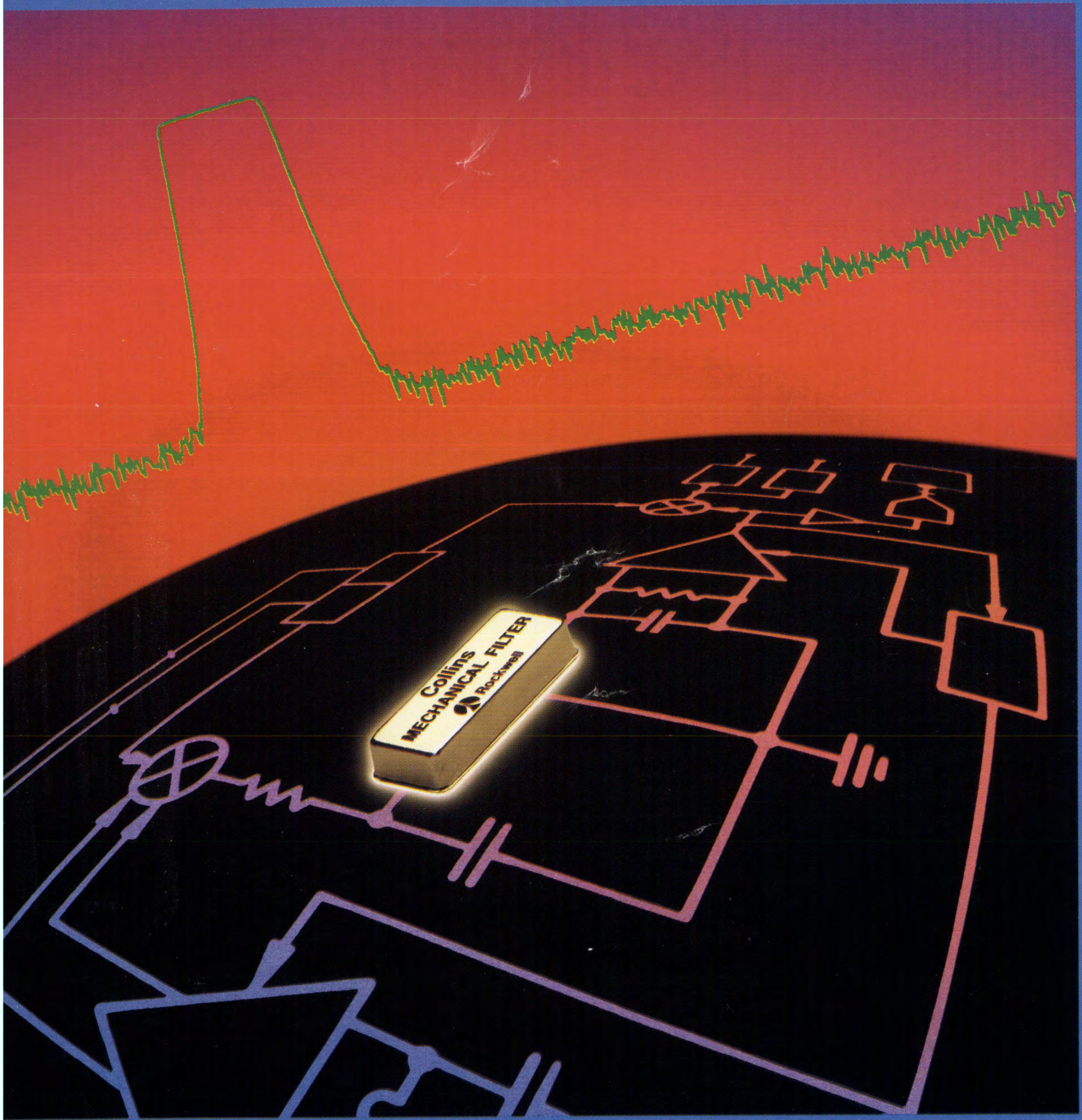
RF design

engineering principles and practices

October 1991



Cover Story
IF Bandpass Filters

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RF System Design

Plus
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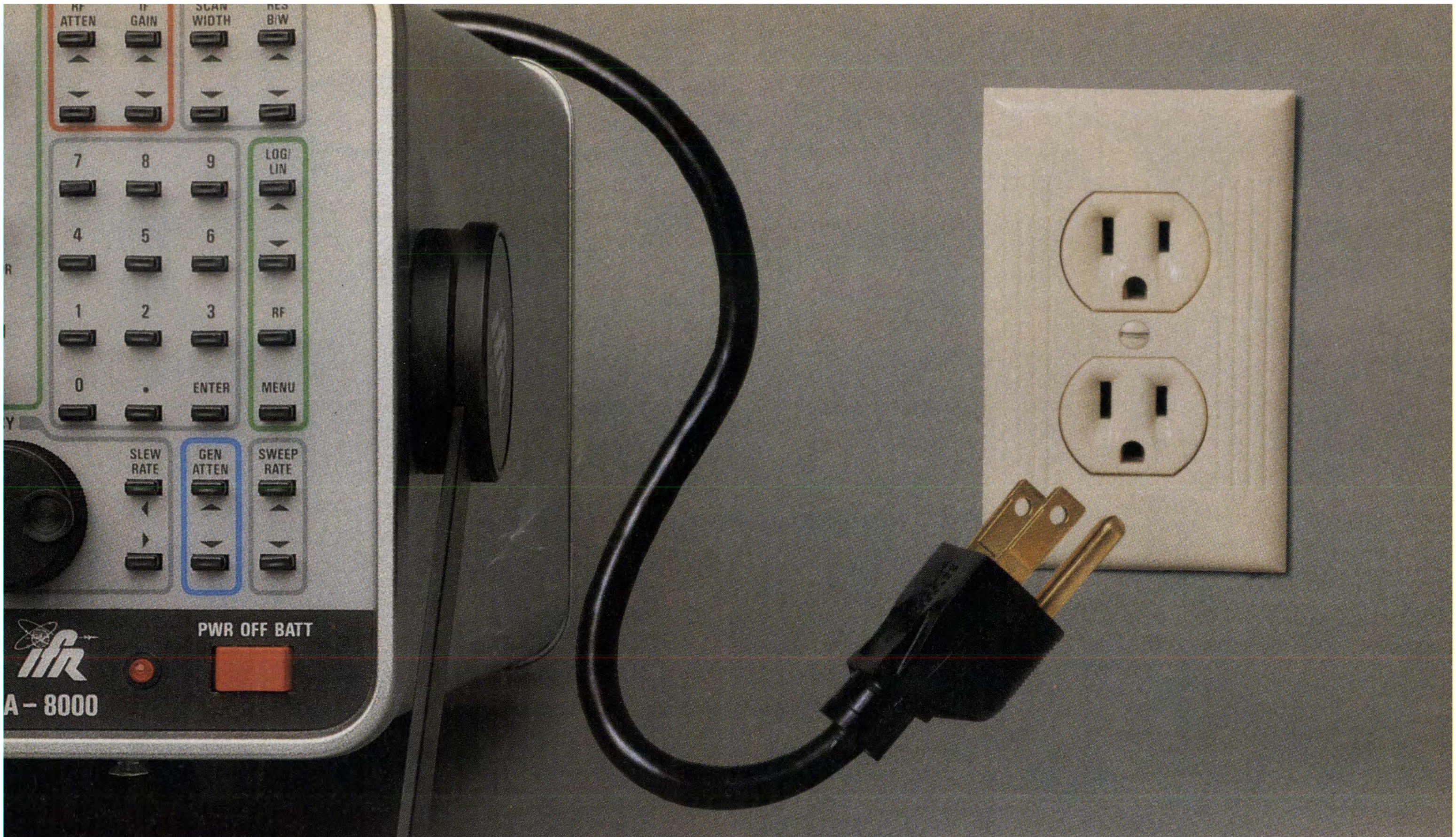

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DS0990	SPST	10-2000	1.5	62	25.0	14 Pin DIP	TTL
DS0850	SP2T	DC-2000	0.4	47	3.0	TO-5	0/-7
DS0813	SP2T	DC-2000	0.7	39	130	TO-5	TTL
DS0812	SP2T	10-1000	0.5	53	50.0	TO-8	TTL
DS0860	SP2T	10-1000	0.7	47	40.0	.380 sq	TTL
DS0602	SP2T	5-2000	1.3	65	26.0	14 Pin DIP	TTL
DS0842	SP2T	5-1500	1.0	75	50.0	14 Pin DIP	TTL
DS0864	SP4T	5-2000	1.3	49	28.0	16 Pin DIP	TTL
DS0874	SP4T	DC-2000	2.2	60	52.0	14 Pin DIP	TTL
DS0838	SP8T	5-1000	2.4	37	40.0	24 Pin DIP	TTL
DS0918	SP16T	DC-4000	4.6	50	170	58 Pin DIP	TTL

*Typical performance measured mid-band.
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INFO/CARD 3

RF design

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October 1991

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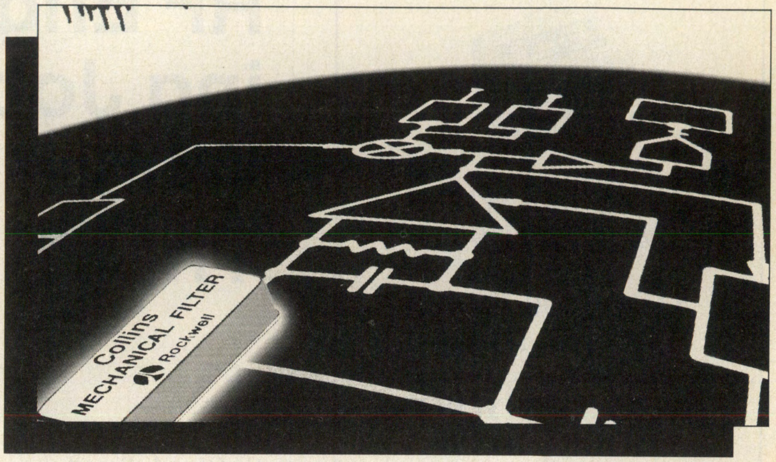
41 Measuring Attack and Release Times for Compandors

Compandors improve performance of many audio transmission systems. The authors explain test procedures for measuring the attack and release times, to assure that a compandor/expandor system complies with established standards.

— *Michael J. Delurio and Alvin K. Wong*



cover story

49 Miniature Precision Bandpass Filters Solve IF Design Problems

Mechanical resonator filters offer an alternative for IF bandpass requirements. Recently improved filter design allows high performance filtering in a small volume of space, at a competitive cost.

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64 Using Diversity to Improve Performance of Part 15 Devices

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68 RF Calculation Programs for DOS

This entry in the RF Design Awards software contest computes component values in a resonant condition, transmission line impedance transformations, plus microstrip dimensions and electrical parameters. Simple data entry and spreadsheet-style continuous updates of all parameters are key features.

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Technical presentations at RF Expo East, to be held October 29-31 in Orlando, Florida, are outlined. Topics include cellular telephone, spread-spectrum, power amplifiers, low-noise amplifiers, filters, MMICs, and much more.

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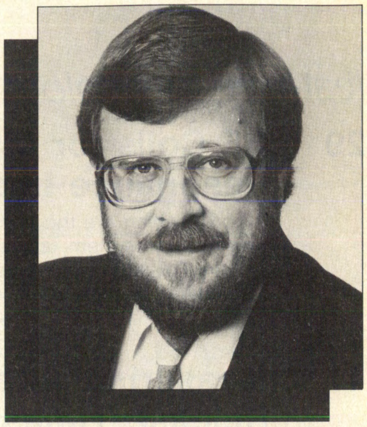
RF editorial

RF Engineering Jobs — Where Are They?



By Gary A. Breed
Editor

I can tell things are changing in the RF job market. I have recently been getting calls and letters asking (or demanding), "Where are these jobs you say are so abundant?" I took a long, hard look at the available data and decided that there are still plenty of RF jobs, but they are getting a lot harder to find. (This is the case in nearly every profession!)

Large aerospace companies and government contractors are no longer hiring, with many laying off engineers. This eliminates a large and easily identified list of prospective employers, especially for new engineers. Hiring for cellular radio development has slowed down, but Motorola, GE-Ericsson, Tandy, Ameritech, PacTel, and U.S. West have all recently advertised for cellular circuit and system designers. However, engineers tell me that widely advertised jobs often don't match their preference or experience.

Unfortunately, this means that RF engineers have to look longer and harder to find smaller companies, the right division of larger companies, or companies that wouldn't be expected to have RF needs. It may be enlightening to point out that *RF Design* readers can be found in medical instrumentation, mining, the automotive industry, oil and gas exploration, computers, optics, law enforcement, business machines, solar energy research, and Hollywood!

The experiences of two of my acquaintances points out how difficult a job search can be. To begin with, both preferred to stay in the local area, which significantly limited their possibilities. One engineer simply answered every help wanted ad that seemed remotely appropriate and sent resumes or called every company he thought had anything to do with RF engineering. Finally, after several months, he found a job with a small firm which develops and installs commercial and upscale residential alarm systems. The job is only partly RF and only partly design, but it offers "something new every day."

The other engineer nearly had to move halfway across the country to find a decent job, but at the last minute a company pulled his resume out of the file when a position opened up. This engineer has a pleasant, outgoing personality which made an impression in his earlier interview. Now he is doing customer technical support and training the sales force about the company's products.

Both of these engineers demonstrated flexibility in their job requirements, which may be the most important factor in how fast a new position can be found. Technical flexibility is another significant advantage. Excellent RF credentials can be a real bonus for an engineer who is also reasonably competent in digital design, optics, software development, materials or manufacturing.

To those who asked: You are right, RF jobs are getting harder to find. But, there are unfilled positions that need your expertise. Locating those jobs requires your patience, persistence, and a willingness to try something a little different.

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Programs from *RF Design*, provided on disk for your convenience.

This month's program: RFD-1091
"RF Calculation Programs for DOS" by Jouni Verronen. Includes the RF Calculations program for resonant circuits, and the T-Line program with Smith chart display and microstrip calculations. (QuickBASIC source code plus compiled versions for EGA/VGA).

September programs: RFD-0991
"A Circuit Analysis Program for Filters" by Jack Porter. Third Place contest winner. Provides fast analysis of passive and active filter networks, including response printout and graphics display. (Fortran, compiled, with examples)
"High Resolution Plotting Routines for BASIC and APL," by Douglas Miron. Easily modified code to add plotting capability to engineering programs. (Annotated source code, requires CGA)

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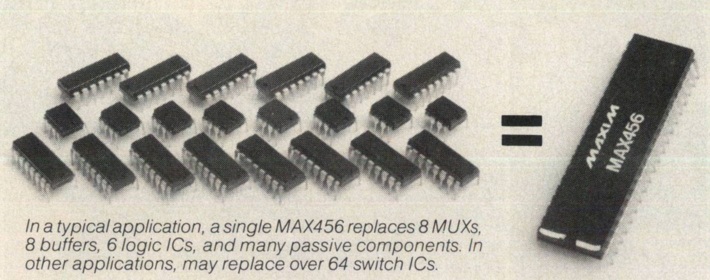

In a typical application, a single MAX456 replaces 8 MUXs, 8 buffers, 6 logic ICs, and many passive components. In other applications, may replace over 64 switch ICs.

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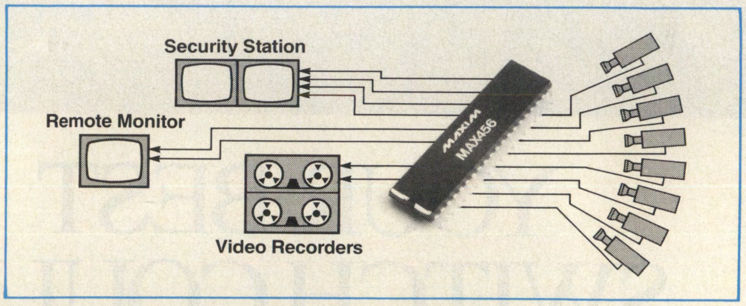

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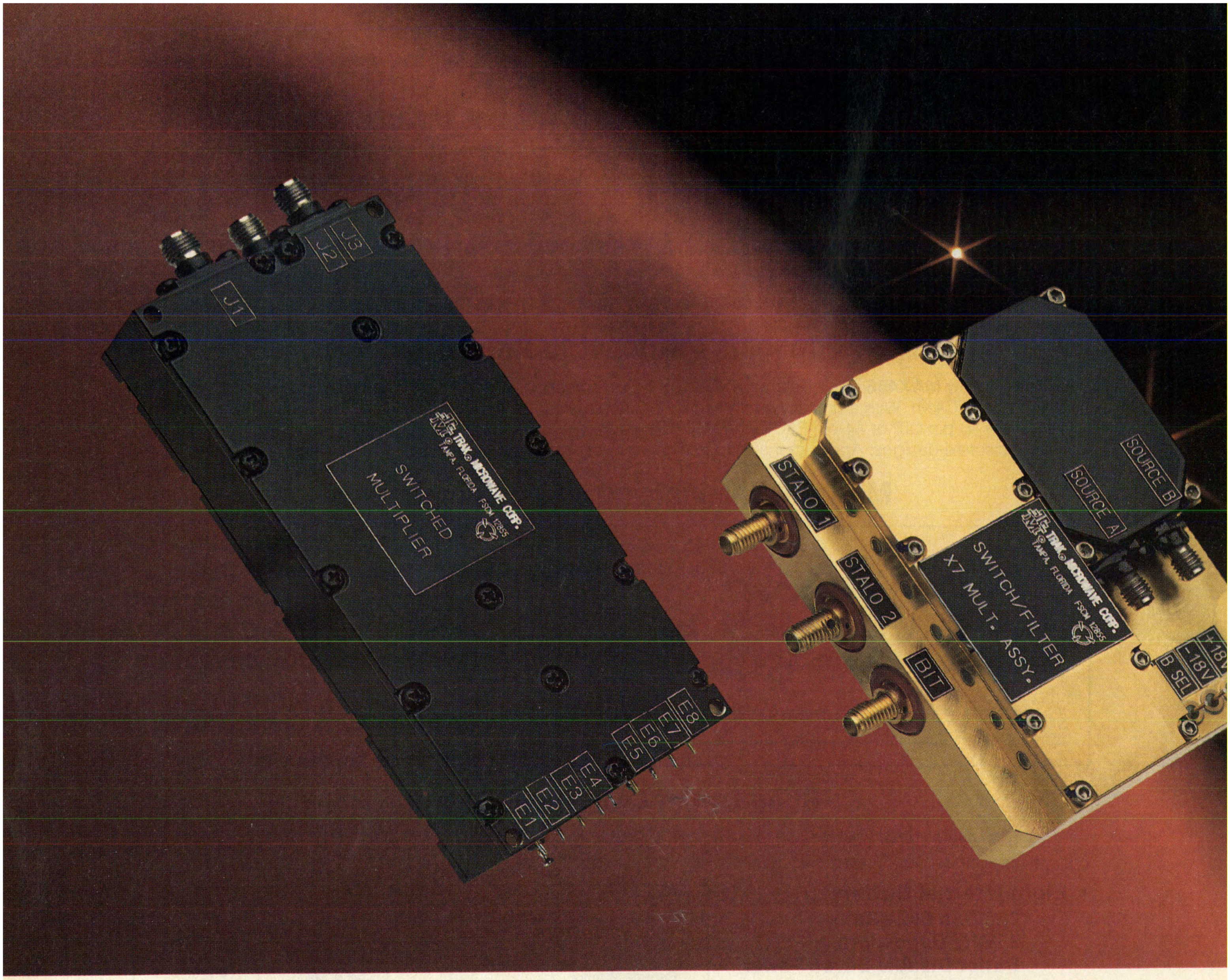

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INFO/CARD 9

Letters should be addressed to: Editor, *RF Design*, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111.

RF Continuing Education

Editor:

Your interesting article on engineering education pointed out that only a handful of universities offer meaningful and practical RF related courses to their students. As Dr. Hertling of Georgia Tech was quoted, "most RF engineers learn it on their own."

While I liked the article, I was disappointed that there was no mention of continuing education programs like those available through Besser Associates. During the last six years we have taught about 150 short courses, ranging from one day to two weeks in length, in seventeen countries, plus videotapes with even wider distribution.

As you point out in the last paragraph of your article, "there are a few places where this communication is happening." One of those places is Besser Associates.

Les Besser
Besser Associates

Languages or Applications Software?

Editor:

The letter by Andrzej Przedpelski ["A 'BASIC' for Engineers", August 1991 Letters] is representative of a trend that I see occurring in the engineering world. With all of the advances in software applications, why do RF engineers still assume that problems must be solved using a language? I thought engineering was supposed to be done using the most cost-effective and reliable solutions available.

The process of designing and maintaining reliable software is very time-consuming and best left to experts, i.e. software vendors. I am tired of seeing code written by someone that "sort of" works, is poorly documented, and is impossible to maintain. To understand a program, I would prefer a variable to be named "LoopBandwidth" rather than A$ (a limitation of most BASICs).

For the price that Mr. Przedpelski paid for his BASIC, one could purchase an application package that can instantly calculate and plot almost any equation imaginable. The application package I use, MathCad (by MathSoft), enables me to implement solutions on the order of an hour instead of days using a language. Furthermore, I can make changes to parameters and equations very quickly and have my solutions instantly available.

The process of "brute force" programming disappeared about 10 years ago. It's time that RF got in step with the rest of the world.

Susan F. Smith
Naval Air Development Center

Few engineers would disagree with Ms. Smith's final statement. We don't make the best use of available computing power. Quite often, however, "the most cost-effective and reliable solutions" only require a short computation routine, or no computer at all. The role of the computer in an RF engineer's job depends on the size of the company, the number and type of projects, the degree of his or her specialization, and the available time and money for writing or learning software. — *Editor*

Power Transistor Note

Editor:

The July 1991 Product Report "RF Transistors — Staying on Top of Technology" left the false impression that Polyfet RF Devices is new in the gold metallized silicon FET field, rather than the pioneer that it is.

We are proud of the fact that we introduced the gold metallized silicon FET back in 1984 and have since been in continuous production of our patented POLYFETs™. We would appreciate such recognition.

Claude Harvey
Polyfet RF Devices

A Correction

Editor:

I am delighted beyond words to have been chosen as the winner in this year's contest. Thank you for the honor and thanks to Hewlett-Packard for providing such a superb instrument.

A small error slipped into my article ["Low Frequency Circulator/Isolator Uses no Ferrite or Magnet," July 1991], in the paragraph dealing with the DC behavior of the circulator. A sentence was omitted, causing the open and shorted cases for Port 2 to be jumbled. If the phrase "reflect in phase" in the third column on page 40 is changed to "reflect out of phase," the text will read as intended for the shorted case, with no reference to the open case.

Charles Wenzel
Wenzel Associates, Inc.

RF calendar

October

20-23 **1991 IEEE GaAs IC Symposium**
Monterey, California
Information: Jo Ann McDonald, The Legacy Company, Legacy Ranch, Box 151, King City, CA 93930. Tel: (408) 385-5321.

22-24 **Second European Conference on Satellite Communications**
Liege, Belgium
Information: Mrs. Ch. Lacrosse, c/o AIM, 31 rue Saint Gilles, B-4000, Liege, Belgium. Tel: (32) 41-222-946. Fax: (32) 41-222-388.

28-31 **The International Digital Signal Processing Applications and Technology Conference and Exhibition**
Berlin, Germany
Information: DSP Associates, 18 Peregrine Road, Newton Centre, MA 02159. Tel: (617) 964-3817. Fax: (617) 969-6689.

29-31 **RF Expo East**
Stouffer Orlando Resort, Orlando, Florida
Information: Kristin Hohn, Cardiff Publishing Company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel: (303) 220-0600, (800) 525-9154. Fax: (303) 773-9716.

November

4-7 **Milcom '91**
McLean, Virginia
Information: Sharon Briggs, Milcom '91, PO Box 10292, McLean, VA 22102-8292. Tel: (703) 883-3300. Fax: (703) 883-3301.

14-15 **NIST Symposium on Science, Technology and Competitiveness**
Gaithersburg, Maryland
Information: Karl Kessler, A505 Administration Bldg., NIST, Gaithersburg, MD 20899. Tel: (301) 975-3089

19-21 **Wescon '91**
San Francisco, California
Information: Wescon/91, 8110 Airport Blvd., Los Angeles, CA 90045. Tel: (800) 877-2668. Fax: (213) 641-5117.

December

3-5 **Technology 2001**
San Jose Convention Center, San Jose, California
Information: Justina Cardillo or Joseph Pramberger, NASA Tech Briefs. Tel: (212) 490-3999.

5-6 **ARFTG**
San Diego, California
Information: ARFTG, c/o Henry Burger, 1061 E. Frost Drive, Tempe, AZ 85282. Tel: (602) 839-6933.

8-11 **1991 IEEE International Electron Devices Meeting**
Washington, D.C.
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RFP0800-100P100	100	30	50	$1,660.00
RFP0800-100P200	200	30	50	$2,200.00
RFP800-100	600	16	50	$2,424.00
FREQUENCY RANGE 1 – 100 MHz				
RFP01100-300	300	46	50	$3,150.00
FREQUENCY RANGE 76 – 108 MHz				
RFP0810-600	600	16	50	$1,780.00
FREQUENCY RANGE 75 – 150 MHz				
RFP0800-150P50	50	30	50	$1,485.00
RFP0800-150P100	100	30	50	$1,660.00
RFP0800-150P200	200	30	50	$2,200.00
RFP800-150	500	14	50	$2,424.00
FREQUENCY RANGE 100 – 200 MHz				
RFP0800-200P50	50	30	50	$1,660.00
RFP0800-200P100	100	30	50	$2,900.00
RFP800-200	400	13	50	$3,636.00
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RFP0204-10	10	30	28	$ 685.00
RFP0204-25	25	30	28	$1,140.00
RFP0204-50	50	40	28	$1,695.00
RFP0204-100	100	40	28	$2,200.00
FREQUENCY RANGE 400 – 500 MHz				
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RFP0405-10	10	30	28	$ 616.00
RFP0405-25	25	30	28	$1,026.00
RFP0405-50	50	40	28	$1,525.50
RFP0405-100	100	40	28	$1,980.00
FREQUENCY RANGE 1 – 500 MHz				
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RFP00105-10	10	30	28	$2,300.00
RFP00105-25	25	30	28	$2,800.00
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RFP00105-100	100	40	28	$5,600.00
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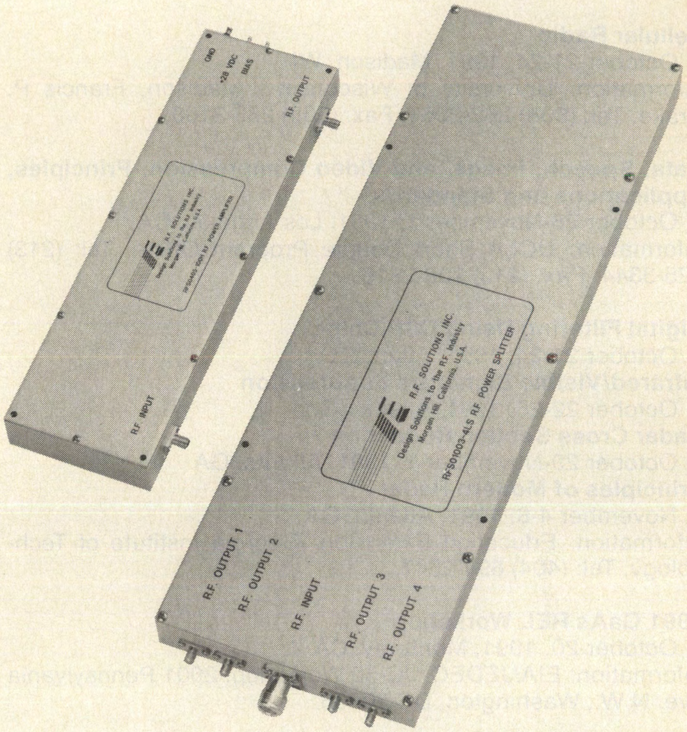

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Management of Electromagnetic Energy Hazards
October 16-18, 1991, New Brunswick, NJ
Information: Cook College Office of Continuing Professional Education. Tel: (908) 932-9271.

