input, VSWR is 1.5:1 max. The unit contains an internal output isolator and operates from 110 V AC.
EM Research Engineering
INFO/CARD #215

Wideband Surface Mount Amp

Petrond Microwave's surface mount amplifier (model S101) covers the 10 to 1000 MHz band. This amplifier has 20 dB gain, maximum VSWR of 2:1 and noise figure of 5.5 dB. The model S101 requires an external decoupling capacitor and bias choke. The unit measures 0.25 × 0.25 × 0.11 inches.
Petrond Microwave
INFO/CARD #214

Redundant Amplifier Controller

AML's redundant amplifier controller continuously monitors amplifier and power supply status and automatically selects a backup component when a failure is detected. The controller works with user supplied or AML supplied amplifiers. AML supplied amps include low noise, high intercept and power types.
AML, Inc.
INFO/CARD #213

High-Dynamic Range SMT Amp

A low noise, low gain, high dynamic range amplifier in the 50-1000 MHz frequency range is now available in the surface mountable TO-8B chassis. The amplifier has nominal 14 dB gain, 1.8 dB max. noise figure from 50 to 150 MHz and less than 1.0 dB above 150 MHz. It has +20 dBm output power and 10 dB min. input/output return loss.
Miteq
INFO/CARD #212

SIGNAL PROCESSING COMPONENTS

High Power Fixed Attenuators and Terminations

JFW Industries announces the expansion of their high power fixed attenuator and termination lines. With standard impedance of 50 ohms (75 ohms optional), these devices are available in capacities of 20, 50, 75, 100, 200, 300 and 500 Watts. N type connectors are standard; BNC or TNC connectors are optional. Frequency ranges are DC-1 GHz for 75 to 500 Watt units and DC-4 GHz for 10 to 50 Watt units.
JFW Industries, Inc.
INFO/CARD #211

Switch Matrix/ Controller

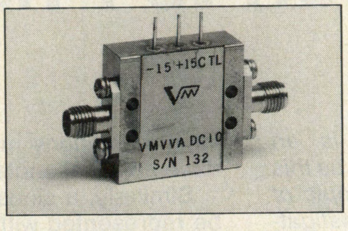
K&L's model 115 series switch matrix controller consists of two integral components; a controller unit offering several interface options and individual switch driver units. One controller unit and one switch driver can be configured in only 1.75 inches of rack space. The model 115 can drive K&L's 10x10 switch matrix, which features an upper operating frequency of 18 GHz.
K&L Microwave, Inc.
INFO/CARD #210

Stripline Filters

Compass Communications introduces the CLF series of filters including tunable and voltage tunable, bandpass and bandstop filters. These filters operate from 500 MHz to 3 GHz and have 3 dB bandwidths of 3 to 25 percent of center frequency. Insertion loss at center frequency can be as low as 1 dB, and tuning range is ±25 percent of center frequency. The filters are available in 4 weeks ARO.
Compass Communications, Inc.
INFO/CARD #209

Voltage Variable Attenuator

The VMVVA DC10-100 voltage variable attenuator provides 0 to 20 dB of continuously variable attenuation from DC to 10 GHz



with low reflection in a 50 ohm system. With a rise time of 50 ps and negligible overshoot, this part is suitable for gigabit data rate systems.
Veritech Microwave, Inc.
INFO/CARD #208

RF Switches

The R4 series of RF switches from Dynatech Microwave Technology is available in DPDT and transfer configurations and with N, BNC and TNC connectors. Members of the series operate from DC to 4 GHz. Power handling capabilities range from 200 W in the DC to .5 GHz band to 50 W in the 2.5 to 4 GHz band. The series is available in failsafe with suppression diodes.
Dynatech Microwave Technology, Inc.
INFO/CARD #207

GaAs MMIC Attenuators

M/A-COM's new family of GaAs MMIC attenuators provides fast switching, very high intercept points (Ip3 ≥ 45 dBm) and low DC power consumption. Available in digital, digital/analog and voltage variable versions with single and dual bias control, these attenuators operate from DC to 2 GHz with excellent temperature stability. The AT-220 provides 30 dB of attenuation in 2 dB steps. Pricing is $6.90 each in quantities of 1000.
M/A-COM Anzac Operation
INFO/CARD #206

Introduction to Phase Noise

By Constantine Fantanas
Trionix

The topic of phase noise is an often-forgotten subject. However, as this article will demonstrate, it is a topic of paramount importance when investigating the stability of oscillators. Herein, a brief introduction to phase noise will be given. To benefit all readers, a brief refresher of amplitude, frequency, and phase modulation is given, as it pertains to phase noise. At the end of the article, some frequency synthesizer topics are touched upon.

A practical oscillator must contain an amplification block to overcome losses in most practical frequency-determining elements, such as L-C tanks, cavities, crystals, and other passive networks. It is well known, however, that every amplifier generates noise of its own. Therefore, the output of any oscillator, if monitored with a spectrum analyzer of a wide enough dynamic range, will exhibit frequency components (sidebands) away from the carrier (the supposed output frequency of the oscillator).

The following discussion will make use of the concept of phasors (3), widely used by electrical engineers. A sinusoidally oscillating magnitude (output voltage, for example) can be represented as a vector on the x-y plane, rotating at the output frequency. Its magnitude will be proportional to the amplitude of the sinusoidally oscillating quantity it represents. Its projection on the x-axis or y-axis will be, therefore, proportional to the instantaneous value of the magnitude it represents. To make initial conditions match, one can introduce an initial angle with the x-axis.

Similarly, a sinusoidal oscillation can be represented with a complex number whose modulus is proportional to the amplitude of the oscillation and its phase angle equal to the phase of the actual oscillation. Then its real part will be proportional to the instantaneous value of the sinusoidally oscillating quantity. Equivalent statements can be made about its imaginary part by properly adjusting the phase angle. On the complex plane, rotation by an angle Φ is accomplished by multiplying the given number by $e^{j\Phi}$, where j is $\sqrt{(-1)}$. Since the frequency of rotation of the vector or complex number is known, they are depicted at one phase angle with the tacit assumption of rotation. In either case, the power of the oscillator is proportional to the square of the magnitude of the vector or complex number.

An equivalent way of describing an oscillation is as the sum of two vectors (or complex numbers), symmetric with respect to the axis on which the projection is taken (3). That sum will always be along the axis of symmetry, which is taken to be the x (real) axis. To maintain symmetry, those two vectors or complex numbers must be counter-rotating. Their y (or imaginary) components will have opposite signs. In the case of complex numbers, they will be complex conjugates of each other. Complex algebra confirms that the conjugate of the product of two complex numbers is the product of their conjugates and that the conjugate of $e^{j\Phi}$ is $e^{-j\Phi}=e^{j(-\Phi)}$, so that the two complex components of the real sum are always counter-rotating.

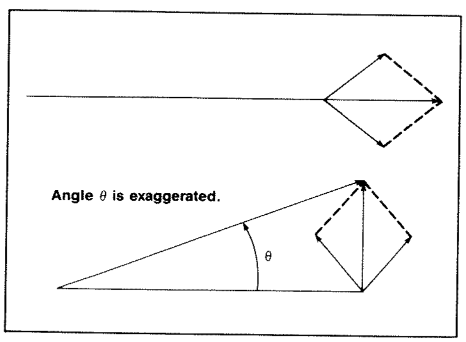


Figure 1. Phasor diagrams showing difference between AM (top) and small-angle PM.

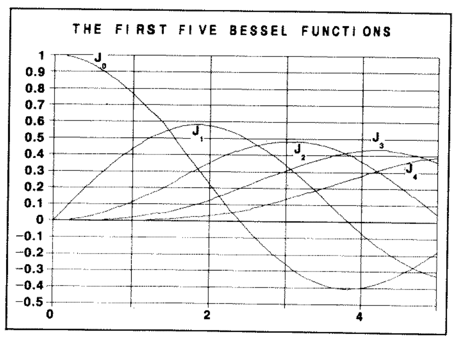


Figure 2. The first five integral-order Bessel functions. Note all functions vanish at zero except for the zeroth order.

Modulation Review

Assuming a perfect (noiseless) sinusoidal oscillation, we will call it the "carrier". Any deviation from this perfect sinusoidal oscillation can be called modulation. One can modulate only the amplitude of the carrier (amplitude modulation, AM) or the phase of the carrier (phase modulation, PM). Noise, therefore, can be regarded as a form of modulation, albeit unwanted, since it causes aberrations from the perfect sinusoidal oscillation.

