rf design

engineering principles and practices

March 1989

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Industry Insight
RF Power Transistors

Plus
More Design Software

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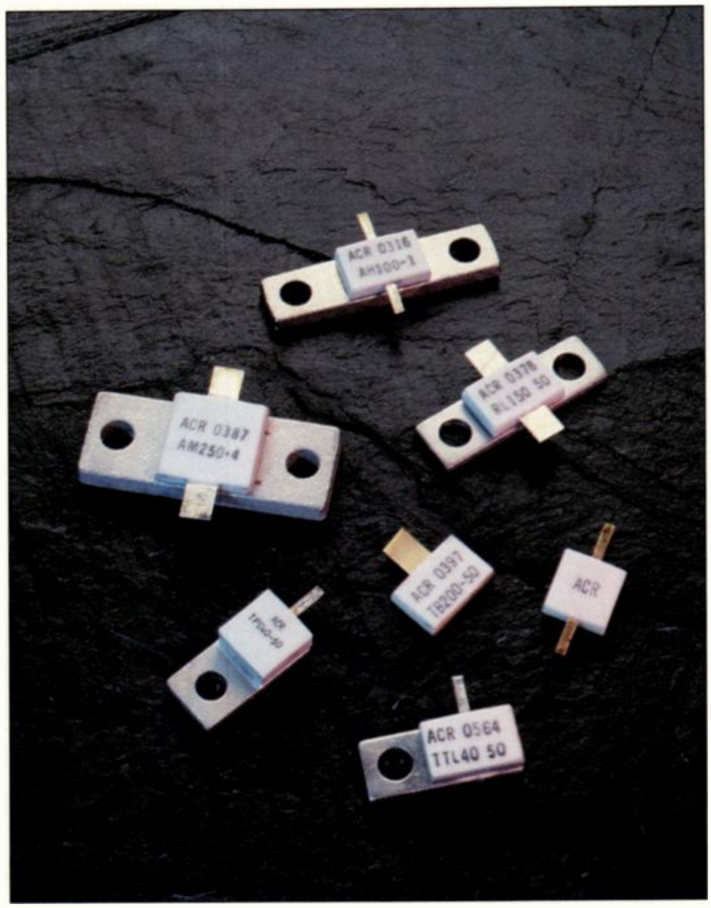

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INFO/CARD 3

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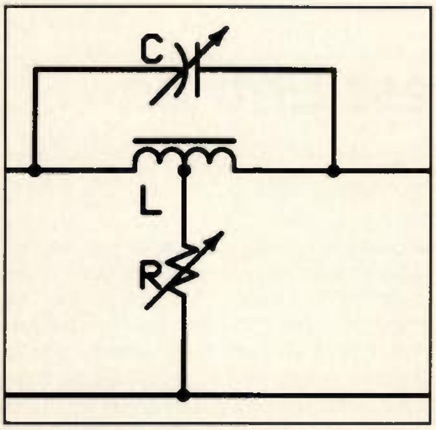
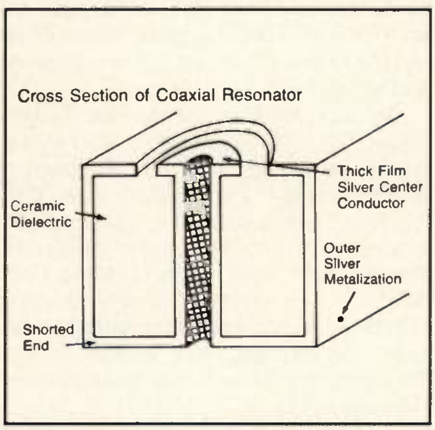
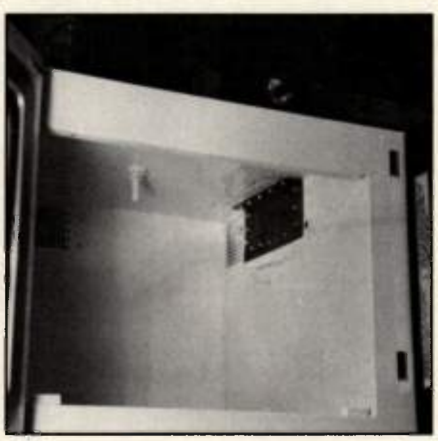
March 1989



Page 27 — Tunable Delay Equalizer



Page 35 — Ceramic Block Filters



Page 48 — Amateur TV Transmitter

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rf editorial

Get Those Contest Entries Finished

By Gary A. Breed
Editor

The last day of March is the deadline for entries in the Fourth Annual RF Design Awards Contest. It's time to buckle down and put the finishing touches on that great idea of yours. (Complete information is on pp. 14-15.)

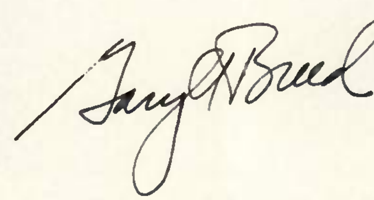
My words of encouragement are the same as I've used for every past contest. We don't expect major technological breakthroughs, just good ideas that save time, save money, or just work better. Our previous winning designs haven't been earthshaking developments; they have primarily been interesting adaptations of existing designs, accompanied by clear descriptions and performance data.

We get occasional letters wondering why one design or another was judged a winner, since it really wasn't a novel idea. To those who wonder, the answer is simple — there aren't many truly novel ideas in the world. However, there are lots of new ways to design, construct, or apply an idea that may have been around for awhile. That is why originality is only one of three different criteria for judging. We put equal weight on the others, *engineering* and *documentation.*

We insist that our winning designs be created in reponse to a need. That's what engineering is — a problem-solving profession. "How do we turn an idea into something that works?" is the ongoing question that must be addressed. And although many engineers hate the time-consuming task of recording the results of their work, we all know how important documentation is. Without it, the same problems will keep returning. Often, the extra work needed to completely describe one design exposes an unexpected performance characteristic that solves an entirely different design problem.

Be assured that the contest judges understand RF engineering. Joining me again this year are our Consulting Editors, Andy Przedpelski and Bob Zavrel. Their experience ranges from advanced military systems to integrated circuits, with solid uncerstanding from RF basics to advanced theory. Joining the team is another experienced engineer, Al Helfrick, last year's winner. Together, we have 80 years or more of RF experience.

We'd like to think that our contest is a microcosm of the entire RF engineering profession. All of you are out there turning ideas into functioning hardware. Along the way, every one of you finds a new way to solve an old problem, or an old idea that can be applied to a new problem. These are the ideas we want you to send us. I'll be watching the mailbox.



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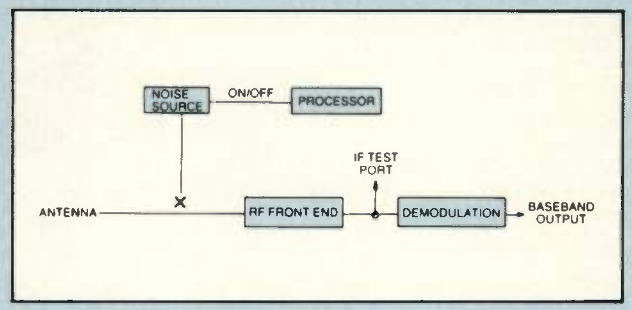

Noise sources can also be used in setting minimum detectable signal level, establishing dynamic range, or setting a reference for go/no-go testing. Frequency response can be measured at a test port prior to the demodulation circuitry. Since noise sources provide constant energy across the receiver bandwidth, frequency response can be measured instantaneously — without tuning an input signal.

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INFO/CARD 30

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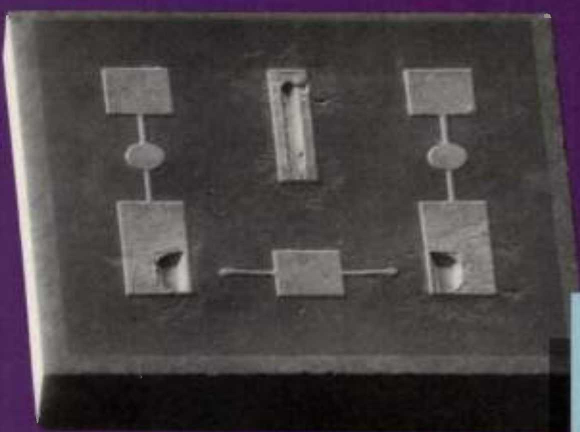

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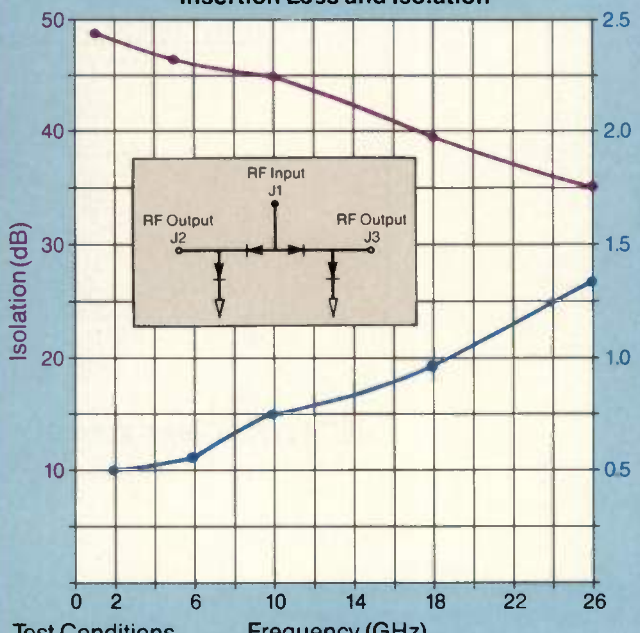

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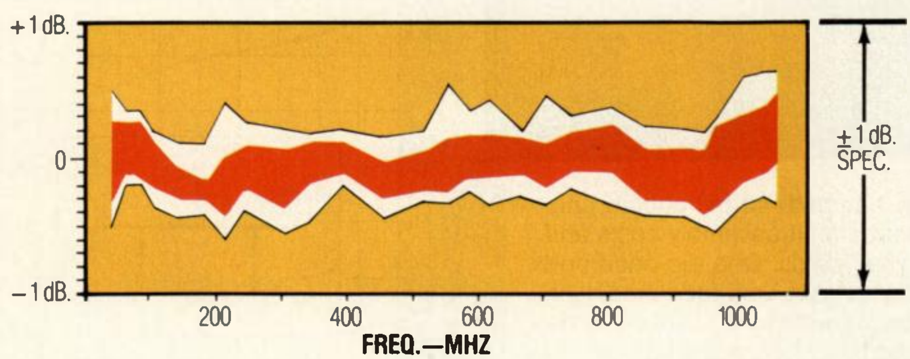

6060B typical level accuracy vs. frequency at −127 dBm.

Sample: 38 units. Solid line: worst case. Shaded: Typical (75%).

Getting the performance you expect from your instruments can sometimes be a pain. But not when it comes to the Fluke 6060B RF signal generator. It delivers more performance than you thought you paid for, even at the extremes.

On paper, most general purpose RF signal generators look pretty much the same.

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Take the Fluke 6060B. Its specified amplitude level accuracy in a typical working environment is ±1 dB. Nothing surprising there. Except that this performance is available over the entire dynamic range of −127 dBm to +13 dBm. What's more, as the chart above shows, typical performance is much better: 2:1 or more. Even at −127 dBm. And in the over range areas to +16 dBm and −140 dBm, the 6060B typically stays within its ±1 dB specification.

That means the devices you test can be specified and measured more precisely with increased confidence. Your test yields go up. And you can process more workload with a single signal generator.

What is the key to this extra margin of performance? Attention to the details. Software compensation techniques. And outstanding linearity and repeatability over the 6060B's amplitude and frequency range.

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Kaman's SiO_2 cable can tolerate greater tensile and torque loads and has superior resistance to impact damage and corrosive breakdown. For critical space applications, no harmful outgassing effects are incurred.

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rf letters

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

Re-Discovery is Important

Editor:

I am writing regarding Harvey Morgan's article "An Emitter Follower Oscillator" (Oct 1988, *RF Design*) and Nathan Sokal's letter (Dec 1988, *RF Design*). As a mature (aw, what the hell — old) analog circuit designer, I see from time to time some clever ideas that were considered many years ago. More than once in my career I have found that the basics of an "original" idea were previously presented. It was much easier 30 years ago to find out whether a circuit had been covered. I had only one circuit design back then (1961), but today several hundred fill my bookcases.

Mr. Sokal points out, "...a recurring problem in our industry — past knowledge is 'lost' and previously available information is re-created." Sad, but true. However, today's circuit designers should be indebted to all the Harvey Morgans for such re-creations. Without them some clever ideas might lie wasted in dusty old books.

Like many analog circuit designers, I have found that emitter followers can (and do) oscillate — with a vengeance. The two references below solved any problem.

1. M.V. Joyce and K.H. Clark, *Transistor Circuit Analysis*, Addison-Wesley, 1961, pp. 264-269.
2. P.J. Beneteau, *Stable Wideband Emitter Follow*, Fairchild Application Data, APP-41, Sept. 1961.

Richard Smith Hughes
U.S. Naval Weapons Center
China Lake, California

Little Computers Aren't Just for Games

Editor:

I have always enjoyed *RF Design*, especially since it occasionally includes submitted programs for my "obsolete" Commodore 64. Herewith submitted is a simple, yet useful, C64/128/Vic20 program (Figure 1) I recently wrote which calculates dB and power levels for those of us still lacking scientific calculators.

I work full time for Los Alamos National Laboratory and operate a part-time mail order business making and marketing 12 volt power supplies and packet radio modems for the C64 computer.

Jim Devenport
DEVCOM
Los Alamos, New Mexico

Correction

The following companies should be added to the listing provided in the *RF Design 1988 Directory* (Dec. 1988):

1. Innovative Frequency Control Products Inc.
   P.O. Box 300
   Plainfield, PA 17081
   (717) 258-5425
   quartz crystals and resonators
2. Power Systems Technology Inc.
   63 Oser Avenue
   Hauppauge, NY 11788
   (516) 435-8597
   power amplifiers

```
10  REM THIS IS A POWER/DB CALCULATOR PROGRAM WRITTEN BY WB5AOX 12/88.
20  REM ENTER POWER IN WATTS AND DB'S IN DECIMAL FORMAT.
21  PRINT"SOLVING FOR (P)WR OR (D)B OR (S)TOP?"
24  GETP$:IFP$="D"THEN100
27  IFP$="P"THEN30
28  IFP$="S"THENSTOP
29  GOTO24
30  PRINT"SOLVING FOR PWR (I)NCREASE OR (D)ECREASE?"
35  GETC$:IFC$="D"THEN200
37  IFC$="I"THEN39
38  GOTO35
39  PRINT"ENTER MEASURED POWER LEVEL":INPUTP
40  PRINT"ENTER TOTAL ATTENUATION IN DB":INPUTD
50  PRINT"ACTUAL POWER IS:"P*(10↑(D/10))
60  GOTO21
100 PRINT"ENTER HIGHER POWER LEVEL IN WATTS":INPUTHP
110 PRINT"ENTER LOWER POWER LEVEL IN WATTS":INPUTLP
120 PRINT"ATTENUATION IN DB IS:"10*LOG(HP/LP)/LOG(10)
130 GOTO21
200 PRINT"ENTER DESIRED HIGHER PWR LEVEL:":INPUTHP
210 PRINT"ENTER ATTENUATION IN DB:":INPUTDB
220 PRINT"ATTENUATED PWR LEVEL IS:"HP/(10↑(DB/10))
300 GOTO21

READY.
```

Figure 1. Devenport's dB and power level program.

★ ★ ★ The Fourth Annual ★ ★ ★

Your idea may win this Grand Prize, provided by Webb Laboratories:

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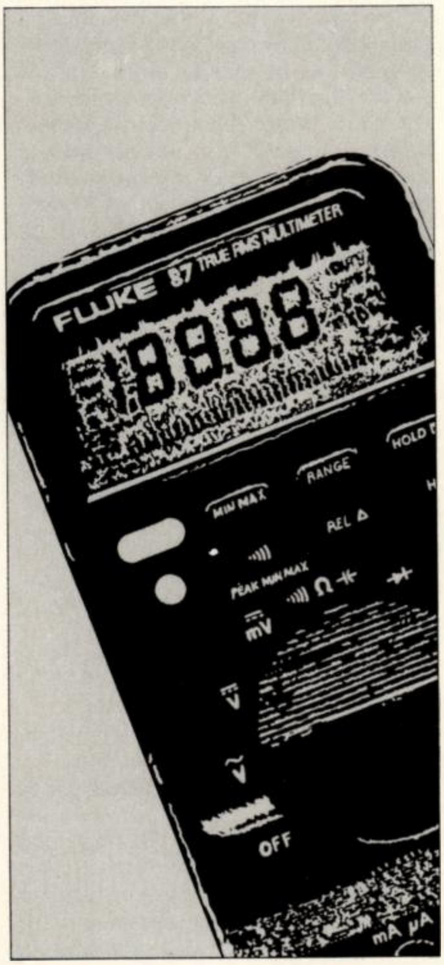
RF Design Awards Contest

or one of five runner-up prizes from Fluke.



The model 87 True RMS Digital Multimeter, with high resolution analog pointer, MIN MAX averaging, 10pF - 5µF capacitance measurement, plus, duty cycle from 0.1 to 99.9% overload protection, 4¾ digit display and ragged, sealed construction are additional features.

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2. The circuit must have an obvious RF function and operate in the below-3 GHz frequency range.
3. Circuits must be the original work of the entrant. If developed as part of the entrant's employment, entries must have the employer's approval for submission.
4. Components used must be generally available, not obsolete or proprietary.
5. Submission of an entry implies permission for *RF Design* to publish the material. All prize winning designs will be published, plus additional entries of merit.
6. Winners shall assume responsibility for any taxes, duties or other assessments which result from the receipt of their prizes.
7. Deadline for entries: March 31, 1989

JUDGING CRITERIA

1. **Originality:** The purpose of the contest is to reward engineers for their unique design contributions. Each design will be evaluated according to its similarity to work by others, unusual application of a device or technique, and other judgments of its contribution to the advancement of the engineering craft.
2. **Engineering:** Engineering is the application of technology to solve a problem or meet a design goal. Entrants should clearly identify how their circuit was created in response to such a need. Judges will evaluate performance, practicality, reproducibility and economy.
3. **Documentation:** Communicating ideas to others is the business of *RF Design* and a necessary part of good engineering. Each entry will be judged on its description, analysis and graphical material. Each circuit should have a complete list of components, explanation of functions, and a summary of performance and test data.

MAIL YOUR ENTRY BY MARCH 31, 1989 TO GARY BREED, EDITOR. . .

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HDTV: The Discussion Continues

A group of nearly 20 U.S. electronics companies have agreed to work together to develop a plan for U.S. development of High-Definition Television (HDTV) technology. The announcement, made by the American Electronics Association (AEA), came at the Winter Consumer Electronics Show held in Las Vegas, Nev., in January. Among the companies involved in the effort are Motorola Inc., Hewlett-Packard, Harris Corp., Texas Instruments and IBM. The proposed partnership has been likened by some observers to Sematech, the semiconductor industry's cooperative effort.

HDTV was also a subject of discussion during January Senate confirmation hearings with now-confirmed Commerce Secretary Robert A. Mosbacher. Mosbacher affirmed that HDTV research and development will be a "high priority" for the Commerce Department under his direction. He indicated that Commerce would be ready to assume a leading role in the fostering of commercial technology in the United States, and would consider providing some funding, or "seed money", for HDTV work.

The Commerce Department's Advisory Committee on Advanced Television has added its voice to those calling for strong U.S. participation in the development of HDTV technology. In a preliminary report, the Committee endorsed the idea of a cooperative effort between government and industry, and also warned of the adverse impact of U.S. non-participation (or weak participation) in this emerging technology.

The report stressed that the lack of a significant U.S. presence in the HDTV market will have effects that reach beyond the area of consumer electronics. "If U.S. semiconductor manufacturers do not have significant access to this market, they will be severely disadvantaged relative to their vertically integrated competitors," warned the Committee. Materials, instrument and equipment manufacturers will also be affected. This assessment echoes the analysis of the AEA's Advanced Television Task Force, which predicted that a weak U.S. presence in the HDTV marketplace would translate into a 50 percent reduction in the U.S. share of the world chip market by 2010.

Proposed 1990 Defense Budget to Increase R&D, Procurement Funding—A budget of $305.6 billion has been requested by the Defense Department for fiscal year 1990, according to an article in *Electronic News* (January 16, 1989). The proposed figure represents an increase of approximately 9 percent in funding of research and development work, and an increase of about 6 percent in procurement funding. Proposed R&D funding for 1990 totals $41 billion, with virtually no additional increase scheduled for 1991. 1990 procurement spending is set at $84.1 billion, with a 9 percent increase to $91.9 billion proposed for 1991. The overall 1990 budget proposal represents a 5 percent rise over fiscal 1989. This amounts to a real growth, after accounting for inflation, of 2 percent over 1989.

Programs receiving increased funding in the proposed 1990 budget include the Strategic Defense Initiative, the Air Force's Advanced Tactical Fighter (ATF), and the Army's Light Helicopter (LHX). Some other major programs, including the B-2 Stealth bomber, will continue to be funded under the proposed budget, but will be put on a somewhat revised timetable. The Defense Advanced Research Projects Agency (DARPA) will continue to fund its MMIC program, with $82 million in spending proposed for fiscal 1990.

D.W. Roth, 1937-1988—The RF community suffered a profound loss when D.W. (Dan) Roth, vice president of Amplifier Research Corp., Souderton, Pa., died December 31 in Evanston, Ill. Mr. Roth had been known and respected throughout the electronics industry for 20 years, having founded Amplifier Research with Donald R. Shepherd in 1969. Roth and Shepherd had worked closely in the design and marketing of broadband ECM equipment at American Electronic Laboratories (AEL) before opening their own power amplifier enterprise.

In addition to his successful career in RF power and testing, Dan Roth was a lifelong civic leader — chairman of the Lower Salford Township Board of Supervisors, founder of the Harleysville Senior Adult Activity Center, and an active member of the local Lions Club, Boy Scout Troop Committee, Lansdale Methodist Church, Indian Valley Library, Jaycees and Toastmasters.