Cellular Radio
October 21-24, 1991, Madison, WI
Information: University of Wisconsin - Madison, Francis P. Drake. Tel: (608) 262-2061. Fax: (608) 263-3160.

Data, Speech, Image, and Video Compression: Principles, Applications and Standards
October 28-November 1, 1991, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (213) 825-3344. Fax: (213) 206-2815.

Digital Filtering Using DSP Chips
October 21-24, 1991, Atlanta, GA
Infrared/Visible Signature Suppression
October 22-25, 1991, Atlanta, GA
Radar Cross Section Reduction
October 29-November 1, 1991, Atlanta, GA
Principles of Modern Radar
November 4-8, 1991, Atlanta, GA
Information: Education Extension, Georgia Institute of Technology. Tel: (404) 894-2547.

1991 GaAs REL Workshop
October 20, 1991, Monterey, CA
Information: EIA/JEDEC, JC-50 Workshop, 2001 Pennsylvania Ave. N.W., Washington, DC 20006.

Satellite Microwave Remote Sensing and Applications
October 28-30, 1991, Washington, DC
Modern Receiver Design
November 4-8, 1991, Vienna, Austria
Frequency Hopping Signals and Systems
November 18-20, 1991, Washington, DC
Electromagnetic Interference and Control
November 18-22, 1991, Washington, DC
Information: The George Washington University, Continuing Engineering Education, Merril A. Ferber. Tel: (202) 994-8522 or (800) 424-9773.

Design for EMC
October 22, 1991, Bloomington, MN
EC-92 EMC Update
October 23, 1991, Bloomington, MN
EMC for Medical Devices
October 23, 1991, Bloomington, MN
ESD
October 23, 1991, Bloomington, MN
MIL-STD 461/462 Testing
October 23, 1991, Bloomington, MN
Information: Amador Corporation, Diane Swenson. Tel: (612) 465-3911.

Principles of Target Tracking and Data Fusion
October 15-18, 1991, Bethesda, MD
Electronic Warfare
October 21-25, 1991, Bethesda, MD
Advanced Digital Communications
October 21-25, 1991, Bethesda, MD
Test and Evaluation of EW Systems
October 30-November 1, 1991, Bethesda, MD
Microstrip Transmission Line Design
November 19-22, 1991, Bethesda, MD
Information: Technology Service Corporation. Tel: (800) 638-2628, (301) 565-2970. Fax: (301) 565-0673.

Seminar on the High Intensity Electromagnetic Radiated Fields (HIRF)
October 23-24, 1991, Mariposa, CA
Design Seminar: Principles of EMC
November 5-7, 1991, Mariposa, CA
Seminar in EMI Software (EMCAD1)
December 4-5, 1991, Mariposa, CA
Information: CKC Laboratories, Registrar. Tel: (209) 966-5240. Fax: (209) 742-6133.

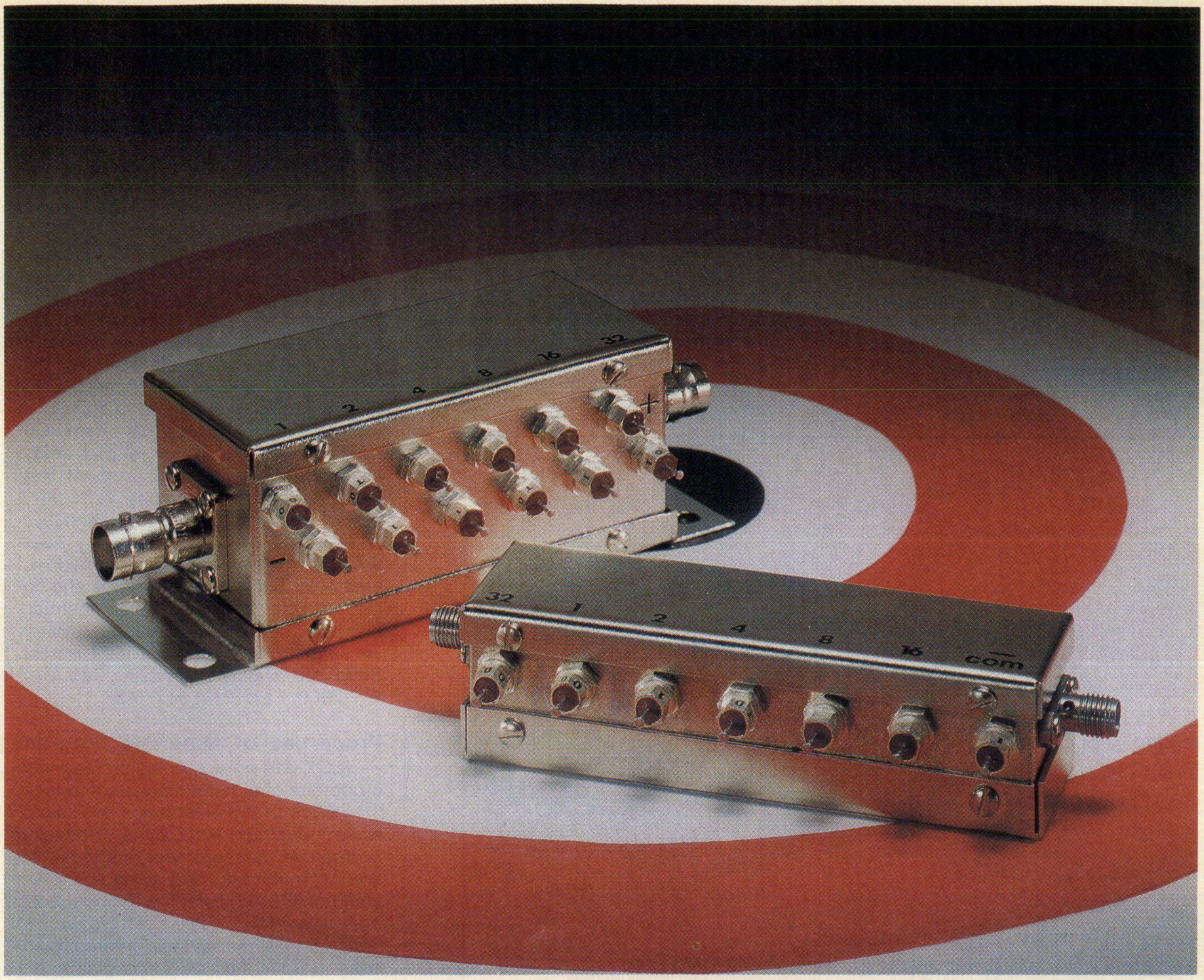
The VXIbus Seminar 1 Day Overview
October 15, 1991, Seattle, WA
October 22, 1991, Hartford, CT
November 19, 1991, Raleigh, NC
November 21, 1991, Richmond, VA
The VXIbus Seminar 2 Day Overview
October 16-17, 1991, Santa Clara, CA
October 23-24, 1991, Atlanta, GA
November 12-13, 1991, Denver, CO
The VXIbus Seminar 3 Day Workshop
November 12-14, 1991, Denver, CO
Information: Testech, Ltd. Tel: (708) 554-1222.

Digital Signal Processing Workshop
October 15-17, 1991, Campbell, CA
Information: Analog Devices, Maria Butler. Tel: (617) 461-3672.

Fast Algorithms for Adaptive Signal Processing
November 4-8, 1991, United Kingdom
Adaptive Signal Processing
November 4-8, 1991, United Kingdom
Array Signal Processing
November 4-8, 1991, United Kingdom
Multirate Signal Processing
November 11-15, 1991, Germany
Sample-Data and Analog MOS
November 11-15, 1991, Germany
Digital Signal Processing
November 11-15, 1991, Germany
RF/MW Circuit Design: Linear/Nonlinear
November 11-15, 1991, Germany
RF/MW Component Modeling
November 13-15, 1991, Germany
Information: CEI-Europe/Elsevier, Mrs. Tina Persson, Box 910, S-612 01 Finspong, Sweden. Tel: 46 (0) 122-17570. Fax: 46 (0) 122-14347.

Modern Power Conversion Design Techniques
October 21-25, 1991, San Francisco, CA
Information: e/j Bloom Associates, Joy Bloom. Tel: (415) 492-8443. Fax: (415) 492-1239.

DSP Without Tears
October 23-25, 1991, Boston, MA
Information: Right Brain Technologies. Tel: (404) 420-3834. Fax: (404) 967-1672.



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Accessories: Loads • Dividers • Terminations • RF Fuses • Bridges

INFO/CARD 14

GPS Information and Sources Available — The U.S. Army Electronic Proving Ground has set up a system to disseminate information acquired during testing of global positioning system equipment. The system called EGRIS (EPS GPS Range Instrumentation System), is a computerized bulletin board accessible via a modem to authorized users anywhere in the world. EGRIS can provide Notice Advisories to NAVSTAR Users (NANUs) including: The most recent information on satellite health and availability, projected outages of satellites and unscheduled satellite outages. EGRIS can also provide other data such as: satellite almanac and ephemeris data for use with satellite visibility prediction programs, status reports with information on satellite rephasing, clocks and current advisories and customized visibility listings. Application programs are also available to run on personal computers. For more information contact: Jack Underwood, USAEPG, Attn: STEEP-TS-R, Fort Huachuca, AZ 85613-7110. Tel: (602) 533-8087.

EOS/ESD Call for Papers — The fourteenth annual symposium on electrical overstress and electrostatic discharge has issued a call for papers for their September 16-18, 1992 show in Dallas, Texas. Papers can deal with work in the following or related areas: failure mechanisms, measurement, testing and tester evaluation, VLSI, III-V, power and photonic devices and systems protection and precautionary measures. The deadline for submission of abstracts, 500-word summaries and figures is December 20, 1991. Abstracts may be sent to Charvaka Duvvury, Texas Instruments, Inc. 12840 Hillcrest, Suite 200, Dallas, TX 75230. Tel: (214) 917-7969. Fax: (214) 917-7487.

Properties of Materials Program — NIST has an active electromagnetic properties of materials program to meet the needs of the electronics and microwave industries. NIST aims to develop or improve measurement methods, reference materials, and a database on commonly used dielectric and magnetic materials. NIST also participates in national and international intercomparisons. Paper no. 22-91 explains the program and is available from Jo Emery, Div. 104, NIST, Boulder, CO 80303. Tel: (303) 497-3237.

Varian Develops 60 MW Magnetron — Varian, under the auspices of the US Army Laboratory Command, has developed the world's most powerful non-relativistic magnetron. The development of the VMS-1873 is a major milestone in the 24-month-long high power transmitter R&D program. The transmitter will consist of multiple phase-locked, S-band magnetrons with a total energy of 1 kilojoule per 1 microsecond pulse.

IBM PCradio Developed — Pending FCC approval, IBM will release a notebook size, ruggedized, battery operated computer that lets users access and input information from remote locations. It connects to larger IBM computers via radio or cellular based communications or through conventional telephone lines by using integrated modems. The computer is useful for service technicians, police officers and sales representatives who need to receive or transmit data on site. The radio or cellular link is provided by the Ardis data radio network, which is a built-in RF modem.

TriQuint Completes Merger — TriQuint has announced that it has completed its mergers with GigaBit Logic and Gazelle Microcircuits. They have also undergone an internal reorganization, with the company organized around three business units. The three units are Computing and Networking, Digital Communications and Signal Processing and Microwave Communications. TriQuint now has more than 13 international distributors and 26 manufacturer's representatives throughout North America.

Schaffner EMC Moves — Schaffner EMC has announced their move to new facilities. Their new address and phone number are: 9-B Fadem Road, Springfield, NJ 07081. Tel: (201) 379-7778, (800) 367-5566. Fax: (201) 379-1151.

Foster AirData Building New Facility — BFGoodrich has announced the construction of a new 51,500 square foot facility for its Foster AirData business unit. Foster's current business is located in five separate buildings at three different areas. Foster supplies primarily navigation management systems, computers, sensors and worldwide databases to the aircraft market. They are also involved with the FAA in developing aircraft Collision Warning Systems and TCAS for use in corporate, commuter airline and military aircraft.

General Microwave Acquires Math Associates — General Microwave Corporation, a designer and manufacturer of microwave and electronic test equipment and components has announced the acquisition of Math Associates, Inc. The terms of the acquisition were not disclosed.

Sciteq Opens New Facility — Sciteq Electronics recently opened their new offices. Their address is now 9280 Sky Park Court, San Diego, CA 92123. The telephone and fax numbers remain the same.

Call for Papers — The 42nd Electronic Components and Technology Conference, May 18-20, 1992, has issued a call for papers. Topics of interest for the conference include: Chlorofluorocarbon substitutes, connectors, components, opto-electronics, hybrid microcircuits, interconnections, manufacturing technology, materials, packaging and reliability. Twelve (12) copies of a 500 word abstract describing the scope, content and key point of the paper should be sent by October 31 to Dr. Iwona Turlik, Microelectronics Center of N.C., PO Box 12889, 3021 Cornwallis Road, Research Triangle Park, NC 27709-2889. Tel: (919) 248-1847. Fax: (919) 248-1455.

Lindgren Buys ShieldCo — Lindgren RF Enclosures, Inc. recently acquired the assets of ShieldCo International. ShieldCo manufactures high performance RF doors and various other shielding products. Terms of the acquisition were not disclosed.

Cimarron Technologies Formed — Cimarron Technologies, a newly-formed company, is developing products for the land-mobile radio market. It plans to introduce its first product, a GE-STAR-compatible ANI encoder, in the fall of 1991. Their address is: 934 S. Andreasen Drive, Suite G, Escondido, CA 92029-1919. Tel: (619) 738-3282. Fax: (619) 480-0233.

AEL Wins Two Contracts — AEL Defense Corporation has been awarded two contracts by U.S. Army Communications Electronics Command and Raytheon Electromagnetic Systems Division. The $5.5 million contract with the U.S. Army calls for the design and development of a complete engineering change proposal to install AN/ARC-201/186 Dual Radio capability in U.S. Army helicopters. The second contract for $1.6 million is for switches and switch filter components for use in Raytheon's ALQ-184 electronic countermeasures system.

Contec Expands Operations — Contec Microelectronics has moved to a new facility in order to accommodate their expanded operations. Their new address is: 2188 Bering Drive, San Jose, CA 95131. Tel: (408) 434-4767. Fax: (408) 434-6884.

Thomson-CSF Awarded Air Traffic Control Contract — A contract was recently signed between Thomson-CSF and Greek Civil Aviation Authority covering the total renovation of the Greek Air Traffic Control System. Thomson-CSF will supply its latest generation equipment: solid state primary radar, S-Mode compatible monopulse secondary radars, high definition television displays and digital radio channel and telephone switching equipment. The contract is worth several hundred million Francs.

Gamma Microwave Signs Contract with PRC — Gamma Microwave announced that it has signed a $7 million contract with the People's Republic of China to supply G-7100 C-band satellite communications transceivers. The transceivers will be used by a major Chinese manufacturer of satellite communications systems for high data rate VSAT and rural telephony applications. The transceivers will allow systems to extend telephone and data communications to small cities and villages throughout China and other Far East countries.

Scholarships Announced — The Foundation for Amateur Radio has announced the 1991 awards of 38 scholarships. These scholarships were open to all radio amateurs meeting the qualifications and residence requirements of the various sponsors. The scholarship amounts ranged from $500 to $2000. The address for 1992 scholarship information is: FAR Scholarships, 6903 Rhode Island Avenue, College Park, MD 20740.

Superconducting Digital Logic Chip Demonstrated — Hypres, Inc. recently demonstrated a superconducting 4-bit shift register that operates at 9.6 GHz and dissipates only 40 uW. The high speed is reached using 3.0 um geometries instead of 0.5 um geometries used for GaAs circuits. The 4-bit shift register serves as a test bed for a unique edge-triggered circuit design developed by Hypres for building logic devices. This work is being done under contract to Rome Laboratories, Hanscom AFB and is funded by the Strategic Defense Initiative Organization.

Radio Networks to Convert to SEDAT — Scientific-Atlanta has announced that CBS and ABC radio networks have converted their satellite audio transmission to Spectrum Efficient Digital Audio Technology (SEDAT). SEDAT increases audio channel capacity and provides compact disk quality sound.

EEsof Users' Group to Meet at GaAs IC Symposium — EEsof Inc. will sponsor the GaAs IC Symposium meeting of its Users' Group, Tuesday, October 22 from 5:00 pm to 8:00 pm. Both members and nonmembers are invited to attend the meeting where technical papers are presented on the use of CAE/CAD software applications in microwave and RF design.

Search and Rescue Contract — CAL Corporation has received a $1 million contract for a search and rescue satellite ground station. The system was purchased by the New Zealand Ministry of Transport and will be installed in Wellington, New Zealand. Together with a system already in place at Alice Springs, Australia, they will ensure full, continuous coverage of the entire region including the waterways between the two countries.

Motorola Signs Cellular Equipment License Agreement — Motorola's Radio Telephone Systems Group recently signed a manufacturing license agreement with the Posts and Telecommunications Industry Corporation of China. The Hangzhou factory, located in the Zhejiang region, will be licensed to manufacture, in progressive phases, Total Access Communication System (TACS) cellular fixed network equipment from material and modules supplied by Motorola. Motorola has also been awarded cellular system supply contracts for nine other cities.

CCL Opens New Facility — Communication Certification Laboratory recently opened a new testing facility. The facility is an FCC listed Open Area Test Site and is capable of testing equipment at 3 and 10 meters. The new site sits on 12 acres at an elevation of 6200 feet and is virtually free from ambient interference.

Report Available on ESD — Frost and Sullivan International has issued a new report on "The U.S. Market for Electrostatic Discharge and Static Control Products and Services." According to the report, the market for ESD products and services will double within five years. Sales are predicted to jump from $429 million to $868 million by 1995. The largest market sectors will be in military and aerospace applications with telecommunications a strong second. The ESD market over the 1990-95 period will consist of a stable base of sales to facilities which have already put ESD protection programs in place, plus new penetration of market areas where awareness of ESD is still developing.

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- ★ Only 16 Pounds
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MODEL	POWER OUT	FREQUENCY RANGE	GAIN	SIZE (CM)	WEIGHT	AC LINE	U.S. PRICE $
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706FC	6W CW	.5-1000 MHz	36dB	25x28x13	3.3kg	100-240V	$ 3,195
410LC	10W CW	.006-400 MHz	43dB	30x35x13	4.5kg	100-240V	$ 4,600
710FC	10W CW	1-1000 MHz	40dB	30x35x13	7.3kg	100-240V	$ 6,695
727LC	10W CW	.006-1000 MHz	43dB	48x46x13	8.5kg	100-240V	$ 7,750
711FC	15W CW	400-1000 MHz	40dB	30x35x13	5.5kg	100-240V	$ 3,620
720FC	25W CW	400-1000 MHz	40dB	48x46x13	8.6kg	100-240V	$ 5,995
712FC	25W CW	200-1000 MHz	40dB	48x46x13	8.8kg	100-240V	$ 7,350
737LC	25W CW	.01-1000 MHz	45dB	48x46x13	10.5kg	100-240V	$ 9,995
747LC	50W CW	.01-1000 MHz	47dB	48x46x26	26.5kg	100-240V	$22,500
707FC	50W CW	450-1000 MHz	47dB	48x46x13	13.0kg	100-240V	$ 9,995
709FC	100W CW	500-1000 MHz	48dB	44x48x18	22.5kg	100-240V	$19,990
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INFO/CARD 19

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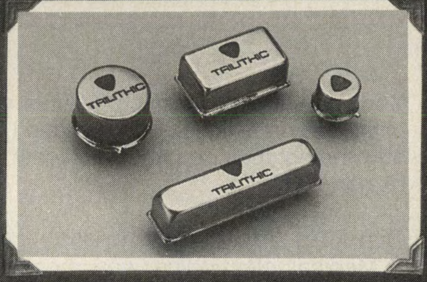
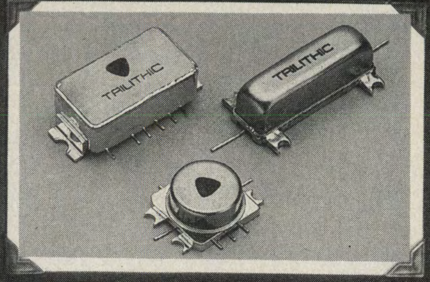
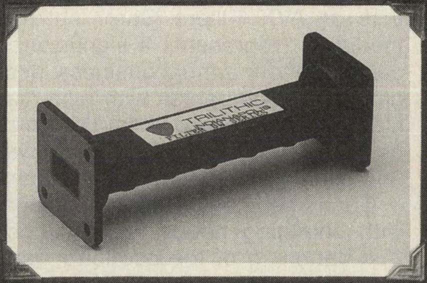


Miniature filters

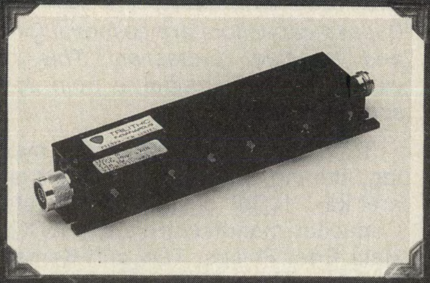


Surface mount filters

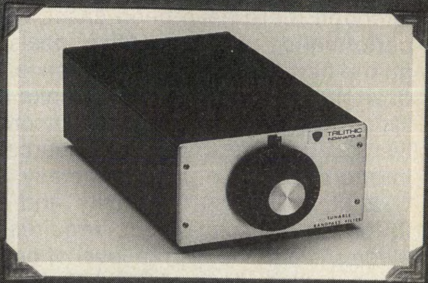
Tubular filters



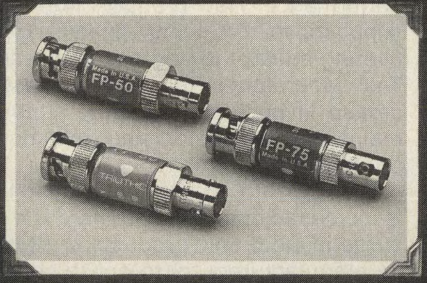
Waveguide filters



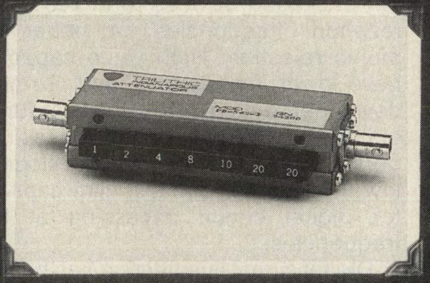
Cavity filters



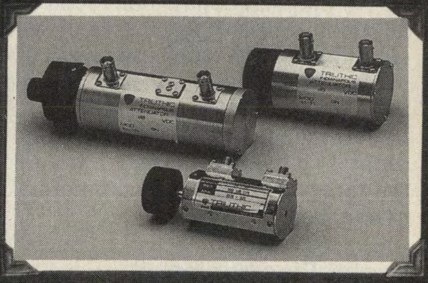
Tunable filters



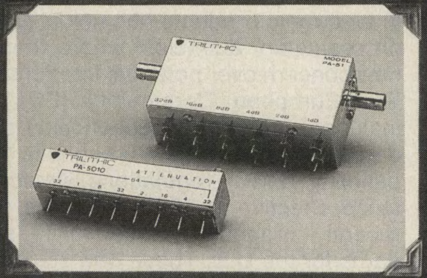
Coaxial attenuators



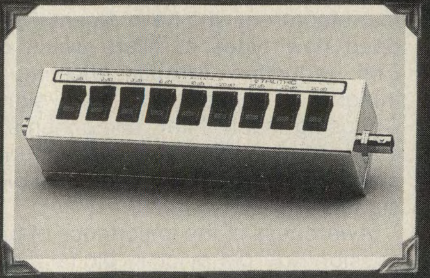
Pushbutton attenuators



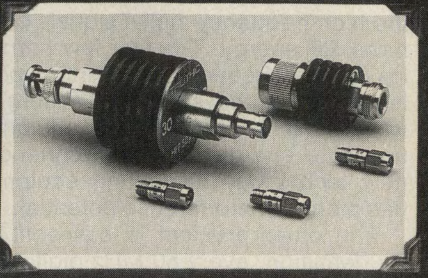
Rotary step attenuators



Programmable step attenuators



Switch attenuators



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INFO/CARD 20

EMI/RFI Control Grows in Importance

By Gary A. Breed
Editor

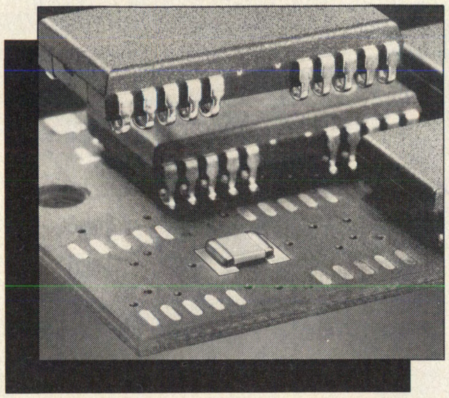
Over the last five years or so, a transition has taken place in electronic engineering. Control of EMI and RFI has become a matter of "good engineering practice," more than just compliance with regulatory standards for radiated emissions. In earlier years, dealing with EMI/RFI beyond the bounds of FCC or foreign agency compliance was largely a matter of wishful thinking, although there have been cases where performance or competitive goals required better control of interference. For example, voluntary efforts to make television sets and videocassette recorders less susceptible to common sources of interference have been generally successful. Now, the sensitivity and performance of equipment requires all electronics to maintain a level of protection from the effects of EMI/RFI that was previously unnecessary.

Digital technology is the main area where EMI/RFI control has received new attention, but RF products and medical electronics have significant new requirements, as well. Military electronics have been undergoing re-examination of EMC performance, but in order to keep this report to a manageable size, we will limit the topic to consumer, commercial and medical electronics.

Faster Electronics

Personal computers operating at 20, 33 or 50 MHz clock rates have created new EMI problems for engineers. First, the high frequency digital signals create more RF energy. The first few harmonics of these frequencies fall into a populated part of the spectrum. Where the waveforms in older, slower equipment had little energy at these frequencies, new technology computing equipment has plenty of interference potential.

The other problem is susceptibility. By definition, every 50 MHz digital chip is a high frequency receiver! CMOS, the dominant logic type, can have significant analog gain, giving it significant sensitivity to low level interfering signals. ECL logic is even more sensitive. The potential for self-interference from one part of a circuit to another is a major EMI problem for digital engineers.



Bypass capacitors are essential for EMI and transient protection. This high-value (0.47 mF) model is from Johanson Dielectrics.

To deal with these problems, bypassing, filtering, shielding and circuit layout are key digital design considerations. Capacitor manufacturers like AVX, MuRata Erie, Philips, TDK and Kemet are developing low ESR (equivalent series resistance) capacitors for more efficient bypassing. Chip capacitors are replacing packaged devices to increase self-resonant frequencies for better harmonic rejection. High value capacitors have lower impedances, and are being developed with low inductance to further enhance bypassing effectiveness. Rogers Corporation recently developed a low inductance, low loss film capacitor for digital circuit bypassing at high frequencies.

Digital signal line filtering has become more important (and more difficult) at high clock frequencies. Coilcraft, TDK, and MuRata Erie are a few of the manufacturers who have recently developed new types of filters which offer EMI reduction without affecting the integrity of these high speed signals. Choosing such filter components requires that engineers have an understanding of the spectral content of digital signals.

Awareness of the importance of transmission line behavior in digital circuits has recently increased. In response, major RF software suppliers like Compact Software, EEsof and Hewlett-Packard have added analysis of interconnections using nonlinear signals, such as digital signals. Also, some of the digital modeling and design software systems have added similar capabilities. Considerations for terminated lines, coupling between lines, and radiation are now being included in the digital designer's job.