In order to understand the fundamental differences between AM and PM, assume that a carrier of angular frequency ω_c and amplitude A is deliberately amplitude-modulated in a sinusoidal manner, at an angular frequency ω_m. Since, by definition, the phase of the carrier does not change, we can write for the resultant voltage (4):

$$v(t) = A[1 + m\cos(\omega_m t)]\cos(\omega_c t) \quad (1)$$

where m is the modulation index. After some trigonometry, we can write the above relation as

$$A\cos(\omega_c t) + \frac{Am}{2}\cos[(\omega_c + \omega_m)t] + \frac{Am}{2}\cos[(\omega_c - \omega_m)t] \quad (2)$$

which says that the resultant spectrum consists of our initial carrier plus two more components (sidebands) of amplitude Am/2 each oscillating so that they combine in phase with the carrier (Figure 1, top). The power of each compo-

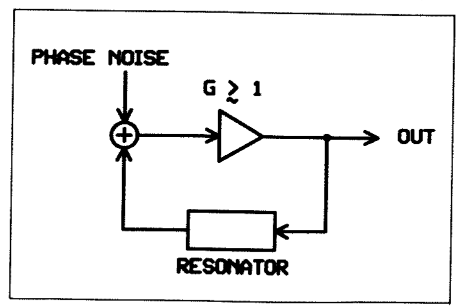


Figure 3. Phase noise injected into an idealized oscillator.

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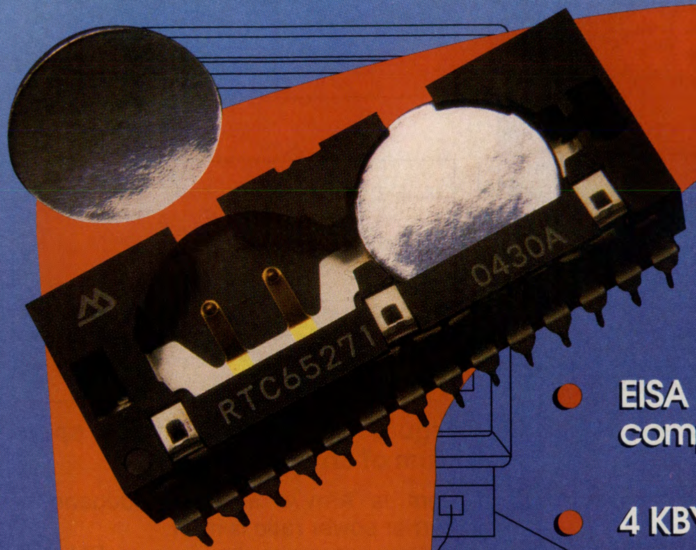

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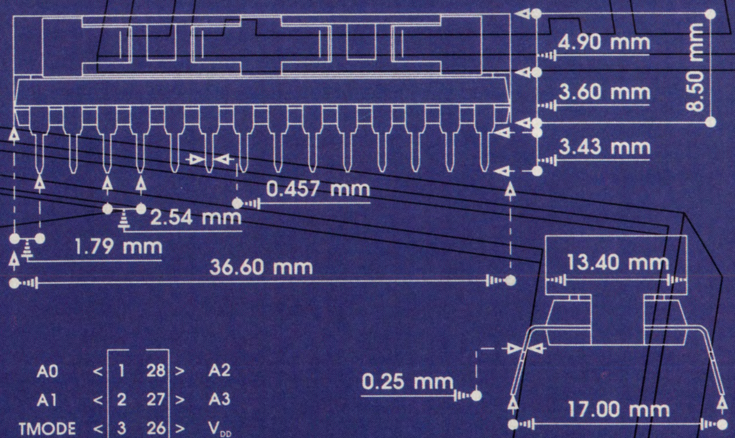

A0	1	28	A2
A1	2	27	A3
TMODE	3	26	V_{DD}
TCLOCK	4	25	SQW
$\overline{STBY}$	5	24	A4
D0	6	23	A5
D1	7	22	N/C
D2	8	21	$\overline{IRQ}$
D3	9	20	$\overline{RESET}$
D4	10	19	$\overline{RD}$
D5	11	18	N/C
D6	12	17	$\overline{WR}$
D7	13	16	$\overline{XRAM}$
V_{SS}	14	15	$\overline{RTC}$

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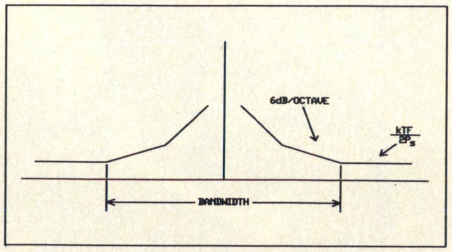


Figure 4. Predicted noise spectrum of an oscillator.

nent is $A^2m^2/8$ and the sideband-to-carrier power ratio is $m^2/4$.

Now, consider the case of PM. We can write the oscillating voltage as (4)

$$v(t) = A\cos[\omega_c t + \theta(t)] \tag{3}$$

where $\theta(t)$ is the phase modulation. The argument within brackets is the phase of the carrier. Interestingly, the resultant frequency is given by

$$f = \frac{1}{2\pi}\frac{d}{dt}[\omega_c t + \theta(t)]$$

$$= \frac{\omega_c}{2\pi} + \frac{1}{2\pi}\frac{d}{dt}\theta(t) \tag{4}$$

Since $\omega_c/2\pi = f_c$, the frequency of the carrier, we can see that the carrier is also frequency modulated. Thus, *phase modulation implies frequency modulation and vice versa* (with a simple integration).

To develop some useful formulas, assume that $\theta(t) = \theta_p\sin(\omega_m t)$, that is, $\theta(t)$ varies sinusoidally in time with an amplitude (in radians) of θ_p and frequency ω_m. The resultant voltage is given by

$$v(t) = A\cos(\omega_c t + \theta_p\sin\omega_m t) \tag{5}$$

As above, the frequency of the resultant waveform is now (4,6,7)

$$f = \frac{\omega_c}{2\pi} + \frac{\theta_p\omega_m}{2\pi}\cos\omega_m t$$

$$= f_c + \theta_p f_m\cos\omega_m t \tag{6}$$

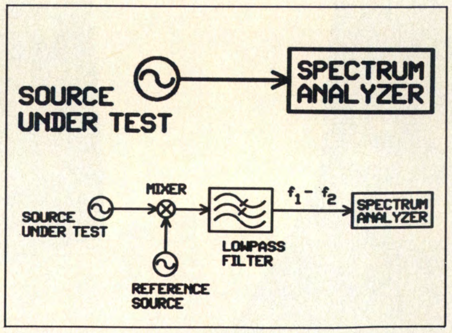


Figure 5. Two different phase shift measurement set-ups.

and from this it can be easily seen that the frequency varies sinusoidally with time with an amplitude (in Hertz) of $\Delta f = \theta_p f_m$. In the case of frequency modulation, it is customary to use the symbol β instead of θ_p, although they are equal (4,6,7). $\theta_p \equiv \beta \equiv \Delta f/f_m$, so that one can write

$$v(t) = A\cos(\omega_c t + \beta \sin\omega_m t) \qquad (7)$$

Expressions like the one above have been extensively studied. It is well known in the mathematical literature (1,2) that

$$\cos(\omega_c t + \beta \sin\omega_m t) = \sum_{\mu=-\infty}^{\infty} J_\mu(\beta)\cos(\omega_c + \mu\omega_m) \qquad (8)$$

where $J_\mu(\beta)$ are the so-called Bessel functions of order μ. A graph of the first few Bessel functions is shown (4) in Figure 2. Some very useful identities are (1,2)

$$J_{-\mu}(x) = (-1)^\mu J_\mu(x) \qquad (9)$$

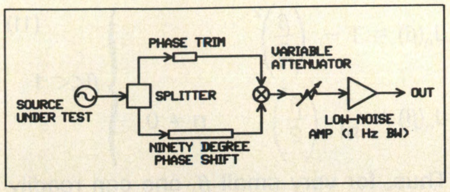
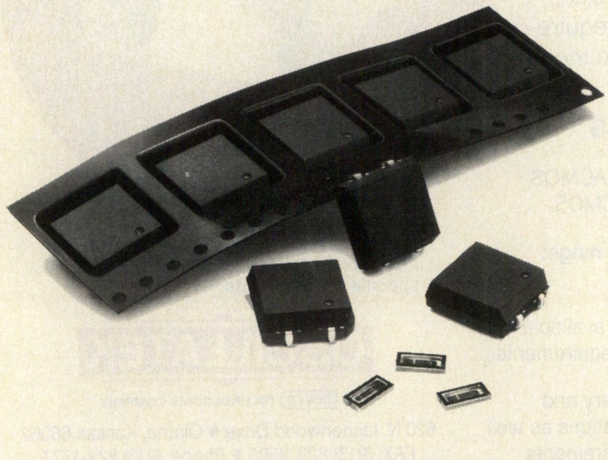


Figure 6. Quadrature technique for measuring phase noise.

which relates Bessel functions of positive and negative integral order, the so-called Parseval identity (1,2,4),

$$\sum_{\mu=-\infty}^{\infty} J_\mu^2(x) = J_0^2(x) + 2J_1^2(x) + 2J_2^2(x) + \ldots. = 1 \qquad (10)$$

indicating that (4), *during pure phase/frequency modulation, the power of the resulting waveform is equal to the power of the unmodulated carrier* (that is, the modulation transfers power from the carrier to the sidebands in contrast to AM, where modulation adds power $A^2m^2/2$ to the sidebands, leaving the carrier power unaffected), and the approximation formulas



$$\left.\begin{aligned} J_0(\beta) &\approx 1 - \left(\frac{\beta}{2}\right)^2 && (11)\\ J_n(\beta) &\approx \frac{1}{n!}\left(\frac{\beta}{2}\right)^n \quad n \neq 0 \end{aligned}\right\} \beta << 1$$

Thus, for very small β, one can readily derive (6,7) that

$$v(t) = A\cos(\omega_c t)[1 - \beta\sin(\omega_m t)] \quad (12)$$

which indicates that the modulation and the carrier are in quadrature (4). Further manipulation of the above identity yields

$$v(t) \approx A\left\{\cos(\omega_c t) - \frac{\beta}{2}[\cos(\omega_c + \omega_m)t - \cos(\omega_c - \omega_m)t]\right\} \quad (13)$$

The above could also be derived by expanding $\cos[\omega_c t + \beta\sin(\omega_m t)]$ and using small-angle approximations.