Siemens Components to Continue GaAs Work—The Special Products Division of Siemens Components Inc. will continue to provide small-signal gallium arsenide (GaAs) microwave/RF components to the commercial and military markets. This Siemens product line is not affected by the recent announcement of the pending sale of Microwave Semiconductor Corp. to Phoenix Monolithics.

The Special Products Division's GaAs components include GaAs FETs and GaAs monolithic microwave integrated circuits (MMICs), manufactured in Munich, West Germany, and marketed by the Iselin-based Siemens division.

Navy Lifts Suspension of Varian's Continental Electronics Division—The U.S. Navy has lifted its suspension of Varian Associates' Continental Electronics Division, Dallas, Texas. Under the suspension, the division was prevented from contracting with any agency in the executive branch of the Federal Government. The suspension was announced last July as a result of the government's nationwide investigation of irregularities in government contracting. In response to the suspension, Varian has reviewed, updated and reissued its written policies and practices governing good business conduct, and has initiated expanded training and internal audit programs to help ensure compliance. No fines or penalties have been assessed as a result of the investigation; however, Varian has agreed to assume the Navy's investigative costs and has established a $250,000 escrow account in order to cover any claims that might arise.

Rockwell International Terminates AIL Purchase Negotiations—Rockwell International has announced the termination of negotiations aimed at acquiring Eaton Corp.'s AIL subsidiary. The action followed the decision by Rockwell not to proceed with the transaction in the absence of definitive contracts with the Air Force on all aspects of AIL work on the B-1B bomber. AIL has been seeking, without success, additional Air Force funding for its work to correct problems with the B-1B's AN/ALQ-161 defensive avionics system. In announcing its decision to withdraw from acquisition negotiations, Rockwell reaffirmed its confidence in the technology of the ALQ-161 and its belief that AIL's proposal to the Air Force can bring the system up to its full potential. Rockwell will continue to assist Eaton on a contractual basis in work on the defensive electronics on the B-1B.

Soladyne Announces Fusion Lamination Process for PTFE-Based Circuits—The Soladyne Division of Rogers Corp. now has the capability to manufacture PTFE-based microwave circuits by the fusion lamination process. Conventional manufacture of stripline and other multi-layer circuit boards based on PTFE (polytetrafluoroethylene) involves the use of adhesive films. The electrical properties of these films, which can differ from those of the laminates, may degrade the electrical performance of the circuit. With fusion lamination, no adhesive films are used. Instead, the multi-layer circuit board is heated to 725 degrees F (385 degrees C). At this temperature, the surfaces of the PTFE layers begin to reflow and melt together. This process, while more expensive than conventional methods, produces circuits which meet tighter tolerances in electrical performance.

Report Predicts Growth for European DSP Market—A report compiled by Frost and Sullivan Ltd., of London presents an analysis of the European market for digital signal processors (DSPs) in the next five years. The report forecasts the overall West European DSP market will rise to $360 million by 1993 (in constant 1986 U.S. dollars). This represents an increase of 300 percent over estimated figures for 1988. General purpose single-chip DSPs are the fastest-rising product category. Special purpose DSP chips, especially those used for telecommunications applications, are forecast to reach $140 million in 1993. Data conversion components used in signal processing, such as analog/digital and digital/analog converters, multiplexers, and sample and hold circuits, will rise from an estimated $169 million in 1988 to $411 million by 1993. *The European Market for Digital Signal Processors and Data Conversion Products* (#E1031) is available for $3,200 from: Frost and Sullivan Inc., 106 Fulton Street, New York, NY 10038. Tel: (212) 233-1080

Chomerics Inc. Receives NSA TEMPEST Endorsement—Chomerics Inc. of Woburn, Mass., a subsidiary of W.R. Grace and Co., has received a National Security Agency (NSA) endorsement of its TEMPEST test services facilities. Companies applying for endorsement under the auspices of the NSA's Endorsed TEMPEST Test Services Program undergo review and inspection of test facilities, equipment and personnel, and must employ a certified TEMPEST engineer. Since 1984, Chomerics has doubled its TEMPEST test capability, with facilities which now comprise two shielded enclosures, three adjacent

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shielded rooms housing equipment, and filtered power lines. Data is generated on the company's Watkins Johnson 8940B receiver and HP 8566B spectrum analyzer.

AEG Completes Siliconix Acquisition—AEG A.G. of Frankfurt, West Germany has completed its acquisition of a 39 percent share in Siliconix Inc. AEG purchased one million shares of stock directly from Siliconix, and also acquired a block of shares held by Westinghouse Electric Corporation. The agreement between AEG and Siliconix includes a 10-year option permitting AEG's acquisition of non-exclusive licenses to selected Siliconix high-power MOSFET and power IC technologies. The agreement between the two companies also grants AEG a one-year option to purchase an additional one million Siliconix shares.

TIW Systems Receives Antenna System Contract—TIW Systems Inc, of Sunnyvale, Calif., has been awarded a contract by Telespazic SpA of Rome, Italy, for an INTELSAT Telemetry Tracking and Control (TT&C) antenna system to be installed by TIW at Telespazio's Fucino Station. TIW will provide a 14.2 meter, full motion antenna which will operate at Ku-band. The antenna system will be used by Telespazio as part of INTELSAT's Post 1989 TT&C Network, which provides worldwide telecommunications capacity.

AEL Defense Corp. Wins $2.0 Million Raytheon Contract—AEL Defense Corp., a subsidiary of AEL Industries Inc. of Lansdale, Pa., has received a $2.0 million contract from Raytheon Co. for switch filters. The components, to be produced by AEL's Microwave Hybrid Division, will become part of the U.S. Air Force's AN/ALQ-184 electronic countermeasures system. The AN/ALQ-184 is designed for installation on F-4, F-15, F-16, A-7, A-10 and F-111 aircraft.

Sage Acquires Pragmatic Test Systems—Sage Enterprises Inc. of Palo Alto, Calif., has announced its acquisition of Pragmatic Test Systems Inc. (PTS), a Milpitas, Calif., manufacturer of benchtop linear, digital and linear/digital test systems for semiconductor devices. PTS will continue its present product line offerings with manufacturing and customer service supported by Sage Enterprises. Future products, expected to be announced within a year, will employ technology from both companies' current products.

Hughes Receives $14.6 Million Air Force Contract—Hughes Aircraft Radar Systems Group has received a $14.6 million contract for AN/APG-63 radar upgrade work for the Air Force's F-15 aircraft. The contract was awarded by the U.S. Air Force Warner Robins Air Logistics Center, Robins Air Force Base, Ga.

Cougar Components Moves—Cougar Components has moved its operations to a new 4600 sq. ft. facility. Their new address is: 2225-K Martin Avenue, Santa Clara, CA 95050. Tel: (408) 492-1400; Fax: (408) 492-1500.

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RF Power Transistors — A Status Report

By Mark Gomez
Technical Editor

The general opinion in the power transistor market is that there will be continued growth. "There are several things occurring in the industry that lead me to believe that this market is growing," says George Krausse, chief technical officer at Directed Energy. According to B.J. McDaniel, marketing manager for the silicon semiconductor division at Acrian, there are many major contracts in the marketplace that range from cellular systems to radar systems. "The cellular marketplace is very large, particularly in base stations," he adds. "Also, in the European market, there is potential growth for linear TV transponder transistors."

Another reason for market expansion is the conversion of existing technology to solid-state. "There is growth in UHF broadcast TV where conversions from tubes to solid-state are taking place," notes John Walsh, product marketing manager of the RF and microwave products group at SGS-Thomson Microelectronics. Fred McAdara, vice president of sales and marketing at M/A-COM PHI, Inc., feels that although the defense market itself is flat to declining, there will be growth due to the replacement of older systems and conversions to solid-state. "There are several commercial applications to offset the general decline in the military sectors. The commercial areas include position locating, mobile satellite applications and medical electronics."

The Packaging Problem

Packaging has always been a problem with power transistors. Package performance in terms of parasitic inductances and capacitances is a limitation, but more obvious is the thermal limitation. "The largest single problem in RF devices is heat," says Terry Simons, vice president of sales — major programs at Microwave Modules and Devices (MMD). "We are able to generate more power than we are able to get the heat out," adds Howard Bartlow, MMD's manager of transistor engineering.

"The best package is no package at all," according to Norm Dye, manager of planning for the RF and optical division at Motorola. "The problem is to minimize the effects of a package yet make the part useful to the customer." The desire for better packaging has resulted in research for other packaging materials and techniques. According to Dye, there is a major effort in the industry to find a substitute for beryllium oxide. He feels that there are some good possibilities that the properties of aluminum nitride will improve the performance of packages, particularly at higher temperatures. Also, new die designs which investigate the possibility of making topside connectors and bottom-side emitters are being researched, especially for the 20 or 25 watt output region. This leads to the elimination of dielectric materials such as BeO for the insulation properties needed to reduce capacitance. "In an effort to reduce packaging problems, we have customers that mount the BeO with leads, cap and no flange directly onto the heatsink. This eliminates one interface and results in better thermal conduction," adds Walsh of SGS-Thomson.

Another problem with packaging is price. "Pricing will creep up because of an increase in package costs," says McDaniel of Acrian. According to John Salzey, product manager at Amperex Electronic Company, the selling price of the device is mostly the cost of the package itself. In general, prices for baseline type products will go up. This is attributed to package costs and environmental issues. "The total market for discrete power devices is so small that the companies involved are not willing to or capable of investing the huge amounts of money that will be required to do a revolutionary package design that could be cost-effectively manufactured for products all across the board," observes Lee Max of Lee B. Max Enterprises, an independent consultant to the RF and microwave industry.

As far as future trends for RF power transistors, consumers should see products with improved specifications. "For power levels in excess of 150 or 200 watts, JFETS or static inductions transistors or solid-state triodes offer higher breakdown voltages than that provided by MOSFETs," notes Dr. Adrian Cogan of Microwave Technology. "A solid-state triode that has a cutoff frequency of about 5 GHz has a breakdown voltage of 120 volts. This number decreases to about 70 volts for MOSFETs and 60 volts for bipolars." He adds that with solid-state triodes, as you go higher in frequency, you see higher impedance levels which enable wider bandwidths or higher gains at a given frequency because of lower combining or matching loss.

"Customers are putting tighter control on a lot of parameters. For example, in radar systems, they pay more attention to pulse droop and thermal resistance. Also, they are looking for stability into load mismatch, and are moving to a more linear class of operation," says McDaniel. "With improved die and packaging technology, as well as demands from the marketplace, designers are trying to accomplish Class AB common emitter devices much higher in frequency than done in the past," adds Lee Max. "The switch to Class AB common emitter from Class C common base is a trend in bipolar." Another direction that RF power is taking is towards complete amplifier assemblies. Instead of buying transistors, more and more people are buying amplifiers to perform a function.

Although the current trend is towards a slight price increase, in the long run the price of power transistors should drop. "Pricing will come down, because as we learn more, we can produce products at a lower price," says Dave Adamson, president of Directed Energy.

There is considerable activity in the RF power transistors industry. This includes the use of new technologies that range from wafer fabrication to packaging techniques. This report only skims the surface of the ongoing work and future trends making a positive change in this field.

rf calendar

March 29, 1989
EMC MINI-CON '89
Inland Meeting Center, Westmont, IL
Information: Radiometrics Midwest Corporation, 2200 Main Street, Lombard, IL 60148. Tel: (312) 932-7262

March 29-30, 1989
1989 National Radar Conference
Sheraton Park Central Hotel, Dallas, TX
Information: Russell Logan, IEEE AESS, P.O. Box 1000-262, McKinney, TX 75069

April 4-7, 1989
6th International Conference on Antennas and Propagation
Coventry, England
Information: ICAP 89 Secretariat, Conference Services, IEE, Savoy Place, London WC2R OBL, England

April 10-13, 1989
Electronic Imaging West 89
Pasadena Convention Center, Pasadena, CA
Information: MG Expositions Group, 1050 Commonwealth Avenue, Boston, MA 02215. Tel: (800) 223-7126; (617) 232-3976

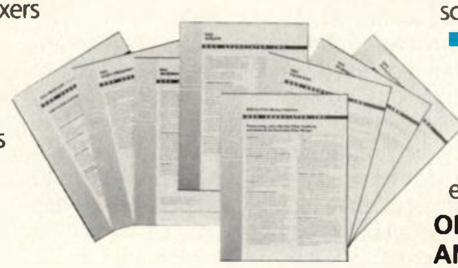
April 11-13, 1989
1989 IEEE VLSI Test Workshop
Bally's Park Place Casino Hotel, Atlantic City, NJ
Information: Wesley E. Radcliffe, IBM, East Fishkill, Department 277, Building 321-5E1, Hopewell, NY 12533. Tel: (201) 323-2560

April 25-27, 1989
IEEE Instrumentation and Measurement Technology Conference
Key Bridge Marriott Hotel, Washington, DC
Information: IMTC, 1700 Westwood Boulevard, Suite 101, Los Angeles, CA 90024. Tel: (213) 475-4571

April 26-28, 1989
Aerospace and Defense 89
Santa Clara Convention Center, Santa Clara, CA
Information: Chuck Jungi, AEA, 5201 Great American Parkway, Santa Clara, CA 95054. Tel: (408) 987-4202

April 29-May 2, 1989
National Association of Broadcasters Annual Convention
Las Vegas Convention Center, Las Vegas, NV
Information: NAB, Conventions and Meetings, 1771 N Street, N.W., Washington, DC 20036. Tel: (202) 429-5300

May 31-June 2, 1989
43rd Annual Frequency Control Symposium
Denver Marriot Hotel — City Center, Denver, CO
Information: Michael Mirachi, Synergistic Management Inc., 3100 Route 138, Wall Township, NJ 07719. Tel: (201) 280-2022



rf courses

The George Washington University

Pulsed-Power Technology
March 27-29, 1989, Washington, DC
Microwave Radio Systems
March 30-31, 1989, Washington, DC
Microwave High-Power Tubes and Transmitters
April 10-14, 1989, Washington, DC
Modern Radar System Analysis
April 10-14, 1989, London, England
Modern Communications and Signal Processing
April 17-21, 1989, Washington, DC
Grounding, Bonding and Shielding
April 20-21, 1989, Washington, DC
Optoelectromagnetics
May 1-3, 1989, Washington, DC
Monopulse Radar Principles and Techniques
May 8-11, 1989, Washington, DC
Radar ECM and ECCM Systems
May 8-12, 1989, Washington, DC
Radar Systems and Technology
May 8-12, 1989, Washington, DC
ELINT: Analyzing Radar Signals
June 6-8, 1989, Washington, DC

Information: Misael Rodriguez, Continuing Engineering Education, George Washington University, Washington, DC 20052. Tel: (800) 424-9773; (202) 994-6106

Georgia Tech Education Extension

Electronic Support Measures
March 21-23, 1989, Atlanta, GA

Information: Education Extension, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel: (404) 894-2547

Amador Corporation

Electromagnetic Emissions: Testing and Design
March 28, 1989, Minneapolis, MN
ESD Immunity for Electronic Equipment
March 29, 1989, Minneapolis, MN

Information: Diane Swenson, Amador Corporation, Wild Mountain Road, Taylors Falls, MN 55084-0270. Tel: (612) 465-3911

The Keenan Corporation (TKC)

Design for ESD and RFI
April 26, 1989, St. Petersburg, FL

Information: Jean Whitney, The Keenan Building, 8609 66th Street North, Pinellas Park, FL 34666. Tel: (813) 544-2597

Integrated Computer Systems

Digital Control Systems: Design Techniques and Tools
March 28-31, 1989, Los Angeles, CA
Fiber Optic Communication Systems
March 28-31, 1989, San Diego, CA
C Programming Hands-On Workshop
April 4-7, 1989, Albuquerque, NM
Digital Signal Processing: Techniques and Applications
April 4-7, 1989, Washington, DC

Information: John Valenti, Integrated Computer Systems, 5800 Hannum Avenue, P.O. Box 3614, Culver City, CA 90231-3614. Tel: (800) 421-8166; (213) 417-8888

Interference Control Technologies, Inc.

Practical EMI Fixes
April 17-21, 1989, Orlando, FL
May 1-5, 1989, Chicago, IL
Intro to EMI/RFI/EMC
April 18-20, 1989, San Diego, CA
May 23-25, 1989, Washington, DC

Information: Penny Caran, Registrar, ICT, State Route 625, P.O. Box D, Gainsville, VA 22056. Tel: (703) 347-0030

Compliance Engineering

EMI
April 25, 1989, Boston, MA
Safety
April 26, 1989, Boston, MA
ESD
April 27, 1989, Boston, MA
Telecom
April 28, 1989, Boston, MA

Information: Compliance Engineering, 271 Great Road, Acton, MA 01720. Tel: (508) 264-4208.

R & B Enterprises

Introduction to MIL-STD-461C
April 5, 1989, Boston, MA
Identification and Control of Microwave/Radiofrequency Hazards
April 17-19, 1989, Washington, DC
Real Life Solutions to EMI Problems
May 2-4, 1989, Washington, DC

Information: Registrar, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428. Tel: (215) 825-1966

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Power Gain	5 Watts CW or Pulse	10 Watts CW or Pulse	20 Watts CW or Pulse	50 Watts CW or Pulse	1.5 Watt CW Minimum	6 Watt CW Minimum
Gain Flatness	40 dB Minimum	45 dB Minimum	45 dB Minimum	50 dB Minimum	33 dB Minimum	38 dB Minimum
Load Mismatch Tol.	Can Withstand Infinite VSWR					
Noise Figure	8 dB typical	8 dB typical	8 dB typical	8 dB typical	9 dB typical	9 dB typical
AC Line Voltage	90-255 VAC, 50/60Hz					
Size (LxWxH)	11 x 10 x 5 inches 28 x 25 x 13 cm	11 x 10 x 5 inches 28 x 25 x 13 cm	11 x 10 x 5 inches 28 x 25 x 13 cm	13 x 10 x 5 inches 33 x 25 x 13 cm	6 x 8 x 4 inches 15 x 20 x 10 cm	11 x 10 x 5 inches 28 x 25 x 13 cm
Weight	14 lbs. (6.3 kg)	14 lbs (6.3kg)	14 lbs (6.3 Kg)	19 lbs (8.6 kg)	7 lbs (3.15 kg)	14 lbs. (6.3 kg)
Price	$1,325.00	$1,995.00	$2,885.00	$3,995.00	$1,295.00	$1,995.00

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INFO/CARD 21

An Active Tunable Group Delay Equalizer

By Vishwajit Mitra,
Radio Div., TRC, India,
and Dr. Ing. W. Rupprecht,
University of Kaisers-Lautern, FRG

Tunable group delay equalizers are frequently needed in analog/digital radio systems to equalize the passband group delays of IF/RF filters. An unequalized group delay causes system degradation due to waveform distortion and consequent intermodulation noise generation in analog FM systems and intersymbol interference manifestation in digital QAM systems. While it is common to equalize the group delay of IF filters at IF (70 MHz), the group delays caused by RF branching filters in a hop are very frequently equalized in the receiver at IF. The hop group delay is system engineering-dependent and, therefore, has to be adjusted in the field. Tunable group delay equalizers can also be used to obtain delay lines for bandpass-type signals. These are required in digital systems to fabricate transversal equalizers.

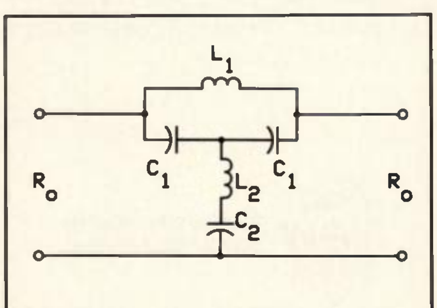


Figure 1. T-type all pass network.

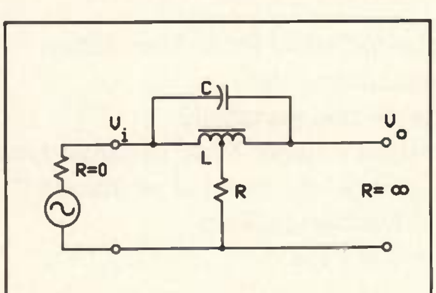


Figure 2. T-type all pass network with 2nd order delay response.

The following techniques have been used to obtain group delay equalization:

a. A standard "T" type all pass network (Figure 1) of constant iterative impedance (R_o) with passive components is used. These sections have second order delay (parabolic) response. The tuning of these sections, however, is very difficult since five components per section have to be varied in order to meet delay, response and return loss specifications simultaneously.

b. In another technique, active devices are used to implement an all pass transfer function of the following form:

$$H(\omega) = \frac{R - jX}{R + jX}$$

A simple all pass network (Figure 2) has been realized to give second order delay response.

The Design Process

At the beginning of the design process the following design objectives were formed:

- Derive an all pass network with second order delay response.
- Tuning for delay has to be independent of both response and return loss.
- The loss of signal has to be minimum in order to have a low noise figure.
- Input/Output impedances are to be of definite resistive value in order to avoid interfacing problems.
- Component count and power consumption has to be minimum for better reliability and cheaper implementation.

The search for an all pass configuration was started from a fundamental symmetrical pole-zero configuration as illustrated in Figure 3. The transfer function was derived as:

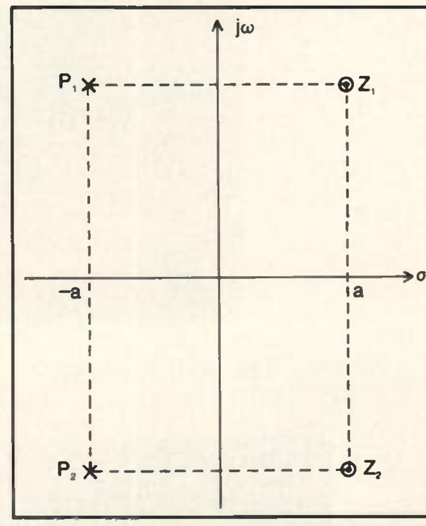


Figure 3. Pole-zero configuration.