Growing Application Areas

Medical electronics was mentioned several times as a growing market for EMI/RFI control products. Steve Makl, Technical Manager for Advanced Products at AVX Filters Corp. notes that medicine "represents a significant percentage of our annual business, and it's growing." Companies with expertise in high reliability and custom design have been the most successful in cultivating new clients with medical applications.

Consumer electronics is another area with changing needs for EMI control. The flattening of the economy has put new cost pressure on all product areas, but the need for approval by FCC or other agencies requires attention to EMI performance. New products from many suppliers for shielding, bypassing and filtering attempt to address both issues. Test laboratories report a modest increase in business recently, attributed mainly to consumer and commercial product measurements.

Also related to economic conditions is increased competition. There is a new surge in electronic products of all types as manufacturers try to entice consumers with the latest features. Also, consumers demand that their products be trouble-free. Recognition of this increase in electronic products has not been lost on regulatory agencies, where there is new concern over potential interference. The European Community (EC) has included immunity (susceptibility) standards in proposed electromagnetic compatibility (EMC) regulations scheduled to be effective in 1992. Also, the FCC recently proposed susceptibility standards for the U.S. These new standards will make the design engineer's job more challenging, but will provide a boost for makers of EMI control components and materials. **RF**

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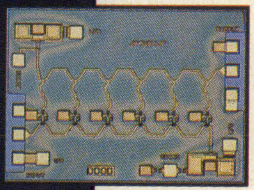

HP's High Frequency Design System (HFDS) brings single-pass design solutions closer to reality. It predicts the performance of your designs using a non-linear simulator that gives you accurate results, even under high levels of compression. So, you can take advantage of the most powerful and sophisticated models and libraries available. Models tested against field simulation tools and verified with actual measurements.

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INFO/CARD 21

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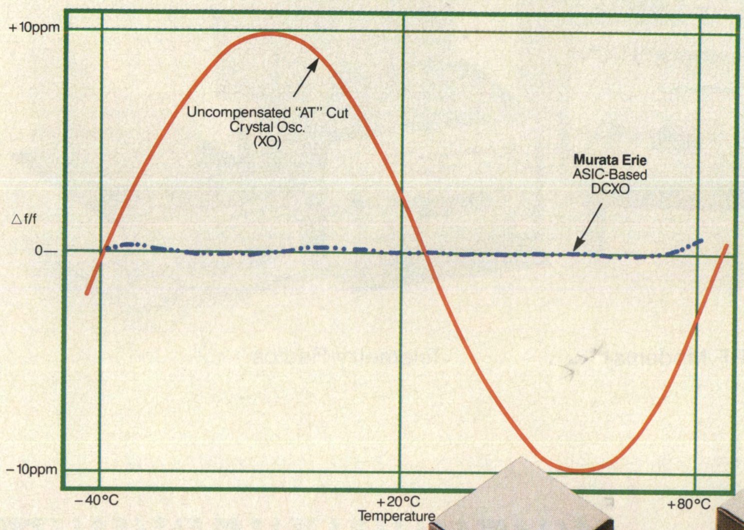
Murata Erie's new ASIC-based DCXO



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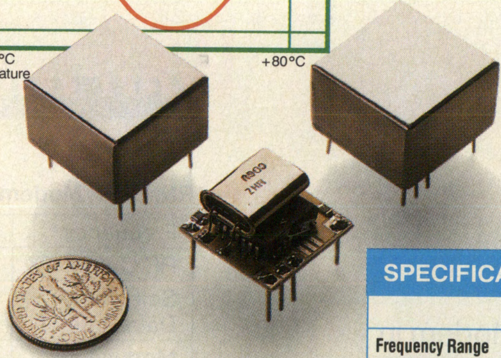

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Stability over –40°C to +85°C	±0.2 ppm	±1 ppm
Output	TTL	"HC" CMOS
Power Dissipation	+5V @ 10 mA	+5V @ 15 mA
Short Term Stability	1×10E–10 @ T=1 sec.	1×10E–9 @ T=1 sec.
Package Size	2″ × 2″ × 0.5″, PC PINS	0.79″ × 0.79″ × 0.45″, PC PINS

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INFO/CARD 23

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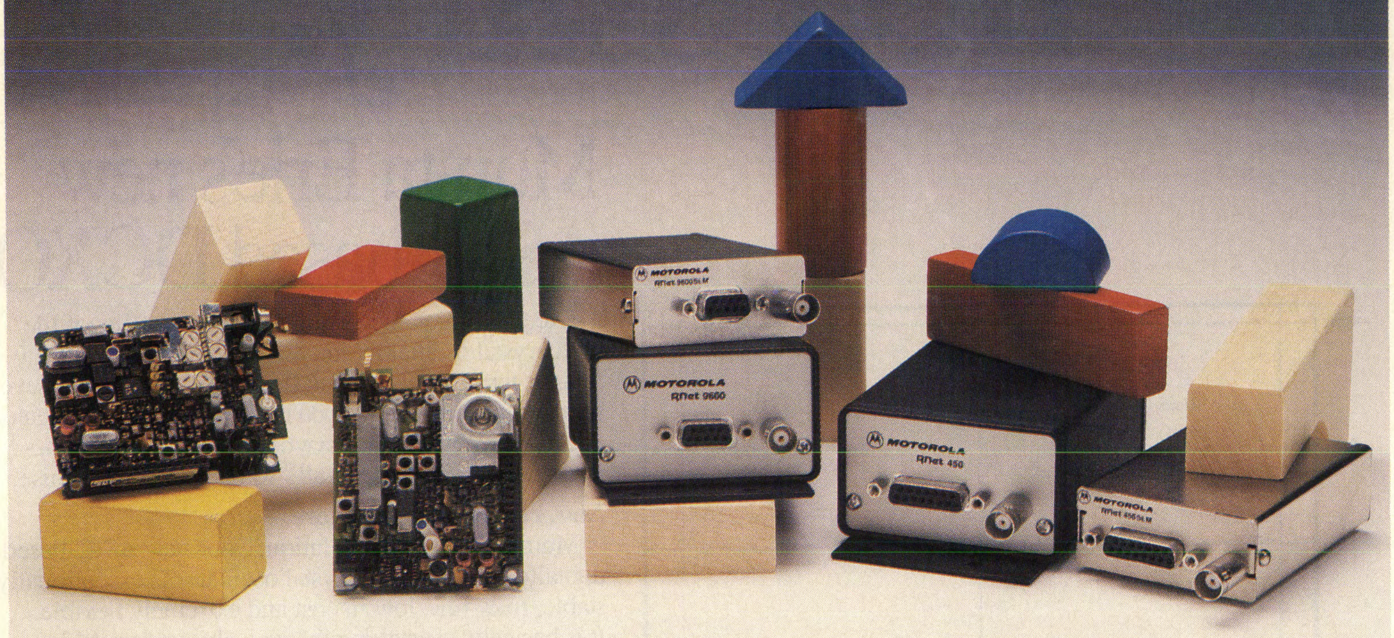

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RF Coils for Magnetic Resonance Imaging

By Mehrdad Mehdizadeh, Ph.D.
Picker International

Magnetic Resonance Imaging (MRI) is the latest medical diagnostic method for non-invasive observation of the body's interior. Many disciplines within electrotechnology are employed in MRI. They include electromagnetics, RF, digital and analog electronics, and computer hardware and software. The purpose of this article is to introduce the RF technology employed in MRI, with a focus on RF probes (commonly known as coils). Among the components used in the RF system, the coil is one which is most non-conventional, with a key impact on the quality of the final image. RF coils in MRI evolved from probes used in NMR spectroscopy of chemical samples. The RF requirements of MRI, however, are vastly different; and new structures and design techniques for MRI RF coils were developed.

A brief discussion of MRI principles is given for understanding the function and operation of RF coils. For a full explanation of MRI physics and instrumentation, the reader is referred to available articles on this subject, for example, References 1 and 2.

MRI is based on the excitation and relaxation of hydrogen nuclei within living tissue in a strong DC magnetic field. Because of its magnetic dipole property, the magnetized hydrogen nucleus has a natural precession frequency which is proportional to the DC magnetic field intensity. This is called the Larmor frequency, which is the main RF frequency used in MRI. Commonly used frequencies are 21.3 MHz for 0.5 Tesla, 42 MHz for 1.0 Tesla, and 64 MHz for 1.5 Tesla DC magnetic fields. An excitation RF pulse at the Larmor frequency takes the nuclei out of their equilibrium state. After the RF pulse is ended the nuclei start an oscillating relaxation to their equilibrium state. This relaxation generates a weak decaying RF signal which is detected and processed. Different living tissues have different rates of decay which distinguishes them from one another when the received data is processed. In order to generate an image there is also a need for spatial information, which is provided by slight spatial variation of the DC magnetic field. Therefore, different locations within the imaging area have slightly different Larmor frequencies. The spatial variation in the DC magnetic field is generated by superimposing a uniform magnetic field from a superconducting magnet with spatially variable fields called gradients. Gradient fields are about three orders of magnitude smaller than the uniform magnetic field, therefore all the RF frequencies needed for spatial encoding are within a few kHz from the center frequency. Due to this, the RF system in an MRI scanner is basically narrowband.

Figure 1 shows the most common arrangement of the superconducting magnet, the gradient coils, and the RF coil in MRI scanners.

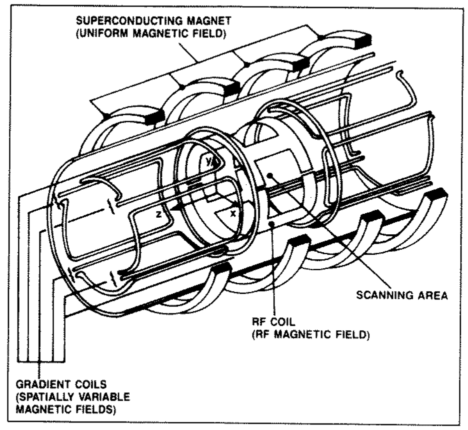

Figure 1. Physical arrangement of MRI scanner.

The RF System in MRI

An analogy can be drawn between the RF system in MRI and pulsed radar. The transmit side of the system sends a series of kW level RF pulses to the subject, and there is a receive period between these pulses where the faint RF signal from the tissue can be detected for processing and construction of an image. In Figure 2 a representation of transmit pulses and receive signals is made. The width of the transmit pulse is on the order of hundreds of usec, and the pulse period is between 40 msec and 3000 msec.

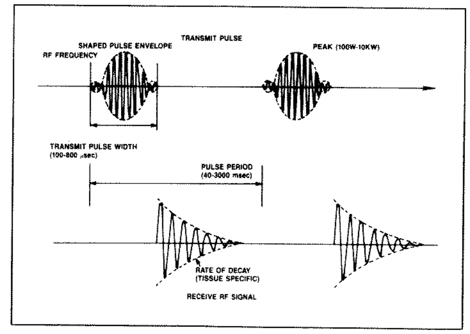

Figure 2. Typical transmit pulse and receive signal.

Figure 3 shows the most basic RF system block diagram. A precision synthesizer generates the frequencies needed within a few Hertz accuracy. The exact center frequency is determined by the strength of the superconducting magnet as described before, and other frequencies are located within a few kHz of the center. The controller generates digital controls for the synthesizer, exciter, and receiver based on the requirements of the desired scan. The exciter generates the RF pulses, and feeds them into the power amplifier. The amplified signal is then fed into the coil via a pin diode duplexer (T/R module).

Keeping the radar analogy in mind, the RF coil plays the role of the antenna for both transmit and receive functions. One difference between radar and an MRI RF system is that the RF coil in MRI is a near-field probe and provides an RF magnetic field coupling to the subject tissue. Another important difference is that, unlike radar, the received signal intensity cannot be increased with more transmitted power. The optimum

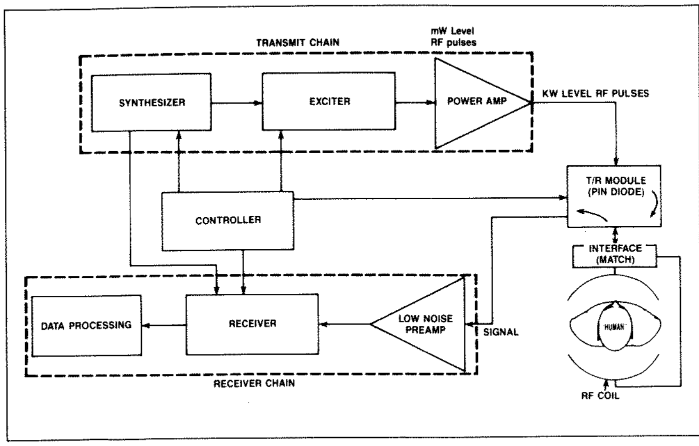

Figure 3. Basic RF system in MRI.

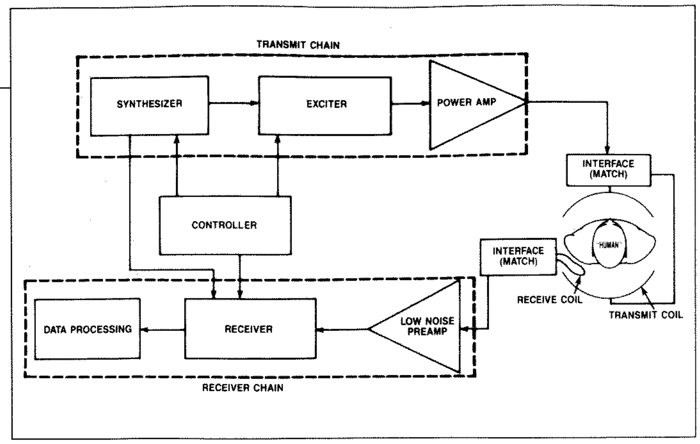

Figure 4. RF system for separate transmit and receive coil.

signal level is achieved when, at the end of the transmit pulse the magnetization vector of the nuclei are tipped from their equilibrium state by 90 degrees. This is achieved by a combination of pulse duration and power. For a given pulse duration, greater transmit power would result in decreased received signal level.

In the receive mode, the signal picked up from the patient is fed into a low noise preamplifier and then into a receiver which detects the envelopes of the signal. These envelopes which contain all the relaxation decay rates and spatial information are processed digitally to form an image.

The RF system described in Figure 3 shows a mode of operation where the same RF coil is used for transmit and receive. In many cases it is advantageous to use separate coils for transmit and receive functions. A block diagram of one such case is shown in Figure 4.

Depending on the requirements of each scan, an MRI scanner is normally equipped with a variety of RF coils with different modes of operation. There is a fixed body coil with a diameter of 50 to 60 cm which is normally attached to the scanner. A head coil with a diameter of 25 to 30 cm is used for brain and other head imaging. There are also a variety of specialty coils (surface coils), which are used for the study of different areas of the body.

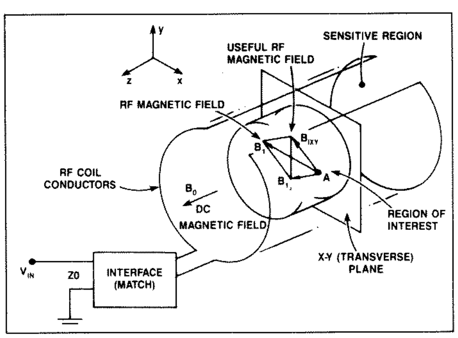

Figure 5. General RF coil terminology.

RF Coil Principles and Figures of Merit

Consider Figure 5, where a generalized MRI RF coil is represented. The magnetic field vector B1 at point A causes a signal voltage V_{in} to appear at the port of the coil, which is matched to impedance Z_0 (normally 50 ohms). Using transmit terminology, an input voltage, V_{in}, causes a magnetic field vector B_1 to appear at point A. The following terms are defined:

Sensitive Region — is all the volume over which the coil can produce any RF magnetic field of measurable significance.

Region of Interest (ROI) — is a part of the sensitive region where imaging is intended.

Usable RF Magnetic Field (B_{1xy}) — is the component of the RF magnetic, B_1 on the X-Y plane (the plane perpendicular to the DC magnetic field). The Z component is not useful in MRI.

Sensitivity — at point A, is a quantity proportional to B_{1xy}/V_{in}. It is a measure of how efficiently the coil turns useful magnetic field into voltage, or vice versa. It also determines the impact of the coil on the signal to noise ratio of the image at point A. In transmit mode it determines how much power is required to optimize the tipping of the nuclei at point A.

Uniformity — is a measure of spatial variation of sensitivity over the region of interest. It is equal to 100 minus the percentage difference between the maximum and minimum sensitivities over the Region of Interest. Good uniformity translates into an image without intense bright and dark areas.

Generally, the design goal is to maximize both the sensitivity and uniformity over the Region of Interest. The first step to maximize the sensitivity is to resonate the RF coil at the Larmor frequency using capacitors. The coil is then a magnetic energy storage device with an overall quality factor Q. The magnetic energy is stored in three places, the Region of Interest, the rest of the Sensitive Region, and the internal inductance of the coil. The key to high sensitivity is storing the largest portion of the energy in the Region of Interest. This means that the coil has to create the largest possible ratio between the Region of Interest and the Sensitive Region volume, and it should have the smallest internal inductance.

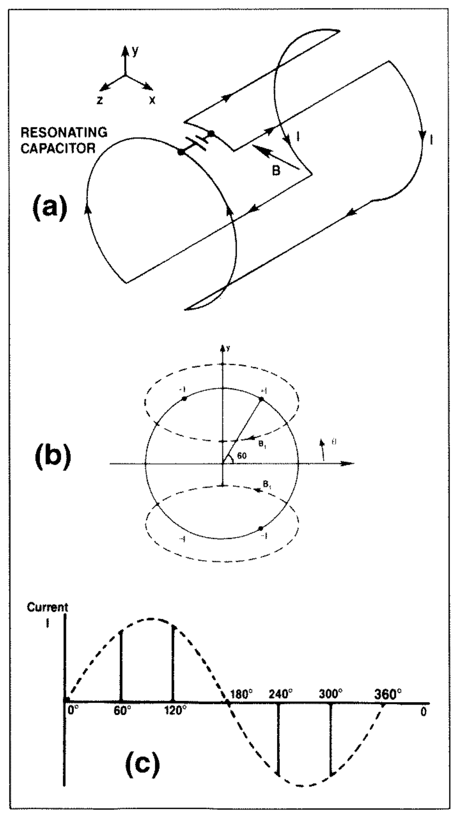

Figure 6. Saddle coil, (a) conductor configuration,(b) cross sectional currents and field configuration, (c) current level fitting to sine function.

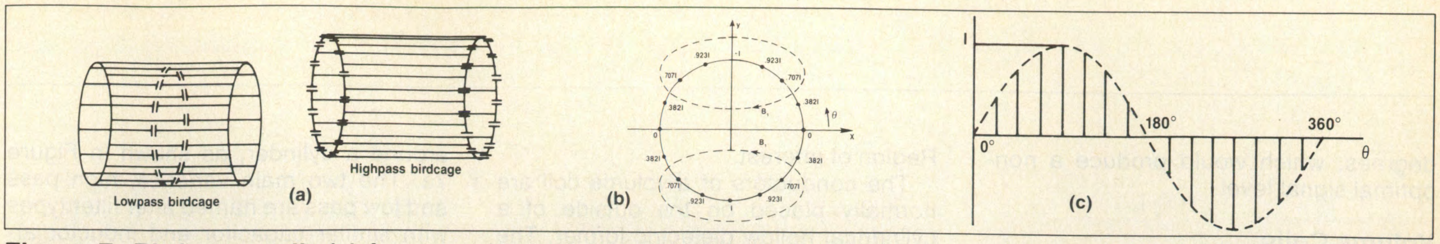

Figure 7. Birdcage coil, (a) lowpass birdcage and highpass birdcage, (b) cross sectional fields and current distribution, (c) fitting of current amplitudes to sine function.

Sensitivity is also proportional to the square root of the overall quality factor, which is highly reduced by the lossy nature of the living tissue. Due to the fundamental nature of this limitation, the only place the designer is able to increase the Q without sacrificing sensitivity is to make the coil system as lossless as possible. This requires high Q capacitors, low loss dielectric materials for mechanical support, and thick copper conductors. It should be realized that, in most cases, especially at higher frequencies of operation, the losses caused by the tissue are so dominant that too much effort in reducing the coil losses would only increase the cost and mechanical complexity with very little return in actual sensitivity.

The electric fields produced in conjunction with the magnetic fields in RF coils not only lack any value in MRI, but they detune of the coil and lower the Q in the presence of tissue. Electric fields can be mostly confined by resonating the coil using multiple capacitors at different locations along the coil's conductors. This also reduces the voltages which can cause arcing when the coil is used in transmit mode. The need for frequent tuning of the coil can be eliminated using this approach.

The system parameter on which the RF coil has the most impact is Signal to Noise Ratio (SNR). SNR, which has a major effect on resolution, length of scan, and degree of graininess of the image, is dependent upon many system and scan parameters. If all these parameters and the noise level are kept constant and optimal, the image SNR at a particular point will be directly proportional to the sensitivity of the RF coil at that point. If the ambient noise is eliminated via proper RF shielding, the only source of RF noise is the thermal noise associated with the output resistance of the interface circuit (which is normally 50 ohms). This noise level is constant for all properly matched coils. The only reason a larger coil gives a lower SNR than a small coil is the fact that the stored magnetic energy is spread over a larger volume, therefore the sensitivity is smaller.

If the transmit field used in excitation of nuclei is perfectly uniform, then the uniformity of the image would be the same as the coil's uniformity at the imaging plane. In reality, the uniformity of the final image is smaller, due to transmit field non-uniformity. If the amount of transmit power is set so that the magnetization vector at one part of the ROI is 90 degrees, then in other parts of the ROI the tipping is not 90 degrees, which would produce a non-optimal signal level.

Volume Coils

The conductors of volume RF coil create a cylindrical volume where the whole body, head, or a limb is placed for imaging. Theoretically, in order to optimize the sensitivity on the axis, the diameter of the volume coil should be as small as the subject anatomy allows. There is a tradeoff, however, between the sensitivity and uniformity over the Region of Interest.

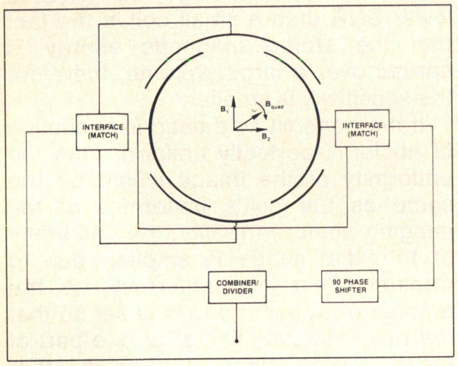

Figure 8. Quadrature coil block diagram.

The conductors of a volume coil are normally placed on the outside of a cylindrical hollow dielectric former. The main conductors are longitudinal, or Z coordinate directed. There are end arcs to connect the Z-directed conductors. In order to optimize the uniformity, the RF current amplitudes in main conductors should be weighted as a sine function of their angular position. The simplest form of volume coils is the saddle coil, which is composed of two parallel sections as shown in Figure 6a. The saddle coil has four Z-directed conductors, a cross section and field configuration of which is shown in Figure 6b. Figure 6c shows how the currents fit the sine function. The disadvantage of the saddle coil is that, even after optimizing the geometry, the uniformity in the transverse plane is limited to 70 percent over an area half the diameter.

Birdcage coils (3), due to their multi-conductor geometry, provide better uniformity than saddle coils. They are composed of multiple conductors and capacitors, arranged in symmetry around a cylinder, as shown in Figure 7a. The two main varieties, high pass and low pass are named after filter types with similar capacitor and inductor arrangements. The sine function current weighting in conductors can be understood if the birdcage coil is considered similar to a one wavelength transmission line closed on itself. Figure 7b shows the cross section field configuration and current amplitudes. Figure 7c shows the fitting of current amplitudes with a sine function. The major advantage of the birdcage coil is that the uniformity in the transverse plane can be improved by choosing a larger number of conductors. Typically 8, 12, or 16 conductors are used. A birdcage coil with 16 conductors has a uniformity of more than 95 percent over a circular area in the X-Y plane half its diameter.

Quadrature (Circularly Polarized) Coils

The magnetic field vector producing the signal in MRI is actually rotating at a rate equal to the operating (Larmor) frequency. The most efficient way to detect the signal is by using a circularly

polarized (or quadrature) coil (4), where the magnetic field vector of the coil is rotating at the same rate and direction. Circular polarization can be produced when two coils which share the same Region of Interest are placed in an orthogonal position with one another, and are fed 90 degrees out of phase. Figure 8 shows the arrangement. The concept of producing rotating fields in this manner is similar to that of circularly polarized antennas, or AC two phase motors. Birdcage coils are particularly adept to quadrature operation due to the fact that the same coil can be used as a quadrature coil using two feeding arrangements which are 90 degrees apart.

The advantages of quadrature coils is that they produce twice as much signal power, therefore the apparent sensitivity of the coils, which is proportional to signal voltage (or signal to noise), is enhanced by a square root of two compared to a linearly polarized coil. Furthermore, in the transmit mode, the power required to produce the same tipping of the nuclei is decreased by half.

Surface Coils

Surface coils (sometimes called local coils) are used when a high signal to noise ratio over a small region of interest is required (5). Surface coils are mostly used for imaging different sections of the spine. Other anatomical regions imaged with surface coils include TMJ (Temporomandibular Joint), limbs, and orbits. Surface coils are placed on the surface of the body closest to the Region of Interest, rather than surrounding it as in the case of volume coils. Because of their asymmetry relative to the Region of Interest they have highly non-uniform field patterns. The sensitivity of a surface coil typically decreases as inverse square of the distance from the surface.

The major design tradeoff for surface coils is imaging coverage versus sensitivity. For example the tradeoff in spine imaging is the number of spine vertebrae covered versus the SNR. The simplest surface coil design is a single circular or rectangular conductor loop, which is resonated and connected to an interface circuit. A comparison of SNR between volume coils and several surface coil sizes versus distance are shown in Figure 9. There are a variety of surface coil designs and functions for optimization of imaging. Among them are contoured surface coils (8) and (9). Note that some forms of MRI coils, especially some that are used for extremity imaging are actually small volume coils; even though they are commonly categorized as surface coils.

Surface coils, due to their non-uniform field pattern can only be used as receive coils, otherwise the combination of transmit and receive non-uniformity would make useful imaging impossible. The body coil is normally used as the transmit coil (Figure 4). Since the resonant frequency of both the receive coil and the transmit coil are the same, heavy RF interference between them would produce detuning and a loss of sensitivity. In some cases, orthogonal placement of the coils can prevent any interference. In more recent systems with quadrature capability, the only way to eliminate interference is by decoupling using switching diodes (10). This is done by deactivating the transmit coil

during the receive period using a PIN diode arrangement, and deactivating the receive coil during the transmit pulse using either PIN diodes or clipping crossed diodes. Decoupling techniques are not limited to surface coils, but are also used in receive only head coils.

Interfacing the RF Coil to the System

The function of the interface (or match) circuit is to optimally transfer the power to the coil in transmit, and transfer the signal to the preamplifier in receive. The system interface of the circuit is matched to the line impedance, which is normally 50 ohms. One method of interface is by flux linkage, as shown in Figure 10a. Mechanical adjustment of the coupling loop provides the optimal matching. The other approach, which is usually preferred due to mechanical simplicity, is direct coupling via inductors or capacitors as shown in Figure 10b. A balun is normally used for balanced feeding of the coil. In some cases, active interface (11) is used for receive only coils (Figure 10c). The FET with high input impedance will act as a one stage preamplifier and boost the signal before it is attenuated in transmission to the receive chain.