In contrast to AM, the modulation now can be represented as two counter-rotating phasors (Figure 1, bottom), each of amplitude $\beta/2$, combining in quadrature with the carrier (that would increase its magnitude slightly but, in actuality, that does not happen because of higher-order terms in equation 8 above, which were neglected in this approximation). The total power of the modulation is $A^2\beta^2/2$, but this time it is *removed* from the carrier. Since this represents only a small fraction of the unmodulated carrier power, it can be assumed that the carrier still carries 100 percent of its power. One sideband is ω_m above the carrier, the other sideband is at ω_m below the carrier and each carries a power of $A^2\beta^2/4$, just like in AM. *Unlike AM, the two sidebands are in antiphase.* If that waveform were observed on a spectrum analyzer, the sideband-to-carrier (power) ratio would be (6,7) $\beta^2/4 = \theta_p^2/4$.

Instead of using the peak phase deviation, θ_p, one can use the rms phase deviation, $\theta_{rms} = \theta_p/\sqrt{2}$. Then, for sinusoidal PM and small θ_p, the sideband-to-carrier ratio at the frequency offset f_m from the carrier, $\mathcal{L}(f_m)$, is given by

$$\mathcal{L}(f_m) = \frac{\theta_{rms}^2}{2} \quad (14)$$

The above relation *is true even for*

non-sinusoidal PM if the noise spectrum is scanned with a filter of bandwidth of 1 Hz, by the definition of the rms function.

Phase Noise

So far, we know that, when a decent oscillator is free of amplitude noise, its spectrum around the carrier will be symmetric and will be directly related to the phase noise. In oscillator design it is usually the case that the AM noise has been reduced to negligible amounts (a lot of frequency synthesis/detection schemes also use limiters, which effectively eliminate AM noise). So, it is the phase noise that is of paramount importance in oscillator design. In practice, from equations 2 and 13 one can deduce that (5,7), *if there is significant AM noise, the spectrum around the carrier will be asymmetrical, otherwise (PM noise only) it will be symmetrical*.

Phase noise implies frequency fluctuations and vice versa. To see how the two are related, let Δf denote rms frequency fluctuation. It is known (1,2) that the Fourier transform of the *derivative* of a function is equal to the Fourier transform of the original function times jω. We have that

$$\Delta f(t) = \frac{1}{2\pi}\frac{d[\Delta\theta(t)]}{dt} \tag{15}$$

so that in the frequency domain

$$\mathcal{F}[\Delta f(t)] = \Delta\vec{f}(\omega_m) = \frac{j\omega_m}{2\pi}\mathcal{F}[\theta(t)] \tag{16}$$

where the arrow of $\Delta\vec{f}(\omega_m)$ emphasizes it is a complex number. Remembering that $\omega_m/2\pi = f_m$, taking squares of magnitudes and rms values,

$$\Delta f^2_{rms}(f_m) = f_m^2\theta^2_{rms}(f_m) = 2f_m^2\mathcal{L}(f_m) \tag{17}$$

using equation 14 and switching the independent variable from ω_m to f_m. f_m is an absolute number; if an oscillator of nominal output frequency, say, 1 MHz has a sideband-to-carrier ratio of −110 dBc measured in a 1-Hz bandwidth at offset f_m = 10 kHz from the carrier, and another oscillator of nominal frequency of, say, 100 MHz exhibits the same SSB-to-carrier ratio at the same offset, it is obvious that the latter is a much better performer than the former, since the offset of 10 kHz is only 0.01 percent of 100 MHz and a sizable 1 percent of 1 Mhz. From similar considerations, it has been justly proposed (6) that the *rms fractional* frequency deviation y(t) = Δf(t)/f_0 be considered (f_0 is the nominal frequency of the oscillator). From the derivation of equation 17 above,

$$S_y^2(f_m) = \frac{2f_m^2}{f_0^2}\mathcal{L}(f_m) \tag{18}$$

Residual FM is defined (6) as the total rms frequency deviation caused by the phase noise within a specified bandwidth. Since the *squares* of rms quantities add,

$$\Delta f_{res} \equiv \sqrt{2}\sqrt{\int_a^b \mathcal{L}(f_m)f_m^2 df_m} \tag{19}$$

By splitting the phase-noise spectrum (plotted "log-log") into regions of constant slope, the evaluation of the above integral can be expedited (6). The validity of the above expression can be verified by the use of Parseval's relation (1,2) of Fourier transforms:

$$(\Delta f_{res})^2 = \int_{-\infty}^{\infty} [\Delta f_{rms}(t)]^2 dt$$

$$= \int_{-\infty}^{\infty} |\mathcal{F}[\Delta f_{rms}(t)]|^2 d\omega \tag{20}$$

(the right integrand has been found in equation 17 above).

Evaluating the stability of ultra-stable oscillators often requires taking data *in the time domain* by taking fractional frequency measurements with no dead time between them. An appropriate measure is the Allan variance, $\sigma_y^2(\tau)$, where τ is the sampling interval for each frequency measurement:

$$\sigma_y^2(\tau) \equiv \frac{1}{2(M-1)}\sum_{k=1}^{M-1}(\bar{y}_{k+1} - \bar{y}_k)^2 \tag{21}$$

where $\bar{y}_k$ is the fractional frequency difference of the kth sample measured over sample time τ. Conversions between the Allan variance (time domain data) and $\mathcal{L}(f_m)$ (frequency domain data) are possible (6) but tedious.

Application of Concepts

The above concepts are very useful. As a first example, consider the effect of the oscillator Q. An oscillator can be thought of as an amplifier with a frequency selective feedback (Figure 3). It is expected that the resonator would suppress any noise outside its bandwidth. The total noise contributed by the amplifier is (4,5,6,7) kTFG, where k is Boltzmann's constant, T is the absolute temperature, F is the noise figure (4,7,8) of the amplifier (the ratio of the noise power at its output over the noise power at its input, the latter being equal to kT per unit bandwidth), and G its gain, which for a decent oscillator should be slightly higher than unity. Since the noise power is split equally between AM and PM/FM noise, and the AM noise is virtually eliminated, the oscillator noise density per unit bandwidth *far from the resonator's passband* would be (8) kTFG/2 (as would be seen on a spectrum analyzer). An oscillator by itself is useless unless it drives something, usually a buffer. If P_s is the signal power delivered by the oscillator, the phase-noise-to-carrier ratio will be (5,6,7,8)

$$\mathcal{L}(f_m) = \frac{kTFG}{2P_s} \tag{22}$$

far from the resonator's passband.

There seems to be no agreement on the noise performance within the resonator passband (6,7,8). As f_m becomes smaller (the carrier frequency is approached), "1/f" type noise adds to the thermal noise and the slope of $\mathcal{L}(f_m)$ changes from flat to 6 dB/octave with corresponding formula (Q here is the *loaded* Q of the resonator)

$$\mathcal{L}(f_m) = \left(\frac{f_c}{2Q}\right)^2\left(\frac{FkTG}{2P_s f_m^2}\right) \tag{23}$$

where $(f_c/2Q)^2$ is the 3 dB f_m above and below the carrier frequency f_c. Dividing that by f_m^2 yields pure 1/f behavior (the remaining factors are just the thermal noise floor). Still closer to the carrier the slope of $\mathcal{L}(f_m)$ changes to 9 dB/octave ($1/f^3$ behavior), Figure 4.

As an example, assume a 147 MHz varactor-tuned VHF oscillator with a *loaded* Q of 100, delivering P_s=−3 dBm=0.5mW of power to a buffer. Further, assume a 10 dB noise figure for the amplifying element of the oscillator. From this, one can immediately estimate that further than 147 MHz/(2×100) = 735 kHz away from the carrier the phase noise must have dropped to the noise floor (equation 19). Since the factor 1/2 corresponds to −3 dB, and, at room temperature, kT ≃ −174 dBm, one gets, assuming that G ≅ 1, $\mathcal{L}(f_m)$ = 10−174−3+3 = −164 dBc. In Figure 4, $\mathcal{L}(f_m)$ will begin to rise at 6 dBc/octave for $|f_m|$ < 735 kHz.

