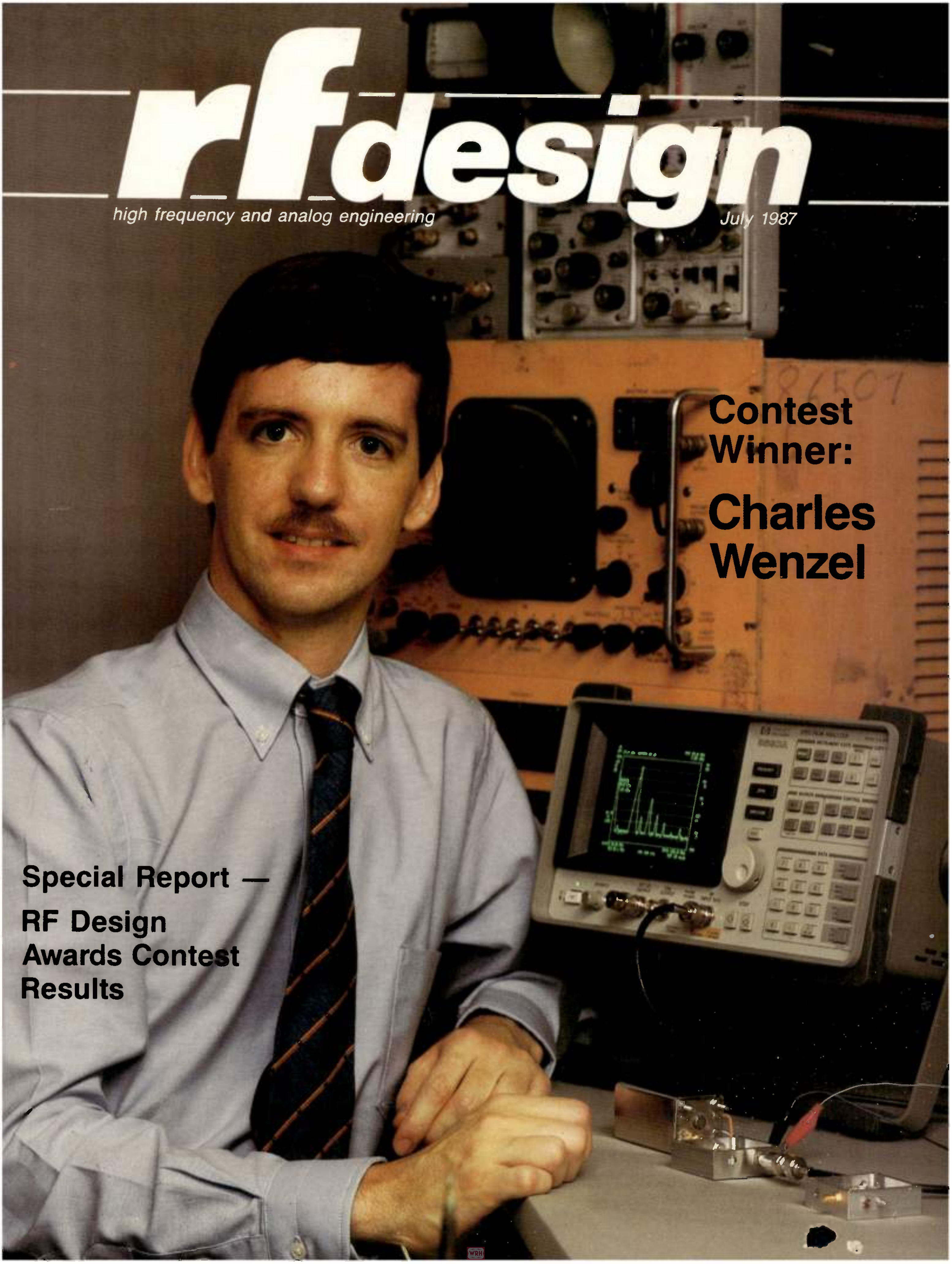


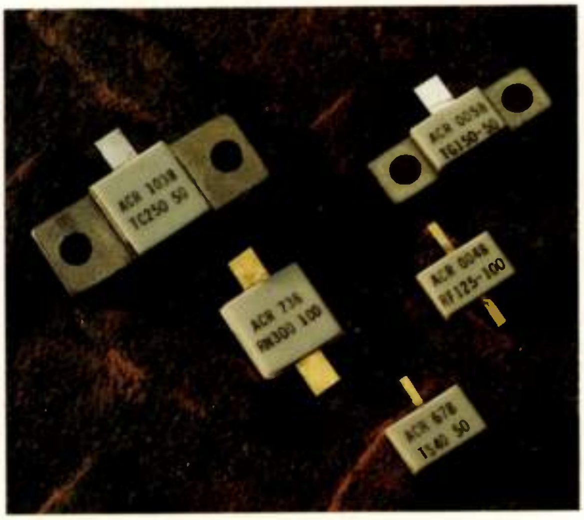
rf design

high frequency and analog engineering

July 1987

Contest Winner: Charles Wenzel

Special Report — RF Design Awards Contest Results



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UPC1658	Low Noise, 1.5 dB NF at 100 MHz
UPC1659	0.6-2.3 GHz, 5 dB NF, 23 dB Gain
UPC1675G	2.1 GHz at 3 dB down, 5.5 dB NF, 12 dB Gain
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UPC1669	− 55 dB Isol at 70 MHz, 10.5 dB Gain, 11 dBm P_{out}
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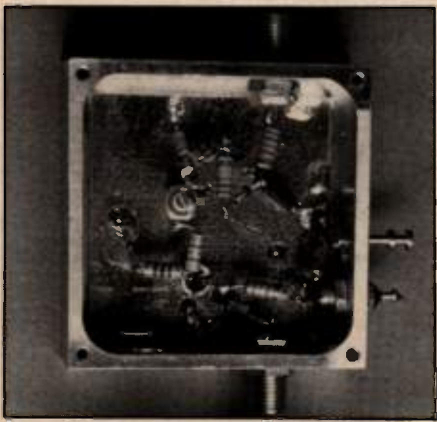
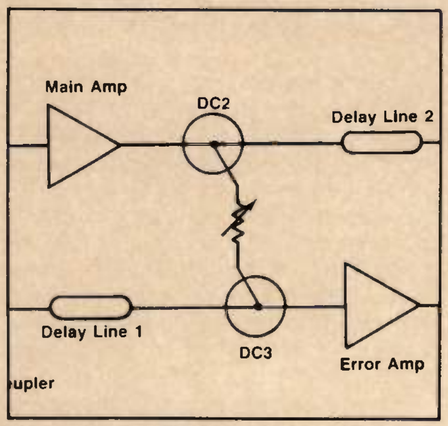
INFO/CARD 3

rf design

July 1987



Page 31 — Contest Winner



Page 50 — Feedforward Techniques

Phenomena	CB	Amateur	Radar*	Pagers (40-60 MHz)	Cnsr ISM
Front End Overload	a	a	x	c	
Spurious Response	b	b	x	c	
IF Susceptibility			x	x	
Adjacent Channel		x	x	x	
Image Response			x		
In Band Spurious Emissions	x	x			
CATV***		c	x		

Legend: *Identified Interactions*
a = High
b = Moderate
c = Low
x = Interaction not established

* Low Priority
** Anything with a TV tuner e
*** Both a source and phenom

Page 60 — Voluntary EMI Standards

Cover Story

Features

Departments

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rf editorial

Pride, Creativity, Judgment — A New Image for Engineers

By Gary A. Breed
Editor

The second annual RF Design Awards Contest has been judged, prizes awarded, and the results published elsewhere in this issue. As you might expect, there were lessons to be learned from examination of the 30 serious technical presentations that made up the entries. But to me, the most important lesson came after reflecting on the group as a whole. A piece of news from MIT underscores that lesson. I'll show you what I mean . . .

About half the entries were clearly results of work-related engineering efforts. Although circuit development was part of these entrants' regular jobs, many hours of extra effort were needed to rethink circuit analysis, collect and prepare performance data, then put the entire process into writing. Any business would like to have a staff of engineers with this kind of pride in their work.

Another third represented hobby-type circuits resulting from amateur radio or other electronic experimentation. If these entries are a result of "fun" projects, I'd like to see their *work!* An important point here is that many engineers don't stop thinking when they leave the office, the effort just shifts to different projects. It is also interesting to note that the same proportion of *RF Design* readers (34 per cent) are radio amateurs.

The remaining five or so seemed to be the result of pure intellectual curiosity. Maybe they had their origins in work assignments that were set aside when different solutions were developed. Some were ideas that "just wouldn't go away." One entrant told me he had been pursuing his idea for over a year, although it no longer had an application for anything he was working on.

The lesson comes through loud and clear — engineers are creative, energetic and proud of their achievements. For those who entered our contest, engineering is more than a job. It is a serious intellectual pursuit that offers the same kind of challenge that drives art, music, literature and "pure" science. We are pleased to provide a way to recognize some of these creative efforts.