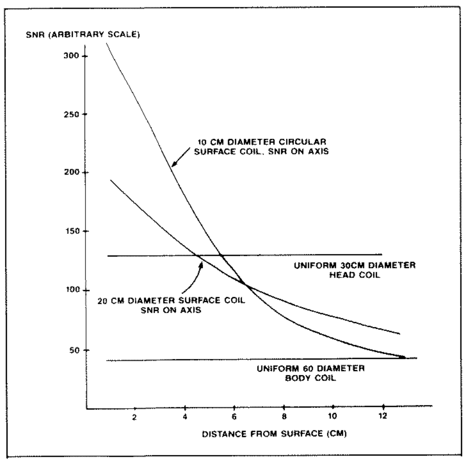

Figure 9. Comparison of SNR between surface coils and volume coils.

Some Areas of Research and Development

Multiple receive coils: The idea is to use several small receive coils to gain expanded imaging coverage while obtaining the high SNR associated with each coil, without moving the patient. In the switched category one coil at a time is activated using a PIN diode scheme (12). In the simultaneous acquisition category (13) each coil is connected to a different receive chain, and then the data is processed and added together. The advantage is that high SNR can be achieved in one acquisition, but this method is complex in hardware.

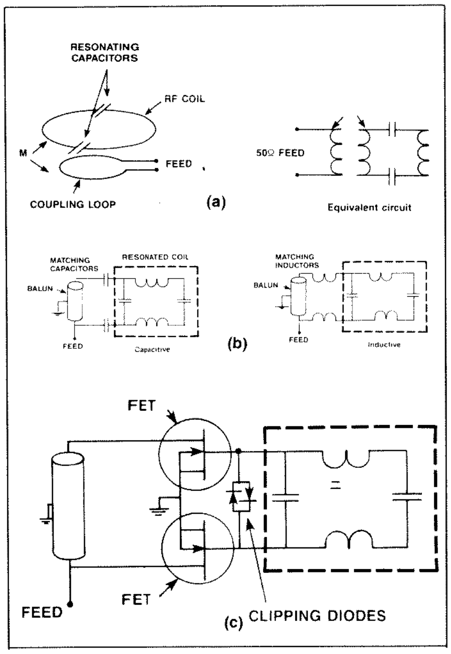

Figure 10. Interfacing of RF coil to the system,(a) flux linkage coupling, (b) direct coupling, (c) receive only.

Multiple tuned coils: An area of MRI research is multinuclear spectroscopy and imaging. This calls for RF coils that are tuned to two or more frequencies at the same time. The most common nucleus other than hydrogen is phosphorus, which at 1.5T has a Larmor frequency of 26 MHz.

RF coil modeling and optimization: The methods used in the design of RF coils are still very experimental. An area of research is mathematical modeling of RF coil field behavior in relation to geometry for further optimization of uniformity and sensitivity (14). ***RF***

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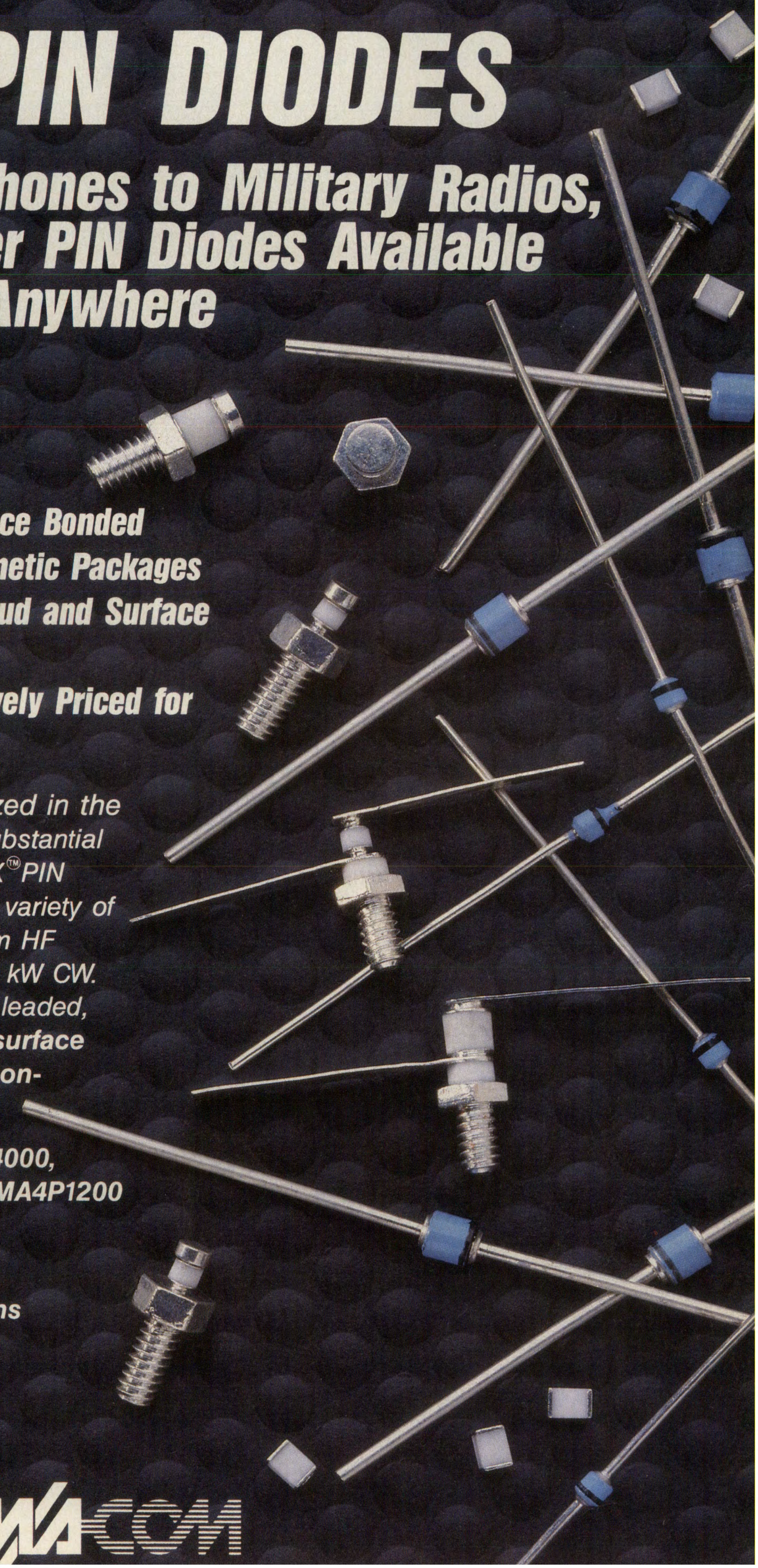

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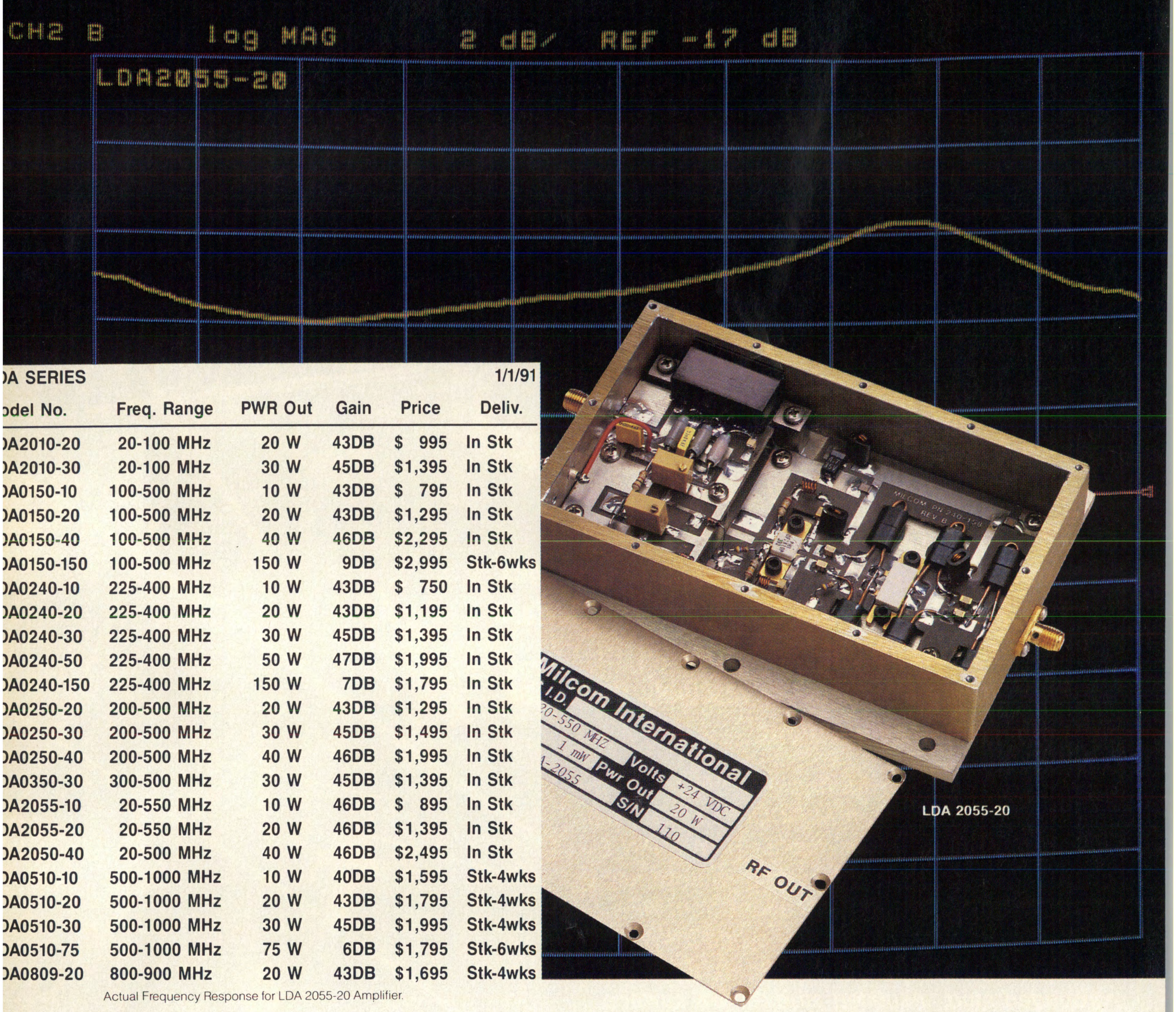

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INFO/CARD 32

Measuring Attack and Release Times for Compandors

By Michael J. Delurio
and Alvin K. Wong
Signetics Company

Compandors have been used for over a decade in a variety of audio applications, including tape recorders and wireless microphones. In these applications, the compandors are used to preserve the dynamic range and quality of an audio signal as it moves along the signal path. The compandor compresses the input signal which is then recorded onto the tape, disk or other memory medium. By compressing the input signal, a larger dynamic range can be recorded which is typically limited by the recording media. In the playback mode, the compressed signal is expanded back to its original dynamic range. Thus the noise introduced by the media and its associated components is reduced. Figure 1 shows a typical compandor application for tape recorders.

Over the last couple of years, compandors have been designed in cordless phones, wireless microphones, and cellular radios. Companding in these systems dramatically improves the overall sensitivity of the system, while preserving the dynamic range of the baseband signal.

When a compandor is used for wireless communication systems, the audio signal is first compressed. The loud voices are attenuated while the soft voices are amplified. This helps the low level signal ''jump over'' the transmitter channel noise while protecting the high level signals from unwanted distortion. The compressed audio signal is then sent over the airwaves. Upon reception, the receiver captures the RF signal and demodulates it. The compandor then expands the audio signal back to its original dynamic range.

Because the results of companding in wireless systems are so encouraging, compandors are required for cellular radio systems. The Electronic Industries Association (EIA) has specific guidelines on compandors in their EIA/TIA standard.

The EIA/TIA standard regarding the attack and recovery times of compandors, though important, is not always well understood. When a large audio signal enters the compandors input, it takes time for the compandor to react. The time it takes the compandor to react is the ''attack'' time. When a smaller audio signal occurs after the large input signal, the compressor must react again. This reaction is the ''release'' time. This type of situation occurs when a person speaks into a microphone and then stops talking.

The specifications for cellular radio require that the compressor have a nominal attack time of 3 ms and a nominal release time of 13.5 ms. Therefore, it is important to make these measurements in the lab in order to ensure that the compandor attack and release times are set properly.

Below are the procedures for measuring the attack and release times of both the compressor and expandor. Figure 2 shows a Signetics NE578 compandor, the left side of which can be configured as an expandor (as shown in Figure 3), while the right side can be configured as a compressor (shown in Figure 4). The capacitor connected to the rectifier block controls the attack and recovery time. For the compressor, this capacitor is $COMP_{CAP1}$ and for the expandor, this capacitor is EXP_{CAP}. (C_{RECT} is the general term and implies that both EXP_{CAP} and $COMP_{CAP}$ are being considered.)

Let's assume that C_{RECT} = 2.2 uF (in most cases $COMP_{CAP}$ and EXP_{CAP} are the same component value) and $R_{INTERNAL}$ = 10 Ohms. Since T = RC, then T = 20 ms. If we wanted a different RC time constant, we would change the C_{RECT} value ($R_{INTERNAL}$ is a fixed value).

Using these component values, let's

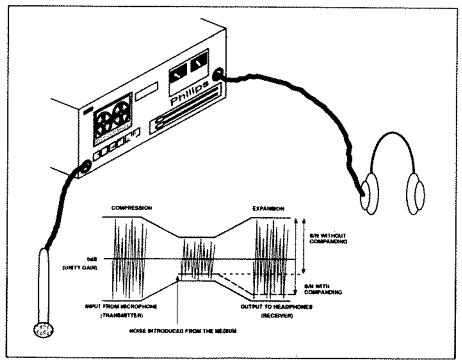

Figure 1. Illustration of a compandor application in a tape recorder.

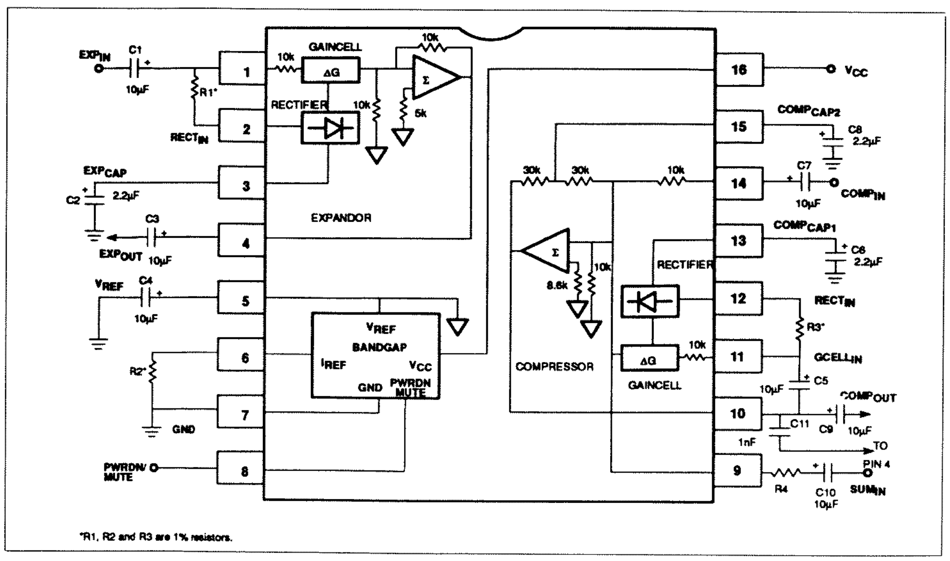

Figure 2. NE578 block diagram.

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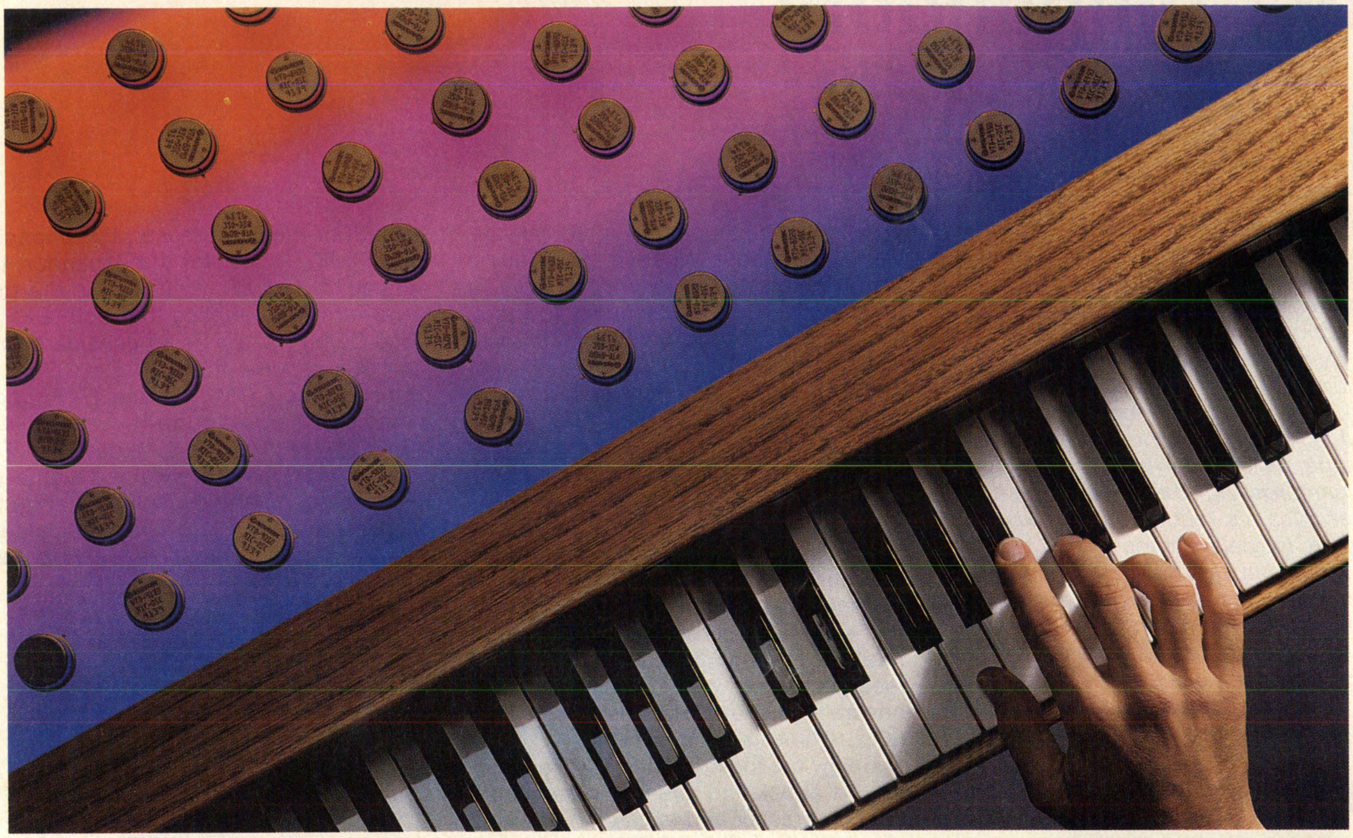

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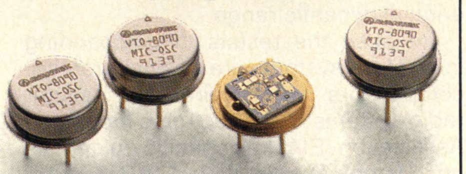

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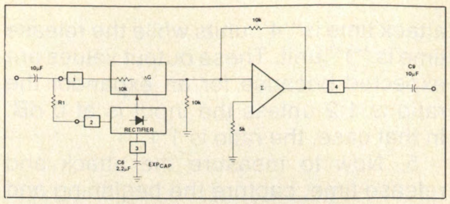


Figure 3. NE578 expandor.

measure the attack and recovery times to see if the CCITT and EIA specifications are being met. Figure 5 shows the test set-up used in the lab.

Compressor, EIA Spec (3.3.2.1.1)

Attack time is the time required for the transmitter deviation to settle to a value equal to "1.5" times the final steady state value for a 12 dB step up. Release time is the time required for the transmitter deviation to settle to a value equal to "0.75" times the final steady state value for a 12 dB step down. The compressor must have a nominal attack time of 3 ms and a nominal recovery time of 13.5 ms as defined by CCITT. The first procedure is:

1. Apply a 1 kHz sinewave signal at 0 dB to the input of the compressor (0 dB is defined where the compandor passes the input signal through to the output ... unity gain level).
2. AM modulate the 1 kHz input signal with a 1 Hz - 2 Hz square wave.
3. Connect an oscilloscope probe to the input of the compressor and adjust both the AM modulation and oscilloscope (uncalibrated) so that a 1:4 ratio is achieved on the screen of the oscilloscope (see Figure 6a).

Adjusting for a 1:4 ratio produces a 0 dB to 12 dB step at the input. The unit "1" represents the 0 dB input level and the unit "4" represents the 12 dB input level (20log(4/1)=12dB).

4. Connect another oscilloscope probe to the output of the compressor and observe the waveform (see Figure 6b). The "final steady-state" value for

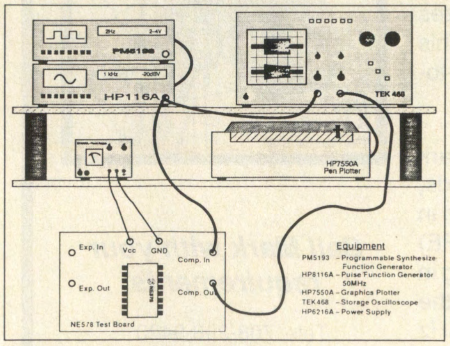


Figure 5. Test set-up.

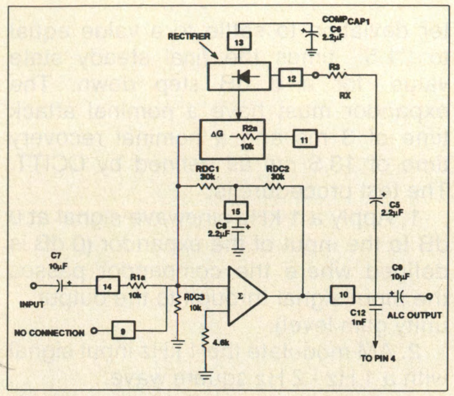


Figure 4. NE578 compressor.

the attack time is "2" units while the release time is "1" unit. These output values are expected because for a compressor the ratio is 2:1 unless the input is at 0 dB. In that case, the ratio is 1:1.

5. Now to measure the attack and release time, capture the beginning and end of the output waveform where the changes occur (see Figures 6c and 6d). Note: Storage scope settings — trigger off the square wave generator; DC couple the trigger source; use normal trigger mode; main time base = 100 ms/div; delay time base = 5 ms/div; and to view attack time followed by the release time, simply change the trigger slope.

To measure the attack time (T_A): According to the EIA specs:
$T_A = 1.5 \times$ Final Steady State Value

Therefore, $T_A = 1.5 \times 2$ units $= 3$ units

Measure the time it takes for the output to drop to the 3rd unit. According to Figure 6c, our attack time is 3 ms. This indeed meets EIA specifications.

To measure the release time (T_R): According to the EIA specs:

$T_R = 0.75 \times$ Final Steady-State Value

Therefore, $T_R = 0.75 \times 1$ unit $= 0.75$ units.

Measure the amount of time it takes for the output to raise up to 0.75 units. According to Figure 6d, our release time is 13 ms. Again the EIA specification is met.

Expandor, EIA Specification (2.2.2.3)

Attack time is the time required for the transmitter deviation to settle to a value equal to "0.57" times the final steady state value, for a 6 dB step up. Release time is the time required for the transmitter deviation to settle to a value equal to "1.5" times the final steady state value, for a 6 dB step down. The expandor must have a nominal attack time of 3 ms and a nominal recovery time of 13.5 ms as defined by CCITT. The test procedure is:

1. Apply a 1 kHz sinewave signal at 0 dB to the input of the expandor (0 dB is defined where the compandor passes the input signal through to the output ... unity gain level).

2. AM modulate the 1 kHz input signal with a 1 Hz - 2 Hz square wave.

3. Connect an oscilloscope probe to the input of the expandor and adjust both the AM modulation and oscilloscope (uncalibrated) so that a 1:2 ratio is achieved on the screen of the oscilloscope (see Figure 7a).

Adjusting for a 1:2 ratio produces a 0 dB to 6 dB step at the input. The unit "1" represents the 0 dB input level and the unit "2" represents the 6 dB input level (20log(2/1)=6dB).

4. Connect another oscilloscope probe to the output of the expandor and observe the waveform (see Figure 7b). The "final steady-state" value for the attack time is "4" units while the release time is "1" unit. These output values are expected because for an expandor the ratio is 1:2 unless the input is at 0 dB. In that case, the ratio is 1:1.

5. Now to measure the attack and release time, capture the beginning and end of the output waveform where the changes occur (see Figures 7c and 7d). Note: Storage scope settings - trigger off the square wave generator; DC couple the trigger source; use normal trigger mode; main time base = 100 ms/div; delay time base = 5 ms/div; and to view attack time follow by the release time, simply change the trigger slope.

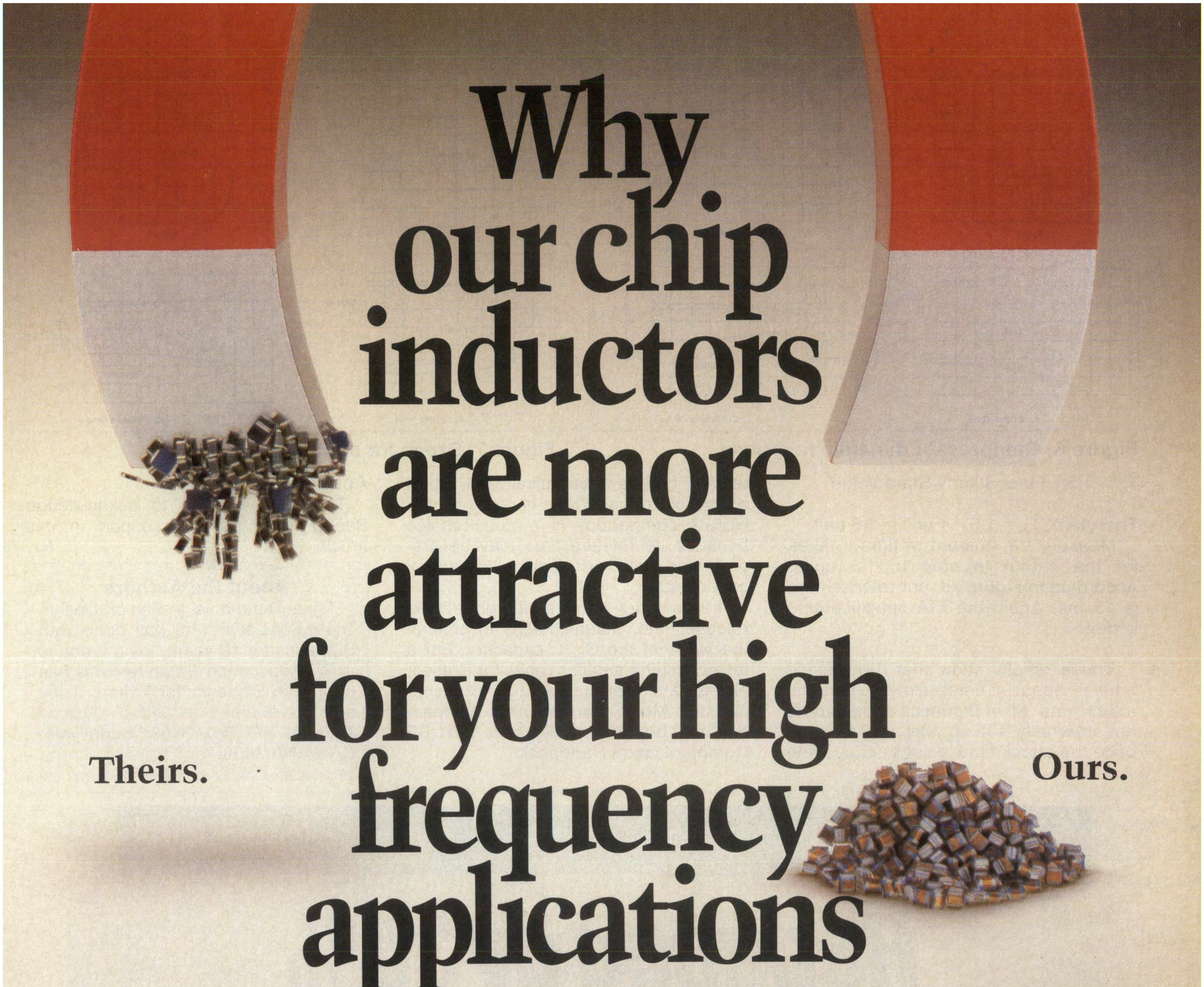
To measure the attack time (T_A):
According to the EIA specifications:

$T_A = 0.57 \times$ Final Steady-State Value

Therefore, $T_A = 0.57 \times 4$ units $= 2.28$ units

Measure the time it takes for the output to reach 2.28 units. According to Figure 7c, our attack time is 3 ms. This, indeed, meets EIA specifications.