The Q of a resonator is defined by

$$Q \equiv \frac{\text{average oscillating energy}}{\text{energy dissipated per cycle}}$$

$$= \frac{U}{\dfrac{P_s}{f_c}\dfrac{1}{2\pi}} = \frac{\omega_c U}{P_s} \tag{24}$$

(since P_s is the average *power* delivered to the load of the oscillator and $1/f_c$ is the period of the carrier, P_s/f_c is the dissipated energy in one period; also, a cycle is 2π radians and U is the energy oscillating between magnetic and electric field storage in the resonator in one period). It is obvious that in one cycle the amplifier must supply P_s for the oscillation to be sustained. So, if L is the inductance of the oscillator, C the capacitance, and V and i the oscillating voltage and current, we know that

$$U = \frac{1}{2} CV^2_{max} = \frac{1}{2} Li^2_{max} \qquad (25)$$

from which the maximum voltage and current in the tuned circuit can be found. In our example, if the resonating capacitance is 4 pF, using equations 25 and 24, we can see that the maximum voltage across the resonating capacitance is about 116 mV. Such calculations are very important because one has to consider the gain linearity of the amplifier (8), and, perhaps, the quiescent points of the active elements involved.

Another issue is frequency multiplication, either by means of a PLL or by nonlinear multipliers. If the multiplication factor is N, using equation 5 one immediately gets that

$$v(t) = A\cos(N\omega_c t + N\theta_p \sin\omega_m t) \qquad (26)$$

from which it is immediately apparent that the peak phase deviation at the *same* offset from the carrier is also multiplied by N (ω_m, and, hence, f_m does not change going from equation 5 to equation 26 above). That means that after multiplication by N, $\mathcal{L}(f_m)$ is multiplied by N^2 (increases by 20logN dBc), as equation 14 above reveals. For example, if the above oscillator was used as a reference oscillator of a "divide by N" type PLL operating at 1.47 GHz, we could immediately deduce that, barring other factors, the SSB-to-carrier ratio of the output would be at least 20 dBc worse at the same f_m than the reference oscillator. Similarly, division by N improves $\mathcal{L}(f_m)$ by 20logN dBc, but only up to a certain point because dividers generate noise of their own (6) in the vicinity of −160 dBc. The above facts are of paramount importance in PLL design.

AM noise can be converted to PM noise in some cases (6,7). An example is the use of a tuning diode. Remembering that Q's of different elements *of the same tuning circuit* add as resistors in parallel, one can easily see that the total Q of the varactor-based tuned circuit, Q_T, is given by

$$\frac{1}{Q_T} = \frac{1}{Q_{diode}} + \frac{1}{(\text{Q of everything else})} \qquad (27)$$

and for a series RLC circuit of resonant frequency ω_0,

$$Q = \frac{1}{\omega_o CR} = \frac{\omega_o L}{R} \qquad (28)$$

and for a parallel RLC circuit of resonant frequency ω_0,

$$Q = \omega_o CR = \frac{R}{\omega_o L} \qquad (29)$$

one can find an equivalent resistance, R_{eq}, from the above expressions based on the circuit configuration (series or parallel). Then, using Nyquist's equation for the thermal rms voltage (4,7,8), V_n, within a measuring bandwidth, Δf,

$$V_n = \sqrt{4kTR_{eq}\Delta f} \qquad (30)$$

one can find the expected V_n (k and T were defined above). So far V_n is just AM noise. That noise, however, is superimposed on the varactor bias, modulating the junction capacitance (6,7). Thus, V_n multiplied by the VCO gain (Hertz/Volt) will result in a Δf_{rms} and equation 17 above can be used to find the $\mathcal{L}(f_m)$ resulting from AM-to-PM conversion (this can be added directly to other $\mathcal{L}(f_m)$'s since $\mathcal{L}(f_m)$ is the *square* of an rms quantity as seen in the discussion around equation 14 above).

Measurement of Phase Noise

Measuring the phase noise of high-quality oscillators imposes daunting demands on RF instrumentation. The most natural way of measuring phase noise is with a spectrum analyzer (Figure 5a). However, the spectrum analyzer used may not have enough dynamic range and, in any event, it will have a phase-noise floor of its own. The spectrum analyzer should be capable of a resolution bandwidth of 300 Hz or less; this places more demands on the instrument. Reference 7 contains the formulas for converting the $\mathcal{L}(f_m)$ and Δf_{rms} measured with a large bandwidth to the $\mathcal{L}(f_m)$ and Δf_{rms} that would be obtained with an ideal 1 Hz bandwidth. For the above reasons, heterodyning and using a spectrum analyzer optimized for low-frequencies is sometimes employed (Figure 5b). A frequency discriminator can be placed between the source and spectrum analyzer in (Figure 5a) or mixer and low-pass filter in (Figure 5b). Then, the required $\mathcal{L}(f_m)$ can be found (6) using equation 17 above: $\Delta f_{rms} = \Delta V_{rms}/K_f$, where K_f is the transfer function of the discriminator and ΔV_{rms} is its rms voltage output. Then, $S_{\Delta f}(f_m) = (\Delta V_{rms})^2/K_F^2$ and $\mathcal{L}(f_m)$ can be found from equation 17.

It must be emphasized that a spectrum analyzer may not have enough dynamic range for measuring the phase noise of a high-quality oscillator (a survey of available instruments will reveal that their dynamic range rarely exceeds 100 dB, even on the very expensive units). Special techniques of attenuating the carrier must be employed. On the other hand, some modern "smart" spectrum analyzers have provisions that ease phase-noise measurements.

The use of a mixer which is fed by the source under test and a replica of that signal shifted by 90 degrees is a very powerful technique for measuring phase noise. Since the mixer is fed in quadra-

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ture, its output should be null (barring any offsets). In practice, quadrature is achieved by feeding the one end of the mixer through a delay line, whose length has been calculated to cause a 90 degree phase shift at the carrier frequency. Any deviation from the quadrature condition will generate an output voltage from the mixer (Figure 6).

It is easy to see that the output of such an arrangement will have a (sinx)/x type dependence (6) on the offset frequency f_m. In reference 6 it is proven that, if the delay time, τ_d, is such that $f_m << 1/(2\tau_d)$, and K_θ is the system's phase-detection constant (Volts/rad),

$$\mathcal{L}(f_m) = \frac{1}{2}\,\frac{(\Delta V_{rms})^2}{(2\pi)^2 K_\theta^2 \tau_d^2 f_m^2} \tag{31}$$

where the output rms voltage ΔV_{rms} is measured with a 1-Hz bandwidth. It must be observed that (6) the noise floor of this setup rises at least as fast as f_m^{-2}, and, for low offsets, as f_m^{-3}. This method is insensitive to AM noise.

A variation of the above technique (6,7) when a *synthesized* source is used, substitutes the quadrature phase-shifting arrangement (phase splitter, delay line) with another synthesized (reference) source providing the quadrature signal, *both sources clocked by the same clock.*

For ultra-high-stability oscillators, the technique of Figure 5b can be used but with the output monitored by a period counter, possibly connected to a computer (6,7). In this fashion the Allan variance can be obtained, which can then converted to the required $\mathcal{L}(f_m)$, as described above.

In the above discussion one should carefully examine the mixer. A mixer may generate intermodulation distortion (7), as well as noise of its own. Also, attenuators may be required immediately after the source(s) for greater isolation, thus minimizing the chances of one source "pulling" the other in the case of heterodyning techniques.

Conclusion

This article explains what phase noise of oscillators really is and how it can be measured. It also shows how the power spectrum of an oscillator can provide information about its frequency/phase stability. ***RF***

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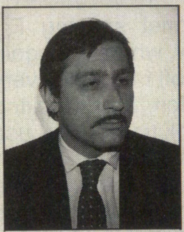
About the Author



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An Infinite Resolution, Single Loop Frequency Synthesizer

By Neil W. Heckt
Almost All Digital Electronics

It is often desirable to design a frequency synthesizer which can be fine tuned with high resolution, for instance, the LO of a receiver. The concept described here allows a low frequency to be added to (or subtracted from) a high frequency VCO without the use of a mixer. The example given adds a low frequency (100-200 kHz), infinite resolution, RC tuned oscillator output to the output of a high frequency, PLL controlled VCO. The target application is a HF receiver local oscillator which tunes 45-75 MHz in 30 bands of 100 kHz each. The technique can also be used to add digitally generated low frequencies or a fixed low frequency, i.e. IF frequency offsets to a high frequency VCO.

In order to explain the concept, we begin with a brief review of phase lock loop principles. Figure 1 depicts the traditional single loop synthesizer which incorporates a divide-by-P prescaler. Since it is the function of the loop to keep the two inputs to the phase detector exactly equal in frequency and phase, the VCO frequency must be $F_{VCO} = (NP)F_{ref}$. A disadvantage of this type synthesizer is that F_{ref} becomes the channel spacing divided by P. As a result, the low value of F_{ref} may set up the loop filter cutoff at too low a frequency for the desired acquisition and tracking speeds.