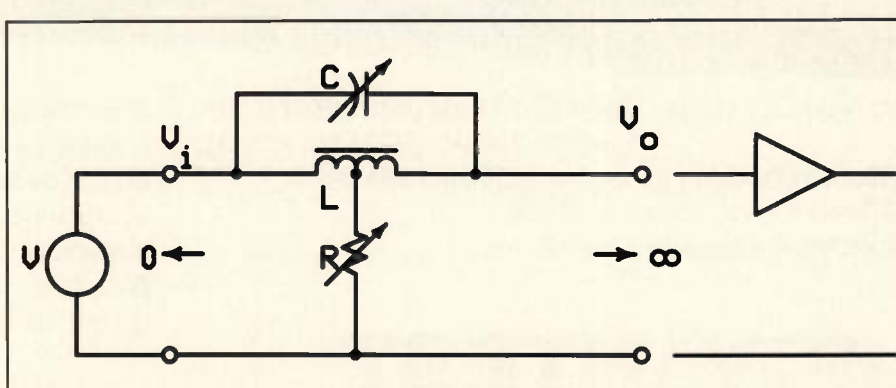


Figure 4. A canonical form realization.

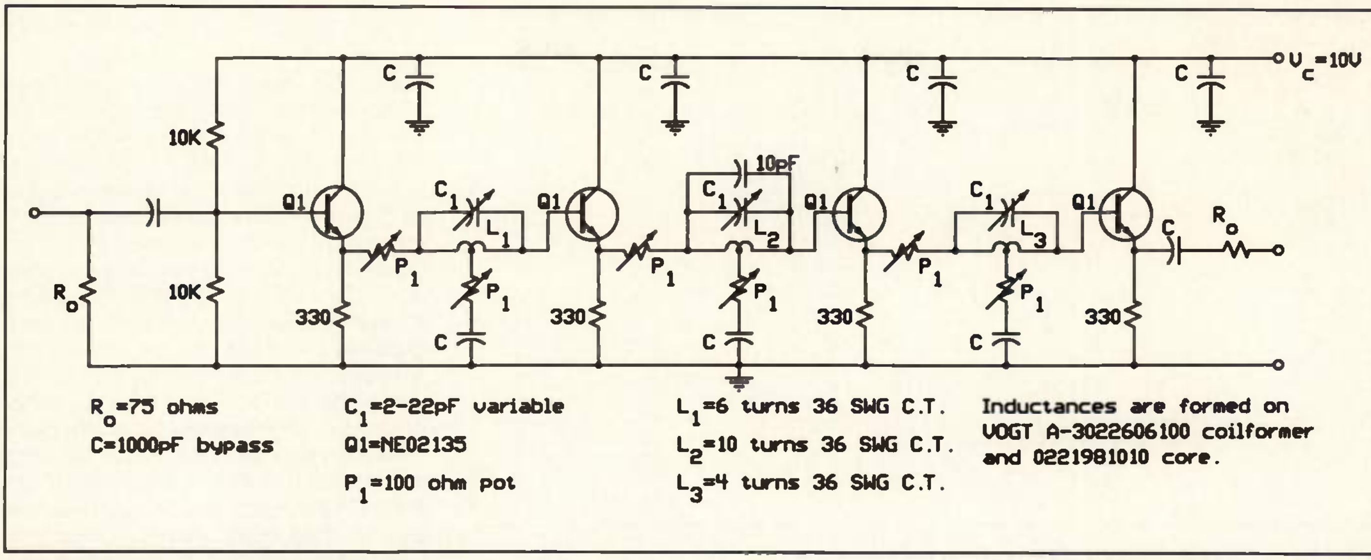


Figure 5. Circuit with multi-sections.

$$H(\omega) = \frac{(S - Z_1)(S - Z_2)}{(S - P_1)(S - P_2)}$$

where
$$Z_1 = a + jb$$
$$Z_2 = a - jb$$
$$P_1 = -a + jb$$
$$P_2 = -a - jb$$

In this network a change in "b" will tune for frequency of peak delay (F_p) and a change in "a" will tune for peak delay (T_p). The tunings are independent of each other.

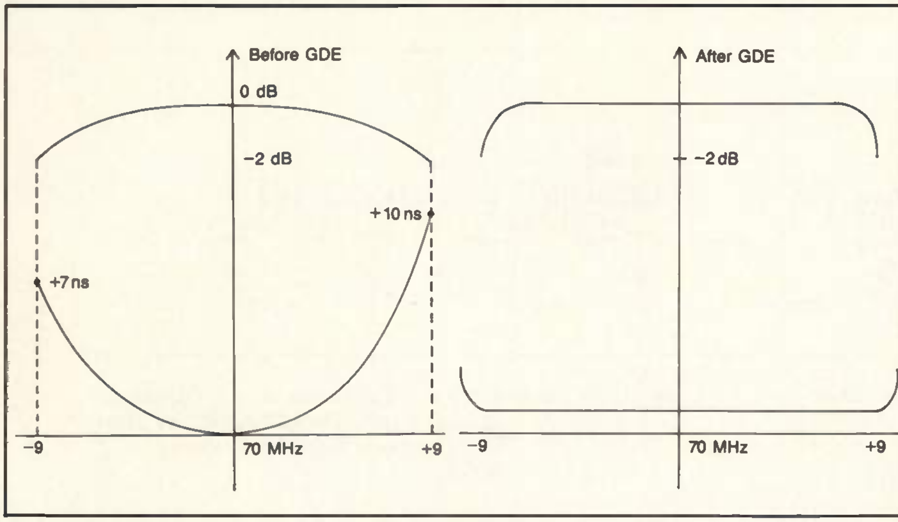


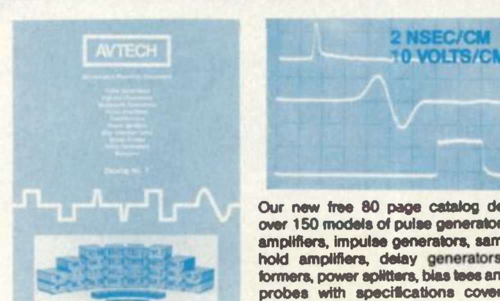
Figure 6. Group delay equalized to within 1 ns.

In the next step the above transfer function was realized as a network (Appendix 1). A canonical form realization was tried in order to have the least component count. This realized network is shown in Figure 4. It uses a capacitor, a resistor and a center tapped inductor of high Q. The circuit is ideally driven from a voltage source and drives into a load of infinite impedance. In this circuit the frequency of peak delay, F_p, and peak delay, T_p, are given by:

$$F_p \cong \frac{1}{2\pi\sqrt{LC}} \qquad T_p = 16RC$$

Thus, the peak delay can be tuned independently through R and the frequency of peak delay can be tuned independently through L. The tuning of C will change both. Since the intended frequency of operation of this circuit is around 70 MHz, the ideal conditions postulated above do not occur in practice. The effects of finite Q, driving source impedance and load parasitic capacitance have to be taken into account. The finite driving point resistance and the finite Q of the inductance result in a non-parabolic response in the network. However, by suitably adjusting the driving resistance, the effect of the finite Q of the coil can be compensated exactly. This effect, therefore, has been used advantageously by providing additional control over the response in the circuit. Thus, the circuit would be able to equalize not only the delay in the system but also, to a certain extent, the response in the system.

The effect of load capacitance is more complex and results in a cubic response in the passband. However, it was estab-



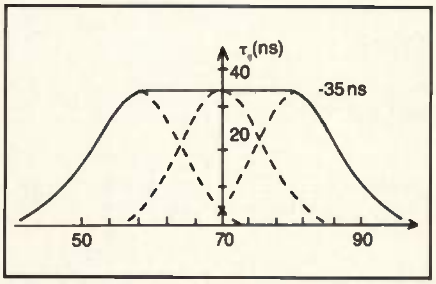


Figure 7. Stagger tuning of three sections.

lished experimentally that the cubic response vanishes for a particular value of R. This resulted in making R fixed in the original circuit.

Design Implementation

For actual implementation of the circuit with multi-sections, emitter followers were used as isolating stages. The advantages of using this practice are:

- Output impedance (driving impedance for all pass network) is low, as is required for proper operation.
- Input impedance (load for all pass network) is high.
- Loss per stage is low (< 1 dB). For matching purposes, the front stage has a 75 ohm termination and this results in 6 dB matching loss.
- Since the circuit has overall passband loss, there will be no chance of oscillations in the circuit.
- The second and succeeding stages do not need a separate biasing arrangement since direct DC coupling is possible through inductor coils.

The overall test circuit configuration is shown in Figure 5. Note that for 70 MHz operation, any coil with a value of approximately 0.05 to 0.47 μH can be used. Similarly, any IF transistor is usable.

Test Results

In the test circuit of Figure 5, group delays of various shapes and magnitudes can be generated very easily while keeping the response to a tight specification of 0.1 dB in the 70 + 35 MHz bandwidth. To check the tunability, a fifth-order Chebyshev bandpass filter whose characteristics are shown in Figure 6 was group delay equalized to within 1 ns in about 2 dB bandwidth (±9 MHz).

In another example, an electronically variable delay line (currently in final development stages), required for a fade simulator, was fabricated. In this case R was replaced by a PIN diode to obtain variations in bandpass delay. The cubic response term which manifests itself in changing the value of R was compensated by the use of a variable capacitor across R. Thus, the circuit gives a very simple implementation of electronically varying the delay in a range of about 10 ns. The authors have not yet come across any other technique by which this could have been done so easily. An equivalent fade simulator for mobile radio uses a high-speed ADC/DAC.

About the Authors

Vishwajit Mitra is affiliated with DD(RD), Radio Div., TRC, Janpath, New Delhi, India 110001. Dr. Ing. W. Rupprecht is associated with the University of Kaisers-Lautern in the Federal Republic of Germany.

A. Derivation of the all pass network (Figure A)

Writing loop equations with the Laplace Transform:

$$V_1 = \tfrac{1}{4}\, SL(I_1 - I_3) - \tfrac{1}{4}\, SLI_3 + RI_1 \tag{1}$$

$$O = \frac{1}{SC} I_3 + \tfrac{1}{4}\, SLI_3 + \tfrac{1}{4}\, SL(I_3 - I_1) + \tfrac{1}{4}\, SL(I_3 - I_1) + \tfrac{1}{4}\, SLI_3 \tag{2}$$

$$V_2 = \tfrac{1}{4}\, SLI_3 + \tfrac{1}{4}\, SL(I_3 - I_1) + RI_1 \tag{3}$$

From equation 2,

$$I_3 = \frac{\tfrac{1}{2} S^2LC}{S^2LC + 1}(I_1) \tag{4}$$

and eliminating I_3 in equations 1 and 2,

$$V_1 = \left(\tfrac{1}{4}\, SL + R - \frac{\tfrac{1}{4} S^3L^2C}{S^2LC + 1}\right) I_1 \tag{5}$$

$$V_2 = \left(-\tfrac{1}{4}\, SL + R + \frac{\tfrac{1}{4} S^3L^2C}{S^2LC + 1}\right) I_1 \tag{6}$$

Since $H(S) = (V_2/V_1)$, after simplification:

$$H(S) = \frac{V_2}{V_1} = \frac{S^2 - S(1/4RC) + 1/LC}{S^2 + S(1/4RC) + 1/LC} = \frac{S^2(4LCR) - SL + 4R}{S^2(4LCR) + SL + 4R} \tag{7}$$

Hence:

$$\text{Poles } P_1, P_2 = \frac{-L \pm \sqrt{L^2 - 64\, LCR^2}}{8LCR} = -\frac{1}{8CR} \pm j\sqrt{\frac{1}{LC} - \frac{1}{64C^2R^2}} = a \pm jb \tag{8}$$

The poles/zeros are as shown in Figure B.

$$a = \frac{1}{8CR},\; b = \sqrt{\frac{1}{LC} - \frac{1}{64C^2R^2}} \tag{9,10}$$

$$\text{or } b \cong \sqrt{\frac{1}{LC}} \tag{11}$$

Thus, b is the resonant frequency.

$$\text{Response } |H(j\omega)| = \frac{\sum_1^n |S - Sz_n|}{\sum_1^n |S - Sp_n|} = 1 \tag{12}$$

$$\text{since } \overline{|S - Sz_n|} = \overline{|S - Sp_n|} \tag{13}$$

B. Derivation of group delay

From equation 6, as $s \rightarrow j\omega$,

$$|H(j\omega)| = \frac{4R - \omega^2 4LCR - j\omega L}{4R - \omega^2 4LCR + j\omega L} \tag{14}$$

Therefore, the phase of $H(j\omega)$ is:

$$\phi(\omega) = 2\tan^{-1}\left[\frac{\omega L}{4R(1 - \omega^2 LC)}\right] \tag{15}$$

Group delay $\tau_g(\omega)$ is given by:

$$\tau_g(\omega) = \frac{d}{d\omega}\phi(\omega) = \frac{d}{d\omega}\left[2\tan^{-1}\left(\frac{\omega L}{4R\,(1 - \omega^2 LC)}\right)\right] \tag{16}$$

or

$$\tau_g(\omega) = \frac{4R(1 - \omega^2 LC)L - \omega L(-2)\omega LC4R}{[4R\,(1 - \omega^2 LC)]^2} \cdot \frac{2}{1 + (\omega^2 L^2)/[4R(1 - \omega^2 LC)^2]^2} \tag{17}$$

After simplification:

$$\tau_g(\omega) = \frac{8RL\,(1 + \omega^2 LC)}{16R^2\,(1 - \omega^2 LC)^2 + \omega^2 L^2} \tag{18}$$

This typically gives a second-order delay response, with maximum delay at f_p:

$$f_p \cong \frac{1}{2\pi\sqrt{LC}} \tag{19}$$

By substituting $\omega_p = 1/\sqrt{LC}$,

$$T_p = \tau_g(\omega_p) \cong 16RC \tag{20}$$

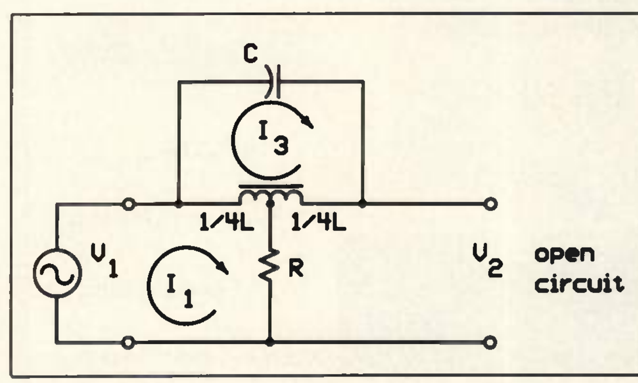


Figure A. All pass network.

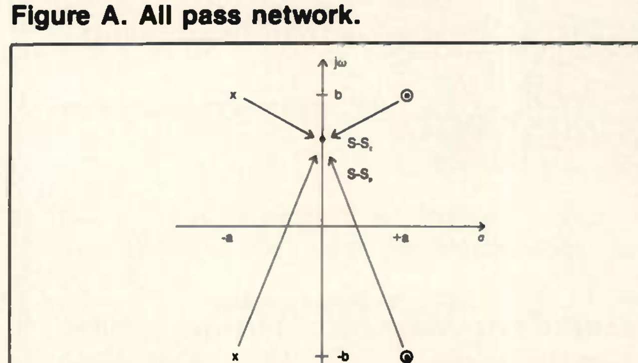


Figure B. Poles and zeros for an all pass network.

Appendix 1. Analysis of group delay equalizer.

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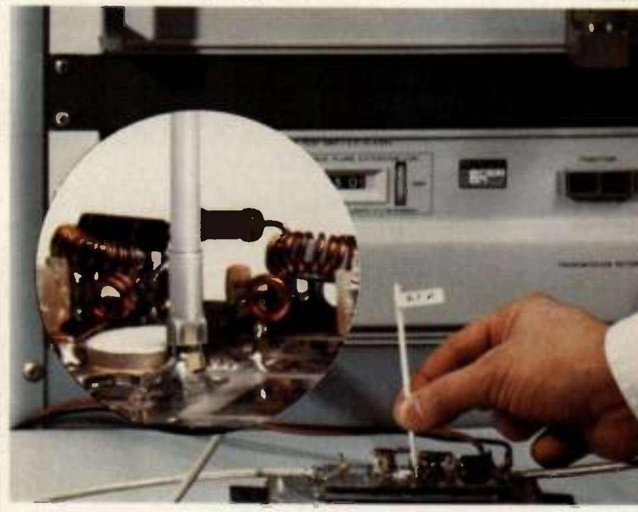

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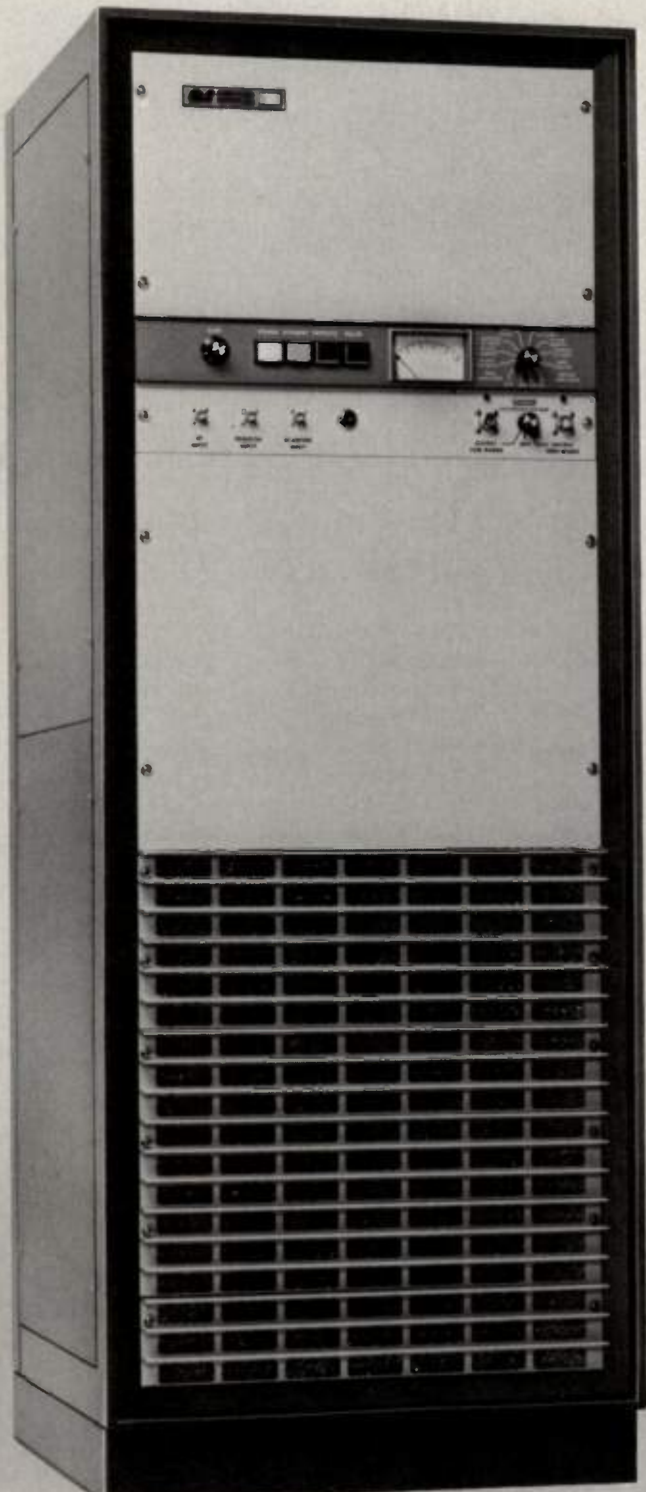

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Monolithic Ceramic Block Combline Bandpass Filters

By Darioush Agahi
Motorola, Inc.

Small size and ruggedness are two important factors in the selection of bandpass filters for military and OEM applications. Monolithic ceramic block combline bandpass filters not only offer a size advantage in UHF through L-band frequencies; they also have other characteristics that make them extremely attractive when compared to other technologies. The filters are characteristically lower in cost and have relatively good insertion loss due to their high Q material (Q>10,000). This paper describes the design technique used for ceramic bandpass filters.

The procedure for designing ceramic bandpass filters is straightforward and relies on standard filter theory. It is only in the construction stage of the realization that the structure becomes unique and the commercial attractiveness becomes apparent. A design example is provided here together with an equivalent circuit for a Chebyshev equal-ripple filter constructed with a material possessing a dielectric constant of 37.

Ceramic materials with low loss tangents (67×10^{-6}) and high dielectric constants (37 and 78) provide a means to create small coaxial structures which could be coupled to form combline bandpass filters. The sketch in Figure 1 shows the basic foreshortened quarter-wavelength coaxial resonator structure. The resulting filters are compact, rugged devices with low insertion loss in bandwidths of 0.5 to 6 percent. It is also possible to realize transmission zeros in these devices and structures.

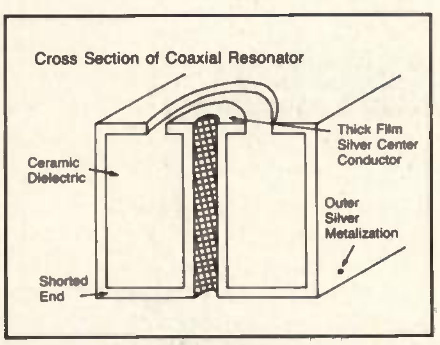


Figure 1. Basic resonator structure.

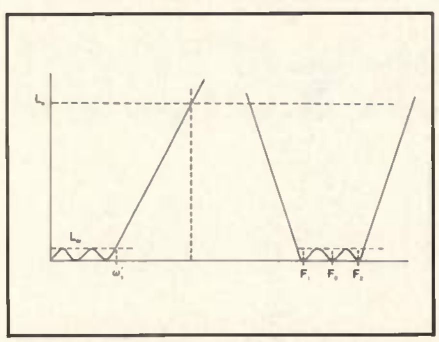


Figure 2. Lowpass to bandpass transformation.