To measure the release time (T_R)
According to the EIA specifications:



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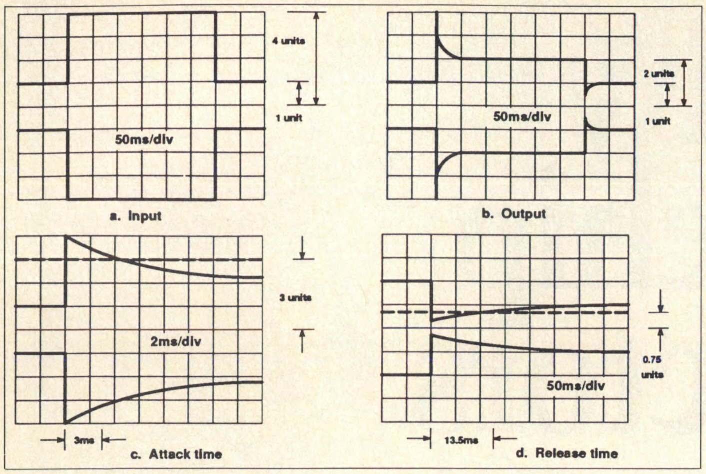

Figure 6. Compressor dynamic response.

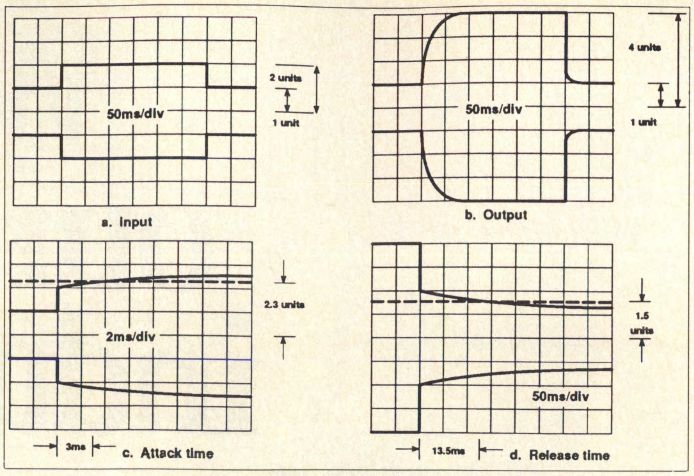

Figure 7. Expandor dynamic response.

$T_R = 1.5 \times$ Final Steady-State Value

Therefore, $T_R = 1.5 \times 1$ unit $= 1.5$ unit

Measure the amount of time it takes for the output to drop to 1.5 units. According to Figure 7d, our release time is 13 ms. Again the EIA specifications is met.

These results show that the release time is about 4 times slower than the attack time. All of Signetics compandors are internally set up this way so that once the attack time is set by C_{RECT}, the release time is automatically set. But if a different release time is required, the NE572 compandor is a good choice because its release time may be programmed with an additional external capacitor.

If a designer wants a different attack/release time, he/she needs to change the value of the C_{RECT} capacitor. For a faster result a smaller capacitor is used, and for a slower time a larger capacitor is used. More information on compandors can be found in Signetics 1991 RF Communication Handbook.

Acknowledgement

The authors wish to acknowledge Saeed Navid for his support in this article. *RF*

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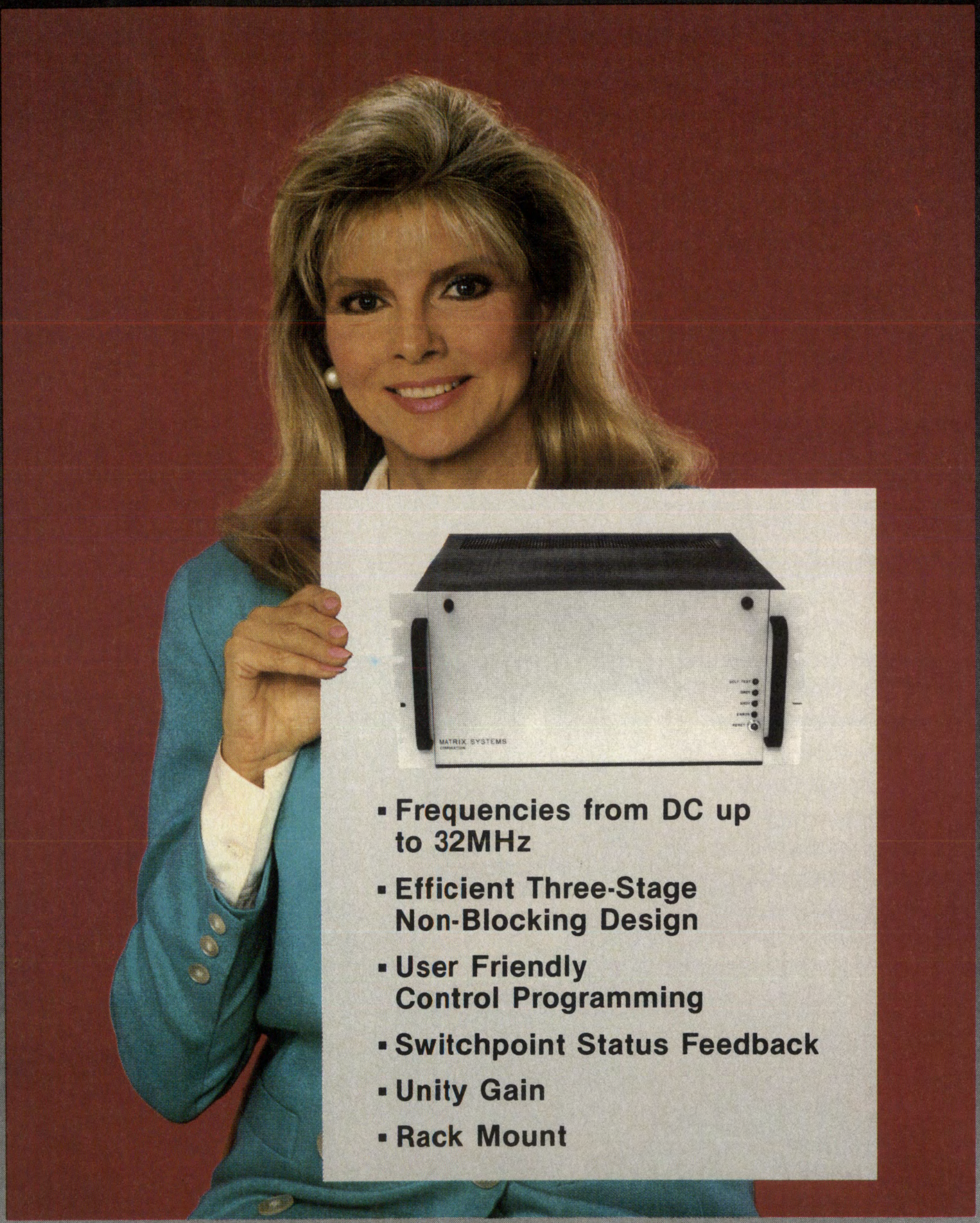

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Miniature Precision Bandpass Filters Solve IF Design Problems

By William J. Domino and
Robert A. Johnson
Rockwell International

Today's designers of communication systems are increasingly challenged to pack higher system performance into smaller packages. The list of design constraints is familiar: constricted space, low power consumption, low parts count, efficient spectrum usage, and high reliability in a demanding environment. In many RF communication systems, such as HF and VHF receivers, system performance is heavily attributable to filter performance in the final intermediate frequency (IF) circuit. A miniature, low-loss IF filter that is stable, rugged, and precise can help bring the designer a long way toward his goal. For final IF frequencies in the vicinity of 455 kHz, these characteristics are embodied in a class of torsional mechanical filters recently developed at Rockwell International.

For several years there has been an emphasis on miniaturization in the design of all types of radio receivers. This, of course, has in turn meant an emphasis on miniaturization of components. However, most types of IF filters have been resistant to miniaturization, particularly in cases where they have had to exhibit great precision and stability.

In the field of receiver design, the intermediate frequency of 455 kHz (along with derivatives such as 450 kHz or 500 kHz) is widely encountered. At this particular IF, filtering can be accomplished by any of several different technologies, most notably ceramic, crystal, or mechanical filters. The choice of which to use is influenced by many factors. Ceramic filters can be extremely compact; discrete crystal filters offer excellent precision, but typically in much larger packages than ceramic filters.

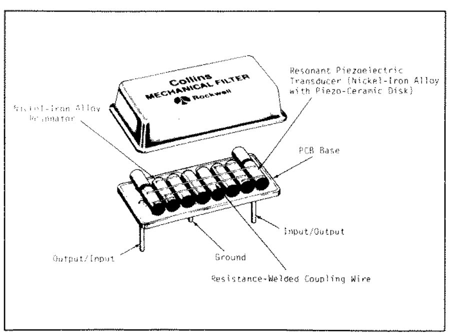

Figure 1. 455 kHz 8-pole torsional mechanical filter in Rockwell SP package.

Mechanical filters, which can provide a precise and stable response, have been designed in various forms for nearly forty years. Early on, 455 kHz mechanical filters became more compact than was possible with other precision filter technologies. The most recent step in miniaturized mechanical filter technology is the 455 kHz torsional mechanical filter, in Rockwell's "SP" package. This filter finds ideal uses in receiver applications such as portable units, data links, differential GPS, and direction-finding.

The Torsional Mechanical Filter

A mechanical filter is primarily a mechanical device; between its input and output circuits, signals must travel in the form of acoustic vibrations. Selectivity is achieved by a mechanical structure, consisting of a set of resonators that are mechanically coupled in ladder-network fashion, as in Figure 1. At the input and output of the structure are resonant piezoelectric transducers that perform the electrical/mechanical energy conversion. So the basic operation is simple to visualize: incident electrical signals drive vibratory motion in the input transducer; this transducer in turn pushes on its adjacent resonator via the stiff coupling wires; and the acoustic signal propagates from one resonator to the next until it finally generates an electrical output at the opposite transducer.

Classical filter functions such as Chebyshev and Butterworth, as well as special shapes that may include transmission zeroes, can be realized. To get a mechanical system to exhibit a desired transfer function requires a two-step design process. First, an analogous LC ladder network is designed. It is at this point that circuit optimization techniques may be applied if the desired response cannot be achieved by a classical function. Second, the mechanical system is realized from the LC circuit model by way of an electromechanical analogy (that is, where velocity and force are taken as analogous to voltage and current, respectively). LC tank resonators and coupling elements are replaced by mechanical resonators and stiff-wire couplers (1).

What sort of resonators are we talking about? In fact many different shapes and many different modes of vibration have been employed in mechanical filter construction. These include thick disks vibrating in flexure, cylindrical rods vibrating in length extension, and rectangular bars vibrating in either flexure or extension. For the filter of Figure 1, the resonators take the form of cylindrical rods vibrating in a torsional, or twisting, mode. Mechanical resonators are fabricated from nickel-iron alloys specially developed to exhibit both high mechanical Q (10,000 to 30,000), and a very small temperature coefficient of frequency.

In the search for a resonator suitable for miniaturization, the torsional rod stands out. Torsional mechanical filters were originally developed using the fundamental mode (Figure 2a) at 200 kHz. Recent work at Rockwell has made higher-order modes useable up to nearly

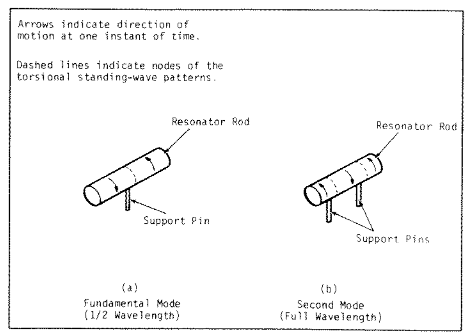

Figure 2. Torsional resonators.

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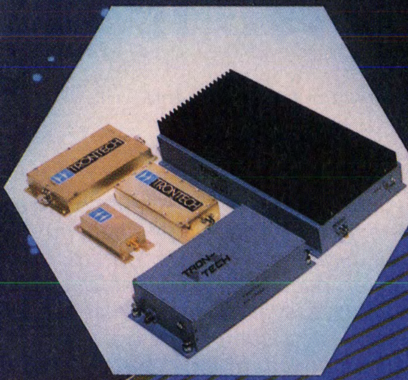

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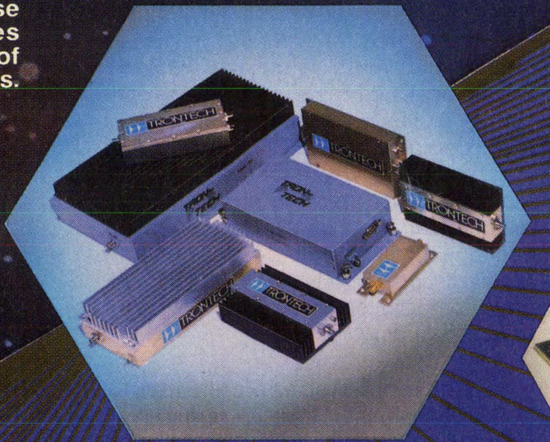

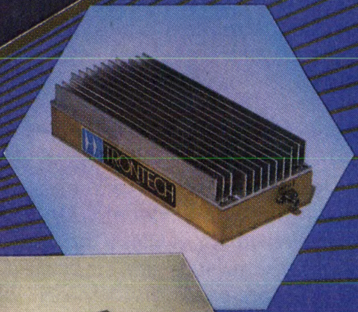

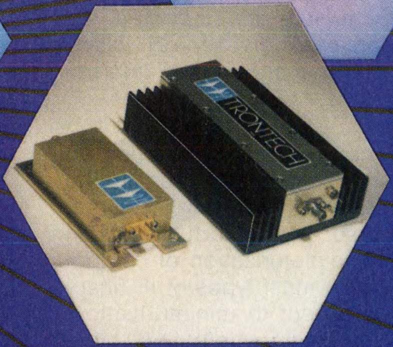

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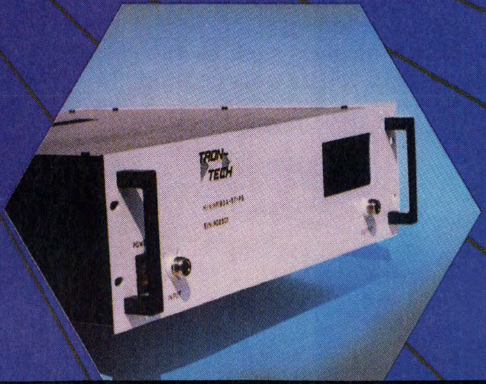

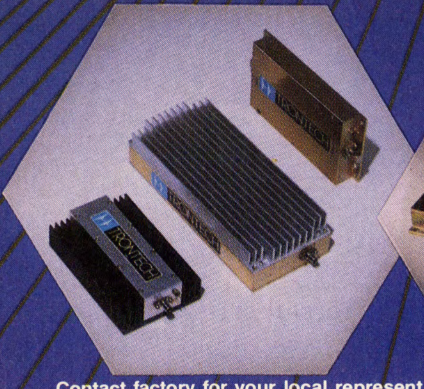

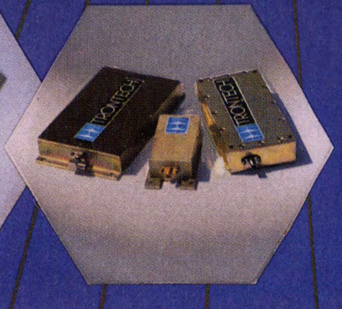

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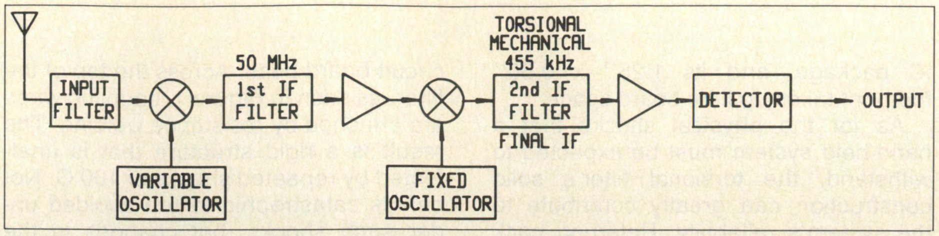

Figure 3. Example of superheterodyne receiver.

600 kHz (2,3). A second-mode resonator at 455 kHz (Figure 2b) measures less than 0.25'' in length, and Rockwell's SP enclosure packs up to eight of these, including transducers, into a volume less than 0.16 cubic inches. (Other larger enclosures fit up to 12 resonators.)

IF Design Solutions

Let us consider several examples of receivers that can make use of a torsional mechanical filter at 455 kHz.

Suppose that a precision receiver must be designed for a hand-held, battery-powered application. A likely design approach would be multiple-conversion superheterodyne; an example appears in Figure 3. In every decision the designer must attempt to minimize the receiver's power consumption and overall size, and maximize its resistance to shock and vibration. How can a torsional mechanical filter help?

The torsional mechanical filter is placed in the second IF section of Figure 3. Here its purpose is to provide the desired-channel selectivity for the receiver, while the first IF filter provides image suppression and the input filter passes the entire tunable band. The torsional mechanical filter's low insertion loss (often less than 1 dB for voice bandwidths and wider) can contribute to the reduction of power consumption, as well as noise, by allowing a reduction

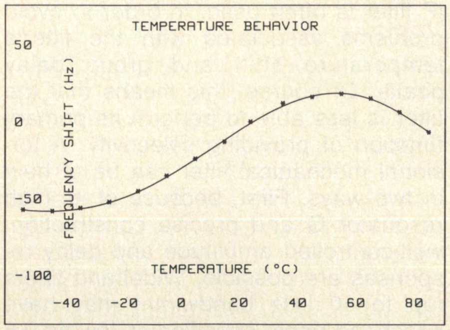

Figure 4. Center frequency shift vs. temperature.

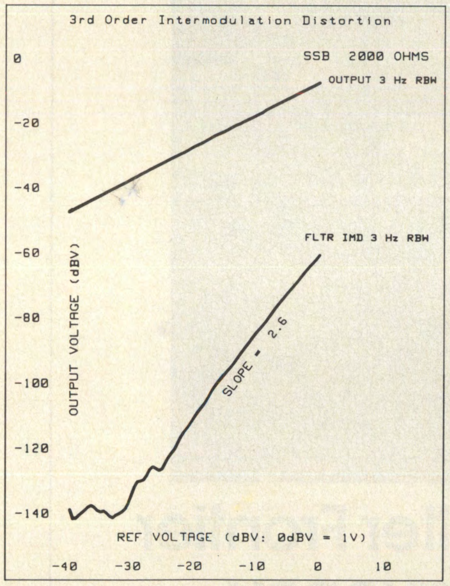

Figure 5. In-band intermodulation-distortion.

in the amount of IF amplifier gain that is necessary. Because most torsional filters terminate at about 1 Kohms to 2 Kohms, they can be designed for direct interface to available integrated mixers and subsystems, such as the Signetics NE602 mixer, or NE605 mixer/FM-discriminator. And with the Rockwell SP package height of 0.25", the filter sits not much higher than a dual in-line IC package, and its 1.25" x 0.50" footprint takes up little board space.

As for the physical shocks that a hand-held system must be expected to withstand, the torsional filter's solid construction can greatly contribute to the system's reliability. Referring back to Figure 2b, every individual resonator is fitted with two welded support pins; these are in turn soldered down into a circuit board base. Across the top of the filter, as seen in Figure 1, coupling wires are attached by resistance welding. The result is a rigid structure that is unaffected by repeated shocks of 100 G. Not only is catastrophic failure avoided under such shocks, but changes in the filter response are barely detectable. One might expect that an acoustic device like a mechanical filter would suffer from microphonic responses, but this is not the case for torsional filters. By design, acoustic energy is not coupled from the supporting base to the filter structure. This is primarily achieved by the precise placement of the resonator support pins at the nodes of each resonator's motional standing-wave pattern.

Suppose now that a receiver is to be connected to a modem that must operate over a broad temperature range. Modems usually impart a signal-shaping function to minimize intersymbol interference, such as a root-raised-cosine amplitude response with linear phase. The receiver should ideally introduce no amplitude or group delay distortion of its own. (An example of the effects of receiver impairments on the reception of pi/4 DQPSK modulated data appears in (4).) In such cases, a relatively wide IF filter is often used, in order to avoid problems associated with the filter's temperature shift and group delay peaks. Of course, this means that the filter is less able to perform its primary function of providing selectivity. A torsional mechanical filter can be of help in two ways. First, because of its high resonator Q and precise construction, well-controlled amplitude and delay responses are possible. Wideband filters (up to 40 kHz bandwidth) may have passband ripple specified as low as 0.5 dB. Second, its frequency shift with temperature is small. Figure 4 graphs the dependence of center frequency on temperature. This stable temperature behavior can allow the designer to choose a narrower filter bandwidth that

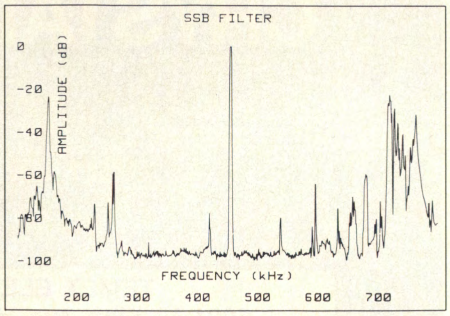

Figure 6. Spurious responses.

Signetics Family of RF Amplifiers

	NE5200	NE5204	NE5205	NE5209	NE5219
Vcc	4 - 9V	5 - 8V	5 - 8V	4.5 - 7.0V	4.5 - 7.0V
Icc	8mA / 85µA	24mA	24mA	43mA	43mA
Bandwidth (3dB)	1.2GHz	550Mhz	550Mhz	850MHz	700MHz
Noise Figure	3.9dB	6.0dB 50Ω 4.8dB 75Ω	6.0dB 50Ω 4.8dB 75Ω	9.3dB	9.3dB
1dB Compression (output)	-6dBm	+4dBm	+4dBm	-3dBm	-3dBm
3rd Order Intercept (output)	+4dBm	+17dBm	+17dBm	+13dBm	+13dBm
Input Impedance	50Ω	50Ω	50Ω	1.2kΩ	1.2kΩ
Output Impedance	50Ω	50Ω	50Ω	60Ω	60Ω
Gain (per amplifier)	7.5dB/-11dB	19dB	19dB	25dB*	25dB*
Package	SO8	DIP8 SO8	DIP8 SO8	DIP16 SO16	DIP16 SO16
Features	+ Dual Gain Stage + Enable Pin + Good Noise Figure + Low current consumption	+ Low-cost amp + Simple Implementation	+ Low-cost amp + Simple Implementation	+ Variable gain and attenuation + Excellent Linearity	+ Variable gain and attenuation + Excellent Linearity

* Single in / Differential out

For additional information call (800) 227-1817, ext. 738AF.

Signetics RF SELECTOR GUIDE 1992

When it comes to RF, Signetics is a World Leader. The product line offers solutions for Cellular Radio, Cordless Phones, Two-way Communications, High Performance Receivers and a variety of other applications. The first company to offer a complete Cellular Chip Set anywhere in the World!

RF Components

NE606/7 Low Voltage Single Chip FM System
- Functional Down to 2.85V
- 3.4mA Supply Current
- 0.31µV Sensitivity at 45MHz
- 90dB Dynamic Range RSSI
- Internal Op-amps on Audio/RSSI Outputs
- IF Frequencies band limited to 2MHz
- >150MHz RF Input
- SSOP (Shrink Small Outline Package)
- Frequency Check Pin (NE607 only)

NE605 High Performance Single Chip FM System
- 0.22µV Sensitivity at 45MHz
- 90dB Dynamic Range RSSI
- IF Frequencies up to 25MHz
- 5.7mA Supply Current
- >500MHz RF Input
- SSOP (Shrink Small Outline Package)

NE604A Low Power FM IF
- 0.22µV Sensitivity at 45MHz
- 90dB Dynamic Range RSSI
- IF Frequencies up to 25MHz
- 3.3mA Supply Current

NE602A Double Balanced Mixer
- 2.4mA Supply Current
- On Board Oscillator will Function up to 300MHz (typ)
- >500MHz RF Input
- 17dB Conversion Gain at 45MHz
- 5.0dB Noise Figure at 45MHz

Amplifiers

NE5209 Wideband Variable Gain Amplifier
- Bandwidth of 850MHz (3dB)
- 60dB of Control Range at 200MHz
- 7dB Noise Figure
- High Impedance Differential Inputs
- 50Ω Differential Output

NE5205 Wideband High Frequency Amplifier
- Bandwidth of 600MHz (3dB)
- 20dB of Insertion Gain
- 4.8dB (Zo=75Ω) Noise Figure
- Input/Output Impedance Matched to 50/75Ω Systems

NE5200 Dual Gain Stage RF Amplifier
- Bandwidth of 1.2GHz
- 7.5dB of Insertion Gain (per amplifier)
- 3.9dB Noise Figure
- Enable/Power Down Pin
- Input/Output Impedance Matched to 50Ω Systems

Compandor Components

NE578/577/576 Low Power Compandor
- Low Power 1.4mA @ 3.6V
- Functional Down to 1.8V
- Low External Component Count
- Programmable Unity Gain (0dB) 10mV to1Vrms *
- Power Down/Mute Mode (Icc=170µA) **
- Multiple External Summing Capability **

  *(577/578 only)

  ** (578 only)

NE575 Low Voltage Compandor
- Operates Down to 3V
- Two Built in Op-amps in each Channel
- 0.12% typical THD
- SSOP (Shrink Small Outline Package)

NE572 High Performance Compandor
- 110dB Dynamic Range
- Independent Attack and Recovery Time
- Low Output Noise: 6µV typical
- Very Low Distortion (0.05% typical at 1kHz)

NE570/571 High Performance Compandor
- 110dB Dynamic Range
- Built in Op-amps
- Excellent for High Quality Audio

Audio Processors

NE5750 Audio Processor - Companding and Amplifier Section
- Adjustable Gain Preamplifier
- Open Collector VOX Output
- Power Down Mode
- Drivers for Speaker and Earpiece

NE5751 Audio Processor - Filter and Control Section
- Switched Capacitor Bandpass Filter
- Programmable DTMF Generator
- Digitally Controlled Volume Control
- Power Down Mode
- I^2C Bus Controlled

Complementary Devices

NE630 Single Pole Double Throw Switch
- Wideband Operation (DC-1GHz)
- Low Power ICC=170µA @5V
- Low Loss 1dB @ 100MHz
- Excellent Isolation 60dB @100MHz
- Extremely Fast Switching Speed 25nsec

98-2000-420

1239L/11M/FP/0991

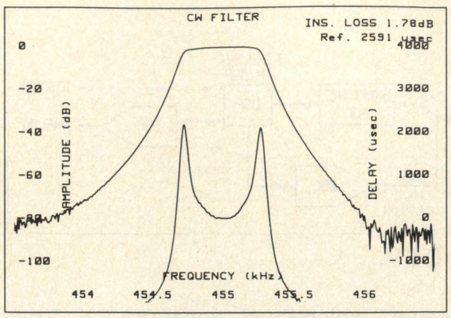

Figure 7. Filter characteristics suitable for differential GPS.

more closely surrounds the desired band.