The solution to this problem is to employ a dual modulus prescaler and dual modulus PLL controller as shown in Figure 2. A divide-by-A counter, control logic and dual modulus prescaler (divide by P or P+1) are utilized such that P will divide by P+1 A times and divide by P (N-A) times. One way of looking at this is that each time the control logic causes P to divide by P+1 the VCO must output an additional cycle if the output of the divide-by-N counter is to continue to equal F_{ref}. Since this is happening at F_{ref} rate, the VCO must put out F_{ref} additional cycles per second. The result is $F_{VCO} = (NPA)F_{ref}$ and F_{ref} is maintained at the desired channel spacing in spite of the incorporation of a prescaler.

For very fine channel spacing F_{ref} must be made very low, which will again force the loop filter cutoff frequency very low, limiting acquisition and tracking times. A traditional solution is the use of a fractional N synthesizer as shown in Figure 3. For this approach, a rate multiplier is clocked at F_{ref}. It produces output pulses at a rate of $A/M \times F_{ref}$, where A is always less than M. Thus the output pulse rate is a fraction of F_{ref}. If each of these pulses causes P to divide by P+1 then the VCO will have to output an extra $A/M \times F_{ref}$ pulses per second causing $F_{VCO} = (NP+(A/M))F_{ref}$.

The concept that each P+1 cycle causes F_{VCO} to increase by one cycle leads to the basis of the infinite resolution, single loop frequency synthesizer of Figure 4.

A characteristic of dual modulus prescalers is that the count modulus can only be changed once each cycle of the counter. If F_t, an asynchronous low frequency oscillator's output, can be synchronized with the overflows of the prescaler, then for each cycle of the prescaler, the modulus can be changed from P to P+1. The result is that the VCO must put out one extra cycle for each cycle of F_t. The VCO frequency becomes $F_{VCO} = NPF_{ref}+F_t$.

The low frequency limit of F_t must be well above the cutoff frequency of the loop filter and the upper frequency limit must be less than $N \times F_{ref}$ at which time the prescaler will divide by P+1 100 percent of the time.

This is a very useful configuration. For a HF LO design covering 45-75 MHz, a nice set of numbers would be:

$F_{ref} = 10$ kHz
P = divide by 10/11
F_t = 100 to 200 kHz, a 100 kHz infinite resolution fine tune range

$N_{min}P = 4490$ producing $F_{VCO} = (NP)F_{ref} = 44.9$ MHz
N = 449, P = 10

$N_{max}P = 7480$ producing $F_{VCO} = (NP)F_{ref} = 74.8$ MHz
N = 748, P = 10

$\Delta N = 1$ for 100 kHz steps

$F_{VCO}min = (N_{min}P)F_{ref}+F_tmin = 45$ MHz
$F_{VCO}max = (N_{max}P)F_{ref}+F_tmax = 75$ MHz

If this results in too low an F_{ref}, the dual modulus PLL controller can be combined with the infinite resolution concept

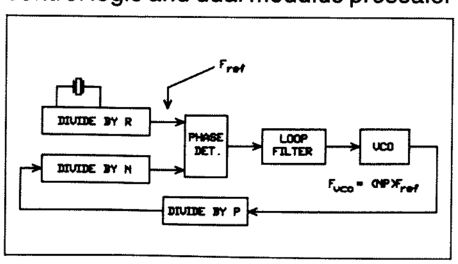

Figure 1. Single loop synthesizer with prescaler.

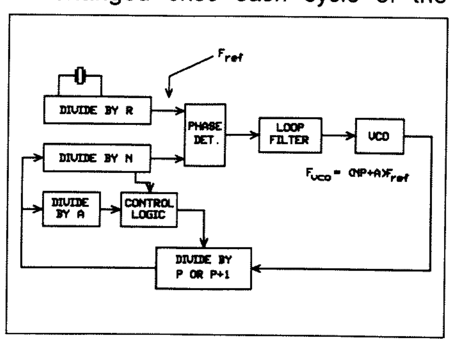

Figure 2. Dual modulus synthesizer.

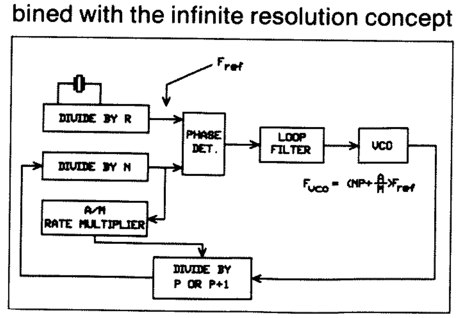

Figure 3. Fractional N synthesizer.

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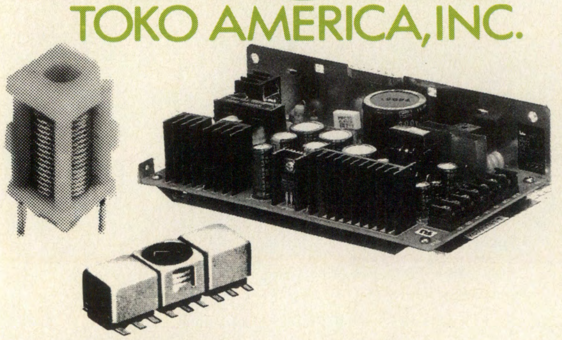

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RFD 8/92

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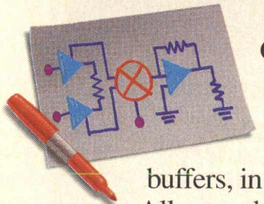

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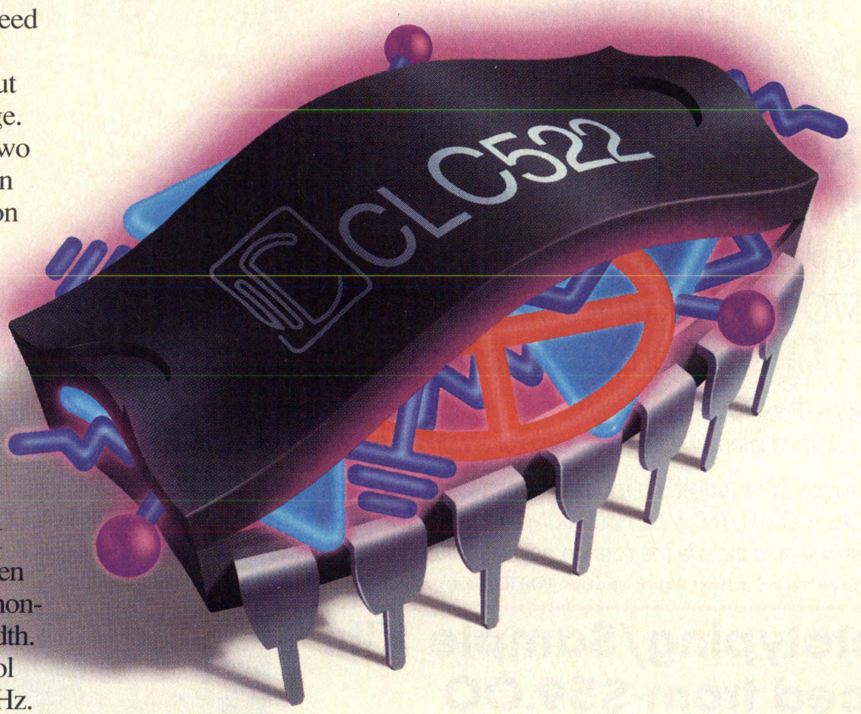

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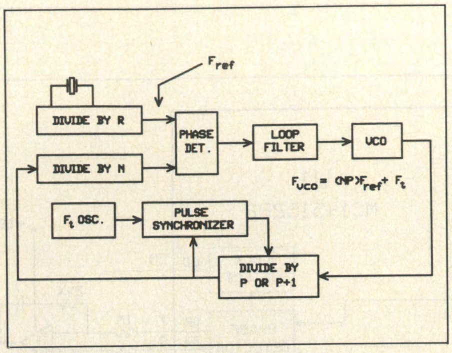


Figure 4. Infinite resolution synthesizer.

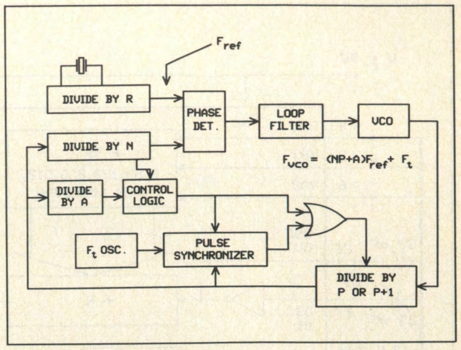


Figure 5. Infinite resolution dual modulus synthesizer.

as shown in Figure 5.

In this configuration the dual modulus prescaler is controlled either by the dual modulus PLL controller or the pulse synchronizer. The pulse synchronizer must be a little more complex in order to store any F_t pulses which might occur while the PLL controller has control of the prescaler and then insert the extra divide by P+1 cycle later, after the PLL controller relinquishes control. The resultant F_{VCO} equals $(NP+A)F_{ref}+F_t$. An example pulse synchronizer is shown in Figure 6.