No More Nerds

The engineer has recently been portrayed as a technical mercenary, attacking physical and mathematical concepts like Rambo with a pocket protector. But like Rambo, he is not considered able to mentally comprehend anything else! Although our contest and thoughtful Letters-to-the-Editor show that engineers have more going for them, the Massachusetts Institute of Technology is doing even more:

Tired of having their top engineering graduates "working for Yale and Princeton graduates and being left out of policy decisions," MIT is revamping their engineering program. Students will get more courses in business and liberal arts, an effort to assure future employers that the engineers they hire are able to use their substantial intellect for sound policy judgment.

It has taken a long time for people to understand that there are a lot of engineers who are capable of more than just circuit design. Hopefully MIT's changes are just the first rumblings in an avalanche of effort to gain more respect for the intellect and judgment of engineers.

Gary A. Breed

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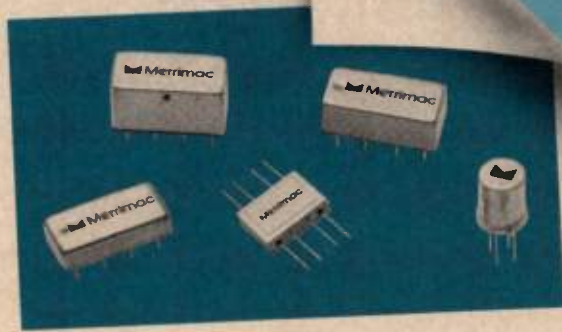

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/1-01S /1-01N	DMS-2-100/57855S DMS-2-100/57855N	0.05-200	DC-200	+4 min. +7 typ. +13 max.	6.5 typ. 8.5 max.	6.5	45 35	40 30	N/A N/A	0.05-30 30-200	+2	0	neg.
/1-02S /1-02N	117A/57834S 117A/57834N	5-500	DC-500	+4 min. +7 typ. +13 max.	7.0 typ. 9.0 max.	7.0	45 35	40 25	N/A N/A	5-50 50-500	+2	0	neg.
/1-03S /1-03N	DMS-2-250/57852S DMS-2-250/57852N	0.5-500	DC-500	+7 typ.	7.0 typ. 8.5 max.	7.0	35 30 25	30 25 20	N/A N/A N/A	0.5-1 1-250 250-500	+2	0	neg.
/1-04S /1-04N	DMS-8-500/57835S DMS-8-500/57835N	RF 2-400 LO 2-500	DC-800	+10 min. +20 typ. +23 max.	7.0 typ. 9.0 max.	7.5	40 35 25	40 35 25	N/A N/A N/A	2-32 32-100 100-500	+16	+14	pos.
/1-09S /1-09N	M119/57836S M119/57836N	1-750	DC-750	+7 typ.	7.5 typ. 8.5 max.	7.5	45 30 25	30 25 20	N/A N/A N/A	1-2 2-375 375-750	+2	0	pos.
/1-10S /1-10N	DMS-4-250/57853S DMS-4-250/57853N	0.4-500	DC-500	+7 min. +13 typ. +17 max.	7.0 typ. 9.0 max.	7.0	45 25	40 25	N/A N/A	0.4-50 50-500	+11	+8	neg.
/1-11S /1-11N	DMS-8-250/57837S DMS-8-250/57837N	1-500	DC-500	+23 typ.	7.5 typ. 9.5 max.	7.5	50 40 30 20	40 30 20 20	25 20 20 20	1-100 100-200 200-300 300-500	+16	+14	neg.
/1-12S /1-12N	DMS-2-25/57838S DMS-2-25/57838N	0.002-12	DC-12	+4 min. +7 typ. +13 max.	6.0 typ. 8.0 max.	6.0	45 40	40 30	N/A N/A	0.002-5 5-12	+2	0	neg.
/2-01S /2-01N	DMF-2A-505/57839S DMF-2A-505/57839N	5-1000	DC-1000	+10 min. +10 typ. +17 max.	7.0 typ. 8.0 max.	7.0	40 30	40 25	30 15	5-100 100-1000	+2	0	pos.
/2-02S /2-02N	DMF-2A-700/57840S DMF-2A-700/57840N	10-1500	DC-1000	+4 min. +7 typ. +13 max.	7.0 typ. 9.5 max.	7.0	30 25 25	30 20 18	N/A N/A N/A	10-600 600-1200 1200-1500	+2	0	neg.
/2-04S /2-04N	DMF-2A-250/57841S DMF-2A-250/57841N	0.5-500	DC-500	+7 min. +7 typ. +17 max.	7.0 typ. 8.0 max.	7.0	40 35	30 20	23 20	0.5-300 0.5-500	+2	0	pos,
/2-05S /2-05N	DMF-2A-250/57854S DMF-2A-250/57854N	0.5-500	DC-500 (IF-1 & IF-2)	+7 min. +7 typ. +13 max.	6.5 typ. 7.0 max.	6.5	35 30 25	30 25 20	25 20 15	0.5-10 10-200 200-500	+2	0	neg.
/7-01S /7-01N	M109/57832S M109/57832N	10-500	DC-500	+7 typ.	7.0 typ. 9.0 max.	7.0	40 35 30 25	35 30 25 15	25 20 15 10	10-50 50-100 100-200 200-500	+2	0	neg.
/7-02S /7-02N	M109/57833S M109/57833N	350-500	DC-500	+7 typ.	7.0 typ. 9.0 max.	7.0	25	15	10	350-500	+2	0	neg.