Modulated data is also affected by intermodulation distortion. Since the torsional mode is one of the more inherently linear modes of mechanical vibration, the torsional filter exhibits low intermodulation distortion. Figure 5 is a typical plot, for a filter with a 2 Kohm termination. Interestingly, mechanical filters do not exhibit a slope of exactly 3.0 in their "third-order" intermodulation curves; rather, the slope generally comes out between 2.0 and 3.0. (This tends to be true of crystals and ceramics as well.) Consequently, it is not possible to specify intermodulation by intercept point alone. It is more meaningful to specify maximum levels of intermodulation products over the intended range of drive levels.

For bandwidths less than 6 kHz, reliability is enhanced by the fact that torsional mechanical filters do not usually require tuning inductors, either internally or externally. However, this means that the spurious responses of the mechanical structure will not be greatly attenuated. Figure 6 is a plot of the spurious responses of a single-sideband filter. These responses are intentionally pushed as far away as possible from the 455 kHz passband, as part of the design. The regions both above and below the passband where spurious responses typically remain be-

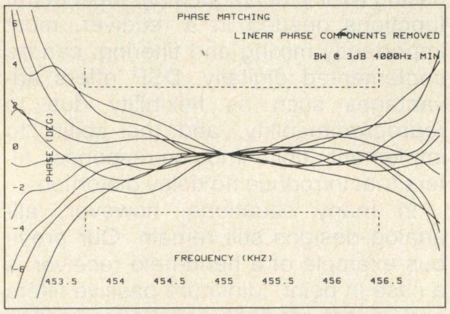

Figure 8. Phase responses of a group of 10 filters.

low -60 dB are roughly 200 kHz wide. The spurious responses at about 150 kHz and 700 kHz are far enough away that in a receiver they can be effectively suppressed by the filters in the previous IF sections; if not, this can be handled by a simple, wideband, low-order "roofing" filter.

Now take the case of a differential GPS (Global Positioning System) receiver, which must receive signals from a fixed ground station conveying GPS positioning error information. A low-data-rate system such as this requires only a narrow channel (typically 500 Hz) but needs to maintain a controlled phase or delay response. Torsional filters are able to provide bandwidths this narrow with relatively low insertion loss; less than 3 dB is typical. Maximally-flat, i.e., Butterworth, passbands are a good choice here (Figure 7), with the exact bandwidth set just wide enough to meet the particular phase or delay specification. Gaussian and transitional filters are also possible, but are more costly due to greater response sensitivities to filter element variations.

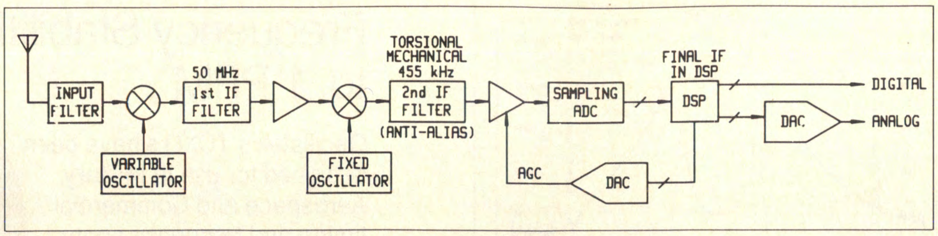

Figure 9. Example of receiver utilizing DSP.

Finally consider a direction-finding receiver, which must implement two or more channels, the phase responses of which must be matched within a few degrees over most of the channel bandwidth. Most of the receiver's phase deviation between the channels is likely to come from its IF filters. Torsional filters can perform particularly well here. In Figure 8 we overlay the phase plots of ten 7-pole filters that were designed for a phase-matched application. Among the ten filters the total phase deviation over the central 70 percent of the pass band is found to be only ±3 degrees.

The DSP Connection

Another way to implement a precision IF section is through digital signal processing (DSP) techniques (5). Most of the functions needed in a receiver, most importantly mixing and filtering, can be implemented digitally. DSP offers advantages such as flexibility due to reprogrammability, and the ability to implement finite-impulse-response filters that introduce no delay distortion.

In many situations, however, all-analog designs still remain. Our previous example of a hand-held receiver is a case in point. Miniature passive filters and mixers are likely to take less space and certainly use less power than a digital signal processor and its peripherals.

Still, DSP is finding ever more applications in receiver design. Using current processor and analog-to-digital converter (ADC) technology, an effective design approach is to implement the final IF and demodulation functions digitally, following an analog front end (Figure 9).

As all DSP specialists know, the analog signal must be bandlimited before it is sampled at the ADC. This is to prevent aliasing, a by-product of sampling where signals outside the band of interest can fold inside. The technique of undersampling (6,7) allows the ADC to be fed with an IF rather than baseband signal; in this case the anti-aliasing function is performed mainly by the bandpass IF filter just before the ADC.

To keep costs down, this filter should have as few requirements placed upon it as possible. But many tradeoffs are actually involved. Usually an anti-aliasing filter's bandwidth is chosen to be wider than the widest band the receiver is intended to receive. Also it may provide only a few poles of selectivity. This way, the filter causes little delay distortion and can be inexpensive. But a narrower and steeper filter would provide better attenuation of adjacent-channel signals, helping to avoid ADC overload and simplifying the receiver's automatic gain control. An ideal anti-aliasing filter would also have minimal passband ripple, leaving as much of the ripple specification budget as possible to the digital filters.

The torsional mechanical filter is well suited to the anti-aliasing application in undersampling digital receivers. Flexibility in choice of center frequency and bandwidth allows placement of the passband precisely where required for a digital system's particular sampling rate. Flat passband ripple, controlled delay, and excellent temperature stability also contribute to system performance, all in a package dimensionally compatible with typical integrated circuits. ***RF***

Acknowledgement

The cover artwork was designed by Phil Young of Rockwell International.

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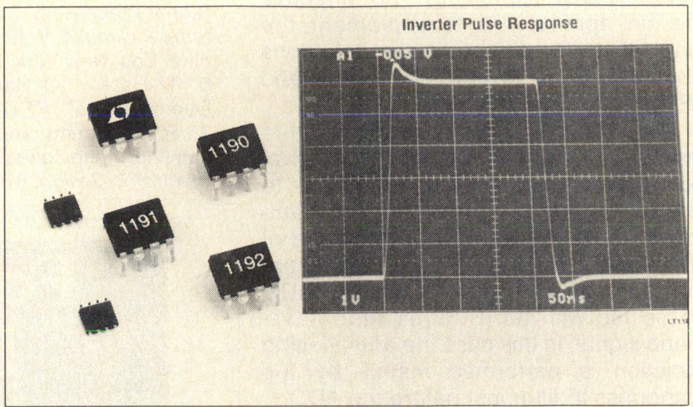
About the Authors

Bill Domino and Bob Johnson are electronics engineers at Rockwell International. They have been involved in all aspects of the business: R&D, design, production, applications, and sales. They can be reached at: Filter Products, Rockwell International, 2990 Airway Avenue, Costa Mesa, CA 92626. Tel: (714) 540-7640.

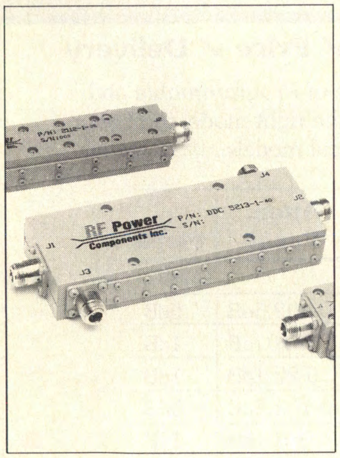
High Speed Op Amps Offered at Low Prices

LTC has introduced the LT1190 family of very high speed operational amplifiers. All three op amps have slew rates of 450 Volts/microsecond, true bandwidths of 50 MHz to 100 MHz and 50 mA of output drive current. The new op amps are voltage feedback amps and can be used in all conventional op amp circuits. They are specified driving 100-ohm loads while operating from a single 5 volt supply as well as ± 5 V to ± 8 V. The op amps have a shutdown feature to reduce power dissipation and three-state the output. The LT1190 amplifiers have an offset voltage of 1 mV, input bias current of 500 nanoamperes, and a gain of 45,000 V/V. The LT1190 and LT1191 video op amps are optimized for unity gain applications, and the LT1192 is designed for closed loop gains of 5 or more. The LT1192 has the lowest input referred noise voltage of the family at 9 $nV/\sqrt{Hz}$ at 10 kHz. Pricing in quantities of 100 or more starts at $2.25 for the LT1190 and $2.45 for the LT1191 and LT1192.
Linear Technology Corporation
INFO/CARD #250



1000 Watt Dual Directional Coupler

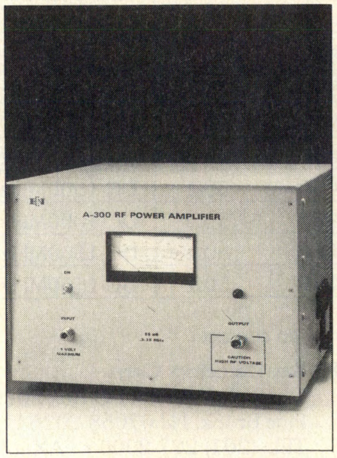
Three high power dual directional couplers have been introduced by RF Power Components



Inc. The couplers have a 40 dB ±0.5 dB coupling, a directivity of 25 dB, an insertion loss of 0.2 dB, and a VSWR of 1.2:1. The DDC-1252-1-40, DDC-2112-1-40, and DDC-5213-1-40 have operating frequency ranges of 100 - 500 MHz, 20 -100 MHz and 500 - 1000 MHz, respectively. The -1252-and -2112- have a power rating of 1000 Watts CW. The -5213-has a power rating of 500 Watts CW with type N connectors and 1000 Watts CW with type SC connectors. Type N Female is the standard connector with SMA female optional at no charge.
RF Power Components Inc.
INFO/CARD #249

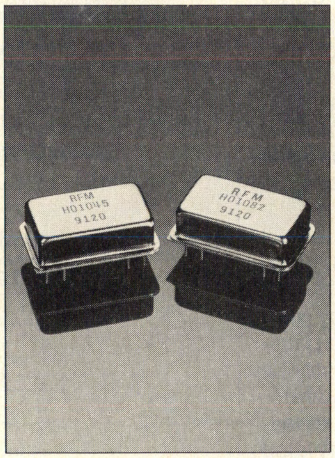
Broadband RF Amplifier

The Model A-300 RF Power Amplifier produces up to 300 Watts of linear Class A output power over the frequency range of 300 kHz to 35 MHz, and is an excellent power source for HF transmitters, nuclear accelerators, plasma equipment, EMC testing, and other applications. With a gain of 55 dB, the A-300 features low harmonic and intermodulation distortion where all harmonics are more than 25 dB below the main signal at 250 Watts output. Pulsed and CW power capability is 500 Watts. The power supply and forced-air cooling system are conservatively rated to permit operation over a wide range of temperatures and AC line conditions. The A-300 is available for 30-day delivery at a cost of $9,365.
ENI
INFO/CARD #248



Frequency Sources

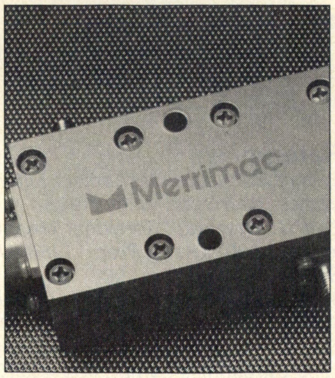
RF Monolithics, Inc. is offering two-frequency sources to speed the design and manufacture of equipment utilizing RF in the 915 MHz ISM band. The



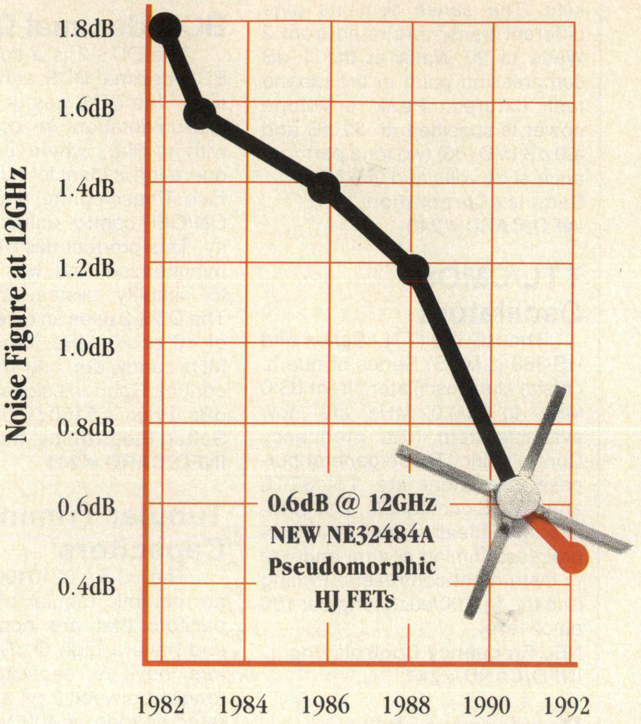
HO1045 and HO1082 feature similar specifications except for output powers of +7 dBm minimum into a 50 ohm load and +10 dBm minimum, respectively. Both frequency sources employ quartz SAW resonators for frequency control, and operate at 915 MHz ± 250 kHz. The frequency sources are designed for +12 VDC power supply, and are housed in 14-pin hermetic metal packages. Applications include communications and non-communications uses such as diathermy. Pricing in small quantities is $165 each.
RF Monolithics, Inc.
INFO/CARD #247

Dual Directional Coupler for Cellular Base Stations

Merrimac Industries, Inc. have expanded their range of dual directional couplers with a unit developed for simple access to the cellular radio base station signal feed. The CGN-30-0.9G is a 500 W Dual Directional Coupler comprised of two opposed 30 dB directional couplers on each side of the main line to keep coupled length short and insertion loss to a value of 0.05 dB. The VSWR is 1.02:1 on either main port. Specifications cover the 820-960 MHz range. Physical dimensions are approximately 3.0 × 1.65 × 1.17 inches, plus connectors. Type N signal connectors and SMA coupled-port connectors are standard. Couplers may be ordered to comply with MIL-C-15370. The Model CGN-30-0.9G is available off-the-shelf for delivery.
Merrimac Industries, Inc.
INFO/CARD #246



Snow Removal Devices



The downward trend continues

Noise in a receiver means snow on the screen. With a noise figure of only *0.6dB* at 12GHz, our new NE32484A is helping keep viewers happy, even in peripheral transmission areas.

No matter what your application, our new family of Low Noise GaAs FETS can provide more margin in your LNA designs, potentially fewer gain stages, and overall lower costs.

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Part No.	Freq (GHz)	NF (dB)	Ga (dB)
NE32484A	12	0.6	11.0
NE42184A	12	0.9	10.5
NE76084	12	1.6	9.0
NE76038	4	0.8	13.0
NE76184A	4	0.8	12.0

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INFO/CARD 48

Power MOSFET

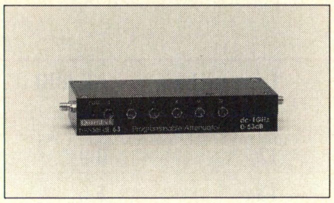
Semetex Corporation has introduced the ST9000 Series Class A RF Power Mosfets specifically characterized for linear application in the cellular radio, UHF TV and broadband EW markets. The series contains nine different transistors rated from 2 Watts to 20 Watts at the 1 dB compression point in broadband test fixtures. Peak envelope power is specified at -32 dB and -60 dB IMD (d3) two tone performance at 24 volts and 950 MHz.
Semetex Corporation
INFO/CARD #245

TTL/CMOS Oscillators

The HS-150 (TTL) Series and HS-360 (CMOS) Series of quartz crystal clock oscillators from 63.0 MHz to 200.0 MHz are now available from NEL Frequency Controls, Inc. These general purpose oscillators are TTL/STTL and CMOS compatible. The oscillators are ideally suited for microprocessor timing control and use in instrument controllers. Pricing is in the $14.00/each range at 100 piece level.
NEL Frequency Controls, Inc.
INFO/CARD #244

Programmable Attenuator

The latest Quartzlock Attenuator targets the air interface simulator/radio path modelling and



GSM embedded test equipment manufacturer. The 1 dB steps to 63 dB are accurate to 0.01 dB with maximum error of 0.3 dB. Zero intermodulation products are achieved with fast electro-mechanical switching in this surface mount attenuator.
Quartzlock Instruments
INFO/CARD #243

Power Meter

With a frequency range from 1 to 1000 MHz, the Directional Power Meter NAS from Rohde & Schwarz is ideal for power and VSWR measurements in the entire field of radiotelephony. Three different insertion units, which can be operated in detached mode, allow power and VSWR measurements from 10 mW to 120 W to be performed anywhere.
Rohde & Schwarz
INFO/CARD #242

BCD/decimal DDS

The DDS-2 is a complete all BCD/decimal DDS with DAC and filter. The DDS was designed for instrumentation in combination with a PLL, where its decimal operation is ideal for human interface. Phase control and >100 dB ON/OFF control enhance its utility. This product has been highly miniaturized and was designed to simplify system integration. The DDS-2 uses an external clock of 10 or 20 MHz, has a 4 or 8 MHz bandwidth, and 10 bit phase control. Spurious signals are −60 dBc. Price is $150 (100s).
Sciteq Electronics, Inc.
INFO/CARD #241

Tubular Trimmer Capacitors

The C.T. 02101006 Series are ceramic tubular trimmer capacitors that are non-magnetic and have a high Q. The capacitors have a capacitance that ranges between 2 pF and 6 pF, a rated voltage of 400 VDC and a test voltage of 800 VDC. The minimum Q factor is 1000 at 5 MHz. The tubular trimmer may be produced with a number of tuning capacitance ranges, in dimensions and mounting styles to meet special requirements.
Ceramic Technology
INFO/CARD #240

Snap-On Connectors

M/A-COM Omni Spectra has introduced their OSX Subminiature Snap-On Connector series. OSX connectors are 30 percent smaller than commonly used SMB connectors and are suited for cellular telephone, GPS and automotive applications. The connectors have an operating frequency range from DC to 6 GHz. The OSX family consists of straight and right angle cable connectors.
M/A-COM Omni Spectra, Inc.
INFO/CARD #239

RF Pulse Amplifier

The Model 3417 covers 20 to 200 MHz and delivers 2.5 kW for MRI applications. A dual mode integrating RF power protection system allows high power pulses

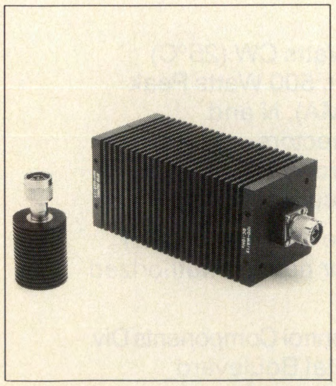
to be intermixed with reduced power CW type levels. This protection system is totally independent of the noise blanking signal. Standard features include a pulse droop < 5 percent, blanking time < 1 microsecond, and linearity to ± 1 dB. The amplifier is priced at $42,000.
American Microwave Technology, Inc.
INFO/CARD #238

Transimpedance Amplifier

The latest gallium arsenide integrated circuit transimpedance amplifier developed by Anadigics, Inc. is a 1.2 Gb/s unit featuring automatic gain control, 4 k ohm transresistance, 900 MHz analog bandwidth, and dynamic range of 50 dB. Other features of the ATA12000 include an optical sensitivity of −31 dBm, low pulse width distortion, an input impedance of 100 ohms, an output impedance of 50 ohms, and a single +5 volt power supply. The ATA12000 is priced at $100 in quantities of 50.
Anadigics, Inc.
INFO/CARD #237

High Power Terminations

JFW Industries has announced the expansion of their High Power Termination line.



Power levels available range from 1 to 300 Watts. The impedance of this line is 50 ohms. Terminations available are N, BNC, TNC, or SMA type connectors. The 50T-032 is a 100 Watt unit with a frequency range of DC-1000 MHz, and has a VSWR which ranges from 1.1:1 to 1.5 to 1. The 50T-054 is 30 Watt unit, has N male connectors, and operates DC-1200 MHz. JFW will also design a custom model to fit a specific application.
JFW Industries, Inc.
INFO/CARD #236

RF Switch Matrices

Switching Matrices allow system designers to connect any or all inputs to any or all outputs by IEEE-488, RS-322 or manual controls. The switch matrices have a standard 19 inch slide rack design with up to 24 inputs × 24 outputs with a built in power supply. Typical specifications are a VSWR of 1.5:1 and an isolation of 70 dB at UHF with flat responses over multi-octave bandwidths.
Lorch Electronics
INFO/CARD #235

Universal Active Filter

Burr-Brown's new UAF42 is a monolithic active filter which can be configured for a variety of low-pass, high-pass, band-pass, and band-reject designs. A DOS-compatible design program, available free of charge, allows implementation of filter types such as Butterworth, Chebyshev and inverse Chebyshev. The UAF42 uses a state-variable analog architecture with an inverting amplifier and two integrators. The UAF42 forms a time-continuous filter, free from aliasing anomalies and digital noise. Key specifications include 0 to 100 kHz frequency range and a maximum Q to 400.
Burr-Brown Corporation
INFO/CARD #234

SPDT Switch with Driver

Mini-Circuits has announced a new SMA connector SPDT reflective switch with a built-in driver. The 3 nsec GaAs super-fast ZYSW-2-50DR offers 1.3 dB insertion loss, 40 dB isolation, and a +20 dBm value for its 1 dB compression point. VSWR (on) is 1.4:1, with 30 mV p-p video breakthrough, and 3 nsec rise/fall time. The switch is priced at $59.95 (1-9 qty).
Mini-Circuits
INFO/CARD #233

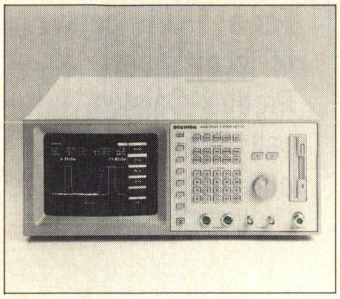
Pin Switches

Narda's super-slim series of hermetically sealed PIN switches cover the frequency rage from 2 to 18 GHz with a maximum switching speed of 15 nsec. Isolation is typically 60 to 70 dB, and the units are available in SPST

through SP6T versions. The packages are gold plated with removable SMA connectors for drop-in applications.
Loral Microwave-Narda
INFO/CARD #232

Power Meter

The Boonton 4400 Peak Power Meter covers a frequency range of 30 MHz to 40 GHz and its dynamic range extends from −40 to +20 dBm. An IEEE-488 interface is provided for ATE applications, plus plotter and RS-232 interfaces. It has a menu-driven setup, and displays a variety of pulse parameters — power, time, and frequency related. Measurements are made at a rate of 40 to 70 measurements per second, and waveforms are digitized at a 1 MHz rate. The Model 4400 is available in single-channel for $11,750 and two-channel $13,000.
Boonton Electronics Corporation
INFO/CARD #231



Thin Film Capacitor

AVX's ACCU-F thin-film microwave capacitor is a low ESR, high Q capacitor. Capacitance values are as low as 0.1 pF ±0.05 pF. The capacitor has a high insulation resistance and low losses to frequencies above 40 GHz. Applications for the capacitor include cellular communications, cordless telephones, satellite television, matching networks, and much more.
AVX Corporation, Inc.
INFO/CARD #230

Crystal Oscillator

Reeves-Hoffman have announced a temperature compensated oscillator series 3119. The frequency range is 8 to 14 MHz. Typical SSB phase noise at 10.23 MHz is −90 dBc/Hz at 10 Hz, −100 dBc/Hz at 100 Hz, −110 dBc/Hz at 1 kHz, and −120 dBc/Hz at 10 kHz. Frequency stability is ±1 × 10^{-6} over a temperature range of 0 °C to +50 °C. The unit will perform to Mil-Std-202, method 204, test condition A. The approximate price is $30 to $50 in quantities.
Reeves-Hoffman
INFO/CARD #229

RF Probe Assembly

The K-50 is a universal broadband 50 ohm coaxial test probe. The probe enables RF functional testing for high density connectorless circuits in the production environment, and can also produce plane-of-incidence impedance measurements when used as a network analyzer port extending accessory. The probe assembly exhibits a return loss greater than 20 dB and an insertion loss of less than .12 dB at frequencies up to 1 GHz.
Everett/Charles Contact Products
INFO/CARD #228

Pushbutton Attenuators

MIDISCO Pushbutton Attenuators are available in four models. There are two types that have an impedance of 50 ohms and frequency range of DC-750 MHz, and two types that have a 75 ohm impedance and operate DC-500 MHz. By selecting the proper combination of pushbuttons, the user can have 0.5 or 1 dB steps through 45.5 dB or 65 dB. All models are rated to 1 Watt average power.
MIDISCO
INFO/CARD #227

Relays

The three Series 172 Centigrid® relays available from Teledyne are supplied in coil voltages of 5.0 VDC, 12.0 VDC and 25.6 VDC. Their features include 100 percent all-welded construction, uni-frame design for high mag-

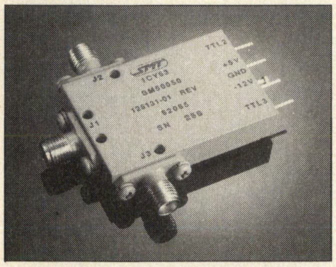
netic efficiency and mechanical rigidity, high force/mass ratios that withstand shock and vibration, and precious metal contact material.
Teledyne Relays
INFO/CARD #226

Phase Locked Oscillators

Communication Techniques Inc. has introduced a range of phase locked coaxial resonator oscillators operating at frequencies from 600 MHz to 3 GHz. Features include a low loss, high Q circuit, small size, low power consumption, excellent SSB phase noise, internal DC power regulator, and no sub harmonics. Output power is normally +23 dBm with a power requirement from +15 VDC to +24 VDC. The oscillators operate at 630 MHz, 960 MHz, 1030 MHz, 1200 MHz, and 1270 MHz.
Communication Techniques, Inc.
INFO/CARD #225

Pin Diode Switches

A series of Pin Diode Switches has been introduced by Sierra Microwave Technology.