In the standard dual modulus approach of Figure 2, N must be greater than or equal to A, or else the prescaler would be required to divide by P+1 more than 100 percent of the time. This sets the lower limit on the VCO frequency. For example, for P = 8 and F_{ref} = 100 kHz, N must be equal to or greater than 8 and $F_{VCO}min = (NP)F_{ref} = (8 \times 8)(100$ kHz) = 6.4 MHz.

In the infinite resolution configuration of Figure 5, N must be greater than A in order to leave room for the additional divide-by-P+1 cycles. The simple pulse synchronizer of the test circuit of Figure 6 requires two cycles of P (and up to one cycle of uncertainty due to F_t being asynchronous) to insert one P+1 cycle and can only store one leading edge of F_t. This forces N_{min} = A+3. Since it can store only one cycle of F_t, an upper limit is established for F_t or a lower limit on F_{VCO}: $F_t max = F_{ref}N/(A+3)$ or $N_{min} = F_t max\ (A+3)/F_{ref}$, $F_{VCO}min = N_{min}PF_{ref}$. In order to get contiguous channels, A_{max} must be equal to P−1. Using the formulas above, one can calculate N_{min} and F_{VCO}min. Assume P = 8 (a dual modulus divide by 8/9), F_{ref} = 100 kHz and $F_t$max = 225 kHz, then:

$A_{max} = P-1 = 7$
N_{min} = (225 kHz)(7+3)/(100 kHz) = 22.5
NOTE: 22.5 is N = 22, A = 4

$F_{VCO}min = (N_{min}P+A)F_{ref} =$
$22.5 \times 8 \times (100$ kHz) = 18 MHz.

A more sophisticated pulse synchronizer employing an up/down counter or left/right shift register could be designed which would store multiple F_t clocks while the modulus control line is low. This would serve to increase the upper frequency limit on F_t. It could also require only one cycle of the prescaler to insert the P+1 cycle therby serving to reduce the lower limit of the VCO.

Again for a HF LO design, using Figure 5, covering 45-75 MHz a nice set of numbers would be:

F_{ref} = 100 kHz
P = divide by 10/11
F_t = 100 to 200 kHz, a 100 kHz infinite resolution fine tune range

$N_{min}P+A$ = 449 producing $F_{VCO} = (NP+A)F_{ref}$ = 44.9 MHz
N = 44, P = 10, A = 9

$N_{max}P+A$ = 748 producing $F_{VCO} = (NP+A)F_{ref}$ = 74.8 MHz
N = 74, P = 10, A = 8

ΔN = 1 for 1 MHz steps
$A_{min} = 0$
$A_{max} = 9$
ΔA = 1 for 100 kHz steps

$F_{VCO}min = (N_{min}P+A)F_{ref}+F_t min$ = 45 MHz
$F_{VCO}max = (N_{max}P+A)F_{ref}+F_t max$ = 75 MHz

If a dual modulus prescaler P/P-1 (ie: 10/9) were employed, then for each cycle of F_t the VCO would have to put out one less cycle and F_{VCO} + $(NP+A)F_{ref}-F_t$.

The "proof of concept" design shown in Figure 6, was constructed and tested

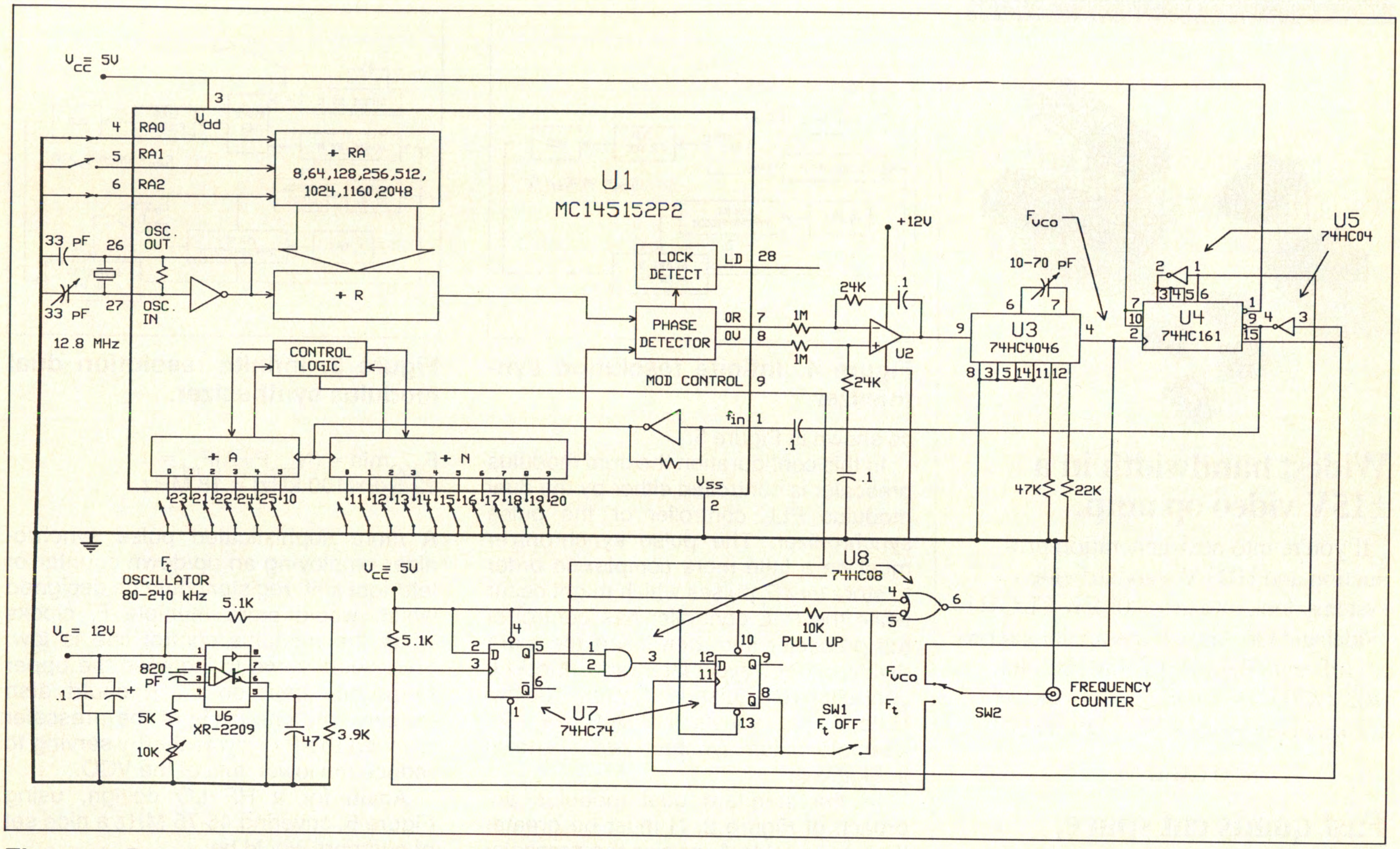


Figure 6. Proof of concept test set schematic.

to verify the approach. In order to keep it simple and use parts on hand, I employed a Motorola MC145152P2, parallel programmable, dual modulus PLL controller, U1. U2 is a conventional loop filter. U3 is the oscillator section of a 74HC4046 PLL which operates from about 8 to 32 MHz.

U4 is a 74HC161 programmed by U5 as a dual modulus divide by 8/9 prescaler. When the control line is low, U4 is pre-loaded with the value 7, meaning 9 more counts will be required to complete the 16 count limit of U4 (divide by 9 mode). When the control line is high, U4 is preloaded with 8, meaning 8 more counts will be required to complete the 16 count limit (divide by 8 mode).

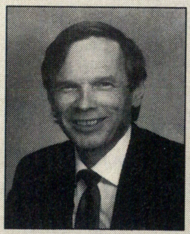
U7 and U8 comprise the pulse synchronizer with U7A being clocked by F_t storing the clock edge from U6. The modulus control line of U1 is low at the start of a cycle and goes high after the A counter reaches zero. When the control line goes high the state of U7A is gated to the D input of U7B. U7B is clocked by overflows from the prescaler U4/U5. If U7A is set then U7B will set and simultaneously reset U7A by its direct clear pin. This pulls the modulus control back low to the prescaler causing a divide by P1 (divide by 9) cycle. Since U7A was reset, the next overflow of U4 will clock a zero state into U7B. This then has inserted an extra divide-by-P1 cycle. If the modulus control line were already high when U7A sets then the P1 insertion will take place on the next overflow of the prescaler.

U6 is the fine tune oscillator, an EXAR 2209 precision oscillator. SW1 inhibits the fine tune option in order to verify the function of the main loop. SW2 simply determines which oscillator is attached to a frequency counter in order to rapidly verify that F_t has been exactly added to F_{VCO}.

The results of this test indicated performance exactly as predicted. U6 is an ultra-stable voltage controlled oscillator with a specified drift of 20 ppm/degree C. Since we are operating it at about 150 kHz, the drift is expected to be about 3 Hz/degree C. Since this is an additive process, the drift is not multiplied by the loop with the overall result being an extremely stable oscillator system.