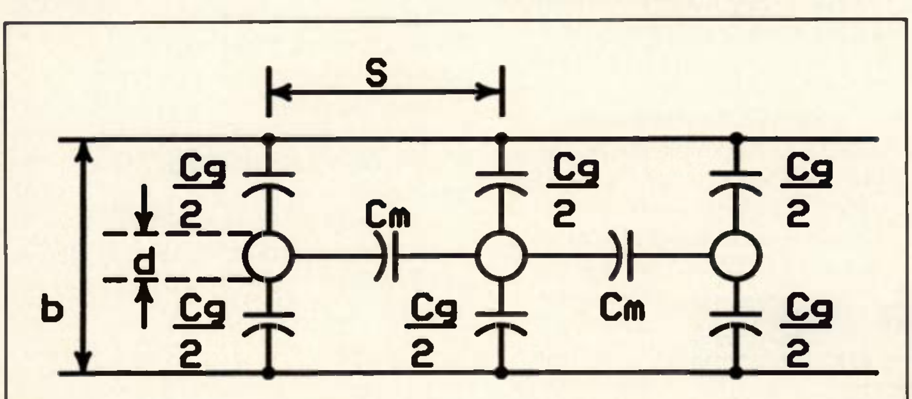


Figure 3. Coupled circular rods between ground planes.

Design Procedure

The design procedure for these combline filters is based on papers by Matthaei (1) and Cristal (2) which include descriptions of the physical structures required for their realization. It is necessary to determine the order of a filter based on a given bandwidth, rejection, loss, etc. Using Reference 1, a low pass to bandpass transformation is performed.

$$\frac{\omega'}{\omega_1'} = \frac{1}{\omega}\left(\frac{F}{F_o} - \frac{F_o}{F}\right) \qquad (1)$$

Where:

$$\omega = \frac{F_2 - F_1}{\sqrt{F_2 F_1}} \qquad (2)$$

(See Figure 2)

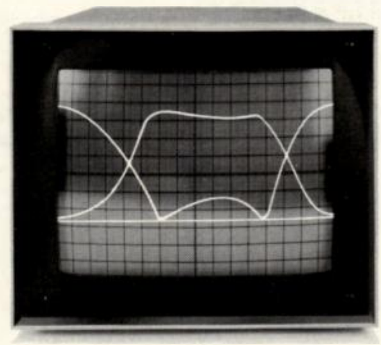
For a Chebyshev response, n is obtained from:

$$n = \frac{\cosh^{-1}\left[(l_o^{L_a/10} - 1)(l_o^{L_r/10} - 1)\right]^{1/2}}{\cosh^{-1}(\omega'/\omega_1')} \qquad (3)$$

Since n cannot be a fraction, it will be rounded up to the next highest integer. Once n is calculated, the low pass prototype element values (or g values) are obtained (1). Using the above information, coupling coefficients are given by (1):

$$K_{j,j+1} = \frac{\omega}{\sqrt{g_j g_{j+1}}} \qquad (4)$$

To excite the TEM mode, resonators are located in close proximity to one another. In doing that they become electromagnetically coupled via their associated electric and magnetic fields. While designing such devices, the desired degree of coupling is usually known, and it is required in order to determine the spacing necessary to achieve this coupling. By using coupling coefficients (from equation 4), Reference 2, and transmission line theory, coupling coefficients are adjusted.



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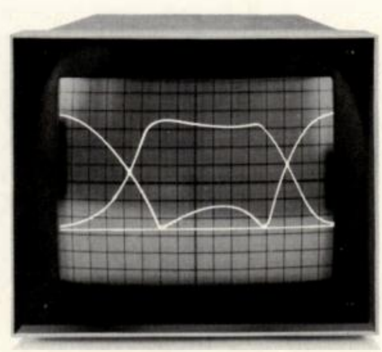

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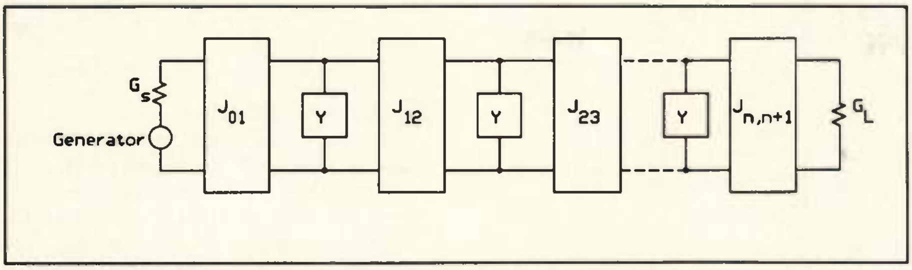


Figure 4. Admittance inverter coupled bandpass filter.

$$K_{adj(j,j+1)} = \frac{K_{j,j+1}}{F(\theta)} \quad (5)$$

Where:

$$F(\theta) = \frac{2}{\tan(\theta)\,[\,\cot(\theta) + \theta \csc^2(\theta)\,]} \quad (6)$$

Where θ is the electrical length of the resonator in radians.

If fringing capacitance beyond the nearest neighbor resonator is neglected, it is possible to describe TEM mode propagation along the structure in terms of two orthogonal modes designated as even and odd. They have different characteristic impedances which are intimately related to the total static capacitances of the rods to ground when in one or the other mode. The total static capacitances are related to the mutual capacitance between successive rods C_m and the self-capacitance C_g of each rod (2). Figure 3 shows that the total capacitance measured between one rod and ground when the rods are driven in the odd mode is (2):

$$C_o = C_g + 4C_m \quad (7)$$

Total capacitance measured between one rod and ground when the rods are driven in the even mode is:

$$C_e = C_g \quad (8)$$

From equations 7 and 8:

$$C_m = \frac{C_o - C_e}{4} \quad (9)$$

Now, adjusted coupling coefficients can be related (equation 5) to these capacitances via:

$$K_{adj(j,j+1)} = \frac{C_m}{C_g + 2C_m} \quad (10)$$

To obtain the spacing, Cristal's (2) graphs are used to interpolate the desired C_m & C_g for given spacing. Alternatively, a less accurate method can be used. This involves replacing the round rods with infinitesimal line charges located at the center of each cylinder using the method of images. It gives a correct asymptotic form to the solutions of the actual round rod problems in the even and odd mode. The following are the equations per Cristal's second-order correction.

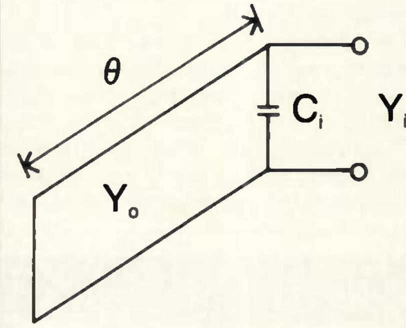
$$\frac{\varepsilon}{C_{odd}} = \frac{1}{2\pi} \ln \left| \frac{(\pi/4)(d/b)}{\sqrt{1-(d/2b)^4}} - \frac{1}{2} \ln \left[1 - \left(\frac{d/b}{2C/b} \right)^4 \right] + 2 \sum_{m=1}^{\infty} (-1)^m \ln \tanh [(m)(\pi/2)(C/b)] \right| \quad (11)$$

$$\frac{\varepsilon}{C_{even}} = \frac{1}{2\pi} \ln \left| \frac{(\pi/4)(d/b)}{\sqrt{1-(d/2b)^4}} + \frac{1}{2} \ln \left[1 - \left(\frac{d/b}{2C/b} \right)^4 \right] + 2 \sum_{m=1}^{\infty} \ln \tanh [(m)(\pi/2)(C/b)] \right| \quad (12)$$

where $C = s + d$ (13)

Equivalent Circuit

In order to simulate the response of such a filter, an equivalent circuit is needed. This is done by Matthaei's (1) generalized bandpass filter using admittance inverters. For this model, the resonators are shorted transmission lines (90 degrees) that are loaded with lumped capacitors. J (or admittance) inverters are formed from stubs of electrical length θ (1). Note that negative admittances will be absorbed into adjacent resonator admittances. Loading capacitors are calculated from:



$$Y_o = \frac{\sqrt{\varepsilon_r}}{138 \log\left(\frac{4b}{\pi d}\right)}$$

Figure 5. Shorted stub resonator.

$$C_r = \frac{1}{W_o Z_o \tan(\theta)} \quad (14)$$

Series shorted stub admittances are calculated from:

$$Y_{r,r+1} = \frac{K_{r,r+1}}{Z_o F(\theta)} \quad (15)$$

An input admittance inverter which determines the series coupling capacitor to external circuits is obtained from (1):

$$J_{01} = \sqrt{\frac{G_s b\omega}{g_0 g_1 \omega_1'}} \quad (16)$$

Where,

$$b = \frac{1}{2Z_o}\left[\frac{1}{\tan(\theta)} + \frac{\theta}{\sin^2(\theta)}\right] \quad (17)$$

Series capacitors are also calculated from (1):

$$C_{01} = \frac{J_{01}}{\omega_0\sqrt{1-(J_{01}/G_s)^2}} \quad (18)$$

Due to the loading effect of the external circuit, the first shunt capacitor needs to be adjusted.

$$C_{01}^{\bullet} = \frac{C_{01}}{1+(\omega_0 C_{01}/G_s)^2} \quad (19)$$

$$C_1 = C_r - C_{01}^{\bullet} \quad (20)$$

Similarly, since the circuit is symmetrical,

$$J_{n,n+1} = J_{01} \quad (21)$$

$$C_{n,n+1} = C_{01} \quad (22)$$

$$C_{n,n+1}^{\bullet} = C_{01}^{\bullet} \quad (23)$$

$$C_n = C_1 \quad (24)$$

Construction of a Bandpass Filter

The specifications for the 0.1 dB ripple Chebyshev filter to be designed are as follows:

- center frequency = 1030 MHz
- 3 dB BW = 40 MHz
- number of poles = 5
- block height = 80 degrees
- ground plane separation = 0.308 in.
- resonator diameter = 0.125 in.

Using equation 4, coupling coefficients are:

$K_{12} = K_{45} = 0.027291$
$K_{23} = K_{34} = 0.020796$

From the equation in Figure 5, the characteristic impedance is calculated:

$$Z_o = \frac{138}{\sqrt{37}} \log \frac{4(0.308)}{\pi(0.125)} = 11.26\ \Omega \quad (25)$$

$$C_r = \frac{1}{W_o Z_o \tan\theta} = 2.4185 \text{ pF} \quad (26)$$

$C_{01} = 1.1137$ pF
$C_0 = 0.3565$ pF

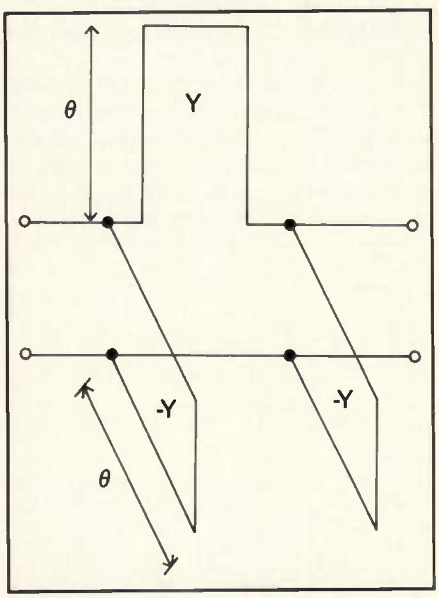


Figure 6. Shorted stub admittance inverter.

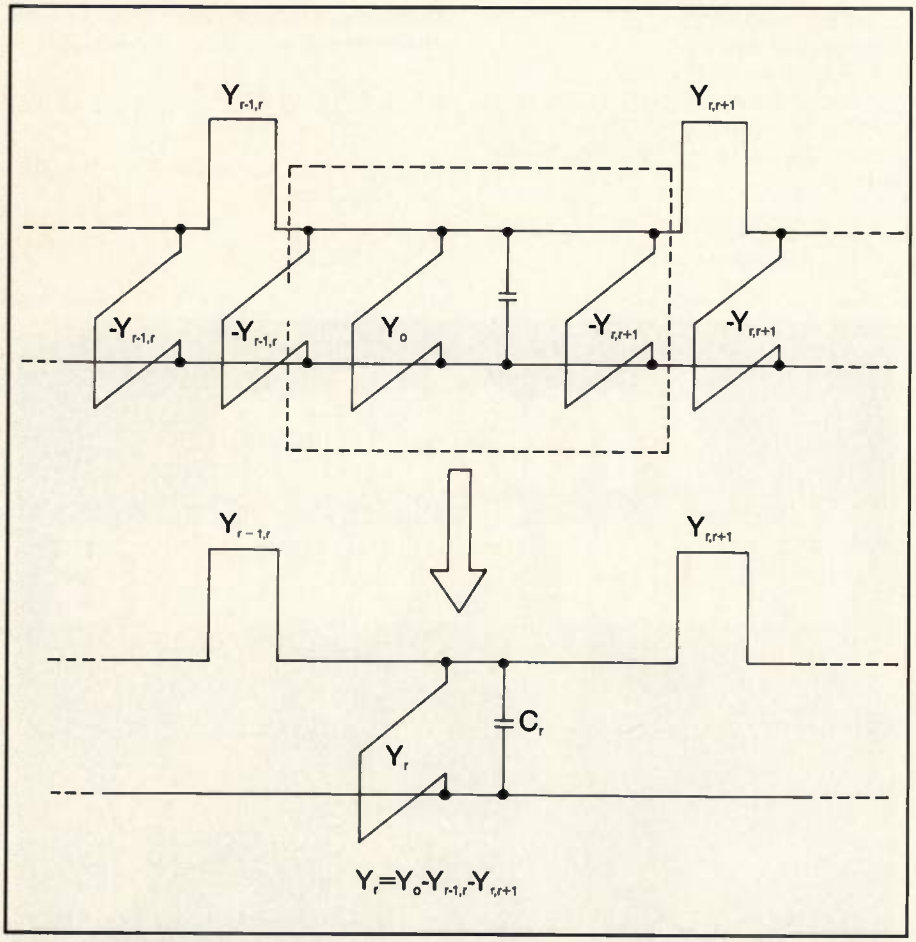


Figure 7. Absorption process of negative branches of J-inverter and their adjacent resonator.

C_1 =1.4632 pF
Y_{12}=0.0111 mhos
Y_{23}=0.00846 mhos
Y_1=0.07767 mhos
Y_2=0.069209 mhos
Y_3=0.071849 mhos

Using the above information, the equivalent circuit will be as shown in Figure 8. Using Cristal's asymptotic approach, the ceramic block was designed with the following dimensions:

Block width (ground plane separation) = 0.308 in.
Block height (physical height) = 0.418 in.
Block length = 1.9 in.

Motorola's patented approach for realizing an I/O means and tuning resonators (3) was used in the construction of the filter. The resonators were formed by metallizing the holes and plating the exterior of the block as well as the bottom. The top of the block was printed using thick film technology in such a way that loading capacitors C_O and C_{O1} were created.

In the course of constructing this filter, the individual resonators are tuned by removing metallization around each resonator, thus reducing the loading capacitance (C_1, C_2, etc) of Figure 9. The measured response and also the simulated response of the equivalent circuit modeled by Touchstone™ are shown in Figures 10 and 11, respectively.

The following results were obtained:

F_o = 1030 MHz
insertion loss at F_o = 1.2 dB
3 dB BW = 40.3 MHz
K_{12} = 0.027437
K_{23} = 0.021822
K_{34} = 0.021881
K_{45} = 0.027201

The center frequency was exactly at desired frequency. The 3 dB BW closely agreed with the specifications. The insertion loss was slightly more than the theoretical value of 0.98 dB which is given by Cohn (4):

$$IL = 4.343 \frac{Q_L}{Q_U} \Sigma g_i \qquad (27)$$

Conclusion

Monolithic ceramic block bandpass filters are preferred for many OEM and military applications since they offer a number of advantages over conventional designs in the UHF to L-band frequencies. They exhibit small size, low weight, little temperature drift (<10 ppm/degrees C), high Qu and low cost in high volume production.

This article has shown that conventional filter and transmission line theory can be applied to ceramic bandpass filters. Equivalent circuits can be generated to predict performance, and dimensions can be calculated as a basis for the

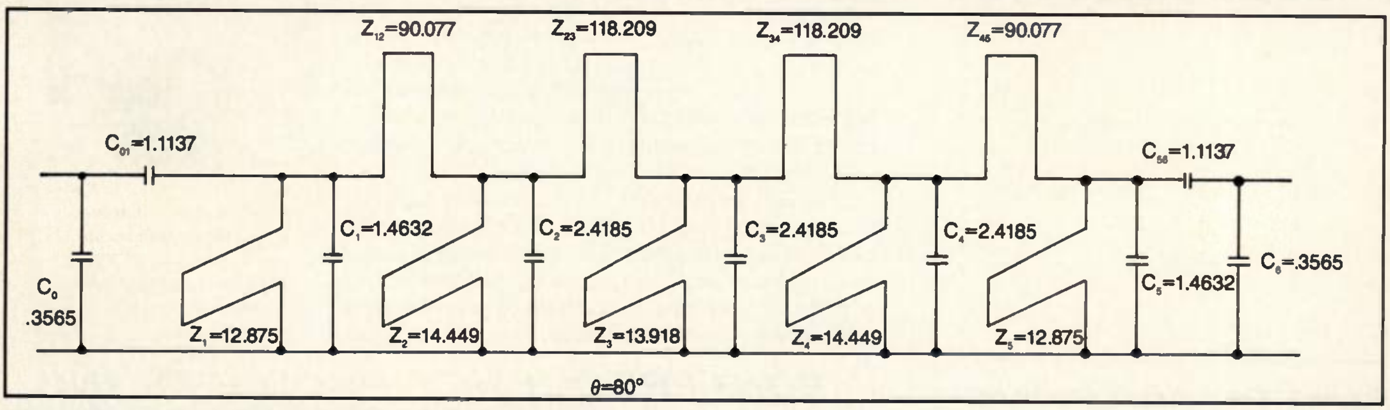


Figure 8. 1 dB ripple Chebyshev bandpass filter.

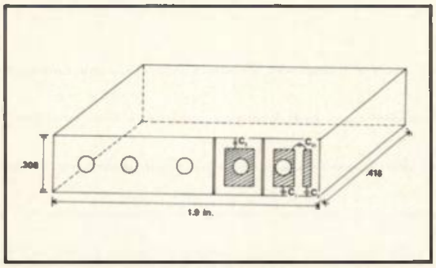


Figure 9. Individual resonators are tuned by removing metallization.

realization. As a result, filter components have improved with the use of existing theory on new materials and structures.

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2. E.G Cristal, "Coupled Circular Cylindrical Rods Between Parallel Ground Planes," *IEEE MTT, July 1964.*
3. US Patent 4431977 and Foreign Equivalents, Ceramic Bandpass Filter, Feb 14, 1984.
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About the Author

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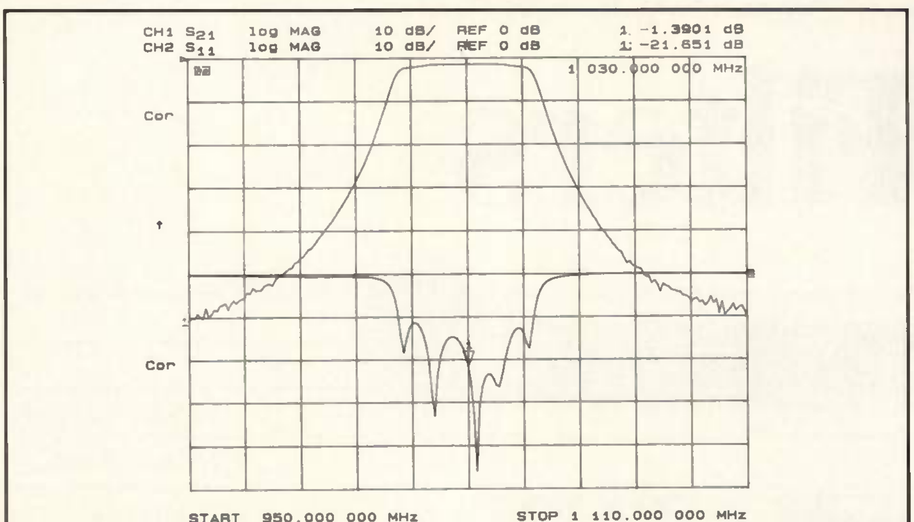

Figure 10. Measured response.

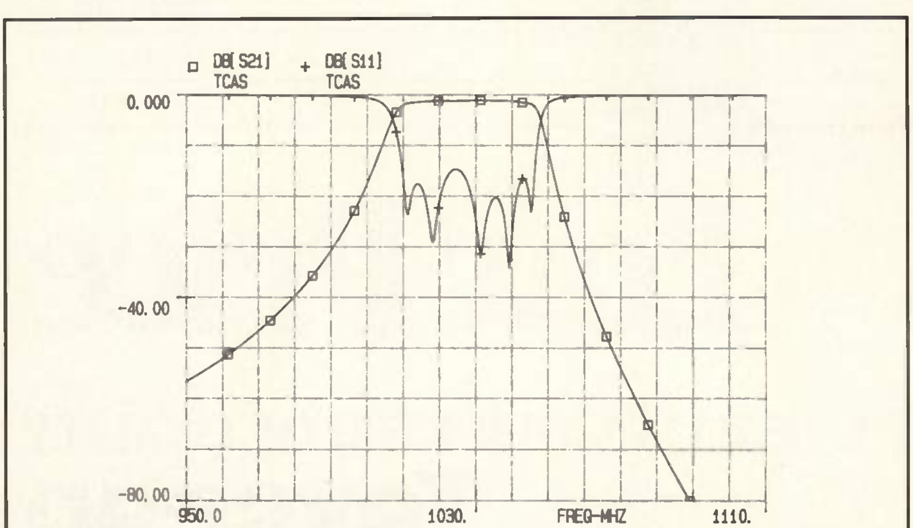

Figure 11. Simulated response.