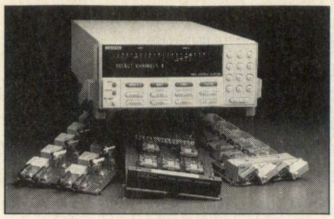
The switches cover an instantaneous bandwidth of 100 MHz to 26.5 GHz. Typical RF parameters include 1.6:1 VSWR, 2.5 dB insertion loss, and 60 dB isolation. The line features SPST through SP5T and are TTL compatible.
Sierra Microwave Technology
INFO/CARD #224

High Efficiency Amplifier

Avantek, Inc. is offering a 10 to 2000 MHz TO-8 amplifier providing typical 19 dB gain, ± 0.5 dB flatness, 5 dB noise figure, and +16 dBm output power at 1 dB gain compression at +25 °C. The amplifier draws 52 mA at +15 VDC, which represents a gain-to-current efficiency of 0.37 dB/mA. The UTO/UTC-2020 amplifiers are designed to meet the reliability requirements of MIL-STD-883.
Avantek
INFO/CARD #223

Switch System and Cards

The Model 7001, Keithley Instruments new two-slot switch system, can handle up to 80



channels of two-pole switching. The system has a built-in Trigger-Link that allows more precise, repeatable triggering of multiple instruments than is possible over the IEEE-488 bus. The three new switching cards combine with more than 30 other Keithley cards to offer switching capabilities from 30 nV to 1.3 kV, 10 fA to 5 A, and DC to 500 MHz.
Keithley Instruments
INFO/CARD #222

Multicoupler

WI-COMM Electronics Inc. has announced a UHF Receiver Multicoupler, Model No. MC34. The model covers the UHF military band 225-400 MHz. It employs a feedforward 'superlam' amplifier with a 3rd order intercept point of 53 dBm min. Multicoupler operational redundancy and high reverse isolation of 50 dB are the two of its features. Overall gain is +0.5 dB for an 8 port unit. Higher gain or more outputs are available on request.
WI-COMM Electronics Inc.
INFO/CARD #221

Bit Sequence Generator

The LRS-200 generates pseudorandom bit sequences using a 32-stage shift register with linear feedback. The register length, feedback pattern, initial register contents, and length of the linear recursive sequence can be set manually via a soft menu on the display, or automatically via an optional GPIB interface. Different modes of operation include BPSK, QPSK, GOLD/JPL, Offset, and Burst, with a maximum bit rate of 25 MHz.
New Wave Instruments
INFO/CARD #220

Phase Locked Loop

QUALCOMM, Inc. has announced the Q3036M-16L, a high speed phase locked loop (PLL) for military applications. This PLL has been designed to interface easily with system architecture allowing either full-parallel hardwiring or an 8-bit data bus mode. The device has a VCO input frequency of DC-1.6 GHz with a reference frequency of DC-100 MHz.
QUALCOMM, Inc.
INFO/CARD #219

Phase Locked Oscillators

The RFM-184 series phase-locked oscillators operate over the frequency range of 1.0-26.5 GHz and are digitally programmable to customer requirements. Typical phase noise at 13.5 GHz: −60dBc/Hz at 1 kHz, −75 dBc/Hz at 10 kHz, and −90 dBc/Hz at 100 kHz. Output power is +10 dBm minimum with a supply voltage of +15 VDC.
RF Microsystems, Inc.
INFO/CARD #218

VCO

Magnum Microwave's HV67T-1 is specified over an octave bandwidth from 1.0 to 2.0 GHz with a minimum output power of +10 dBm. Single sideband phase noise at 50 kHz offset is typically −105 dBc/Hz. Tuning voltage is confined within 0 to +20 VDC. Supply requirements are +15 VDC and 50 mA. TO-8, flat-pack and connectorized packages are available.
Magnum Microwave Corporation
INFO/CARD #217

Polycarbonate Capacitor

Electronic Concepts, Inc. is offering a metallized polycarbonate capacitor that is subminiature in size, hermetically sealed, radial leaded, and qualified to MIL-C-39022/11. Capacitance is from .001 to 1 microfarad. Voltages are 30 VDC, 50 VDC, 100 VDC, 150 VDC, 200 VDC and 300 VDC.
Electronic Concepts, Inc.
INFO/CARD #216

Using Diversity to Improve Performance of Part 15 Devices

By Bernard Kasmir
ADEMCO

There has been much recent interest in unlicensed radio devices operating under FCC Part 15, at traditional operating frequencies and in the new 900 MHz spread-spectrum allocation. A review of basic communication principles, and their effect on low-power, short-range communications is essential for engineers working on these products.

A previous Part 15 article (1) discussed reliability and signal margin. A relationship was discussed which equated system reliability in terms of signal margin. This signal margin was defined as the signal in excess to the minimum level for detection. The greater the signal margin, the greater the system's reliability. This margin is determined by items such as transmitter power, receiver sensitivity, antenna efficiency, signal absorption, attenuation and phase cancellation. What choices do we have to increase the signal margin and thus improve reliability?

Transmitter Power— The maximum signal level is defined in Part 15 by the FCC. Some level increase is possible by utilizing the transmitter duty cycle specifications of 100 milliseconds average. Also, the effective range is enhanced by providing as much of the omni pattern as possible. However, if there were no power restrictions, power would be limited by practical considerations such as cost and battery life. Therefore, choices are rather restricted.

Receiver Sensitivity— Sensitivity is limited by system bandwidth, noise figure, noise floor, antenna efficiency, costs and other practical considerations similar to that of transmitters.

Environment— Signal attenuation caused by such factors as absorption and reflections must also be contended with. Some system performance enhancement can be achieved by good installation techniques. This topic requires a separate article.

Multiple Reflections— This is one area where practical improvement in systems reliability can be realized. The indoor environment is hostile and the range is limited. We need as strong a signal as possible. Nulls caused by reflections can be severe. Although good installation techniques will tend to reduce these nulls, these nulls are not constant but change with changing environment and time. For example, reflections may change if the furniture is rearranged. Some data indicates that signal levels in fixed installations change with weather and season.

A reduction of these nulls is equivalent to an increase in power without the penalties. Signal fading and nulls caused by multiple reflections can be helped by some form of diversity. The signal at the receiving antenna is comprised of a direct signal and a number of reflected signals. The resultant signal can either be higher or lower. If the direct and reflected signals are out of phase, the resultant signal can be significantly attenuated.

In the real world, there are many different signal and multiple reflection paths. Because of the variations of the indoor environment, the final resultant signal vector cannot be accurately described except in a probabalistic model. In order to simplify the analysis, we will take one special case of a simple 2 ray model. This model will not accurately predict propagation characteristics but is useful in showing trends and general characteristics.

In this model, the direct signal is equal to:

$V_1 = A \sin(x)$

and the reflected signal is equal to:

$V_2 = B \sin(x + W)$

where:

A = amplitude of direct wave
B = amplitude of reflected wave
W = relative phase shift between V_1 and V_2

Theoretically, complete cancellation will occur when:

$A = B$, and $\sin(x) + \sin(x + W) = 0$

This will happen if W = 180 degrees since $\sin(X + 180) = -\sin(x)$.

If we normalize the amplitude of A to unity, then the amplitude and phase shift of the reflected wave is a function of difference in path lengths, the angle of incidence and reflection as well as the reflection coefficient of the reflecting media.

To better understand the concept of signal cancellation, refer to Figure 1. This shows the phase relationship between two RF sine waves of equal amplitude but 180 degrees out of phase. The resultant is a completely nulled signal. Assume that one signal is caused by a direct wave and the second signal is caused by a reflected wave impinging on the same antenna. The instantaneous phase of any particular signal changes with distance where 180 degrees phase shift occurs in one half

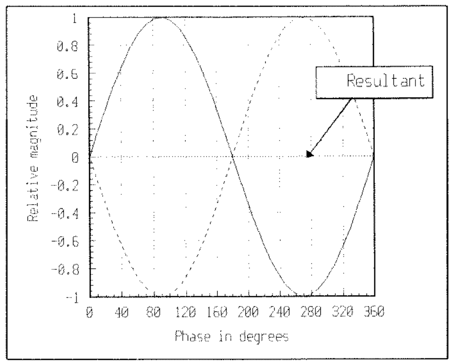


Figure 1. Complete signal cancellation.

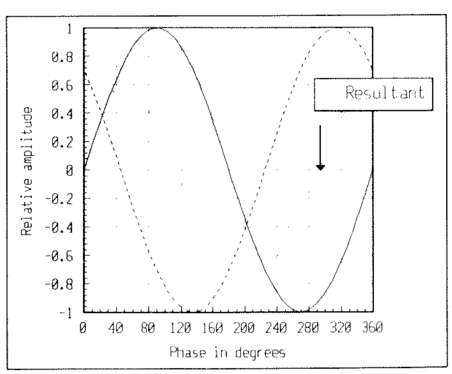


Figure 2. Resultant of two waves 135 degrees apart.

S_1	S_2	S_3	S_4	Amplitude and phase differential	@ 300 Mhz
25	5	0.5	0	.37	20.3
26.64	5	0.5	0	.157	19.28
25	5	0.5	1.64	.218	23.9
50	5	0.5	0		10.76
50	10	0.5	0		20.38
50	5	1.0	0		21.5
50	5	0.5	1.64		12.56
51.64	5	0.5	0		10.76
100	5	0.5	0		5.4
100	10	0.5	0		10.7
100	5	1.0	0		10.9
100	5	0.5	1.64		6.36
101.64	5	0.5	0		5.37
100	10	1.0	0		21.5

S_1 = Distance between transmitter and receiver
S_3 = Antenna separation
S_2 = Distance from centerline to reflector
S_4 = Offset of transmitter from centerline

Table 1. Phase differential vs. path length.

wavelength. If the phase shift due to path length differences and phase shift due to reflections is 180 degrees (or multiples thereof) there will be a cancellation of signals. At phase displacements other than 180 degrees, the resultant signal can either add or subtract.

Figure 2 shows two signals displaced 135 degrees apart (or 45 degrees from complete cancellation). The resultant signal is less than each individual signal. Figure 3 shows the resultant of a 90 degrees phase displacement. In this case, the resultant signal is greater than each individual signal.

Therefore, the magnitude of the received signal changes with the resultant phase shift as well as relative amplitude of these two signals. Maximum attenuation occurs where the signals are 180 degrees out of phase and the amplitudes are equal. We are interested in phase shifts close to the 180 degree case because this will tell us the magnitude of the signal null as a function of the differential to 180 degrees. This can then be related to differences in path lengths between the direct and reflected signals. Figure 4 is a plot of relative attenuation in dB of two signals of equal amplitude with phase angle differences from just above 180 degrees to 270 degrees. From this curve, it can be seen that the change in null as a function of phase differential is dependent upon the initial magnitude of the null.

It is interesting to note that two in-phase signals can result in a 2/1 or 6 dB improvement, but that two out-of-phase signals can result in complete cancellation or attenuation approaching infinity. Actually, this "improvement" is only on paper because the transmitter signal level is measured at a test site with maximum signal addition.

The phase delay due to path length differences is equal to:

$$\text{Phase delay} = 2 \times \pi \times P \times T_D$$

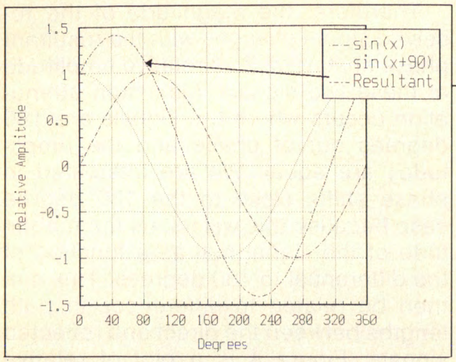


Figure 3. Phase resultant for signals 90 degrees apart.

where:
F is the frequency in questions
π is 3.14
T_D is the time delay caused by a different path length.

Each wavelength produces a phase shift of 2π or 360 degrees. As an example, at 300 MHz, a wavelength is 1 meter. A half wave would be 1.64 feet. At this frequency, a difference in path length (all other things being equal) of 1.64 feet would result in a relative phase difference of 180 degrees which could cause complete cancellation.

For short range radio systems (operating within the confines of a protected premises), the distances involved are usually not more than 100 feet. At these distances, the multiple reflection vectors act on a cycle to cycle basis and can result in direct RF signal cancellation rather than as pulse distortion due to multipath encountered where the distances are miles rather than feet.

Figure 5 shows a theoretical simple two ray model. The transmitter is located at some defined distance away from two receiving antennas and some distance to a reflecting surface. Each antenna receives a direct wave and one reflected wave from the reflecting surface.

We will assume that one reflection occurs at a distance halfway between the transmitter and receiver. For this example, the antenna spacing is 1/2 foot. The difference in signal paths are calculated at various distances, (25, 50 and 100 feet) for a distance to the reflecting wall of 5 feet. As part of the calculations, the transmitter is displaced one half wavelength to the right and one half wavelength to the rear. The magnitude of the reflection and the reflection coefficient of the reflecting media is canceled out because in this model, we are interested only in the difference in path length. If we can assume that one antenna is in a null, this model will show the difference in path length from which we can evaluate the improvement in null reduction from Figure 4.

For the left antenna, the direct path length is line a. The indirect paths are lines b + c.

For the right antenna, the direct path length is line d and the indirect paths are lines e + f. Table 1 lists the difference in path length to both antennas and the phase differential between antennas. This phase differential is important because is describes how effective the diversity system is. If, for example, one antenna is in a null, the phase differential to the second antenna will define the improvement. The results of these calculations are shown in Table 1.

Phase displacement was calculated from the path length difference at 300 MHz. This frequency was chosen as a convenient, typical short range frequency.

Note: a displacement of 1.64 feet represents a half wavelength at 300 MHz. The choice of 300 MHz was simply for convenience. The relative phase shift at any frequency can be calculated for any path length difference.

This model will not calculate actual signal vectors in a real world situation. The purpose of these calculations is to identify trends. Of importance is the differential phase angle between the two antennas as various parameters are varied.

From Figure 4 we can see much phase shift can be used to correct for a null. For example, if one antenna is in a complete null, a 20 degree phase differential will reduce this null to 9 dB. Therefore, it becomes important to know how this phase differential is affected by the geometry of the system. To facilitate this analysis, numerical calculations were made at different distances and displacements.

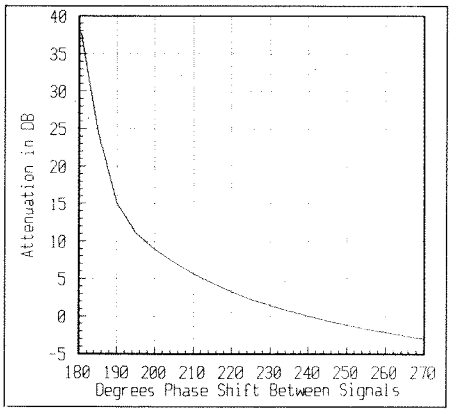


Figure 4. Attenuation due to phase cancellation.

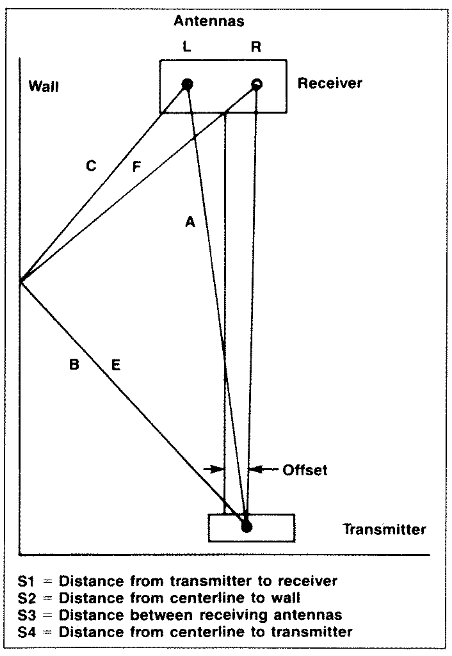


Figure 5. Direct and reflected waves.

Calculations were made at distances of 25, 50 and 100 feet for various distances to the reflecting media as well as antenna displacement and both vertical and horizontal displacement of the transmitter.

We can now make some interesting observations. Some results are intuitively obvious and some may not be:

a) Displacing the transmitter by 1/2 wavelength does not similarly change the phase shift due to path length by 180 degrees. For example, at 50 feet, a horizontal displacement of the transmitter of 1.64 feet resulted only in a 1.8 degree change in the differential phase between antennas.

b) The further the distance, the less position sensitive the system is. For example, a horizontal displacement of 1.64 feet at 25 feet produced a differential of 3.6 degrees as compared to 1.8 degrees for 50 feet.

c) The further the distance, the weaker the relative amplitude of the reflected wave. The chart does not show this calculation, but it should be intuitively obvious that the angle of incidence to the reflecting media decreases as the distance increases. This results in a lower amplitude reflected signal.

d) The further the distance, the smaller the phase differential between both antennas. For example, at 0.5 foot spacing, the phase difference between 25 and 50 feet is 9.54 degrees.

e) The greater the distance between antennas, all other things being equal, the greater the phase difference. For example, at 50 feet the phase difference between 0.5 foot and 1 foot antenna spacing is 10.74 degrees.

How to Achieve Diversity

Basically, diversity requires two or more separate antennas. The question often arises, "How about if we take two separate antennas and connect them together by some harness arrangement?" Any multi-element antenna can be represented as a composite equivalent. It is really still a single antenna, but with different directivity patterns and gain. If this were not so, then any antenna such as a Yagi, log periodic, etc. could serve as a diversity antenna.

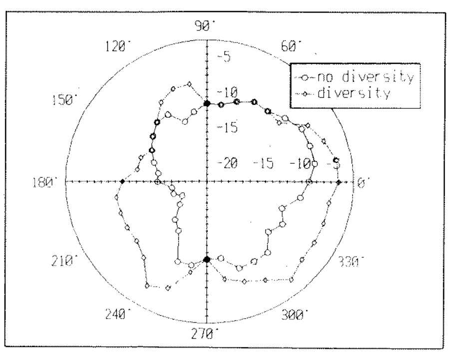


Figure 6. Polar plots for diversity system.

In order to obtain diversity, the antennas must be independent and not specifically interactive. There are various ways of combining antennas. For example, with selection diversity, the signal from each of several (at least 2) antennas are sensed and the best signal is selected. With switched combining, each antenna is selected one at a time and fed to a receiver. If the transmitting signal is redundant (the signal repeating the same message), each antenna has the opportunity to present a signal to the receiver. If one antenna is in a null, the second antenna can produce an adequate signal for detection and processing.

In order to measure how diversity works in the real world, an experiment was conducted where a diversity receiver was placed on the edge of a rotating turntable 4 feet in diameter. The received level for both diversity and a single antenna was measured as the turntable was rotated. The graph in Figure 6 was produced. The results clearly show improvement of 10 dB or more under this configuration was achieved. If the transmitter or receiver was deliberately positioned for a maximum null, greater results would have been obtained.

With Part 15 communication devices, we need every microvolt we can get to obtain sufficient signal margin for good reliability. While other factors involving reliability are not completely in our control, the reduction of signal nulls by diversity processing is an area available to use to take advantage of. ***RF***

References

1. B. Kasmir. "Communications Range and Reliability of Part 15 Devices," *RF Design*, April 1991, pp. 65-68.

About the Author

Bernard Kasmir is Senior RF Design Engineer at Alarm Devices Manufacturing Company (ADEMCO), 165 Eileen Way, Syosset, NY 11791. Tel: (516) 921-6704 ext. 6350. He holds BSEE and MSEE degrees and a P.E. license. Mr. Kasmir has worked with Part 15 devices for ten plus years.

RF Calculation Programs for DOS

By Jouni Verronen
Engineering Consultant

Now that personal computers have been with us for several years, RF programs have begun to appear frequently in publications. It is typical for an engineer to have a collection of programs for various calculations. Most of these programs would be more usable if more consideration had been given to the user interface. This contest entry presents two programs: "RF-Calculations," a spreadsheet-like presentation for some common RF equations, and "T-Line," which performs Smith chart calculations with numerical and graphical display, plus with microstrip calculations.

In BASIC, for example, the easiest way to write a program is to use PRINT and INPUT statements. But the user has to step through a series of inquiries, a time-consuming process. A program with a menu helps, but such techniques can also waste keystrokes. In a menu system, the program steps through an INKEY$ loop or corresponding loop waiting to be branched to the appropriate input, calculation or output. If this can be accomplished using one keystroke, why waste more time?

It is also common that the user returns to a previously used program after having done something else. In a standard DOS environment, this is not possible, but the simple procedure of saving variable values in a data file allows a program to be re-started as it was last used.

The units used (i.e., nH, pF and MHz) can make data entry easier, and can usually be matched to the application. Finally, humans easily read data in columns, and the extra time needed to include this format in a program will save much time in operation.

RF-Calculations Program

This program (screen shown in Figure 1) performs three common RF computations:

"fLCX" includes frequency, inductance, capacitance and reactance in a resonance condition. All can be calculated when any two of these are known. As soon as two new entries are made, the program updates the display with new results.

The "Impedance" calculation makes conversions between equivalent forms — series R_s and X_s, parallel R_p and X_p, and vector magnitude Z and phase angle Θ. Inputs are selected by number, and when any one variable is entered, all are updated.

"$C_s + L_s$" calculates effective C and L values for a series LC circuit at a given frequency, as well as the total reactance. The most common use to check effective capacitance of a capacitor at a

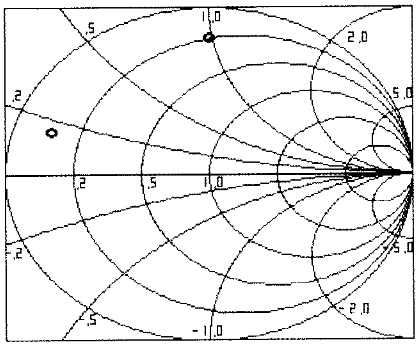
```
T - L I N E

Input values:

1. Zo       :  50.00 ohm
2. s/lambda:  -0.1000
3. R1s      :  10.00 ohm
4. X1s      :  49.00 ohm

5. f        :  145.00 MHz

6. vf       :   0.543
```




```
s =-112.39 mm         =-4424.7 mils

Φ1 = 89.99 deg    Q1 =  4.90     R2s =     5.18 ohm     R2p =   17.06 ohm
Φ2 =161.99 deg    Q2 =  1.52     X2s =     7.84 ohm     X2p =   11.26 ohm

Γ  =  0.817       RL =  1.8 dB   C2s = -139.96 pF       C2p =  -97.50 pF
                                 L2s =     8.61 nH      L2p =   12.36 nH

F1: help   F7: exit
```

Figure 2. Typical screen for the T-Line program.

```
RF-Calculations  1.01  by JV

1. f L C X :            2. Impedance :          3. Cs + Ls :
                                                ------------------
f =  144.00 MHz         1. Rs =    1.00 ohm        f =  833.00 MHz
L =  100.00 nH          2. Xs =    1.00 ohm        Ls =    1.30 nH
C =   12.22 pF          3. Rp =    2.00 ohm        Cs =    3.00 pF
X =   90.48 ohm         4. Xp =    2.00 ohm     -> Xt =  -56.88 ohm
                        5. Z  =    1.41 ohm     -> Lt =  -10.87 nH
                        6. θ  =   45.00 deg     -> Ct =    3.36 pF

Num. to choose   Bar to menu level   F7: exit
```

Figure 1. Screen display for the RF calcuations program.

```
Microstrip Zo and vf

Input values:

1  Er  :    4.50                               units: mm
2  h   :    1.60 mm
3  t   :      30 um

4  w   :    0.25 mm
5  dw  :    0.25 mm
6  N   :       8

 w / mils   w / mm      Zo / ohm      vf        wef /mm
-----------------------------------------------------------
   10        0.25        129.3       0.576       0.30
   20        0.50        107.6       0.570       0.55
   30        0.75         94.3       0.566       0.80
   39        1.00         84.8       0.563       1.05
   49        1.25         77.4       0.560       1.30
   59        1.50         71.4       0.557       1.55
   69        1.75         66.3       0.554       1.80
   79        2.00         62.1       0.551       2.05

Bar: next N   Del: CLS   F7: exit   F9: units   F10: save Zo, vf
```

Figure 3. Display information for the microstrip program.

frequency of interest. The results are indicated by -> to keep them distinct from the inputs. The results are updated when any input is changed.

A SHIFT-PRINTSCREEN will send data on the screen to the printer at any time. All three calculation routines are always displayed, allowing the user to go back and forth between them as desired. When initiated, the program recalls the last entries from earlier use.

T-Line Program

This program contains a calculation of the impedance transformation in a transmission line, along with a display of the input and output impedances on a Smith chart (Figure 2). Input values are line impedance, series source impedance, frequency and velocity factor. The program calculates line lengths, magnitude and phase, series and parallel output impedances and the equivalent C and L values for the reactance. Input and output impedances are plotted on the Smith chart. Each input value (except velocity factor) can be tuned up and down by using the left and right arrow keys, with the results immediately updated.

A sub-program calculates microstrip electrical parameters. From the inputs of dielectric constant, thickness and board height, a series of calculations of impedance and velocity factor are made. The user defines a starting width, the width increment, and the number of widths to display. The program computes parameters for increasing linewidths. A tap on the spacebar brings up the next group with greater widths. Figure 3 is a typical screen showing this feature.

A printed report can be generated as desired. First, F5 prints a report heading with time date. F6 prints the currently displayed information in the program being run, either impedance transformation or the microstrip calculations.

Conclusion

These programs can save considerable time for routine RF calculations, with their simple keystroking and constant updating of the results. Both programs retain the latest information in a datafile, so the program can continue from the same point after an interruption. These concepts can be applied to other programs that engineers write for their own purposes. The programs were written for EGA monitors. For other monitors the QuickBASIC source code should be modified, then compiled for stand-alone operation.

These programs are available on disk from the RF Design Software Service. Source code and EGA/VGA compiled versions are provided. See page 8 for ordering information. **RF**

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1. Steven Nameroff, *QuickBASIC: The Complete Reference*, Osborne McGraw-Hill, 1989.
2. Robert A. Chipman, *Theory and Problems of Transmission Lines, Shaum's Outline Series*, McGraw-Hill, 1968.
3. D.R. Hertling, R.K. Feeney, "Microstrip Analysis and Design for Various Substrate Materials," *RF Design*, June 1988.
4. Thomas V. Cefalo, Jr., "Microstrip CAD Program," *RF Design*, October 1990.
5. H.A. Atwater, "Simplified Design Equations for Microstrip Line Parameters," *Microwave Journal*, November 1989, errata February 1990.

About the Author

Jouni Verronen is an independent consultant, specializing in RF and analog design. His most recent design work has included various RF units for the Scandinavian radiotelephone industry. He holds a M.Sc. in electrical engineering. Mr. Verronen can be reached at Kannokkotie 13, 90550, Oulu, Finland, telephone 358 81 561790.

RF Expo East Technical Program Covers Current RF Applications

TUESDAY, OCTOBER 29, 8:30-11:30 a.m.

Session A-1: Using CAD in RF Engineering

State of the Art Nonlinear CAD for Microwave/RF
J. Gerber, L. Mah and C. Chang, Compact Software
A review of the various approaches to nonlinear CAD are presented, covering pure time domain to pure frequency domain techniques.

New Nonlinear Noise Model for MESFETS Including MM-Wave Applications
Raymond S. Pengelly and Ulrich L. Rohde, Compact Software
This paper shows a linearized time-domain approach for calculating the dynamic elements of the hybrid Pi, MESFET model. A novel enhancement to the basic equivalent circuit guarantees its use into the MM-wave area.

Design Desensitization
T. Zhang and Murat Eron, Compact Software
Methods for estimating and maximizing design yields of mass produced circuits can also be used to reduce the sensitivity of circuits to parameter variations and uncertainties.

Microwave/RF System Simulation
Raymond S. Pengelly and Ross G. Hicks, Compact Software
This paper will refer specifically to two available simulators, Microwave Success from Compact Software and OmniSys from EEsof. After a discussion of requirements for and computations available from such simulators, two design examples are given.

E-M Theory-Based Simulations of Passive Microstrip RF Components on Single and Multiple Metallization Layers
A. Hill, J. Burke and K. Kottapalli, Compact Software
It will be demonstrated that E-M theory-based simulation tools have become practical and friendly enough to exploit unique passive structures in the design of high performance circuits.

Session A-2: RF System Performance

A Unified Look at Spurious Performance of Multiple Conversion Receiving and Transmitting Systems
Dick Webb, Webb Laboratories
While spurious behavior of mixers is generally well-understood, system architectures, especially those involving multiple frequency conversions, are often defined without full anticipation of undesired tuned and coincident responses. A nomenclature is proposed for quick identification of spurious product type and origin.

Specifying Local Oscillator Phase Noise Performance: How Good is Good Enough?
Robert Gilmore, Qualcomm
Under- or over-specifying local oscillator phase noise requirements can result in unsatisfactory performance, or unnecessarily high cost. This paper examines the factors to be considered in determining the required performance of a local oscillator.

Receiving Subsystem RF/IF Design Methodology
John D. Summerville, AIL Systems
A systematic approach to microwave multioctave receiving subsystem design and implementation is presented. The major factors that must be considered in selecting a cost-effective, reproducible RF input to IF output are addressed.