Since this was a "proof of concept" circuit, no attention was paid to optimizing the design of the loop filter or oscillator and no measurements of phase noise were made, however, phase noise performance should be nearly identical to that of a fractional N synthesizer. *RF*

About the Author



Neil Heckt is the owner of Almost All Digital Electronics, which designs and manufactures test equipment and kits for hobbyists. He is also a full time senior design engineer with the Boeing Company in Seattle. He received his BSEE from South Dakota State College in 1960 and has 32 years experience in analog, digital and software design. He can be reached at Almost All Digital Electronics, P.O. Box 3246, Kent, WA 98032, or at the Boeing Company phone (206) 773-8633.

More Choices for Boards and Substrates

By Liane G. Pomfret
Associate Editor

RF designers have considerably more choices today when it comes to choosing a board or substrate material for their project. PTFE has been joined by a host of other materials such as ceramics or fiberglass with various resins that offer a variety of performance characteristics and costs to fit every application. The markets for boards and substrates are widely varied, growing but relatively mature.

The list of materials for board and substrate use is as varied as the number of applications. Among the most common materials are: lower cost PTFE, polyphenol oxide, fiberglass/cyanite ester, ceramics, thermo-plastics, kevlar and fiberglass resins, aluminum oxide, aluminum nitride and high performance glass epoxies. Each material has its own specific characteristics and some are better suited than others for certain applications.

There are advantages and disadvantages to using these materials. Most of them tend to be low cost which makes them suitable for high volume commercial applications. However, there is a tradeoff. Many of these materials suffer from increased electrical noise. While this may eliminate them from use in high performance, low noise products, they can still find a great deal of use in commercial and industrial products. In addition, the dielectric constants of the materials vary greatly. Some have constants as low as two or three while the constants of others may be around ten. Depending on the desired application, this may work out to the designer's advantage.

On the Plus Side

This group of materials tend to be easy to manufacture and therefore, cost less. Advances in the last few years have allowed for small improvements in the physical properties of the materials. Today's boards and substrates tend to be denser yet thinner than those manufactured even three years ago. Some companies, such as Compositech, are manufacturing boards with a more uniform X-Y coefficient of thermal expansion. As a result, they can make thinner, stronger and more uniform boards that don't oscillate. Many of the new materials also offer greater thermal dissipation than the older ones which allows for easier miniaturization. According to Win Richardson, a senior engineer in technical service at Electro-Science Laboratories, many of these new materials also offer cleaner surfaces. This is a boon in two ways. Companies can worry less about what to do with the residues left over from cleaning boards, especially CFCs. And, because the cleaning step has been reduced or eliminated, their manufacturing time is also reduced. In the long run, this too, saves them money.

The physical characteristics of many of these new materials have opened the door for some changes in manufacturing techniques. Despite the fact that there are often performance tradeoffs to be made when using these materials, designers are learning to work around them and as a result are coming up with better designs. Miniaturization is on the top of everyone's list of recent trends. The "smaller is better" philosophy holds true for substrates and boards as well. Paul Solan, general manager of the thin film division at Mini-Systems notes that "the number of traces as well as the power requirements are increasing while board geometries are decreasing." The miniaturization of components has different requirements such as thinner boards that also must be very stable. As a result, manufacturers have had to learn how to make materials to accommodate these components. Because improvements in board and substrate materials have reached the point of diminishing returns, manufacturers have had to take a new approach. Many are now looking at the requirements for the finished product and working back from there. This way they can design a board for an exact application rather than designing a variety of boards for engineers to pick and choose from.

Strong Markets

Opinions vary as to the growth of the market for substrate and board materials. Companies such as Rogers have seen an explosion in the commercial arena for microwave related products. But their market has also shifted in the past few years to a more commercial focus. Joel Dryer, company team leader at Poly-Circuits sees a very mature market, but still very healthy. There is plenty of business for companies supplying into the market. Fred Klimpl, president of Compositech notes, "The industry spent about 18 months in the doldrums. Now, however, shops are busy with newer, more complex designs." Those 18 months of slow business did take their toll. There were some major reductions and consolidations of suppliers and start-up operations are rare. Now that business is picking up however, companies are finding plenty to keep them busy. It is a customer driven market and it is their demands that have brought about many of these new and not so new materials.

Because of their very nature, boards and substrates are found in virtually every RF application. The newer materials are finding uses in areas such as avionics, communications products, consumer electronics, automotive electronics, GPS, DBS, tracking systems and virtually any wireless products. PTFE is still an important board and substrate material in the RF marketplace and will remain so in the years to come. However, other materials have a lot to offer the design engineer, provided he makes the right choice. **RF**

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Flam & Russell's new software package uses an alternative to Fourier transforms to move data from the frequency domain to the time domain. This time domain data has 30 times the resolution of Fourier derived data. Used primarily to locate electromagnetic discontinuities, the new software will allow analysts to resolve smaller objects with a standard bandwidth or get standard resolution with far less bandwidth.
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MMIC Foundry Software

EEsof has introduced Generic SMART (Simulatable Microwave ARTwork) Library, the first user-definable MMIC element library that can be customized to virtually any analog GaAs IC foundry. Called "Generic" because the user can easily fit the parameters for each library model to match the characteristics of any foundry, the Generic SMART Library is unique in that it integrates electrical element models with physical MMIC element layout representations in perfect synchronization.
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Analog Devices' newest version of ADSpice includes 36 completely new component models and is free. The new models, which bring the total number of models to 300, include models of the AD743, AD745, AD843, OP-275, OP-282, OP-482 and AD630. Additionally, the AD645 and AD712 have been converted to noise models. ADSpice Revision "F" is available on a 5.25 inch, 1.2 Mbyte PC compatible diskette.
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Spectrum Analyzer Control Software

Anritsu Wiltron Sales Company introduces software for its MS2601 spectrum analyzer which allows it to be controlled via RS-232 serial communications. The MS2601/RS-232C software allows a user to query the instrument, issue commands, and receive responses from the instrument. The spectral waveform is automatically acquired, graphed and continuously updated.
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RF literature

Discrete Products Catalog
Calogic's 1992 discrete component catalog has been released. The catalog covers their standard line of products in Bipolar, CMOS, DMOS, JFET and Dielectrically Isolated (DI) technologies, including devices from the Harris/Intersil line of small signal discrete components.
Calogic Corp.
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SAW Products Catalog
A new catalog from the Special Products Division of Siemens Components details the complete line of Siemens surface acoustic wave products now available. The catalog features satellite receiver filters, surface acoustic wave resonators and a wide range of TV IF filters. In addition to general technical information, the catalog lists frequency, insertion loss and group delay characteristics for intercarrier and parallel sound applications, among others.
Siemens Components, Inc.,
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Attenuator Catalog
A new eight-page catalog describes Kay Elemetrics line of manual step and programmable attenuators for use in bench or OEM applications. The catalog describes electrical and mechanical specifications, product dimensions, optional logic adapter and warranty information.
Kay Elemetrics Corp.
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Sub-Mini Push-On Connectors
An eight-page catalog describing the new MMCX subminiature push-on microwave connector is available from Huber + Suhner. The MMCX connector offers "snap-on" mating, which is reliable over hundreds of mating/unmating cycles. The connectors operate up to 26.5 GHz and allow high density mounting.
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Full-Line Amplifier Catalog
A new catalog from Kalmus Engineering provides information on their full line of amplifiers operating between 25 Hz and 1 GHz and with outputs of 5 kW CW and 12 kW pulsed. The 31-page catalog is available for no charge.
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Time & Frequency Instruments
FTS/Austron offers a new product guide that includes photos and brief descriptions of their oscillators, time code equipment, loran/GPS transfer standards, cesium standards, time and frequency instruments, and integrated systems.
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Selector Guide
Motorola has announced the availability of a revised RF Products Selector Guide and Cross Reference. A special feature of the new guide is the classification of devices to aid the user in selecting appropriate products for new designs. The three categories are "Preferred", "Current" and "Not For New Design". The updated book contains over 100 new devices.
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Cable Brochure
Micro-Coax Components™ has released a 30-page brochure on its full line of UTiFLEX® flexible microwave cable assemblies. The brochure provides complete descriptions and specifications on Micro-Coax's UTiFLEX low loss cable assemblies, power cable assemblies, high flex-life cable assemblies and others.
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High Voltage Trimmer Capacitors
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Voltronics Corp.
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Flight Electronics Catalog
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INFO/CARD 66

INFINITE CHALLENGES

E-Systems ECI Division is in need of engineers with military satellite communication experience (ground, manpack/man-portable, airborne, or spaceborne); a BSEE/BSCE; and at least 2 years' experience in one of the following areas:

SOFTWARE

- ADA, C
- 1750A, of 68020 Microprocessors
- VAX VMS, Sun UNIX
- Real-time, Embedded Microprocessor
- DOD-STD-2167A, CASE Tool

DIGITAL HARDWARE

- ACTEL FPGAs
- Microprocessor based systems
- 1553 bus interface

DIGITAL SIGNAL PROCESSING

- Discrete Fourier Transforms
- Control Loops
- PSK Demodulation

EMBEDDED CRYPTO

- Security Fault Analysis
- TEMPEST, Red/Black Isolation
- Related interface hardware

RF and MICROWAVE

- Synthesizer Design, Direct Digital
- Power amp and filter design
- MMIC design

ANTENNA DESIGN

- Parabolic Antenna Design
- Gimbal, Positioner
- 10 TO 60 GHz

SYSTEMS

- BSEE/MSEE, minimum 4 years' experience
- Strong communication background
- Requirements Analysis, Functional Analysis
- System Synthesis, System Analysis
- RF Link Budget Analysis
- System Integration/Test
- Customer Interface

Background: Hardware, Software Architecture Cryptographic; BIT/BITE; Antenna Pointing, Tracking, and Platform Stabilization; MIL-STD-1582; SI-1135, SI-2035, LL1005.