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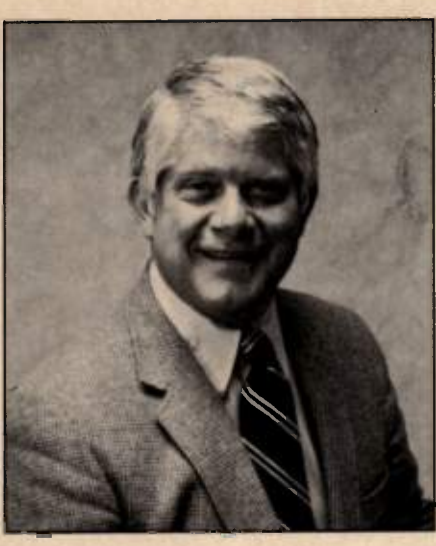
rf viewpoint

An Expanded Charter:
High Frequency *And Analog* Engineering



By Keith Aldrich
Publisher

On this month's cover you'll discover a new title under our *RF Design* logo. It reads: "high frequency and analog engineering."

This phrase amounts to a significant expansion of our editorial charter. The expansion is embodied in the words "and analog."

Of course, RF engineering *is* analog for the most part . . . but it is a fairly distinct subset within the analog world, set apart in a number of ways:

1) in the frequencies that are dealt with (everything above audio, says one engineering dictionary);

2) in types of application (some variation of radio communications, mostly);

3) and it even has its own language (one speaks of "harmonics" and "bandwidth" instead of "Fourier coefficients" and "rise and fall times").

The new subtitle implies a pushing out of these traditional boundaries to provide a convenient and quite appropriate home for some significant new developments in electronics technology. These developments are perhaps typified by the chip pictured on the cover of *RF Design's* May issue: the AD9002 from Analog Devices, an ultra-high-speed 8-bit analog-to-digital converter.

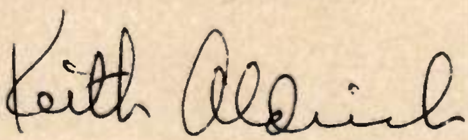
This device violates two of the accepted boundaries of "RF" referred to above. One, it is not intended necessarily or primarily for use in RF transmission or reception, but in data conversion. Two, while its high speed is due to operation in RF frequencies, it is expressed as a "Megasample-per-second" rate — which is not one of your usual RF locutions.

To put it as simply as possible, the current trend to "high-speed electronics" is bringing "radio frequencies" into many applications that have nothing to do with radio — medical instruments, computers, industrial controls, among many others. The phenomena that occur at these frequencies do not care about application. They are the stuff and substance of RF technology.

So, *RF Design*, as the one magazine devoted to RF technology, is led inevitably into a new area of coverage, which turns out to be not so new after all. In fact we have mounting evidence that we already have readers involved in the "non-radio" applications mentioned, and will be reclassifying our circulation to bring some of those involvements more clearly to light (computers, medical instruments, et. al.).

In this brave new world there will be some learning of new customers and new idioms on both sides of the fence, and one of the missions of our coverage will be to facilitate the interchange.

It's an exciting time for RF engineers. They are moving from being a relatively insular community to being a critical part of the mainstream of technological development. The new expansion in our charter is a direct reflection of this expansion in our readers' responsibility.