Session A-3: Design & Manufacturing

RS-232 Communication for Turn-Key Test Stations
Warren Walls, Erbtec Engineering
Many PC-based automated test stations use a combination of GPIB and RS232 communication formats to control test equipment and interface with the device under test. The different formats of RS232 communication hardware were investigated and a couple of C libraries were generated in order to produce a reliable test station.

Chemical Vapor Deposited Diamond Heat Carriers for Cooling High Temperature Electronic Components
Thomas N. Tuma, U.S. Army CECOM Center for Signals Warfare
This paper describes a plasma-enhanced chemical vapor deposition techniques for creation of diamond films. The improved thermal conductivity and low electrical conductivity of diamond makes this process attractive for heat-generating semiconductors.

Transceiver Characteristics and Their Impact on Battery Life Performance in Land Mobile and Cellular Portable Radios
Masood Ghadaksaz, GTE Laboratories
This paper presents a method of characterizing battery life performance in terms of RF transceiver parameters, giving measured and analytical results of the studies conducted.

Session A-4: Test and Measurement

Optimize Mixer Performance Through Swept-Frequency and Power Characterization
Barry Brown and Joel Dunsmore, Hewlett-Packard Co.
The mixer is a key element in frequency conversion systems. This paper discusses the basics of non-linear mixer behavior, and presents measurement techniques to view this behavior directly using a vector network analyzer.

Testing Dual Mode North American Cellular, Japan Digital Cellular Transceivers
Dave Hoover, Hewlett-Packard Co.

A method for generating and testing accuracy of PI/4 DQPSK modulated signals is presented, along with a test system for the North American Digital Cellular system.

Power Triode Tube Curve Tracer
Lee Erb and Warren Walls, Erbtec Engineering
Power triodes remain an economical choice for high power RF systems. This paper presents a general purpose curve tracer for incoming test and engineering characterization of power triodes.

TUESDAY, OCTOBER 29, 1:30-3:30 p.m.

Session B-1: Filter Design Techniques

Filters With Improved Delay Characteristics
William B. Lurie, Consultant
Amplitude characteristics are no longer sufficient for defining filter performance. This paper presents a variety of methods for predicting or controlling phase or delay parameters in filters.

Design of Filters with Unsymmetrical Stopbands
William B. Lurie, Consultant
The most common filter design techniques result in filters with symmetrical stopbands. For some applications, unsymmetrical stopbands are desirable. A relatively simple technique for designing filters with desired stopband shape is presented.

Approximation of Filters with Shaped Passbands
George Szentirmai, DGS Associates
An optimization procedure is described that was developed for the approximation of filter transfer functions to provide arbitrary passband loss (and possibly delay) shapes. The method is implemented on an interactive program running on a personal computer.

Session B-2: Oscillators

The MCXO, Characteristics and Applications
Brian Rose, Q-Tech
The new aspects of the design of a Microprocessor Controlled Crystal Oscillator (MCXO) are presented, including crystal self-temperature sensing and external compensation.

Defining VCO Tuning Linearity
Allan Coon, RF Monolithics
Tuning linearity of a VCO is often poorly defined, leading to misunderstandings. The various definitions of VCO linearity are presented and defined in sufficient detail to be unambiguous.

Microwave Oscillators
Robert Weber, Iowa State University

Session B-3: RF Power

Class-E Power Amplifier Output Power, Efficiency, and Output Impedance vs. Loaded Q and Component Parasitic Losses
Nathan O. Sokal, Istvan Novak and Laszlo Drimusz, Design Automation
Design equations are presented to calculate the output power, efficiency and output impedance of nominally tuned Class E amplifiers.

Design and Performance of High Power Pin Diode T/R Switches for VHF and UHF Land Mobile Voice and Data Communications Systems
Masood Ghadaksaz, GTE Laboratories
This paper describes a PIN diode switch that replaces an electromechanical design used in a 110 watt land mobile radio used for data communications.

Directions and Developments in Very High Power RF at LAMPF
Richard Cliff, Mark Parsons and Harlan Ward Harris, Los Alamos National Laboratory
The RF power sections of the LAMPF 800 MEV linear accelerator are described, including four 2.5 megawatt, 201.25 MHz sections, and forty four 805 MHz, 1.2 megawatt sections.

Session B-4: Special Open Session -- 1991 Contest Winners

Low Frequency Circulator/Isolator Uses No Ferrite or Magnet
Charles Wenzel, Wenzel Associates
An active structure using high-speed current-feedback operational amplifiers performs the same functions as the ferrite or magnet-type circulators common at microwave frequencies.

A Comprehensive Filter Design Program
Michael Ellis, U.S. Army Corps of Engineers
This paper discusses the theoretical basis and software writing techniques used in the development of a major filter synthesis and analysis program.

WEDNESDAY, OCTOBER 30, 8:30-11:30 a.m.

Session C-1: Low Noise Amplifier Tutorial

Design of Low Noise RF and Microwave Amplifiers
Dick Webb, Webb Laboratories
A comprehensive tutorial beginning with a discussion of system noise contributions, proceeding to RF and microwave small-signal amplifier design considerations of gain, VSWR, stability and noise performance. Theory and practice of noise measurement is included, as well.

Session C-2: Application of MMICs

Microwave EW System Enhancements Using MMIC Technology
John D. Summerville, AIL Systems
The small, reliable and cost-effective designs required by the military market can be met with GaAs MMIC technology. This paper discusses how both MIMIC program results and commercial GaAs chips can be utilized in EW systems.

Effective MMIC Testing Strategies for Engineers
Jesse D. Sheinwald, AIL Systems
Testing MMICs can be done at the chip level and substrate (carrier) level. The conditions under which each of these must be done are described, as well as the operational requirements of the necessary test stations.

Silicon MMIC Amplifier Hits the 20/20 Gain/Power (dBm) Mark at UHF
David M. Osika and Ronald Green, SGS-Thomson Microelectronics
This paper introduces a medium power 50 ohm silicon MMIC, producing +20 dBm power output with 20 dB gain, using a 9.0 VDC supply.

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Session C-3: Receivers

Distribution of Gain and Selectivity in Receivers
W.J. Vogel, MATE Electronics
Optimum gain distribution and selectivity in receiver circuitry is investigated in this paper, with considerations for noise, linearity and intermodulation. Practical design rules for receivers are presented.

Tunable Notch Filter for Interference Rejections
Eric D. Adler and Edward Viveiros, Harry Diamond Laboratories
Wideband receiving systems are constantly plagued by the effects of overpowering narrowband interferers. This paper presents the design of a fixed notch filter with additional frequency tuning hardware that is capable of reducing such interfering signals.

Spurious Analysis of Superhetrodyne Receivers and Frequency Synthesizers
Sherman Vincent, Raytheon Company
Determining optimum system architecture can be time consuming. This paper presents spurious signal considerations, and a novel computer program to help speed the analysis of a typical receiver.

Session C-4: New RF Applications I

RF Modem Design for Indoor Radio
Gregory S. Rawlins, Signal Technologies
This paper covers several system concerns for indoor data links, including a case study for a direct sequence spread spectrum RF modem operating in a CDMA/TDMA mode.

Survey of Component Technologies for 900, 2400 and 5700 MHz Unlicensed Spread Spectrum Transceivers
Al Ward, Avantek
This paper surveys the device technologies available on the market today for use in unlicensed spread spectrum transceivers in UHF and microwave bands. Comparisons of performance, frequency and cost are presented, along with specific circuit examples.

Integrated RF Interfaces for Rural Central Offices
M.V. Pitke
RF interfaces for rural central offices can provide a cost-effective solution to rural communications. Implementation of such a system is discussed in this paper.

WEDNESDAY, OCTOBER 30, 1:30-4:30 p.m.

Session D-1: Power Amplifier Tutorial

Classes of RF Power Amplifiers A Through S, How They Operate, and When to Use Each
Nathan O. Sokal, Istvan Novak and John E. Donahue, Design Automation
With at least ten lettered classes of RF power amplifiers, confusion is an common result. This tutorial presents a review of the various classes of power amplifier and the behavior of the devices as switches, current sources, or as a combination of both.

Session D-2: Spread Spectrum/Mobile Radio

Upper Limits of a Phase Multiplexed Correlator in a Multiple Access Spread Spectrum System
Madjid A. Belkerdid and Glen G. Koller, University of Central Florida
The relatively new concept of Phase Modulated Correlation (PMC) is applied to the CDMA DSSS environment to determine coarse acquisition advantages. Simulation results graphically illustrate performance trends.

Mobile Data Packet Networks
John Kilpatrick, James L. Troe, RAM Mobile Data
Mobile data is here, and this paper presents an overview of one option available to users, the Mobitex network, and includes some details of its over-the-air protocols.

The Development of an 8 kbps GMSK-Like Modem for Mobitex
D. Peter Noel, George Dew, Sasi Kumar,
Marie Fiala-Timlin and Karl Mann Presentation of the design and development of a modem for the 1200 bps/8000 bps land mobile data communications system commonly known as Mobitex.

Session D-3: New RF Applications II

Making It In The USA
Albert Helfrick, Consulting Engineer
This paper describes the design of a high-volume consumer RF product for manufacture in the United States. De-

sign techniques and experiences derived from the design effort are presented.

A Versatile UHF Data/Telemetry FM Transmitter
Harry J. Swanson, Motorola Bipolar Analog IC Division
A UHF FM transmitter featuring the MC13175 is presented, demonstrating the use of the ICs divide-by-8 or divide-by-32 prescaled PLL configuration.

Session D-4: CDMA Spread Spectrum

Spread Spectrum Cellular Communications: Benchmarks for Cost, Power and Spectral Performance
Steve Morley, Qualcomm

Field Test Experiments Using Broadband Code Division Multiple Access
D. Schilling, L. Milstein, R. Pickholtz, F. Bruno, E. Kanterakis, W. Biederman, D. Fishman, D. Salerno, City University of New York

An Adaptive Technique for Improving Spread Spectrum Interference Rejection
John Doherty, Iowa State University

THURSDAY, OCTOBER 31, 8:30-11:30 a.m.

Session E-1: Microwave and Military Applications

Design and Performance of a Novel Broadband Combiner/Impedance Transformer Using 1/16 Wavelength Microstrip Transmission Lines
M. Abdollahian and R. Gage, GTE Laboratories
Combining high power amplifiers is usually accomplished using multiple stages of 1/4 wavelength sections and isolation resistors. This paper presents a four-stage, 1/16 wavelength per stage combiner that can also achieve necessary impedance transformation.

Simulation of Millimeter-Range High-Power CW Frequency Doubling Using Multi-Junction Varactors
Stephen Bren and Numan S. Dogan, Washington State University
Improved epitaxial growth techniques have allowed single-crystal growth of multiple p-n junctions with high precision. Theoretical performances and test results for two diodes are presented.

Own Jamming Excision Program
James J. Yolda, Jr. and Michael Russell, U.S Army CECOM Center for Signals Warfare
The Army's development of a continuous listen-while-jam system is described, along with presentation of test data demonstrating the system's achievement of more than 150 dB jammer suppression.

Session E-2: Antennas and Electromagnetics

Studies of the Cross Antenna
R. P. Haviland, Mini Lab Instruments
The cross antenna developed by Antoine G. Roedere is an alternative for radiating circularly polarized signals. The radiation patterns and driving impedances for this type of antenna are presented.

RF Propagation Anomalies for Indoor Radio
Gregory S. Rawlins, Signal Technologies
Various propagation hazards present in indoor communications are presented, including the results of experiments performed for a system application.

A Simple Expression for the Mutual Inductance of a Wire Current Source and a Non-Coplanar, Parallel, Rectangular Loop
Byron D. Berman
A simple expression for the low frequency mutual inductance between an infinite straight wire and a rectangular loop is derived by geometrical means and verified empirically by indirect measurement. A known formula for this configuration is then derived as a special case.

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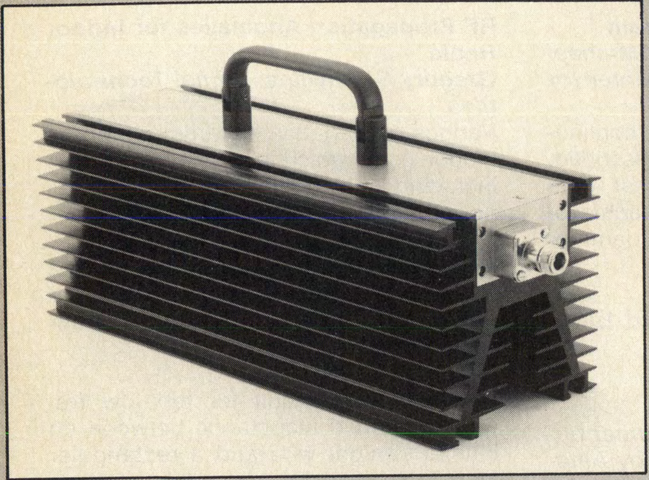

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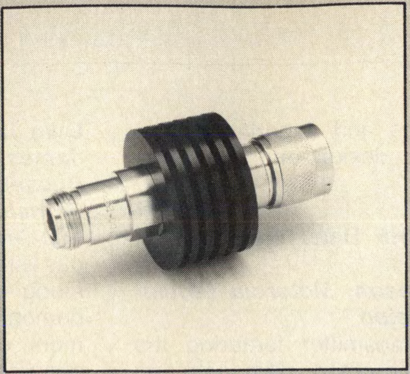
Attenuation
3 thru 60 dB any 1 dB increment



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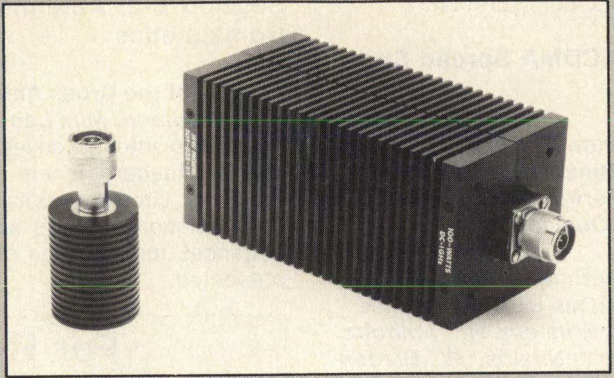

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1.0:1	2.5:1
1.1:1	3:1
1.2:1	5:1
1.5:1	

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Programmable Attenuators

50P-076
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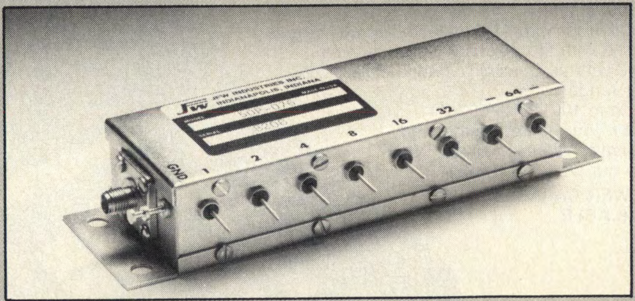
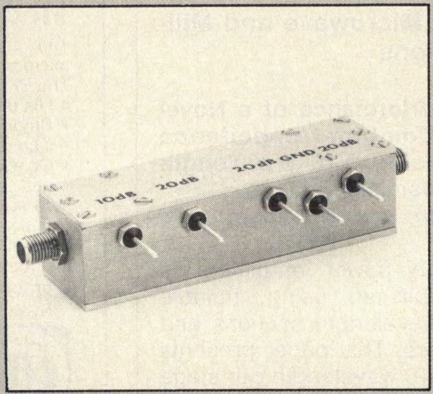
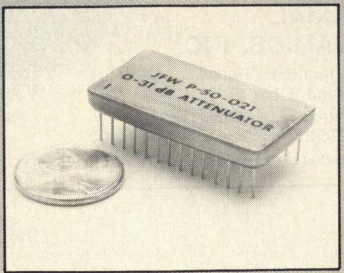
Attenuation Range
0-127 dB in 1 dB steps

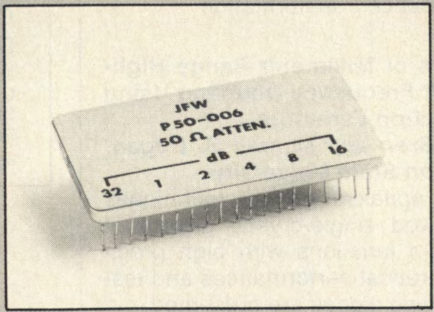




50P-766
Frequency Range
DC-5 GHz
Attenuation Range
0-70 dB in 10 dB steps

P-50-021
Frequency Range
50-250 MHz
Attenuation Range
0-31 dB in 1 dB steps





P50-006
Frequency Range
10-600 MHz
Attenuation Range
0-63 dB in 1dB step

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Diversity Drives Signal Processing and Control Components

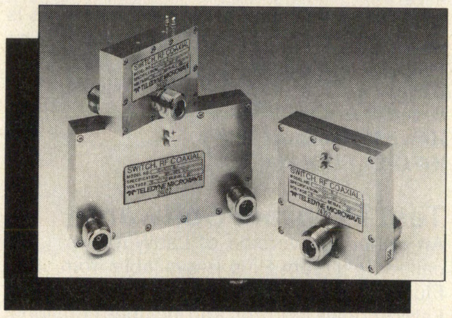
By Liane G. Pomfret
Associate Editor

The control component market is very much customer driven, far more so than it was ten years ago. The demand for these products stems from the development of new technologies and the upgrading of present applications. It's not so much that the components themselves are evolving, but rather that the market is evolving. Changes such as miniaturization and surface mount are occurring all over the industry and are not just limited to control devices.

As we've seen in the past few months, the RF market is holding its own despite a shaky economy. In some cases, such as communications, the picture is even brighter. Each manufacturer has a different story depending on their market focus and their marketing policy. For those who supply primarily into the military market, there are some interesting changes occurring. Some companies, such as Daico, attribute their increase in business to "some new products and also to some major programs," says president Bill Grunau. Other companies are finding it more profitable to move to the commercial sector in search of business. Blayde Kennedy of Alan Industries noted that his company was pursuing such an avenue.

While many companies are refocusing their efforts in the commercial sector, it doesn't necessarily mean they're changing their product line or quality standards. Indeed, an important issue in today's market is product quality and reliability. For companies who previously focused on supplying to the military market, the switch to high reliability commercial parts has been relatively easy. The one limiting factor in switching from military to commercial is the differences in pricing. Military parts tend to be higher priced to compensate for certification and testing, while commercial parts are usually lower cost. If the military suppliers can manage to lower prices while keeping quality close to mil-spec then they should have no problem breaking into the commercial sector, as long as they are careful about their marketing goals.

The trend towards higher quality, high volume commercial parts is no accident. Components for mobile phones, PCNs, portable handsets and other "personal communicators" must be able to withstand a wide range of environmental and performance conditions. Consequently, there has been a push by the manufacturers to have their vendors supply parts that are reliable and low cost. As Dr. John Howard, executive vice president



of Microwave Research and Development explains, "Customers are shopping around, they know the prices." At the same time, they are also looking at availability and quality. James Penny, Chief Engineer at MicroSignals states, "Customers are in a hurry, they want everything yesterday and 100 percent right the first time. For some, getting to the market first is more important than cost. We can always engineer the cost later." Tight vendor specifications are becoming increasingly common according to Carrie Glover, sales manager at JFW, "Our major customers have very tight vendor ratings with regards to quality, on-time delivery, and customer service." Tony Ramsden, vice president of sales and marketing for Merrimac agrees, "Customers are looking for price versus quality and they're also looking for engineering help." Quality control is an important issue especially with the emergence of new technologies.

There will always be a traditional market for signal processing components or circuits — test equipment, radar, TV, satellites, missiles and so forth. However, in the past few years some new technologies have emerged which have proved to be excellent markets for control devices. The medical market is emerging with new technologies constantly. Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) are two of the most common applications and more are appearing daily. Blood plasma analysis and diathermy are two areas that Sage Laboratories is involved in. They're also looking to find other areas within the medical sector according to Peter Alfano, marketing coordinator for Sage Laboratories. Communications has also grown tremendously. Cellular, mobile, PCNs, and wireless LANs are just some of the areas where demand is especially high. The traditional markets have also managed to hold their own. Troy Rodriguez, vice president at Sierra Microwave Technology, notes that a lot of their business is "in the broad bandwidth simultaneous coverage. People buying those products would be in broadband receivers, ELINT, radar warning receivers, broadband jammers and so forth." With some of the larger companies, business ranges across the board "From missiles to cellular," says Rich Levitsky, senior engineer for modular components at Avantek.

Control devices cover a large number of components — modulators, phase shifters, switches, attenuators, amplifiers, and mixers. Applications are just as diverse and range from traditional RF to experimental RF. It's a tougher market, but the manufacturers represent classic examples of adapting and staying competitive. **RF**

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RF software

Materials Measurement Package

Wiltron has a new materials measurement package for its Model 360 Vector Network Analyzer system. The package includes a MS-DOS computer/controller with software and a GPIB interface fully installed. Included are manuals and a one year warranty. The price is $12,000.
Wiltron
INFO/CARD #215

Device Model Program

Meta-Software has developed a software program called MetaTestchip for layout and device characterization services. The program is used to facilitate the generation of model parameters for GaAs ICs. It can also be developed for other process technologies such as CMOS, BiCMOS and Bipolar/ECL.
Meta-Software, Inc.
INFO/CARD #214

HP Root Model

The recently announced HP Root Model program produces data that is directly usable in the HP Microwave Design System. The software provides large-signal, nonlinear simulations that are based on processed measured data rather than coefficients or parameters. No optimization or extraction process is required to obtain the model data. The software is available as part of the Microwave Design System and delivery is estimated at 8 weeks ARO.
Hewlett-Packard
INFO/CARD #213

Test Program Software

An enhanced version of LabWindows® 2.0 called TestTeam Plus is available from John Fluke. The software includes all standard LabWindows features and includes additional functions such as an automatic configuration program and framework applications for immediate system startup. Instrument drivers are also included for products such as oscilloscopes, data acquisition instruments, generators and more. Price is $1095.
John Fluke Manufacturing Co., Inc.
INFO/CARD #212

DSP Design Tool Sets

Analog Devices has released two DSP software design tool sets one for fixed-point and one for floating point DSP families. The floating point tools include an assembler, linker, assembly library, librarian, simulator and PROM splitter. Single user price is $995. The fixed point tools include an assembler, linker, simulators, PROM splitter and a C compiler package as an option. The fixed point tool set is available for PCs, Sun 3/4 workstations, and DEC VAX systems. Prices are $795, $1295 and $5995 respectively.
Analog Devices, Inc.
INFO/CARD #211

Computer Simulation Service

TEMAG is now offering a high frequency computer simulation service bureau. Using CAD and EM simulation software developed by Hewlett Packard and Ansoft, TEMAG can handle a wide range of microwave and other high frequency applications. They can handle simulation of both planar and three-dimensional structures as well as electromagnetic fields within a structure.
TEMAG Corporation
INFO/CARD #210

Translation Software for DECs

Artwork Conversion's line of CAD translators and postprocessors has been ported to Digital Equipment Corporation's DECstation 5000. The translators include bidirectional ones between Calma's GDSII stream, Gerber photoplot code, AutoCAD's DXF format and IGES. The translators are also available on PC, Sun, HP and Apollo platforms.
Artwork Conversion Software, Inc.
INFO/CARD #209

SPICE Cookbook

A reference book and floppy disk from Intusoft detail more than 100 examples of analog circuit simulations. "A Spice Cookbook" assists users in modeling and simulating a wide variety of circuits. A complete technical overview, including related equations, background information, circuit schematic, associated IsSpice netlist and output graphs are provided for each circuit example. The disk contains all the schematics, circuit netlists and SPICE models included in the book. Price is $50.
Intusoft
INFO/CARD #208

Noise Parameter Test System

A device characterization and advanced measurement system for microwave semiconductor device design is available from Cascade Microtech on IBM PC/AT compatibles and the HP 9000 platforms. Some features include 2-18 or 2-26.5 GHz broadband noise parameter measurement, choice of noise parameter or corrected 50 ohm noise measurements with data extrapolation and user selectable smoothing algorithms, model extraction, LRRM calibration software utility and more.
Cascade Microtech
INFO/CARD #207

RF literature

GaAs FET Parameter Files

A data disk containing S-parameter and noise parameter text files is available for MwT's line of GaAs FET devices. The files are compatible with most commonly used microwave computer-aided design software. Also on the disk is a library of hybrid gain modules and a program which allows amplifier designers to cascade a selection of modules and predict broadband results at three temperatures.
MicroWave Technology
INFO/CARD #200

Soft Ferrite Catalog

A revised soft ferrite product catalog that covers a range of soft ferrite materials, components and accessories is now available. New products featured include: SM Beads, PC Beads and Composite Toroids. The catalog also has several tutorial articles, magnetic design formulas and other soft ferrite references.
Fair-Rite Products Corp.
INFO/CARD #199

Ceramic Filters for Telecommunications

A new 28-page catalog, describing Murata-Erie's line of piezo-electric ceramic filters and discriminators is available. Filters for 455 MHz, 3.8-4.5 MHz and 10.7 MHz as well as discriminators for 4.5-6.5 MHz and 10.7 MHz, and traps and signal detectors are described in the catalog. Filters for SMT applications as described as well.
Murata-Erie North America
INFO/CARD #198

Guide to Specifying VCOs

M/A-COM Semiconductor is offering a guide to specifying their new line of voltage controlled oscillators. The oscillators are available in TO-8 surface mount packages and cover a frequency range from 25 MHz to 10 GHz.
M/A-COM Semiconductor Division
INFO/CARD #197

Vacuum Components Catalog

A 40th anniversary vacuum components catalog is available from Ceramaseal. The catalog illustrates hundreds of ceramic-metal sealed products including feedthrus, connectors, thermocouples, cables, viewports and related hardware. Some new products include 8- and 10-conductor versions of a push-pull double-ended instrumentation connector; 37-conductor high-density connectors and an array of new contacts.
Ceramaseal
INFO/CARD #196

Quartz Crystal Components

A wide range of passive components is featured in a new catalog from M-tron. Products include quartz crystals, hybrid clock oscillators and custom hybrids for requirements in industrial, commercial, and military applications. Illustrations and engineering data sheets are also included.
M-tron Industries, Inc.
INFO/CARD #195

Shielded Coil Forms

Lodestone Pacific is now offering a line of shielded coil forms formerly offered by Micrometals. The catalog includes Q curves, application and design information as well as product descriptions. They are also offering a catalog containing component and toroid mounts as well.
Lodestone Pacific
INFO/CARD #194

Complete Catalog on Disk

MF Electronics has released their complete catalog available on disk. The disk describes their complete line of crystal clock oscillators and includes diagrams, waveforms, charts and selection by attribute. The disk is a 360 K floppy and can run on any IBM compatible machine. Multiple copies can be made of the catalog or it can be copied to the hard drive.
MF Electronics Corp.
INFO/CARD #193

Cable Assemblies

Catalog 82158 provides information on custom coaxial ribbon cable assemblies and receptacle kits, Pro-G receptacle cable assemblies, and accessory hardware. Ordering forms and the associated proposal are also included. Ribbon cable assemblies are available in standard and custom lengths and low profile versions are also available.
AMP Incorporated
INFO/CARD #192

Polycarbonate Capacitor Brochure

A line of subminiature hermetically sealed polycarbonate capacitors is described in a 4-page technical bulletin from Electronic Concepts. Applications are described including suitability for military and sophisticated industrial/commercial applications, as are special operating characteristics such as self-healing properties, no piezoelectric effect and non-frequency and non-voltage sensitivity.
Electronic Concepts, Inc.
INFO/CARD #191

Discrete Semiconductor Disks

Philips Semiconductors has released an updated version of their discrete semiconductor data disks. A quick-search features allows the user to locate specific type numbers, obtain competitor information, and order products. The disks contain information on more than 3600 type numbers in the discrete semiconductor range.
Philips Semiconductors
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RF design

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