Simulation and lab test of FSK demodulator (block diagram below)

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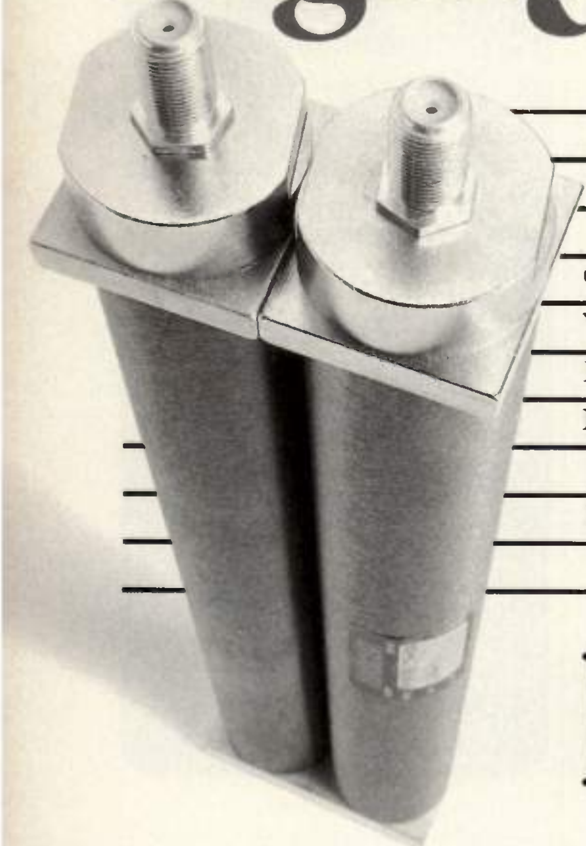

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A Design Program for Butterworth Lowpass Filters

Simplified Computation of Element Values for This Common Configuration

By David C. Greene
NAP Consumer Electronics Corp.

This article describes a computer program which determines the values of series and shunt elements in Butterworth lowpass filters. The program also can determine the required filter order for a specified stopband rejection. A computation of zero-frequency group time delay is also included.

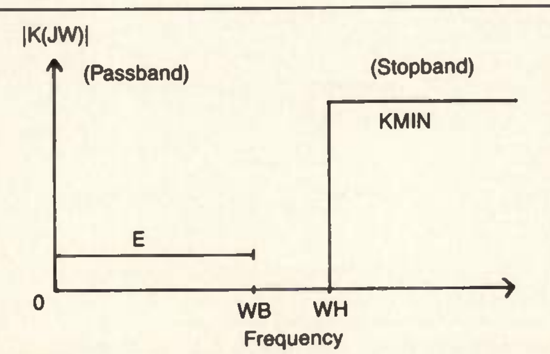
In 1936, S. Butterworth wrote a paper describing a type of filter that since has become known by his name. More precisely, his design is the Butterworth approximation which defines the Butterworth polynomial B(n). The Nth-order polynomial B(n)(W) = WN has the following properties:

B(N) (W) is a polynomial
B(N) (0) = 0
B(N) (W) is maximally flat at origin
B(N) (1) = 1

This polynomial describes a network with an attenuation given by:

A(W) = 10 LOG |H(JW)| ^ 2
= 10LOG (1 + |K(JW)| ^ 2) (1)

Then, when either H(JW) or K(JW) is infinite, the attenuation is infinite. Only when K(JW) is zero is there an attenuation zero. For an ideal lowpass filter, |H(JW)| is unity in the passband and infinite in the stopband. Since this is impossible to realize, the following practical lowpass filter characteristic function is used:



where the maximum passband loss is:

A(MAX) = 10 LOG (1 + E ^ 2)

and the minimum stopband loss is:

A(MIN) = 10 LOG (1 + KMIN ^ 2)

For the Butterworth lowpass, the characteristic function is chosen as:

K(JW) = E*B(N) * (W/W(B)), and

B(N) * (W/W(B)) = (W/W(B)) ^N

Combining these terms with equation (1) gives:

A(W) = 10 LOG(1 + (E ^ 2) * (W/W(B))^ (2*N)

Solving for the loss at WH,

A(WH) = 10 LOG(1 + (10^(.1*AMAX)–1)* (WH/WB)^(2*N))

Solving for the degree N,

N = LOG((10^ (.1*AMIN) – 1)/(10^ (.1*AMAX) –1))/(2*LOG(WH/WB))

The equation for A(W) is solved in line 380 of the program, and the equation for N is solved in line 360. For more information on the above mathematical development, see reference (1).

Determining Component Values

Orchard has derived equations to solve for the normalized component values for doubly-terminated and singly-terminated maximally flat filters. The equations for normalized values for the doubly-terminated case are:

AMAX = 3 dB, (W/WB) = 1, G(0) = 1

G(K) – 2*SIN((2*K–1)*PI/(2*N)), K = 1,2,...,N

G(N+1) = 1

These are the normalized component values solved for in lines 1000–1050 of the program.

```
THIS IS AN EXAMPLE OF USING THE PROGRAM TO DESIGN A 5TH ORDER
BUTTERWORTH LOWPASS FILTER WITH EQUAL 75 OHM TERMINATIONS. THE
3DB DOWN PASSBAND FREQUENCY IS 2MHZ AND THE STOPBAND FREQUENCY IS
4MHZ. THE FOLLOWING IS THE OUTPUT GENERATED BY RUNNING THE
PROGRAM USING THIS EXAMPLE.

Amax = 3DB,   ENTER PASSBAND FREQUENCY (FC) IN HZ ? 2E6
DO YOU KNOW THE ORDER OF THIS LOWPASS (Y/N) ? Y
WHAT IS THE ORDER (MUST BE LESS THAN 20)? 5
ENTER THE STOPBAND FREQUENCY (FS) IN HZ ? 4E6
ATTENUATION OF THIS LOWPASS AT (FS) WILL BE:  30.08663 DB  N=  5
ENTER THE TERMINATION RESISTANCES IN OHMS ? 75
SELECT TERMINATION TYPE ( 1 ) EQUAL OR ( 2 ) EXTREME ? 1

ZERO FREQUENCY GROUP TIME DELAY IN SECONDS =  25.752E-08
```

```
BUTTERWORTH MAXIMALLY FLAT LCWPASS FILTER

       ****R****       R=  75.000E+00(OHMS)
       *       *
       ****C****       C= 0.65575E-09(FARADS)
       *       *
       *       L       L= 0.96569E-05(HENRYS)
       *       *
       ****C****       C= 0.21221E-08(FARADS)
       *       *
       *       L       L= 0.96569E-05(HENRYS)
       *       *
       ****C****       C= 0.65575E-09(FARADS)
       *       *
       ****R****       R=  75.000E+00(OHMS)

TO CONTINUE PRESS <ENTER> :
TO EXIT PROGRAM PRESS <Q>
```

Figure 1. Program example.

```
50   REM    Maximally Flat Butterworth Lowpass Filter Program,
David C. Greene  2-2-1988
60   CLS : PRINT : PRINT
70   REM
80   REM
90   DIM G(20), C(20), L(20), A(20), B(20)
100  PRINT "THIS PROGRAM DETERMINES ALL THE NECESSARY PARAMETERS
TO DESIGN"
110  PRINT "EQUAL OR EXTREME TERMINATION BUTTERWORTH LOWPASS
FILTERS"
120  PRINT "DAVID C. GREENE   PHILIPS CONSUMER ELECTRONICS
CO.,KNOXVILLE,TN"
130  PRINT : PRINT : PRINT "Amax = 3DB,   ENTER PASSBAND
FREQUENCY (FC) IN HZ "; : INPUT FC
135  IF FC <= 0 THEN 130
140  PRINT "DO YOU KNOW THE ORDER OF THIS LOWPASS (Y/N) "; :
INPUT Z$
150  IF Z$ = "N" OR Z$ = "n" THEN 190
160  IF Z$ = "Y" OR Z$ = "y" THEN 170 ELSE 140
170  INPUT "WHAT IS THE ORDER (MUST BE LESS THAN 20)"; N
175  IF N <= 0 OR N > 20 THEN 170
180  GOTO 220
190  INPUT "ENTER THE MINIMUM STOPBAND ATTENUATION (Amin) IN DB
"; A2
200  IF A2 < 0 THEN A2 = -1 * A2
210  IF A2 <= 3 THEN PRINT : PRINT : PRINT "NOT MUCH OF A
LOWPASS!!...Amin<=Amax": GOTO 130
220  INPUT "ENTER THE STOPBAND FREQUENCY (FS) IN HZ "; FS
230  IF FS < FC THEN PRINT : PRINT "LOOKS LIKE A
HIGHPASS!!...FS<FC": GOTO 130
240  REM
250  IF FS = FC THEN PRINT "YOU ARE NOT LOWPASSING
ANYTHING...FS=FC!!!": GOTO 130
260  F1 = 1: F2 = FS / FC: A1 = 3
270  REM
280  REM
290  REM
300  DE = .4342944819#: DEF FNLGT (X) = LOG(X) * DE: PI = 4 *
ATN(1#)
310  REM
320  REM    Butterworth Order or Attenuation
330  IF Z$ = "N" OR Z$ = "n" THEN 360
340  A2 = 10 * FNLGT(1 + (10 ^ (.1 * A1) - 1) * (F2 / F1) ^ (2 *
N)): A = A2
350  GOTO 390
360  N = FNLGT((10 ^ (.1 * A2) - 1) / (10 ^ (.1 * A1) - 1)) / (2
* FNLGT(F2 / F1))
370  IF INT(N) <> N THEN N = INT(N) + 1
380  A = 10 * FNLGT(1 + (10 ^ (.1 * A1) - 1) * (F2 / F1) ^ (2 *
N))
390  PRINT "ATTENUATION OF THIS LOWPASS AT (FS) WILL BE: "; A;
"DB"; : PRINT "  N= "; N
400  IF N > 20 THEN PRINT "PROGRAM CANNOT ACCOMODATE THIS HIGH OF
AN ORDER!!": GOTO 130
410  IF A < A2 THEN PRINT "ORDER IS TOO HIGH !!!": GOTO 130
420  INPUT "ENTER THE TERMINATION RESISTANCES IN OHMS "; TER
430  IF TER <= 0 THEN 420
440  INPUT "SELECT TERMINATION TYPE ( 1 ) EQUAL OR ( 2 ) EXTREME
"; TEX
450  IF TEX < 1 OR TEX > 2 THEN 440
460  CR = 1 / (TER * 2 * PI * FC): LR = TER / (2 * PI * FC)
470  IF TEX = 1 AND INT(N / 2) = N / 2 THEN GOSUB 1000 ELSE 500
480  GOSUB 1200
490  GOTO 2000
500  IF TEX = 2 AND INT(N / 2) = N / 2 THEN GOSUB 1400 ELSE 550
510  GOSUB 1200
520  GOSUB 1000
530  GOTO 2000

540  REM
550  IF TEX = 1 AND INT(N / 2) <> N / 2 THEN GOSUB 1000 ELSE 580
560  GOSUB 1600
570  GOTO 700
580  GOSUB 1400
590  GOSUB 1600
600  GOSUB 1000
610  GOTO 700
620  REM
630  REM
700  REM     Printing Routine for odd order
710  PRINT : PRINT "ZERO FREQUENCY GROUP TIME DELAY IN SECONDS =
"; : PRINT USING "###.###^^^^"; TD
720  PRINT : PRINT : PRINT "  BUTTERWORTH MAXIMALLY FLAT LOWPASS
FILTER ": PRINT : PRINT
730  PRINT "          ****R****      R= "; : PRINT USING
"###.###^^^^"; TER; : PRINT "(OHMS)"
740  FOR K = 1 TO N - 1 STEP 2
750  PRINT "          *       *"
760  PRINT "          ****C****      C= "; : PRINT USING
"#.#####^^^^"; C(K); : PRINT "(FARADS)"
770  PRINT "          *       *"
780  PRINT "          *       L      L= "; : PRINT USING
"#.#####^^^^"; L(K + 1); : PRINT "(HENRYS)"
790  NEXT K
800  PRINT "          *       *"
820  PRINT "          ****C****      C= "; : PRINT USING
"#.#####^^^^"; C(N); : PRINT "(FARADS)"
830  PRINT "          *       *"
840  IF TEX = 2 THEN 900
850  PRINT "          ****R****      R= "; : PRINT USING
"###.###^^^^"; TER; : PRINT "(OHMS)"
900  PRINT : PRINT "TO CONTINUE PRESS <ENTER> : TO EXIT PROGRAM
PRESS <Q> "
910  A$ = INKEY$: IF LEN(A$) = 0 THEN 940
920  IF ASC(A$) = 13 THEN 130
930  IF ASC(A$) = 81 OR ASC(A$) = 113 THEN 950
940  GOTO 910
950  END

1000 REM    Calculation of normalized values for equal
termination
1010 FOR K = 1 TO N
1020 G(K) = 2 * SIN((2 * K - 1) * PI / (2 * N))
1030 NEXT K
1040 TD = 0: FOR K = 1 TO N: TD = TD + G(K): NEXT K: TD = TD / (4
* PI * FC)
1050 RETURN

1200 REM     Calculation of Component Values for Ever Order
1210 FOR K = 1 TO N STEP 2
1220 L(K) = G(K) * LR: C(K + 1) = G(K + 1) * CR
1230 NEXT K
1240 RETURN

1400 REM   Calculation of normalized values for Extreme
Termination
1410 FOR K = 1 TO N
1420 A(K) = SIN((2 * K - 1) * PI / (2 * N)): B(K) = (COS(K * PI /
(2 * N))) ^ 2
1430 NEXT K: G(1) = A(1)
1440 FOR K = 2 TO N
1450 G(K) = A(K) * A(K - 1) / (B(K - 1) * G(K - 1))
1460 NEXT K
1470 RETURN

1600 REM   Calculation of component values for odd order
1610 FOR K = 1 TO N STEP 2
1620 C(K) = G(K) * CR: L(K + 1) = G(K + 1) * LR
1630 NEXT K
1640 RETURN

2000 REM    Even Order Printing routine
2010 PRINT : PRINT "ZERO FREQUENCY GROUP TIME DELAY IN SECONDS =
"; : PRINT USING "###.###^^^^"; TD
2020 PRINT : PRINT : PRINT "  BUTTERWORTH MAXIMALLY FLAT LOWPASS
FILTER ": PRINT : PRINT
2030 PRINT "          ****R****      R= "; : PRINT USING
"###.###^^^^"; TER; : PRINT "(OHMS)"
2040 FOR K = 1 TO N - 1 STEP 2
2050 PRINT "          *       *"
2060 PRINT "          *       L      L= "; : PRINT USING
"#.#####^^^^"; L(K); : PRINT "(HENRYS)"
2070 PRINT "          *       *"
2080 PRINT "          ****C****      C= "; : PRINT USING
"#.#####^^^^"; C(K + 1); : PRINT "(FARADS)"
2090 NEXT K
2100 PRINT "          *       *"
2110 IF TEX = 2 THEN 2130
2120 PRINT "          ****R****      R= "; : PRINT USING
"###.###^^^^"; TER; : PRINT "(OHMS)"
2130 GOTO 900
```

Butterworth filter design program listing. This program is available on disk, **see page 64 for details.**

The equations for normalized values for single termination are:

AMAX = 3 dB, (W/WB) = 1, G(0) = 1

A(K) = SIN((2*K−1)*PI/(2*N)), K = 1,2,...,N

B(K) = (COS(K*PI/(2*N) 2,K = 1,2,...,N

G(1) = A(1)

G(K) =A(K)*A(K−1)/(B(K−1)*G(K−1)), K = 2,3,...,N

(solved in lines 1400–1470)

The actual component values for even order filters are:

L(K) = G(K)*LR
C(K+1) = G(K+1)*CR } K = 1,3,5,...,N (lines 1200–1240)

LR = TER/(2*PI*FC)
CR = 1/(TER*2*PI*FC) } (line 460)

where, TER = termination resistance, PI = π, and FC = passband −3 dB frequency.

The actual component values for odd order filters are:

C(K) = G(K)*CR
L(K+1) = G(K + 1)*LR) K = 1,3,5,...,N (lines 1600-1640)

For the calculation of group delay at zero frequency, if RS = RL (the network terminations are equal), then the group time delay as W/WB approaches zero is as follows:

$$T'(d0) = (d\Phi/dW)|W' \rightarrow 0 =$$

$$(1/2) \sum_{K=1}^{N} G(K) \text{ seconds (normalized delay)}$$

Actual Delay = T'(d0)/(2*PI*FC) (line 1040)

For extreme termination, the program goes back and calculates the G(K) values for equal termination and then computes the time delay. For more information on these equations, see reference (2).

The Program

A program has been written in Microsoft QuickBasic™ to solve the above expressions and calculate the component values for a given filter. The program prompts for passband frequency WB and the attenuation at this point, AMAX (default is 3 dB). It then asks if the order N of the filter is known. If it is, the stopband frequency WH is requested and the attenuation AMIN at WH is calculated. If the order is not known, the program prompts for minimum stopband attenuation AMIN and the stopband frequency WH. From here, the program calculates the required order N.

At this point, the program prints out the stopband frequency, the attenuation at this frequency, and the order N of the filter. It then asks for the termination resistance in ohms and the termination type, equal or extreme. The normalized component values are calculated and from these the normalized group delay at DC is calculated and denormalized to give actual group delay for the passband frequency FB. The actual component values are then calculated and printed out in such a format as to form the connection schematic diagram for the filter network.

Figure 1 is an example of program operation for a 5th order filter with equal 75 ohm terminations. The 3 dB down passband frequency is 2 MHz and the stopband frequency is 4 MHz.

For this example, the program has calculated an attenuation of 30.08 dB at 4 MHz using the specified N = 5. The group delay at DC is calculated to be 257.5 nanoseconds. The connection schematic is printed showing the equal 75 ohm terminations, with inductors equal at 9.65 μH, equal end capacitors of 655.7 pF, and the center capacitor at 2122 pF.

One note about program operation: Output data for filters larger than 9th order will scroll off the screen. Use a scrolling program (such as "Snipper" from *PC Magazine*) to allow you to look at the complete results. There are also programs to make the printer follow the screen display, allowing the entry data and computation to be saved.

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

References

1. Richard W. Daniels, *Approximations Methods for Electronic Filter Design*, McGraw-Hill, 1974, pp. 7-12.
2. Matthaei, Young, and Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, McGraw-Hill, 1964, pp. 83-113.

About the Author

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EMC News Report

This month, RF Design *takes a look at some EMC-related news items in this column. The highlights include the NAB's disagreement with the FCC proposal for AM interference reduction, a new Canadian EMI standard, and a report on EMC growth in the United States. Various EMC-related publications are also mentioned.*

NAB Contests FCC Proposal to Reduce AM Interference

The National Association of Broadcasters (NAB) disagrees with a Federal Communications Commission (FCC) approach to combatting adjacent channel interference for AM radio. NAB contends that the agency should not adopt the National Radio Systems Committee NRSC-2 standard as the sole means for reducing interference before it implements the initial NRSC-1 standard.

The two standards are complementary systems designed to improve the quality of the AM broadcast signal and reduce interference. The initial implementation of NRSC-1 would foster the improved manufacture of receivers, which in turn would improve the quality of AM broadcasting as heard by the public. NRSC-2 builds on these receiver improvements by providing additional safeguards against distortions in the transmitted signal.

In its filing, NAB pointed out that the NRSC-1 standard, in addition to being designed to reduce interference to adjacent channels, is intended to aid manufacturers in developing high-fidelity receivers keyed to the NRSC characteristics of AM transmission. NAB said that this meets the policy goals of the Commission, the AM radio industry, and the public by improving the AM broadcast band.

NAB also expressed its opposition to an FCC proposal to eliminate restrictions concerning daytime contour protection, because it would only increase interference in the already congested AM band.

Directory of Federal Labs

This directory guides readers to hundreds of Federal agencies, laboratories, and engineering centers willing to share their expertise, equipment and sometimes even their facilities to aid in U.S. research efforts. Price is $36.00. To order specify PN PB88-100011/CAU from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 or call (703) 487-4600.

New Canadian EMI Standard

Recently, the Canadian Gazette Part II published new mandatory Canadian EMI standards. According to these standards, as of January 31, 1989, all digital apparatus manufactured, modified or imported into Canada must be compliant. It is important to note that the Gazette notice spells out that after the January 31, 1989 deadline there will be no "grandfathering-in" of equipment currently being sold in Canada. The Canadian standards are technically equivalent to the U.S. Federal Communications Commission (FCC) EMI standards.

Seminar Proceedings

The National Technical Information Service (NTIS) has announced the availability of a report summarizing a seminar sponsored by ERA Technology of Leatherhead, Surrey, England entitled EMC Susceptibility of Electronic Equipment in Civil and Military Applications. The seminar focused on the fact that the increasing use of electronic systems and the harsh electromagnetic environments in which they must operate reliably make it important to consider susceptibility and immunity at the early stage in the design, development, and installation of electronic systems.

A total of 10 papers were presented at this seminar covering standards, civil and military issues relating to susceptibility. The cost is $130. To obtain a copy of these seminar proceedings, contact the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Tel: (703) 487-4650. Request ERATL88/01/KJP, *EMC Susceptibility of Electronic Equipment in Civil and Military Applications — Seminar Proceedings.*

Grounds Improve Imaging Room

The UCLA Medical Center selected a Lyncole XIT grounding system to improve image clarity and continuity of its Magnetic Resonance Imaging (MRI) room. Recent testing of the electrolytic ground proved that the patented rods continue to lower resistivity over time.

Continuous testing, using the same current and range, has revealed that the resistance of UCLA's grounding system has dropped from 0.523 ohms upon installation to 0.505 ohms 18 months later. For the MRI user, that translates into improved images.

MRI equipment, which provides cross-section images of patients' bodies, requires a low resistance ground to maintain image clarity and to provide protection for equipment, personnel and patients. The sophistication of MRI equipment demands an environment free of radio frequency and other electromagnetic interference.

The grounding system used for this installation uses a unique electrolytic process. Metallic salts used inside the system's copper tube absorb moisture and form an electrolytic solution which filters out through holes to form roots in the soil. The result is a continuing reaction in the ground resistance. Additional information may be obtained from Lyncole XIT Grounding, 22412 South Normandie Ave., Torrance, CA 90502. Tel: (213) 320-8000.