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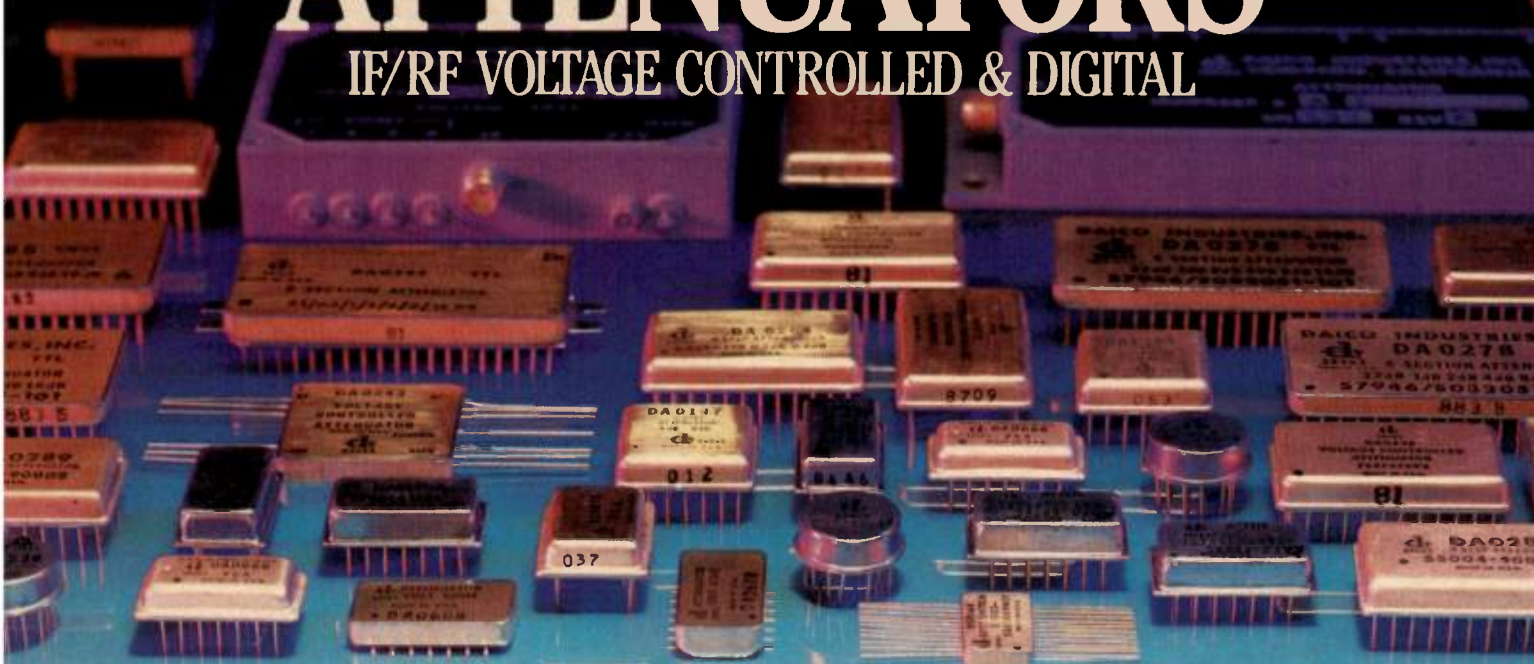
IF/RF VOLTAGE CONTROLLED & DIGITAL



ATTENUATORS

Number Steps (Bits)	Attenuation LSB/Range (dB)	Frequency (MHz)	Part #	Max. Switching Speed (μ/sec)	Typ/Max. Insertion Loss (dB)	Max. RF Operating Power (dBm)	DC Power (V/mA)	Control	Package
1	4	50-500	DA0240-4	10.0	0.8 / 1.2	+10	+15 / 12	CMOS	T08
1	8	50-500	DA0240-8	10.0	0.8 / 1.2	+10	+15 / 12	CMOS	T08
1	16	50-500	DA0240-16	10.0	0.8 / 1.2	+10	+15 / 12	CMOS	T08
4	2 / 30	10-100	DA0104	0.050	4.2 / 5	+10	+ 5 / 300	TTL	38 PIN DIP
4	1 / 15	300-1300	DA0446	1.0	2.0 / 4	+10	+ 5 / 40	TTL	24 DIP
6	1 / 63	30-300	DA0204	1.0	3.8 / 4	+10	+ 5 / 250	TTL	38 PIN DIP
6	1 / 63	40-150	DA0296	0.050	5 / 8	+10	+ 5 / 660	TTL	38 PIN DIP
7	0.5 / 63.5	30-500	DA0285	20.0	4.8 / 6	+10	+15 / 50	CMOS	38 PIN DIP
7	0.5 / 63.5	30-500	DA0295	20.0	4.2 / 6	+10	+ 5 / 85	TTL	38 PIN DIP
7	0.5 / 63.5	45-250	DA0617	0.035	7 / 8	+10	+ 5 / 640	TTL	38 PIN DIP