MILSTAR or other military satellite design experience a plus. E-Systems offers very competitive salaries and an excellent benefits package which includes an Employee Stock Ownership Plan, 401(k), and major medical and dental insurance. Qualified candidates should forward a resume and salary history to: Manager of Staffing, E-Systems, Inc., ECI Division, Post Office Box 12248, St. Petersburg, Florida 33733-2248.

E-SYSTEMS
The science of systems.

U.S. Citizenship Required.
An Equal Opportunity Employer, M/F, D,V.

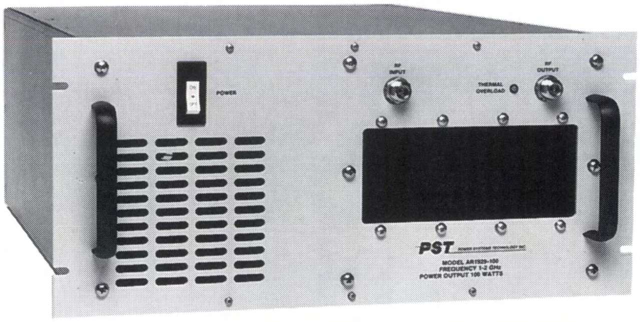
Advertising Index

RF engineering opportunities

100 WATTS 1-2 GHz BANDWIDTH

Class A Linear Power Amplifiers For Advanced Performance Plus Super Solid State Reliability: 30,000 Hrs. MTBF

- Modular Maintainability
- Reduced Spares Inventory
- IEEE 488 Bus (option)



- Automatic Circuit Protection
- Built-In Thermal Protection

These new generation Series AR rack-mount instruments are truly the state-of-the-art in Class A linear power amplifiers for RF/microwave applications. The Model AR1929-100, for example, delivers 100 watts over an instantaneous bandwidth of 1-2GHz. Design and performance features include excellent linearity, wide dynamic range and a 50dB gain rating. Other AR models offer power outputs from 2 to 100 watts and frequency ranges from 1-500MHz to 1-2GHz. All models include a built-in power supply, forced-air cooling, and completely modularized design for maximum maintainability – common, pre-aligned spare modules allow easy field replacement plus reduced spares inventory. They are ideal TWT replacements, for applications such as EMI/RFI susceptibility testing, frequency-agile multi-carrier ECM/EW jammers, fast rise time pulse amplifiers, and broadband sweep generator boosters.

Write or call for complete tech information – ask for Product Data 1010B – or to inquire about any of our other product areas: Class AB, C, narrow band and pulsed; powers up to 10KW; frequencies up to 4,000MHz.

PST

A SUBSIDIARY OF COMTECH TELECOMMUNICATIONS CORP.

POWER SYSTEMS TECHNOLOGY INC.

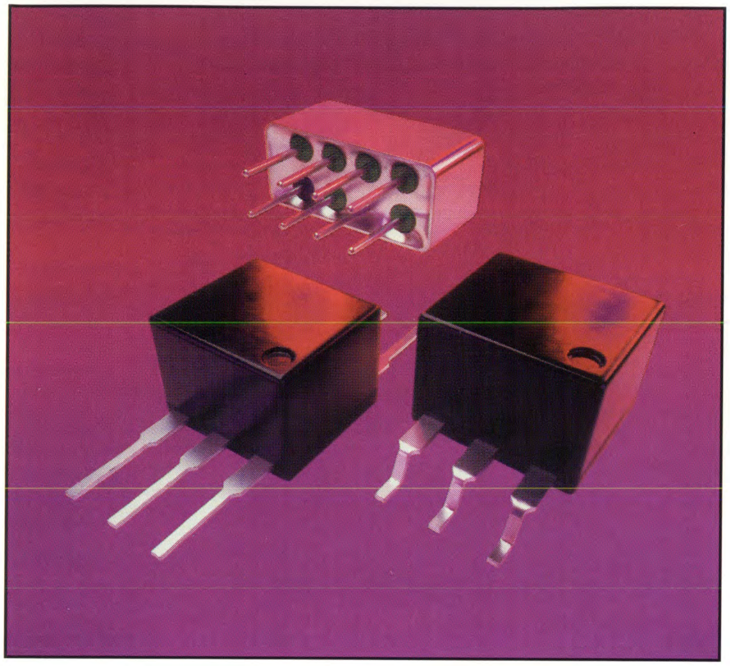
105 BAYLIS ROAD, MELVILLE, NY 11747

TEL. 516-777-8900 • FAX 516-777-8877

INFO/CARD 60

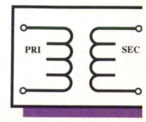
RF Transformers

3 kHz to 1000 MHz



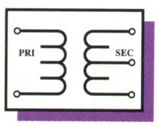
BROADBAND IMPEDANCE TRANSFORMATIO

ANZAC transformers offer low insertion loss, fast rise times f pulsed signals, and extremely wide bandwidth. They are offered in unbalanced to unbalanced, unbalanced to balanced, and balanced to balanced configurations, and hav impedance ratios from 1:1 to 16:1.



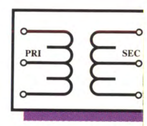
UNBALANCED/UNBALANCED

MODEL #	Ω Ratio	FREQUENCY MHz	INSERTION LOSS 3 dB MHz	INSERTION LOSS 2 dB MHz	INSERTION LOSS 1 dB MHz
ET1-1	1	.15 - 400	.15 - 400	.35 - 200	2 - 50
ET1-6	1	.01 - 150	.01 - 150	.02 - 100	.05 - 50
ET1.5-1	1.5	.1 - 300	.1 - 300	.2 - 150	.5 - 80
ET2.5-6	2.5	.01 - 100	.01 - 100	.02 - 50	.05 - 20
ET4-6	4	.02 - 200	.02 - 200	.05 - 150	.1 - 100
ET9-1	9	.15 - 200	.15 - 200	.3 - 150	2 - 40
ET16-1	16	.3 - 120	.3 - 120	.7 - 80	5 - 20
ETMO-1.5-1	1.5	.1 - 300	.1 - 300	.2 - 150	.5 - 8
ETMO-4-6	4	.02 - 200	.02 - 200	.05 - 150	.1 - 100



UNBALANCED/BALANCED

MODEL #	Ω Ratio	FREQUENCY MHz	INSERTION LOSS 3 dB MHz	INSERTION LOSS 2 dB MHz	INSERTION LOSS 1 dB MHz
ET1-1T	1	.05 - 200	.05 - 200	.08 - 150	.2 - 80
ET1-6T	1	.003 - 300	.003 - 300	.01 - 150	.02 - 50
ET2-1T	2	.07 - 200	.07 - 200	.1 - 100	.5 - 50
ET2.5-6T	2.5	.01 - 100	.01 - 100	.02 - 50	.5 - 20
ET3-1T	3	.05 - 250	.05 - 250	.1 - 200	.5 - 70
ET4-1	4	.2 - 350	.2 - 350	.35 - 300	2 - 100
ET4-6T	4	.02 - 250	.02 - 250	.05 - 150	.1 - 100
ET5-1T	5	.03 - 300	.03 - 300	.6 - 200	5 - 100
ET8-1T	8	.03 - 140	.03 - 140	.10 - 90	1 - 60
ET13-1T	13	.3 - 120	.3 - 120	.7 - 80	5 - 20
ET16-6T	16	.03 - 75	.03 - 75	.06 - 30	.1 - 20
ETMO-1-1T	1	.05 - 200	.05 - 200	.08 - 150	.2 - 80
ETMO-5-1T	5	.3 - 300	.3 - 300	.6 - 200	5 - 100



BALANCED/BALANCED

MODEL #	Ω Ratio	FREQUENCY MHz	INSERTION LOSS 3 dB MHz	INSERTION LOSS 2 dB MHz	INSERTION LOSS 1 dB MHz
ETT1-6	1	.004 - 500	.004 - 500	.02 - 200	.1 - 50
ETT2.5-6	2.5	.01 - 50	.01 - 50	.025 - 25	.05 - 10
ETT4-1	3	.05 - 200	.05 - 200	.2 - 50	1 - 30

OPTIONS

- MIL qualified models are available.
- Package options include plastic with flat leads, bent leads, or gull wing, and relay headers.

For more information on this product or our complete line of affordabl high quality components, Call 617-273-3333 or fax us at 617-273-1921.

ANZAC

A M/A-COM COMPANY

INFO/CARD 61

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