Army Considers EMI Protection for the Black Hawk

According to a report in *Defense Electronics* (January 1989), Sikorsky Aircraft, Stratford, Conn., has delivered its 1000th UH-60 Black Hawk helicopter to the Army and plans to produce and develop upgraded versions that will include enhanced survivability and safety features. Among the features being considered are methods to protect Black Hawks from electromagnetic interference (EMI). The Army said that the helicopters are expected to be hardened to withstand EMI of 200 volts per meter — a specification identical to that of the SH-60B Seahawk, the Navy's Black Hawk variant. If the entire UH-60 fleet becomes EMI-hardened, the total cost could approach $450 million. Sikorsky would not be responsible for paying this amount because it met the aircraft's original hardness specifications, the Army said.

Some of the news items reported here were reprinted with permission from Electromagnetic News Report (ENR). ENR *is published by Liberty Labs, Inc., 4920 Johnson Ave. NW., Cedar Rapids, IA 52405. Tel: (319) 390-3646.* rf

A Microwave Oven to Amateur TV Transmitter Conversion

By David Pacholok
Creative Electronics Consultants

There are still a few areas where amateur radio experimentation can be a significant contributor to the advancement of engineering. Two of those areas, microwave communications and low-cost equipment, are represented in this unusual application. The author has developed a method of converting a microwave oven into a transmitter with acceptable performance for amateur television. This design was a prize winner in the 1988 RF Design Awards Contest.

The past twenty years have seen a change in the amateur radio community, away from that which sparked an interest in RF engineering among many people who today practice the profession. As youths, they often had no choice but to build their own equipment, given the economic realities of the day. The low-cost imports of recent years have changed all that, and amateur radio has gone from a substantial source of technical innovation to a substantial consumer of technically innovated products.

Most amateur allocations lie above 1300 MHz, yet one can often scan those bands and hear nothing but kTB noise. The common conception is that microwave equipment is complex, expensive, or just unavailable. The overall design goal here was to provide an inexpensive, relatively simple high power microwave transmitter using a microwave oven as the foundation. The goals were these:

1. Low cost, < $200.

2. High power output, 250 watts minimum.

3. Parts readily available from consumer electronic supply houses.

4. Emission type compatible with standard low-cost B/W television receivers.

5. Frequency of emission in the 2390-2450 MHz amateur band, compatible with MDS TV downconverters. Historically, these have been misused to "pirate" television movie distribution at 2156 and 2162 MHz. Tens of thousands of these downconverters are in existence, having been widely sold through magazine advertisements and electronic flea markets.

6. The basic transmitter scheme should be adaptable to other emission modes,

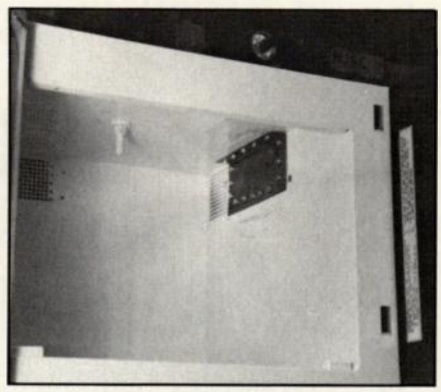


Figure 1. Interior of oven with waveguide short in place.

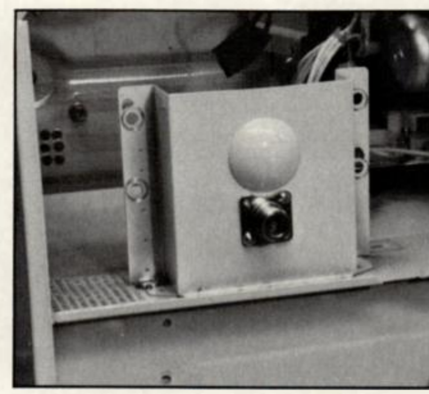


Figure 2. Close-up of TE_{10} waveguide with E-field probe installed.

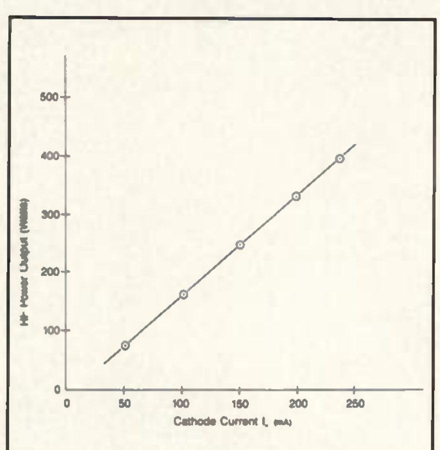


Figure 3. Power output versus I_k.

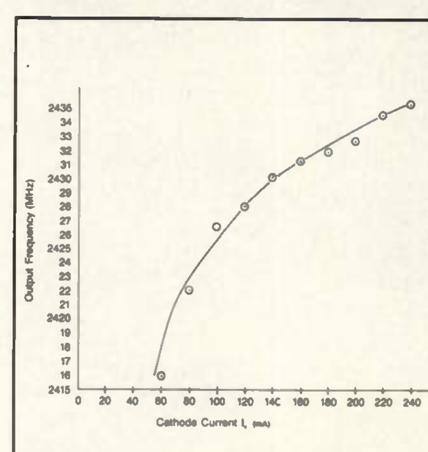


Figure 4. Frequency versus I_k.

such as narrow-band FM, with additional phase-lock circuitry.

Magnetron Characteristics

A microwave oven magnetron is a self-contained, crossed-field power oscillator. Built-in cavities primarily determine oscillation frequency, with anode voltage and magnetic field having a second-order effect on this parameter.

First, the magnetron cavity was modified to couple RF to a transmission line instead of the oven compartment. This is shown in Figures 1 and 2. The interior radome/splatter cover, field stirrer blades, and magnetron output matching section were removed. The waveguide open end was then shorted with a plate and an E-field probe installed to couple the RF to an N-connector output jack. Magnetron current, voltage, and frequency were measured and plotted independently to quantify performance in this modified cavity. Figures 3, 4, and 5 present this data, which leads to the following conclusions:

1. The 2M189A magnetron is a current-operated device — anode-to-cathode voltage changes only about 1 percent with a 2:1 change in cathode current (I_k).

2. Power output is a linear function of I_k.

3. Output frequency is a non-linear (but monotonic) function of I_k, with increased current causing an operating frequency

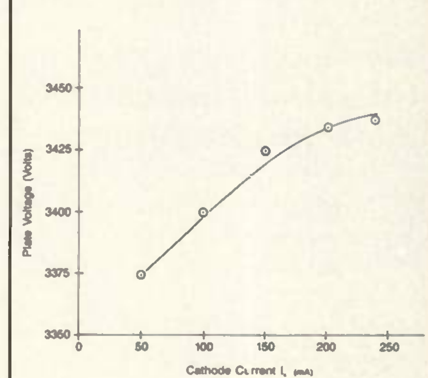


Figure 5. Plate voltage versus I_k.

increase. The average frequency "pushing" coefficient is about 0.1 MHz/mA, with a useful frequency swing of about 20 MHz.

From this, AM double-sideband video was ruled out, owing to the large incidental FM that would result. On the other hand, an FM deviation of 2 MHz would cause incidental AM of only 15-20 percent, so wideband FM video transmission was investigated.

To check compatibility with existing TV receivers, an FM video modulated signal generator was used as a signal source for an MDS downconverter and 5-inch monochrome receiver. With the television adjusted for IF slope detection, a fair quality picture was obtained, with sync and vertical lock achieved at deviations of 700 kHz to 3.0 MHz. Best picture quality occurred at 2.2 MHz deviation.

Modulator Circuit Description

The modulator serves two purposes. First, it is a high-voltage current source with high open-loop gain, setting the magnetron current to a known value, establishing a frequency and power output. Referring to the circuit diagram in Figure 6, U2, a 7805 5-volt regulator, establishes a reference voltage adjusted by R5 and R6. This is applied to the non-inverting input of high-speed op amp U1, which drives source follower Q1. The output of Q1, plus R9 and R7 provide negative feedback to U1 in the ratio 5.7:1. At equilibrium, Q1's drain-source current produces a voltage drop across R11 that equals 5.7 times U1's non-inverting voltage.

Temporarily ignoring screen grid current, plate current equals cathode current in V1(a,b combined). Since V1's cathode current equals Q1's drain current, V_D rises or falls until the V1 grid 1-to-cathode bias causes $I_P = I_k = I_D = I_S$. V1 is therefore a grounded-grid voltage amplifier with a current gain of unity, with enough voltage capability to drive the magnetron. However, to an input voltage at U1, a transconductance amplifier is formed, with transconductance given by:

$$\frac{\Delta I}{\Delta V} = \left(\frac{R9 + R7}{R7}\right)\left(\frac{1}{R11} + \frac{1}{R9 + R7}\right) = .22\ \mho$$

Bandwidth of this amplifier must be sufficient for the modulator's second purpose — video modulation. This must be 4.5 MHz if an audio subcarrier is to be included. Frequency response measured with a current probe in the plate leads of V1 was down 4 dB at 4.5 MHz. Adding C6 (1200 pF) provides a pole for this frequency, flattening the response to beyond 6 MHz. C1 and R8 are provided to couple an external 4.5 MHz subcarrier generator to the modulator.

A floating screen supply of about +100 volts is provided, with R28 included to limit screen dissipation. The floating supply allows only plate current (magnetron current) to be included in the control loop. Additional component functions are: R3, R14 and R15 prevent parasitic oscillation in U1 and V1, R12 and R13 aid current sharing in V1a and V1b, D3 protects Q1 in the case of V1 arc-over, and conventional power supply rectifiers, filters and bleeders are used.

Waveguide/Cavity Operation

The waveguide circuit is deceptively simple. The oven's TE_{10} waveguide feed (from tube to cavity) is shorted with a copper plate. This is analogous to a coaxial or microstrip short, where wavefronts are reflected back with a 180 degree phase inversion. At a quarter guide wavelength from the short,

$$\lambda g = \frac{\lambda}{\sqrt{(\lambda/\lambda c)^2 - 1}}$$

where λc = 2X guide broadwall dimension

The reflection is in phase with the incident wave from the magnetron, and an E-field probe is inserted at this voltage maximum. Ordinarily, maximum power transfer occurs when this probe is $\lambda/4$ in length. Deliberately shortening the probe introduces a reactive mismatch at the magnetron output port. After an unknown number of degrees rotation within the feed structure (Matsushita would not provide tube data), this causes the magnetron to be pulled lower in frequency by some 25 MHz from its design frequency, ensuring legal amateur band operation.

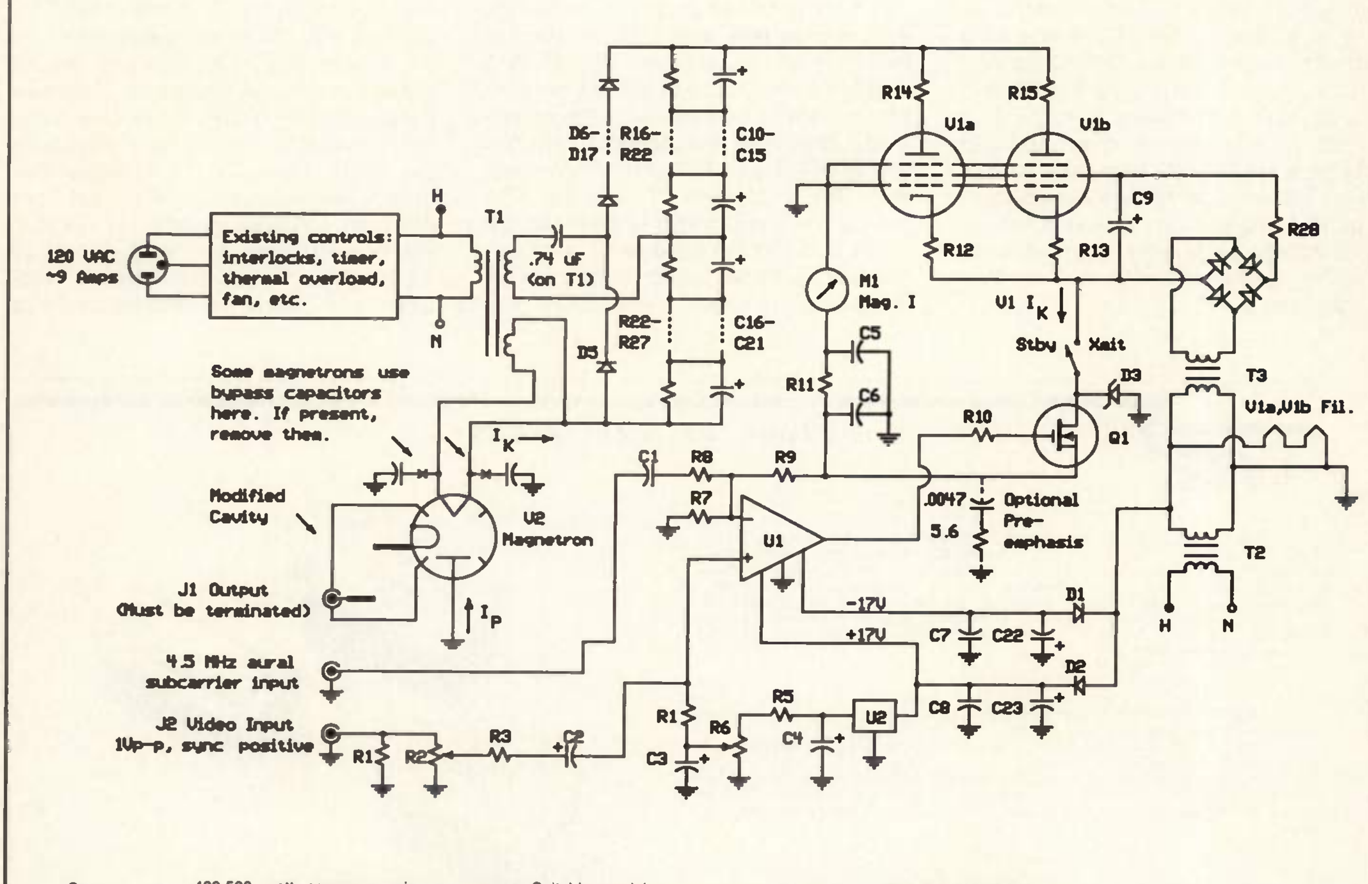
One important feature of this conversion is the modification of the high voltage power supply for floating operation. The original power transformer had one end of the secondary grounded to the frame. This was lifted and attached to a high-voltage lead wire. Hi-pot tests sat twice the rated voltage confirmed this modification to be reliable. This modification eliminates the need to float the entire modulator above ground, which also requires video-bandwidth opto-isolators.

Performance

Spectrum analyzer photos indicate the performance of the transmitter. Figure 7 shows carrier and noise skirts with no modulation. The Bessel null display in Figure 8 shows that the modulation is primarily FM. Figure 9 is a spectral display of a video signal (cross hatch pattern) at 2.5 MHz deviation.

Additional Comments and Observations

Narrow band FM (± 5 kHz deviation) requires a clean RF source low in noise and incidental FM. A phase-lock or frequency-lock loop can be used, with the non-inverting input of U1 being equivalent to the varactor control voltage in a conventional VCO. The usual considerations for prescaling, low-noise reference, loop gain and loop bandwidth all should be followed. The author has developed a circuit suitable for narrow-



Oven	400-500 watt consumer microwave oven. Suitable models include Hotpoint RE6002, Whirlpool MW 1000XS-0 or MW 1200XS-0, Tappan 56-1007-10/02, and Goldstar ER-4020.
V1a,b	6JE6/6LQ6
V2	2M189A or 2M226A magnetron
Q1	VN66AF or similar power FET
U1	LF357 wideband op amp
U2	7805 regulator
D1, D2	1N4001
D3	1N4760, 68V, 1W zener diode
D4	1 amp, 200 PIV bridge rectifier
D5	10 kV, 250 mA diode
D6 - D17	1N4007
C1	.001 uF ceramic
C2	10 uF, 25V
C3, C4	100 uF, 10V
C5	330 uF, 6.3V
C6	1200 pF polystyrene
C7, C8	0.1 uF ceramic
C9	47 uF, 160V

C10 - C21	100 uF, 400WVDC
C22, C23	470 uF, 25V
R1	390 ohm
R2	100 ohm panel-mount potentiometer
R3, R8, R9	470 ohm
R4, R5	3.3 kohm
R6	1 kohm p.c. mount potentiometer
R7	100 ohm
R10	22 ohm
R11	27 ohm, 1 W
R12, R13	120 ohm, 1 W
R14, R15	100 ohm, 1 W
R16 - R27	470 kohm, 1/2 W
T1	Magnetron plate and filament transformer
T2	117 VAC to 12.6 VAC 3.0 A
T3	117 VAC to 12.6 VAC 450 mA
M1	0-200 mA DC
S1	SPST, 0.5 A 125 V
J1	Type "N" female panel mount connector

Figure 6. Circuit diagram for the complete transmitter.

band FM phase-locked operation. Interested readers can contact him for details.

Warmup drift is significant over the first ten minutes of operation, representing about 15 percent of the available tuning range (2.5 MHz). A simple frequency-lock loop could be used to stabilize this drift if it is deemed unacceptable.

Avoid magnetron "moding," appearing on a spectrum analyzer as a comb instead of a CW signal. This can be caused by a VSWR greater than 1.5:1, or by operation below about 50 mA. If low power operation is desired, raise the filament voltage to 3.4 - 3.6 V, since internal RF contributes to proper filament (cathode) temperature in normal operation.

If used with a true FM television receiver, such as a modified satellite TVRO unit, the simple pre-emphasis network shown on the schematic diagram will improve video S/N by up to 10 dB. Also, TVRO receivers use greater than 20 MHz IF bandwidth, greatly reducing the effects of warmup drift.

Small "hum bars" are visible in the picture, due to the floating high-voltage power supply. The effect is caused by the 60 Hz switching of the diodes, varying the capacitance to ground at the magnetron cathode. These transients are out of the control loop. Grounding the power supply and floating the modulator at high voltage is a solution, as is floating the magnetron and cavity. Either would increase circuit complexity and increase exposure to hazardous voltages.

As with any non-locked oscillator, a change in system load impedance will change the frequency of operation. A high power isolator is one solution, albeit an expensive one. A stretch line was used to measure the load pulling effects of a 1.5:1 VSWR over all phase angles. Frequency was observed to change ± 6 MHz as the phase angle was varied. At the design frequency of 2430 MHz, all modulating products should remain within the amateur band. This is not a trivial problem, and may require line trimming or line stretchers to place the phase angle in a stable region. The lowest possible antenna VSWR is the best solution to the line-pulling problem.

Finally, safety is paramount. 4 kV DC and high power microwave energy are present in the transmitter. An inexpensive microwave leakage detector should be used to check the integrity of the modified unit, and door interlocks should be retained (the modulator was installed in the now-unused cooking cavity). Antennas can easily have high gain at this frequency, so avoid pointing them at people, buildings, etc.

Conclusion

Although this is not a "high performance" television transmitter, it represents a low-cost effort to achieve significant power output at microwave frequencies. Some of the shortcomings of this configuration are discussed above, along with possible improvements.

About the Author

David Pacholok is the Chief Engineer of Creative Electronics Consultants, 1815 W. Higgins Road, Sleepy Hollow, IL 60118, providing design services for switchmode power supplies, electronic ballasts, and RF/microwave product development. He holds a BSEE from Oakland University. Dave can be reached by telephone at (312) 428-5676.

INFO/CARD 48

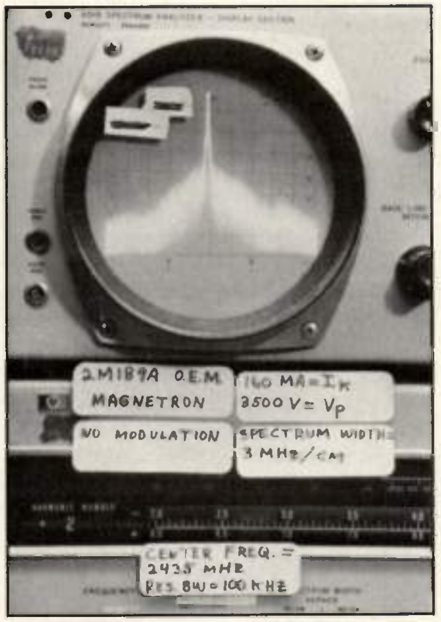


Figure 7. Carrier and noise skirts of unmodulated magnetron.

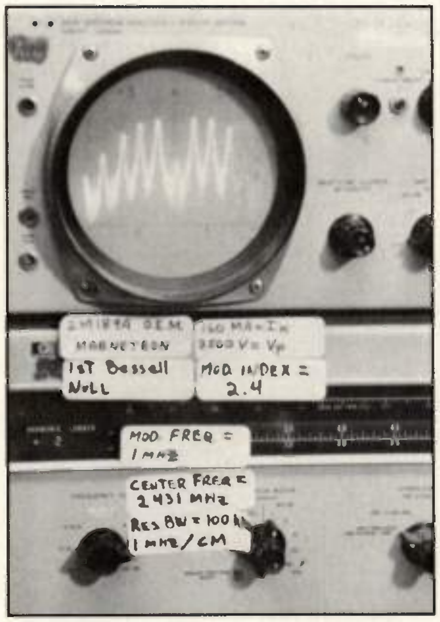


Figure 8. Bessel null display showing primarily FM modulation. I_k variation from + to − deviation is 130-200 mA.

Figure 9. Spectrum display of emitted signal, with cross hatch pattern modulation, 2.5 MHz deviation.

A Parallel-Coupled Resonator Filter Program

By Andrew W. Westwood
Hughes Network Systems

This program serves as an aid in the design of Parallel-Coupled Transmission Line Resonator Filters (PCTLRF), a form familiar to most microwave engineers. While this form is commonly used at C-band and above on ceramic or PTFE compound printed circuit boards, the author's design group has found that in an L-band application, it provides performance that no other inexpensive filter type satisfies.

A recent application is an FR-4 based 7.5 percent bandwidth filter centered at 1.35 GHz, where helical and dielectric resonator filters are not readily available, and where lumped-element implementations either are unrealizable or require excessive alignment time. PCTLRFs are intrinsically inexpensive, with real estate consumption being the only severe drawback. If required at all, tuning is minimal.