VOLTAGE CONTROLLED ATTENUATORS

Min. Attenuation	Frequency (KHz)	Part Number	Control Voltage	Max. Insertion (dB)	Linearity (dB)	Attenuation slope (dB/V)	DC Power (V/mA)	RF operating power (dBm)	Package
18	20-300	DA0035	0-5	1.5	± 0.8	6.5	± 15 / 25	+10	14 PIN DIP
40	20-300	DA0098	0-5	2.0	± 2.0	15.0	± 15 / 60	+10	14 PIN DIP
30	50-1300	DA0243	0-5	3.5	± 2.0	13.0	± 15 / 20	+10	1x1 Planar

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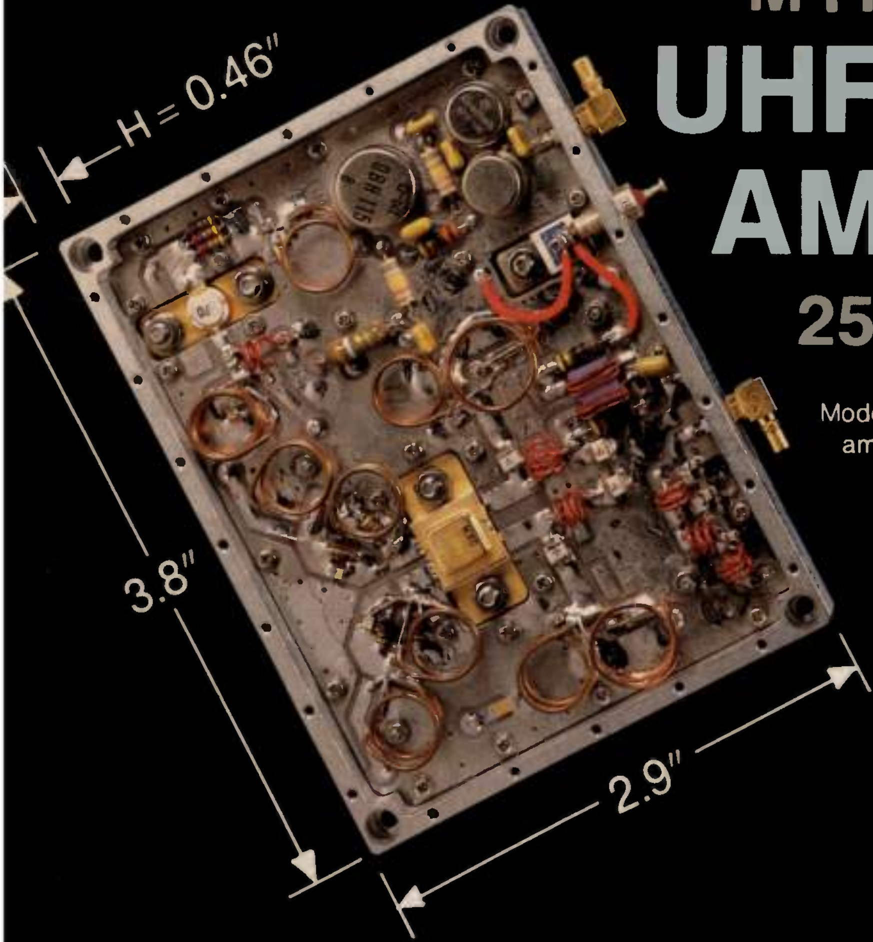

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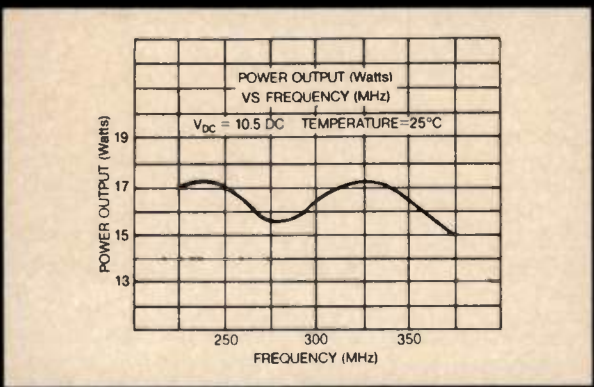