While calculations for element parameters are straightforward, the decision process for various applications was found to involve choosing an appropriate characteristic and proceeding with several assumptions, only to find that the resulting filter was mechanically unacceptable. The program includes an idealized response projection section that solves this problem.

Operation of the program begins with prompts asking for the number of resonators, Butterworth or Chebyshev filter type, impedance information, with output impedance and passband ripple requested for the Chebyshev case. The user may then choose to see an idealized amplitude response plot, with an option to see the response from center band out to a selected number of passband multiples.

Following the satisfactory selection of filter parameters, the even and odd impedance of the microstrip coupled pairs necessary to form the filter are presented. Several common CAD programs and algorithmic formulas can determine the mechanical realization of these sections from this information. When the proper substrate material is chosen, bandpass filters with 0.1 to 15 percent passband widths, from L-band through 30 GHz are possible. One quick tip: don't forget to compensate for the stray capacitive coupling to ground at the open sections on the filter. This coupling "stretches" the effective line length. Also, the response plots are ideal; allow for more practical results.

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

References

1. Seymour B. Cohn, "Parallel-Coupled Transmission Line Resonator Filters," *IRE Transactions on MTT*, April 1958, pp. 223-231.
2. Seymour B. Cohn, "Direct Coupled Resonator Filters," *Proceedings of the IRE*, Vol. 45, February 1957, pp. 187-196.
3. S. Akhtarzad, T. R. Rowbotham, and P. B. Johns, "The Design of Coupled Microstrip Lines," *IEEE Transactions on MTT*, June 1975, pp. 486-492.
4. R. J. Wenzel, "Exact Design of Wideband (and Narrowband) Bandpass Filters on the Insertion Loss Basis," *IRE Transactions on MTT*, November 1960, pp. 580-593.

About the Author

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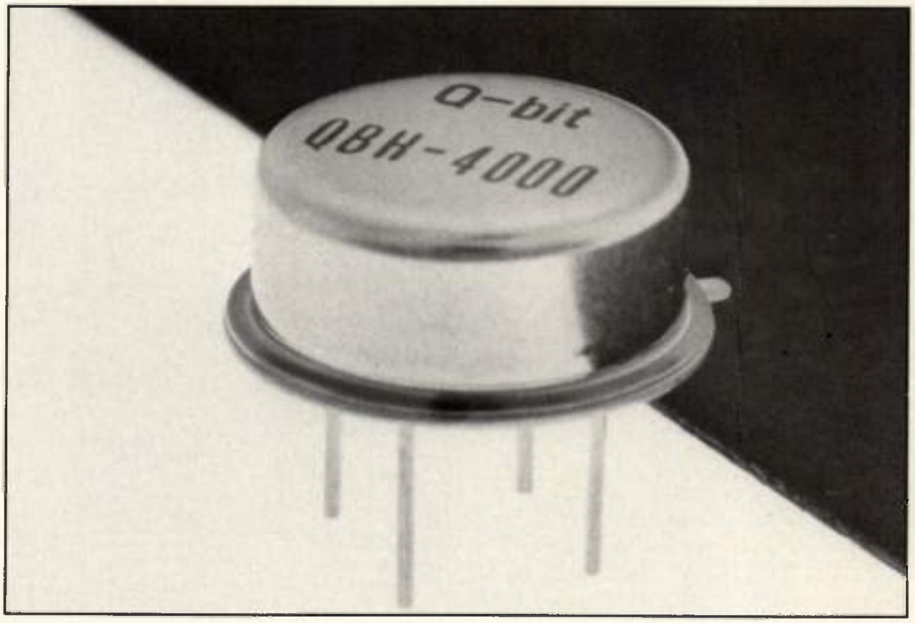
```
Print
Print
Print
Print
Print "Welcome to the Parallel Coupled Transmission Line Resonator Filter"
Print "Computer Aided Design (PCTLRF CAD) program."
Print
Print
Print
Print
Print "This program assists in the design of printed circuit RF filters"
Print "of the PCTLR form.  The program will prompt you to enter basic"
Print "design information regarding the filter, and will give you the"
Print "the opportunity to view an idealized filter response prior to "
Print "proceeding with the filter calculation.
Print
Print "When considering the values for your filter, remember that"
Print "PCB material `Q' and imperfect coupling will hold results to"
Print "familiar skirt slopes, and a typical maximum of 70 dB out-of-"
Print "band (OOB) rejection.  Good layout and sheilding will make a"
Print "dramatic difference."
Print
Print "Please press `Return' key to continue.  Ready";
Input A

    REM ######## TRIG FUNCTION DEFINITIONS ########

DEF FNARCOS(X)=1.570796+ATN(X/(SQR(1-X^2)))
DEF FNCOSH(X)=(2.718281828^X+2.718281828^-X)/2
DEF FNARCOSH(X)=LOG(X+(X^2-1)^0.5)
DEF FNSINH(X)=1/2*(2.718281828^X-(1/2.718281828^X))
DEF FNTANH(X)=FNSINH(X)/FNCOSH(X)
DEF FNCOTH(X)=1/FNTANH(X)

    REM ************ BEGIN MAIN BODY *******************

    REM ######## QUESTIONS COMMON TO TCHEB AND BUTTER ########

BEGIN:
CLS
Questions:
Print "How many resonant elements do you wish to have in the filter"
Print "an integer between 1 and 15)";
Input N
Print

Print "What is the fundamental characteristic impedance of the filter"
Print "Note: Default is 50 Ohms";
Input O
If O=0 then O=50
Print
Print "Which type of filter response do you wish (`B' for Butterworth"
Print "or `T' for Tchebycheff)";
Input R$
Print

Print "Do you wish to see and idealized filter response in graphical form"
Print "(Y or N)";
Input T$
Print

If T$="Y" or T$="y" then Gosub FILRES

IF R$="B" OR R$="b" THEN GOTO BUTTER

Print "Please be advised that unless the number of sections in a "
Print "Tchebycheff filter is odd, the terminating impedance cannot be"
Print "the same as the characteristic impedance.  Please choose now"
Print "whether you wish to see the correct terminating impedance or "
Print "continue with the filter calculations.  Your choice (C for "
Print "continue, I for impedance)";
Input C$

If C$="I" or C$="i" THEN GOTO TERMIMP
GOTO TCHEB
```

```
    REM ######## THIS SECTION CALCULATES BUTTERWORTH IMPEDANCES ########
CLS
BUTTER:
CLS
Print
Print "Please enter your center frequency in the following format:"
Print "GG.MMMKKK Gigahertz";
Input CF
Print

Print "Please enter your lower 3dB point and then your upper 3dB point"
Print "(Format GG.MMMKKK,GG.MMMKKK)";
ENTRY:
Input LF,UF
IF LF=<UF THEN GOTO BAND
PRINT "UNACCEPTABLE VALUES, PLEASE TRY AGAIN."
GOTO ENTRY
BAND:
DIM G(15)
Let G(0)=3.141593*((UF-LF)/(UF+LF))
Let G(N+1)=G(0)

For V=1 to N
G(V)=2*sin(((2*V-1)*3.141593)/(2*N))
Next V

    REM ######## CALCULATES PROTOTYPE ELEMENTS ########
DIM I(16)
For L=1 to N+1
Let I(L)= G(0)*SQR(1/(G(L-1)*G(L)))
Next L

    REM ######## CALCULATES EVEN AND ODD IMPEDANCES ########
DIM ZO(15)
DIM ZE(15)
For B= 1 to N+1
ZO(B)=O*(1-(I(B)*I(B)+I(B)))
ZE(B)=O*(1+(I(B)*I(B)+I(B)))
Next B

PRINTER:
    REM ######## PRINTS OUT ODD AND EVEN IMPEDANCES ########
PRINT
X$="SECTION NUMBER" : Y$="     EVEN IMP"  :Z$="          ODD IMP"
PRINT X$;Y$;Z$
For C= 1 to N+1
PRINT "       ";C;"          ";ZE(C);"        ";ZO(C)
NEXT C
PRINT
PRINT "DO YOU WISH TO CONTINUE";
INPUT O$
IF O$="Y" OR O$="y" THEN GOTO BEGIN
PRINT "I HOPE THIS PROGRAM HAS BEEN USEFUL, AND IF ANY FURTHER"
PRINT "INFORMATION OR SUGGESTIONS ARISE, FEEL FREE TO CONTACT ME."


TCHEB:
    REM ######## THIS SECTION CALCULATES TCHEB IMPEDANCES ########

    REM ######## TCHEB COEFFICIENTS ########
DIM a(15)
DIM b(15)
DIM j(15)
CLS
IF E<>0 THEN GOTO SKIP
Print "What do you wish the peak amplitude ripple across the passband"
Print "to be (in dB)";
Input E
Print

SKIP:

BET=LOG(FNCOTH(E/17.37))
GAM=FNSINH(BET/(2*N))
FOR k=1 TO N
a(k)=SIN(((2*k-1)*3.141592)/(2*N))
b(k)=GAM^2+(SIN(K*3.141592/N))^2
NEXT k
j(1)=2*a(1)/GAM
For k=2 to N
j(k)=(4*a(k-1)*a(k))/(b(k-1)*j(k-1))
Next k

Print
Print "What is the filter center frequency (in the format"
Print "GG.MMMKKK Ghz)";
Input CF
Print
Print "What are the lower and upper passband cutoff frequencies"
Print "(in the format GG.MMMKKK,GG.MMMKKK Ghz)";
Input LF,UF
Print
j(0)=3.141593*((UF-LF)/(UF+LF))
j(N+1)=j(0)

    REM ######## CALCULATES PROTOTYPE ELEMENTS ########
For L=1 to N+1
Let I(L)= j(0)*SQR(1/(j(L-1)*j(L)))
Next L

    REM ######## CALCULATES EVEN AND ODD IMPEDANCES ########
For B=1 to N+1
ZO(B)=O*(1+I(B)^2-I(B))
ZE(B)=O*(1+I(B)^2+I(B))
Next B
GOTO PRINTER

FILRES:  REM ##########################################
         REM ######## FILTER RESPONSE ROUTINE ########
         REM ##########################################

If R$="T" or R$="t" THEN GOTO TCRES
CLS
PRINT
PRINT
PRINT
Print "This routine will display an idealized filter response"
Print "over a specified band of frequencies, starting at zero radians"
Print "and ending at N times the normalized 3dB cutoff frequency."
Print
Print "What do you wish the multiplier (N) to be";
Input M

    REM ######## BUTTERWORTH ATTENUATION ROUTINE ########
CLS
U=10*(LOG(1+(M+1)^(2*N))/LOG(10))
SCREEN 2
For Q= 0 to M+1.1 step 0.1
A=10*(LOG(1+Q^(2*N))/LOG(10))
PSET (640*(Q/(M+1)),200*(A/U))
IF ABS(INT(Q)-Q)<.1 THEN GOSUB WO
NEXT Q
GOTO QUES:

WO:
LINE-(640*(Q/(M+1)),200)
DIM ATTN(15)
ATTN(Q)=FIX(A)
RETURN

QUES:
LOCATE 24,1
L=74/(M+1)
PRINT "0dB";
FOR Q=1 TO M+1
LOCATE 24,L*Q
PRINT ATTN(Q);"dB";
NEXT Q

LOCATE 2,35
PRINT "<VALUES AT MULTIPLES OF 3 dB BW!>"
LOCATE 4,45
Print "Now, do you wish to perform"
LOCATE 5,45
PRINT "element calculation routines,"
LOCATE 6,45
PRINT "or return to parameter selection"
LOCATE 7,45
PRINT "(`C' for calc., `P' for param.)";
Input F$
If F$="P" or F$="p" then GOTO Begin
RETURN
    REM ######## TCHEBYCHEFF ATTENUATION ROUTINE ########

TCRES:
CLS
Print "This routine will display and idealized filter response "
Print "based on the following conditions: 1) If the user desires"
Print "to see only the passband, enter a `1' for the requested"
Print "number of cut-off multiples, 2) If any other number is entered,"
Print "attenuation values will be displayed at multiples of the cut-off"
Print "bandwidth.  The graph starts at zero radians."
Print
PRINT "What do you wish the peak passband attenuation to be (in dB)";
Input E
Print
Print "What do you wish the number of cut-off multiples to be";
Input M

    REM ######## TCHEB CALCULATIONS ################
CLS
SCREEN 2
U= 10*(LOG(1+(10^(E/10)-1)*((FNCOSH(N*FNARCOSH(M)))^2))/LOG(10))
IF M=1 THEN V=E
IF M>1 THEN V=U
For Q=0 to 1 Step 0.02
A= 10*(LOG(1+(10^(E/10)-1)*((COS(N*FNARCOS(Q)))^2))/LOG(10))
PSET ((640*Q/M),(200*A/V))
NEXT Q
IF M=1 THEN GOTO QUEST

For Q=1 to M+M/20 Step M/20
A= 10*(LOG(1+(10^(E/10)-1)*((FNCOSH(N*FNARCOSH(Q)))^2))/LOG(10))
PSET ((640*Q/M),(200*A/V))
IF ABS(INT(Q)-Q)< M/25 THEN GOSUB WO
NEXT Q

LOCATE 24,1
PRINT "0dB";
FOR Q=1 TO M
LOCATE 24,74*Q/M
PRINT ATTN(Q);"dB";
NEXT Q
GOTO QUEST

WO:
LINE-(640/(M)*Q,200)
ATTN(Q)=FIX(A)
RETURN
QUEST:
LOCATE 2,35
PRINT "<VALUES AT MULTIPLES OF CUT-OFF BW!>"
LOCATE 4,45
Print "Now, do you wish to perform"
LOCATE 5,45
PRINT "element calculation routines,"
LOCATE 6,45
PRINT "or return to parameter selection"
LOCATE 7,45
PRINT "(`C' for calc., `P' for param.)";
Input F$
IF F$="P" or F$="p" then GOTO Begin
GOTO TCHEB

TERMIMP:
CLS
Print "What do you wish the peak amplitude ripple across the passband"
Print "to be (in dB)";
Input E
R=O*(FNTANH(LOG(FNCOTH(E/17.37))/4))^2
PRINT
PRINT "The resistive termination of your filter must be";R;"ohms, to"
PRINT "acheive a proper match."
PRINT
PRINT "Do you wish to try another peak ripple (Input `R'), another"
PRINT "order of filter (Input `O'), or move on to the calculations"
PRINT "(Input `C')";
INPUT A$
If A$="R" or A$="r" then GOTO TERMIMP
If A$="O" or A$="o" then GOTO BEGIN
GOTO TCHEB
```

GaAs FET Amplifiers From Q-Bit

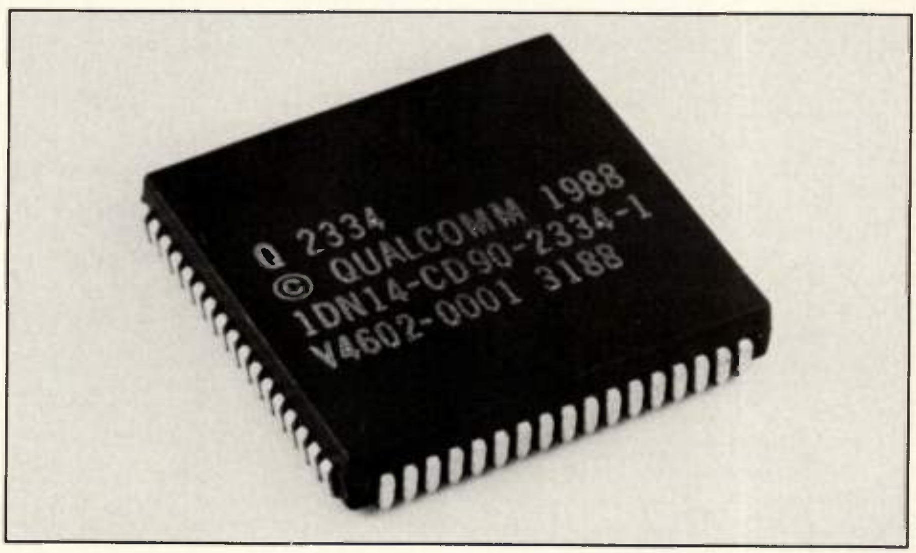


The QBH-4000 has a gain of 18.5 dB over the 100 to 2500 MHz frequency range with 3.0 dB typical noise figure. Input and output VSWR is 1.5:1, power output at the 1 dB compression point is +15 dBm, and second- and third-order output intercept points are 36 and 25 dBm, respectively. Reverse isolation is typically 41 dB and gain variation is less than ± 1 dB over the -55 to +85 degrees C temperature range. Packaging options for the QBH-4000 include TO-8 and 0.5 in. flatpacks suitable for microstrip or surface-mount. The device is priced at $190.

Also being introduced is the QBH-189 TO-8 hybrid amplifier with 10.5 dB gain over the 5 to 2000 MHz range. Gain flatness is 1.0 dB p-p, noise figure is typically 6.0 dB, and input and output VSWR is 1.5:1. Output at the 1 dB compression point is +16 dBm and gain variation is ± 0.6 dB over the same temperature range. The amplifier is packaged in a low-profile TO-8 package and costs $95.

The QBH-814 exhibits 10 dB gain with flatness of less than 1.0 dB p-p over the 10 to 1000 MHz frequency range. Noise figure is typically 8.0 dB and input and output VSWR is the same as the QBH-189. Output power at the 1 dB compression point is +25 dBm and third-order intercept point is 38 dBm. Gain variation is less than ± 1.0 dB over the -55 to +85 degrees C range. In quantities of 1 to 9, the amplifier costs $134. **Q-Bit Corporation, Palm Bay, FL. INFO/CARD #230.**

QUALCOMM Introduces a 50 MHz Dual DDS



Q2334-C2 is a dual direct digital synthesizer on a single-chip CMOS VLSI device which generates digitized sinewave signals using phase accumulation techniques combined with on-chip sine lookup. Two independent DDS functions are included on-chip to provide cost-effective implementations of quadrature oscillators and full-duplex systems. A microprocessor interface is used to control the frequency and mode of operation while synchronous inputs are provided for phase and frequency modulation of the synthesized waveform.

The device operates at a maximum sampling rate of 50 MHz, allowing synthesis of waveforms from DC to 25 MHz with frequency resolution better than 0.012 Hz. The on-chip sine lookup function generates sine waves with better than -70 dBc spur rejection. Double-buffered frequency registers provide phase coherent frequency switching at rates in excess of one million frequency changes per second. It is housed in a 68-pin PLCC package and operates over the 0 to +70 degrees C range. A Q2334 DDS evaluation kit which implements a digitally controlled frequency synthesizer system on a single printed circuit card is available.**QUALCOMM, Inc., San Diego, CA. INFO/CARD #229.**

Microminiature Bandpass Filters

TTE introduces a line of microminiature bandpass filters covering the 10 MHz to 500 MHz range. Size ranges from 0.5 in. X 0.8 in. X 0.5 in. to 0.5 in. X 1.5 in. X 0.5 in. Specific IF filters are available from stock at under $30 (Qty. 5-9). The T Series is available in Bessell, Butterworth and Chebyshev configurations and any number of poles from 2 to 6 may be specified. A T Series unit with a center frequency of 140 MHz in a four-pole, Chebyshev configuration, 50 ohm impedance, PCB package, and 40:3 dB bandwidth ratio of 5:1 is priced under $125 each in quantities of 100. **TTE, Inc., West Los Angeles, CA. INFO/CARD #228.**

500 MHz Analog Multiplier

Analog Devices introduces the AD834 four quadrant multiplier with 500 MHz bandwidth and a typical total error of ±0.5 percent. The device implements a transfer function of W(XY) (4 mA). It accepts two differential voltage inputs (XX1-X2, YY1-Y2) and delivers a differential current output (WW1-W2). At 10 MHz and 100 MHz input frequencies, harmonic distortion is -60 dB and -4 dB respectively for the X input, and -65 dB and -50 dB respectively for the Y input. The multiplier is available in either 8-pin CERDIP or 8-pin SO with prices ranging from $19.20 to $68. **Analog Devices, Inc., Norwood, MA. INFO/CARD #227.**

Waveform Recording and Playback System

The 7900 WaveCorder is a digital waveform recording and playback system designed for long, fast waveforms. It can capture over 3 seconds (640 megasamples) of continuous waveform data from two analog signal inputs digitized at 200 megasamples/sec (8-bit samples). Featured is analog playback of simulated digitized waveforms at user-selected rates. This system supports VAX™/MicroVAX™, VME-based systems, and IBM-AT™ hosts. **LeCroy, Chestnut Ridge, NY. Please circle INFO/CARD #226.**

Class A Amplifier

Model AM 2728-100/1133 operates from 20 to 200 MHz with power of 100 W at 1 dB compression. Second and third harmonics at 100 W are -30 dBc.

RF gain is 50 dB min and minimum spurious is at -60 dBc. The amplifier uses type N female rear panel connectors for input and output. **Power Systems Technology, Inc., Hauppague, NY. Please circle INFO/CARD #224.**

New 25-Ohm SMA Connector

Micro-Coax unveils a 25 ohm SMA connector compatible with UT 90-25 standard semi-rigid cable. This connector virtually eliminates the possibility of mismatch in the assembly. **Micro-Coax Components, Inc., Collegeville, PA. INFO/CARD #225.**

Stable 100 MHz Oscillator

Model 500-0827A is a 100 MHz multiplied source which utilizes a 10 MHz SC-cut crystal and a X10 multiplier circuit that has a theoretical noise degradation of 20 dB. Phase noise is -140 dBc at 100 Hz and -115 dBc 20 kHz from the carrier. Aging rate is 5 X 10^{-10} per day with frequency stability of $\pm$ 1 X 10^{-9} over the 0 to 60 degrees C temperature range. Harmonic content is 40 dBm down and output signal level is +10 dBm into 50 ohms. In single quantities, price is $1,504. **Wenzel Associates, Inc., Austin, TX. INFO/CARD #223.**

7-Section SMT Attenuators

Daico introduces two surface-mount 35 ns, 7-section attenuators — the DA0717 and DA0775. The DA0717 operates from 45 to 250 MHz with a 63.5 dB attenuation range and 0 5 dB resolution. It is available with 7 dB typical insertion loss, 8 dB maximum and a maximum VSWR of 1.35:1. The DA0775 operates from 45 to 75 MHz with a 12.7 dB attenuation range and 0 1 dB resolution. Insertion loss is typically 4 dB, 5 dB maximum with VSWR of 1.35:1.

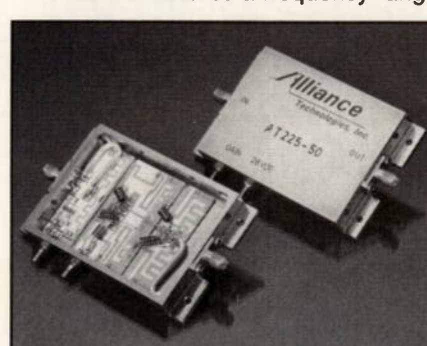
Also from Daico is a surface-mount SP4T switch. DS0778 operates from 50 to 500 MHz with +13.5 dBm power and 63 dB typical isolation. Switching speed is typically 0.5 microseconds. The DS0632, an SP2T switch, is specified from 5 to 2000 MHz with +10 dBm power handling from 5 to 50 MHz and +25 dBm from 300 to 2000 MHz. Insertion loss is 1.6 dB typ and switching speed is 26 ns typ. **Daico Industries, Inc., Compton, CA. INFO/CARD #222.**

Shock-Resistant Crystals

Piezo Crystal has announced the development of quartz crystals with shock survivability to 100,000 g's with a 500 microsecond pulse duration. These AT-cut crystals are housed in TO-5 (HC-35) packages and can be specified from 18 to 65 MHz. **Piezo Crystal Company, Carlisle, PA. Please circle INFO/CARD #221.**

RF Power Amplifier

AT225-50 features a frequency range



of 225 to 400 MHz with output power of 50 watts. The amplifier features a hermetically sealed gold metallized package and is available with SMA or 50 ohm pin terminations. In 250-piece quantity, price is $595 each. **Alliance Technologies, Inc., Redmond, WA. Please circle INFO/CARD #220.**

Hybrid Clock Oscillator

This hybrid clock oscillator utilizes an AT-cut crystal and is available for frequencies between 448 Hz and 60 MHz. The unit uses a tri-statable bus-driver output with source/sink capabilities to 24 mA and is capable of driving 50 or 75 ohm transmission lines. **Piezo Technology, Inc., Orlando, FL. Please circle INFO/CARD #219.**

FFT Controller IC

The TMC2310 FFT-controller is a single-chip CMOS integrated circuit that contains the arithmetic functions, on-board coefficient storage and address generation needed to execute up to a 1,024-point complex FFT at 100 ns per butterfly when it operates at a 20 MHz clock rate. The device also executes an inverse FFT. In 1000-piece quantity, the device costs $120 each. **TRW LSI Products, Inc., La Jolla, CA. Please circle INFO/CARD #218.**

VXI-Bus Microwave Counter

Model 2151 is a counter-on-a-card featuring measurements from 10 Hz to 20 GHz with resolution of 1 Hz in 1

second at 20 GHz. Sensitivity is -27 dBm at 20 GHz and tolerance is 60 MHz p-p in the manual mode. Measurement functions include frequency, period, ratio B/A, ratio C/A and ratio C/B, as well as full math capability scale, offset and smooth. **Racal-Dana Instruments, Inc., Irvine, CA. INFO/CARD #217.**

I and Q Phase Detectors

Merrimac introduces a line of close-tolerance I and Q phase detectors and quadrature modulators that feature an IF balance of 90 ±2 degrees and an amplitude balance of 0.2 dB max. Applications include use in digital transmission systems as QPSK modulators, in image rejection circuits, single sideband modulators, and as phase correlators in closed loop and vector modulator sub-systems. Prices commence at $375. **Merrimac Industries, Inc., West Caldwell, NJ. INFO/CARD #216.**

Phase Locked Crystal Source

Model PLXM376 is a phase locked crystal source designed to provide multiple outputs with a tight phase relationship to the reference. It is available at output frequencies from 1 MHz through 10 GHz while typical phase noise at 50 MHz output is -140 dBc/Hz at 1 kHz offset. **Techtrol Cyclonetics, Inc., New Cumberland, PA. INFO/CARD #215.**

Fixed Attenuators

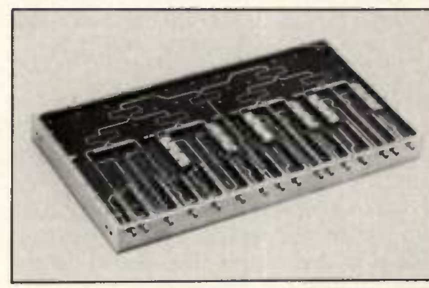
Alan Industries has added a Type N connector, per MIL-C-39012, to its MHP line of fixed attenuators. The devices cover from DC to 18 GHz at 5 W average and 5 kW peak. Attenuation values of 1, 3, 10, 20, and 30 dB are standard with other values available upon request. Specifications over the DC to 18 GHz range include 50 ohm impedance, 1.35:1 maximum VSWR and accuracy of ± 3 dB from 1 to 6 dB and ± 5 dB from 7 to 40 dB. Price ranges from $105 to $120 each in quantities of 1 to 24. **Alan Industries, Inc., Columbus, IN. Please circle INFO/CARD #214.**

Miniature UHF Transmitters

Aydin Vector unveils the T-700S/L Series transmitters. They are available in 2, 5, 8 and 10 watts and operate at S-band from 2200 MHz to 2300 MHz, and L-band from 1435 to 1450 MHz. These FM telemetry transmitters are capable of transmitting analog or digital multiplexed signals. **Aydin Vector Div., Newtown, PA. INFO/CARD #213.**

Eight Way Power Divider

This eight way power divider operates from 1.2 to 1.4 GHz with up to 2 watts



input power and insertion loss of 30 dB nominal. Phase tracking is better than 10 degrees and amplitude tracking is 1 dB between all outputs. **KDI/triangle Electronics, Whippany, NJ. Please circle INFO/CARD #212.**

Frequency Synthesizer

The SI-160 frequency synthesizer is a 5-digit unit which provides ECL signals into a 50 ohm load from 20 to 160 MHz with 1 kHz resolution. Options for the instrument include external BCD programming for computer control, external reference input, and a 19 in. rack mount adapter. In unit quantities, the instrument costs $1007. **Syntest Corp., Marlboro, MA. INFO/CARD #211.**

PC-Controlled HF Receiver

Comer Communications introduces the R232 line of communication receivers. The receiver is controlled through the use of a central processor in the receiver that is accessed with a PC serial port. The displayed alphanumeric menu of the receiver displays all receiver control functions. Frequency range is 10 kHz to 29.999995 MHz in 10 Hz steps. AM, FM, USB and LSB, CW, FSK, RTTY, and FAX modes are possible. Third-order intercept point is +25 dBm and second-order intercept point is +50 dBm. The receiver costs $1,350. **Inline Components, Inc., Irvine, CA. Please circle INFO/CARD #210.**

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Now, your favorite ANZAC Quality components are available in Surface Mount packages for high performance RF applications. . . *from stock*! These fully hermetic, Kovar housings provide excellent RF and DC ground transitions with tabs for inspectable circuit mounting. In addition, our solderless manufacturing technique insures vapor-phase-mountability without sacrificing circuit performance.

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rf software

Antenna Analysis Software

This program will analyze almost any antenna made of wire or tubing. MN will compute antenna forward gain, front-to-back ratio, beamwidth, sidelobes, angle of radiation, current, impedance, SWR, near-fields, and far-fields. Antennas may be modeled in free space or over real earth. It will plot antenna radiation patterns in polar or rectangular form on CGA, EGA or HGC graphic screens with hardcopies available on dot-matrix printers. The interaction among several nearby antennas or structures can also be calculated, allowing detailed analysis of stacked arrays. MN is an enhanced version of the U.S. Navy's MININEC program and costs $75.

Also available is YO — a Yagi optimizer program. The software will automatically adjust the element lengths and spacings of a Yagi-Uda design to maximize forward gain, optimize pattern, and minimize SWR. Radiation patterns at the center and edges of a band, and a scale drawing of the antenna, are plotted on CGA, EGA or HGC graphic screens during optimization. Yagis having up to 50 elements may be modeled. The YO design package includes models for gamma and hairpin matching networks, element tapering, and frequency scaling. YO is priced at $90. **B. Beezley, Vista, CA. INFO/CARD #205.**

Electromagnetic Analysis Software

Ansoft introduces Maxwell PC-386 — a 2-D computer-aided engineering tool for the 386-based personal computers. This electromagnetic finite element analysis software package provides 32-bit addressing capabilities and predicts electrical characteristics by solving Maxwell's equations. Available modules include applications to analyze electrostatics, eddy currents, MMIC devices, waveguides, and cavities. System requirements include an 80387 math co-processor, a recommended minimum of 3 MB of extended memory and a 20 MB hard drive. Versions for IBM PC and PS/2, Apple Macintosh II, Sun, Apollo, MicroVAX and Hewlett-Packard workstations are also available. A one-year license for Maxwell PC-386 ranges from $4,495 to $12,995. **Ansoft Corp., Pittsburgh, PA. INFO/CARD #204.**

RF Design Software Service

As a convenience to our readers, computer programs published in *RF Design* are now available on disk. For a minimal cost, you can avoid the time-consuming (and error-prone) task of typing program listings into your computer.

This month's disk includes programs (MS-DOS format) described in these articles:

"A Design Program for Butterworth Lowpass Filters," p. 43
"A Parallel-Coupled Resonator Filter Program," p. 55
Request disk number RFD-0389

Last month's disk included the following programs:

"CAD for Lumped-Element Matching Circuits"
"Modeling PLL Tracking of Noisy Signals"
Request disk number RFD-0289

Prices are $9.00 each for a 5 1/4 in. diskette, or $10.00 for a 3 1/2 in. mini-floppy, postpaid. Outside of the U.S. and Canada, add $8.00 (disks will be sent airmail). Make check or money order payable to *RF Design Software Service*, and send orders to:

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rf literature

Inductor Measurement Application Note

Testing Inductors at Application Frequencies is an application note that highlights the difficulty of making coil measurements at AT frequencies. The main problem with this kind of measurement is that coil inductance, Q, and coil parasitics are frequency-dependent. The note discusses inductor parameters, test equipment, traditional methods of specifying and testing inductors, application frequency testing, specifying inductor tests at application frequencies, a specification example, and specifications with correlation. **Coilcraft, Cary, IL. INFO/CARD #202.**

RF Selector Guide

This guide combines the RF products from Motorola Phoenix, Motorola Lawndale and Motorola Bordeaux. It is divided into two major parts — discrete devices and amplifiers. Products such as Class A linear transistors, VHF/UHF ultra-linear transistors for TV applications, and amplifier modules are included. Many other additions have also been made to the cross-reference. **Motorola, Inc., Phoenix, AZ. Please circle INFO/CARD #201.**

Test Equipment and Microwave Catalogs

Lectronic Research Labs has released its 1989 test equipment and microwave catalogs. Listed are over 10,000 reconditioned and new products. Catalog #119 offers test equipment from 207 manufacturers including HP, Tektronix, General Radio and L&N. Catalog #120 offers 6,000 microwave products including waveguides and microwave test equipment from 181 manufacturers including HP, DeMornay-Bonardi, Waveline, FXR, and Narda. An index which lists products by manufacturer, part number and price is featured. **Lectronic Research Laboratories, Camden, NJ. INFO/CARD #200.**

Note Describes TDA of SPICE

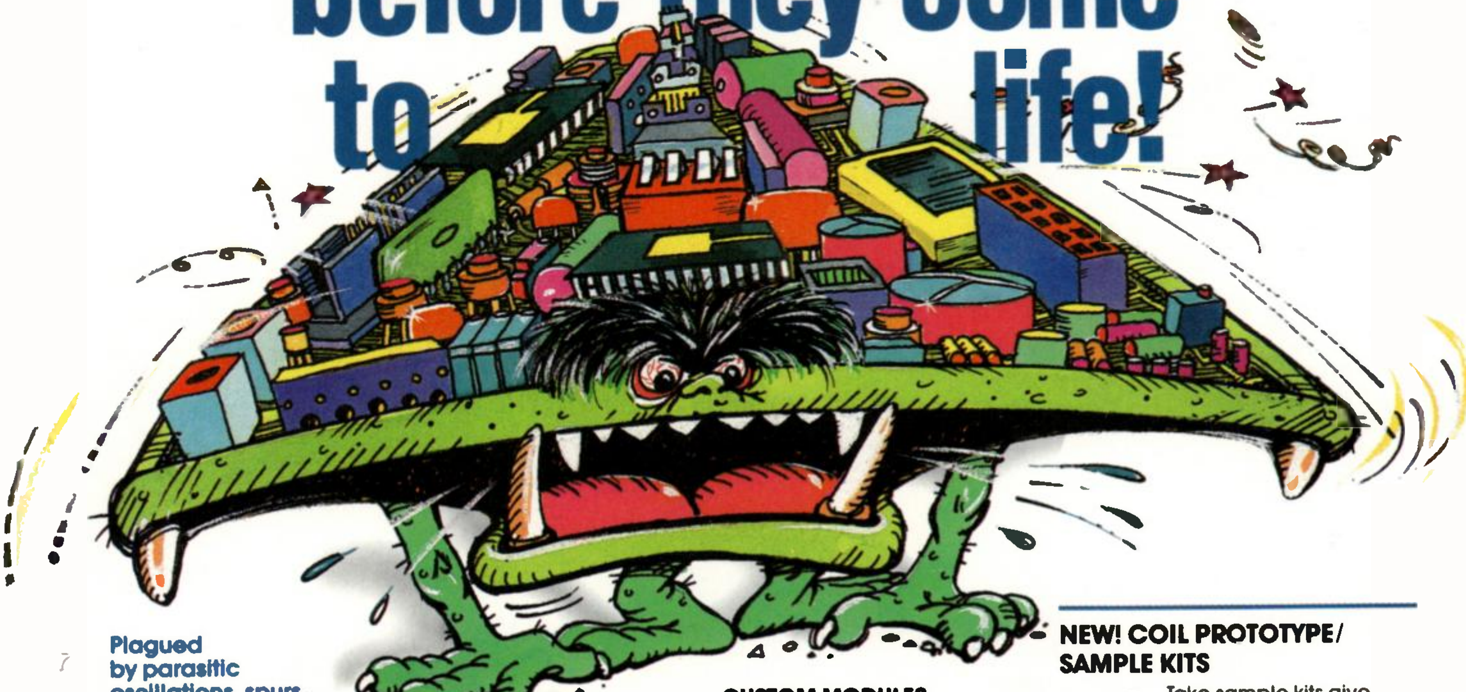
This application note describes the steps required to run a time-domain analysis on a Microwave SPICE™ circuit, simulating the technique of time-domain reflectometry (TDR). The text and related examples demonstrate how the utilization of the TDA feature allows the designer to build up an accurate simulation of the parasitic discontinuities associated with a particular circuit. A circuit example is included. **EEsof, Inc., Westlake Village, CA. INFO/CARD #199.**

Test and Measurement Equipment Catalog

Product lines from John Fluke Mfg. and N.V. Philips are integrated in this catalog into 16 major categories. Featured are 19 new products and 19 new service programs. Included is an update on the Fluke and Philips alliance. An index of all products and services is arranged both functionally and numerically. Also given is warranty information and listings of Fluke and Philips technical literature, worldwide sales offices and technical services centers. **John Fluke Mfg. Co., Inc., Everett, WA. INFO/CARD #198.**

ADVERTISER'S INDEX

Toko coils and filters attack RF design problems before they come to life!

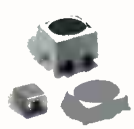


Plagued by parasitic oscillations, spurs, harmonics and feedback? The problem may not be your design, but the coils and filters you selected. Toko is the world's largest manufacturer of quality small coils and filters, with a selection so large, you're sure to find the right components to neutralize your rf design problems.

SUBMINIATURE ADJUSTABLE AND FIXED

Toko has what you need, so you won't need to compromise... subminiature adjustable coils and transformers, molded coils, radial fixed coils and fixed coils with axial leads. Toko high-Q coils are engineered in sizes from 5mm to 15mm, and inductance ranges from .02 µH to 500 mH.

CHIP AND ADJUSTABLE SMD

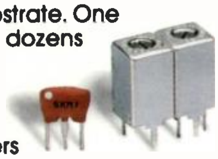


Need to reduce the size of your products or automate production? Toko solves these problems with a wide range of surface mountable coils and LC, ceramic and helical filters in fixed and adjustable configurations. Packaged for automatic insertion and available for reflow or solder dipping.

For more information on:
Subminiatures, INFO/CARD 61
Chip/SMD, INFO/CARD 69

CUSTOM MODULES

Toko hybrid modules are a great way to simplify design and production tasks. With short lead time, Toko can develop compact custom modules utilizing a variety of components, surface mounted on a ceramic substrate. One module replaces dozens of components.



FILTERS

For i-f or tuned rf circuitry. Toko filters simplify attenuation of out-of-band signals, while cleanly passing your desired signal. Ultra-miniature ceramic and LC filters at popular i-f frequencies fit tight spaces and tight budgets. With frequencies up to 1.2 GHz Toko helical filters are the right choice for communications transceivers.

ACTIVE FILTERS

If you're advancing the state-of-the-art in digital audio or PCM products you'll appreciate Toko active filters. Especially designed for small size and low distortion, they're also very cost-effective.

Custom Modules, INFO/CARD 72
RF & I-F Filters, INFO/CARD 73

NEW! COIL PROTOTYPE/ SAMPLE KITS

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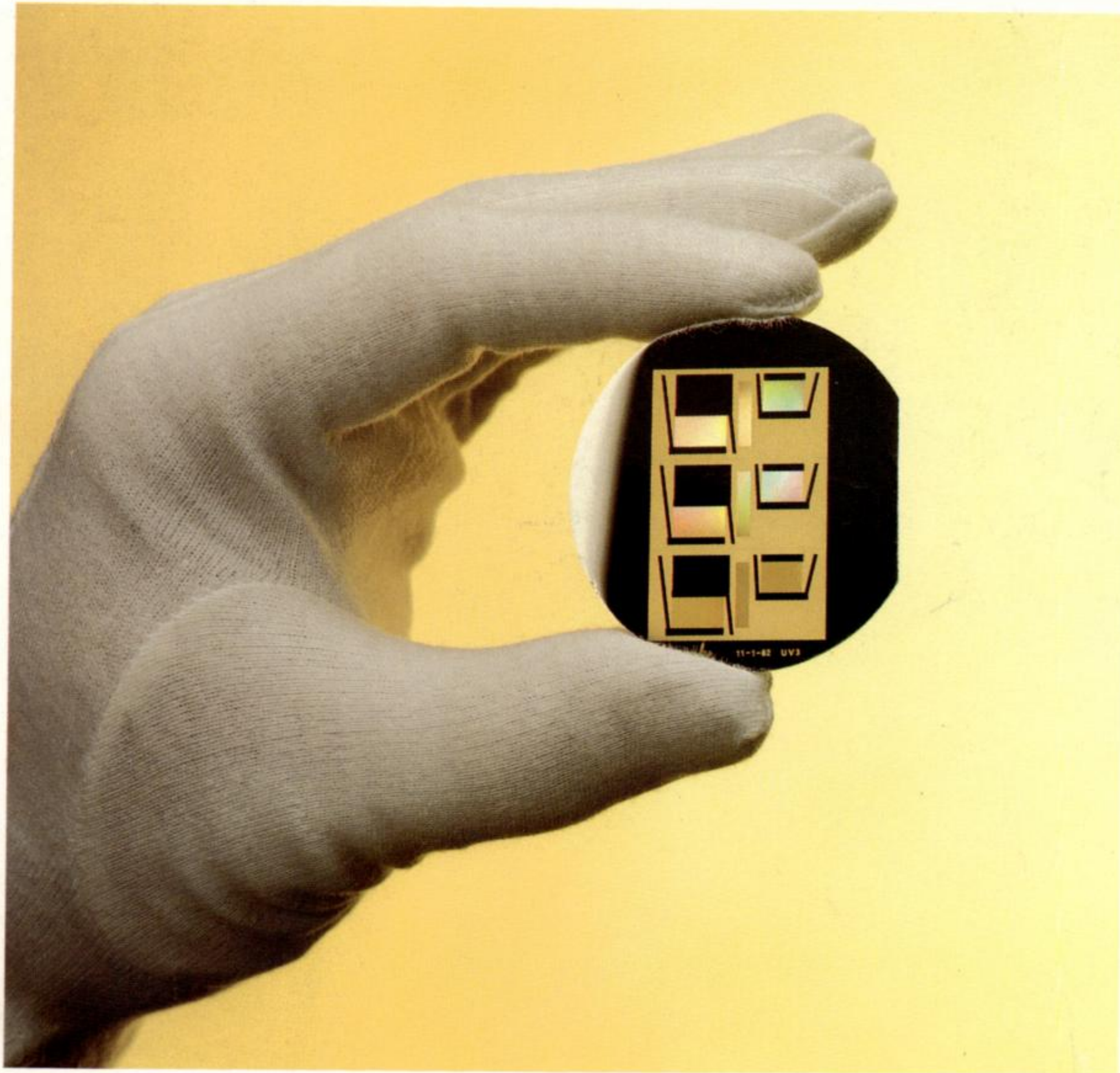
Active Filters, INFO/CARD 74
Sample Kit, INFO/CARD 75



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Producing high-reliability SAW filters takes an investment. In time. In people. In state-of-the-art technology. Andersen did it.

We expanded our facilities to include a dedicated, high-volume, Hybrid Production Plant. We built Class 100 and Class 1000 clean rooms. We also installed one of the world's most sophisticated direct-imaging mask-making systems. Which means you can choose from a line of Andersen production SAW devices at center frequencies up to 1.3 GHz with linear phase and superior rejection.

We'd like you to see our facilities. But to protect our investment, you do have to dress for the occasion. White gloves are mandatory. For the grand tour, contact Andersen Laboratories, 1280 Blue Hills Avenue, Bloomfield, CT 06002. Phone (203) 242-0761. TWX 710 425 2390 FAX 203 242 9876.

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