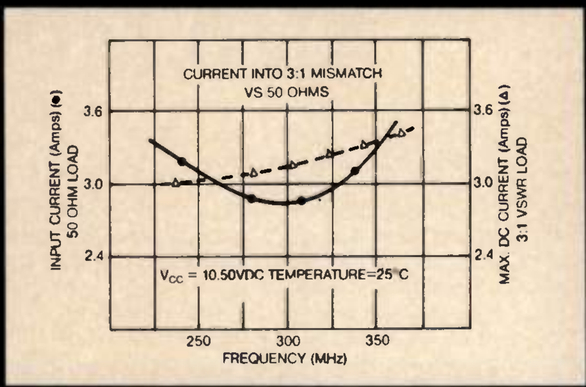

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INFO/CARD 8

WRH

rf letters

Please address letters to: Editor, *RF Design*, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111.

Analog vs. Digital Commentary

Editor:

I was sorry to read the editorial in the May issue of *RF Design* in which you tried to justify analog circuit design as opposed to digital. Apparently, you have not had any hands-on experience with working equipment or systems that use the technology that is documented in your magazine. I have, and probably at least 25 per cent of your readers have also worked with systems that are described in the magazine.

There will not be a digital revolution as you spoke of in the editorial. The dichotomy which appears is only a result of the growth of the digital circuitry approach to problems which have been previously handled with analog circuits. We should not mistake a solution which is digital for an equivalent analog solution and give the digital solution the "revelation" just because it is new or easier to do. I have seen parts of systems implemented because it was easier to do in software, or because the program management couldn't find a good RF design engineer to solve the problem. The result has been, in most cases, non-optimal, to say the least.

The pendulum swings both ways. This year, fellow engineer, get ready for a digital revolution. In five years, get ready for the analog revolution. In any case, at least you inspired me to do this thinking.

Keep up the good work!

Paul E. Gili
Sanders Associates

The editorial didn't say "digital is better," Paul, just that the "digital revolution" gives RF engineers more digital options than ever. Now they need to learn the same lessons you have learned for determining when digital or analog is the better implementation.

Now, about those 75 per cent of our readers who, like me, really have had hands-on experience. . . — Editor

Variable Phase Shifter — A Construction Suggestion

Editor:

"A Variable Phase Shifter and BPSK Modulator" (May '87 *RF Design*) presented a new (for me anyway) and potentially very useful application for a familiar RF device.

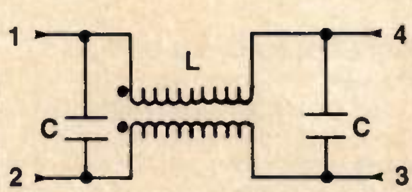
Readers who wish to experiment with the circuits and who do not require the high reliability packaging of the Merrimac part can make their own quadrature hybrid very easily. A review of July/August 1979 *RF Design* might be in order for those not familiar with the part. The toroid is made by winding 9 outside turns of #30 bifilar wire (MWS 2302211) on a Ferronics 11-120P. Fair-Rite 5967000101, or Krystinel L21-6K3F-1Q core. Inductance should be 743 nH. 150 pF silver mica capacitors complete the part. The one I made had almost exactly 90 deg. phase difference, less than 0.1 dB loss, and isolation of 40 dB.

For a limited time, Communication Associates will send, free of charge, a wound toroid and 2 capacitors to anyone requesting them on a company letterhead.

Thanks and keep up the good work.

John Green
Communication Associates
P.O. Box 2707
Anniston, AL 36202

On behalf of all our readers, thank you for a most generous offer! The circuit from the July/Aug. 1979 article is included below. — Editor



Configuration of a narrow band hybrid.

Errata

In "The RF/Digital Connection," May 1987 *RF Design*, p. 28, synthesizer instruments were incorrectly characterized. Products from Programmed Test Sources and Comstron use the synthesis method referred to as "direct analog" to generate the output frequency, rather than PLL synthesis.

In May 1987 *RF Design*, page 58, General Electric's listing should read: Marc Rideout, (315) 456-6007.

We regret any inconvenience created.

rf news

SMT Standards

Companies using surface mount technology (SMT) to manufacture printed circuit boards will have the assurance that equipment purchased from several suppliers will work together compatibly in an in line production line. This assurance is stated in the *Interface Standards* published by the Surface Mount Equipment Manufacturers Association (SMEMA). SMEMA was formed last year by companies who manufacture equipment for SMT. This publication includes guidance for mechanical interfaces, electrical interfaces, and the interface to a cell controller (or host computer).

The standard for mechanical interfaces includes definitions of the conveyor height, width, edge clearance and tooling pins. This will permit users to more easily install equipment from various suppliers since the physical size and method of conveying printed circuit boards will be standardized.

Electrical interface standards include a definition of the type of power connections, grounding, inter-equipment logic, and shielding. By complying with these standards, equipment suppliers can eliminate power and grounding problems and will be able to sequence the board properly from machine to machine.

Any company supplying equipment to the SMT industry is welcome to join SMEMA. Membership information can be obtained by contacting Mr. Robert Puhr at (614) 890-0511.

M/A-COM MAC and DEC Join Forces

M/A-COM MAC and Digital Equipment Corporation have signed a joint marketing agreement to promote the sale of communication systems capable of connecting remote Local Area Networks via microwave radios operating at 23 GHz. LAN's up to 4.5 miles apart can be linked via M/A-COM's MA-23LAN microwave radio and Digital's Metrowave bridge.

Japanese Information in English

Japan Technology is an online information service that makes current Japanese information available in English by computer access. UMI (University Microfilms International) and Dialog Information Services, Inc., have joined resources to introduce this service that offers English abstracts and indexes of articles from 600 Japanese technical and business journals.

Technology areas covered include microelectronics, fiber optics, telecommunications and robotics. The business areas covered include production management, quality control and product reviews.

More information on this service can be obtained by calling Tom Satoh of UMI at (202) 785-1160.

English abstracts from Japanese magazines are now available.

Achievement in Radio

Achievement in Radio is a comprehensive and exhaustive treatment of the accomplishments and the people of the National Bureau of Standards, set in the context of external events and developments. It begins with a chronology of landmark events in the development of radio, then traces the early years when the NBS effort consisted of two to four researchers. Information contained includes NBS involvement in WW1 and WW2. WW2 brought NBS several projects in radar countermeasures and proximity fuse development, plus an increased emphasis on microwave standards and measurements. The current work has branched off into interference characterization, fiber optics, electromagnetic compatibility and various other areas.

The book can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $55 prepaid. Stock no. 003-003-02762-6.

Martin Marietta Forms Separate Commercial Titan Unit

Martin Marietta Corporation announced the formation of a new organization to commercially market the Titan space launch vehicle and named Richard E. Brackeen President of the unit. The new organization, Martin Marietta Commercial

Titan Systems, will focus on commercial sales of a modified version of the Air Force Titan III space launch vehicle.

Perkin-Elmer Celebrates 50th Anniversary

Perkin-Elmer entered the semiconductor equipment field in 1973 with the introduction of the Micralign projection mask aligner, an instrument based on a new approach for printing circuit pattern lines on wafers. Founded in 1937 by Richard S. Perkin and Charles W. Elmer, the corporation has been and is involved in electron beam and X-ray systems, infrared spectrometers, optical telescopes, and various other systems.

Cornell Dubilier Buys Sangamo

Cornell Dubilier Marketing, Inc. (a subsidiary of Kaplan Electronics, Inc.) has purchased Sangamo Weston's Components Division. The division manufacturers and sells mica and electrolytic capacitors at its plant in Pickens, South Carolina while Cornell Dubilier produces and sells DC and AC capacitors, EMI filters and miniature relays.

ERI Awarded Boeing Contract

Electro-Radiation, Inc. (ERI) EW systems division of Totowa, New Jersey has been awarded a contract worth approximately $500,000 by the Boeing Military Airplane Company, Seattle, Washington, to support the BI-B defensive avionics integration program. ERI's efforts will be primarily in the area of the AN/ALQ-161 ECM system requirements, performance and effectiveness evaluation.

Electrospace Receives $5.4M Contract

The U.S. Navy's Space and Naval Warfare Systems Command, Washington, D.C., has awarded Electrospace Systems, Inc., of Richardson, TX., a contract for production of antennas and control systems for the Navy's AN/WSC-6 shipboard SHF satellite communications terminals. The contract calls for the production of seven OE-279 antenna groups to be delivered during the next 24 months.

Antenna Tower is Non-Metallic

Precision Composites, Inc. announced a delivery to NCR Corporation of an all composite antenna positioner tower. In order to avoid distortion in the radiation pattern of the antenna by metallic materials the entire structure including the nuts, bolts, wheels and control mechanisms is made from composites.The antennas mounted on the tower may be rotated and tilted with a gear mechanism self contained in the tower. The entire tower assembly may be moved fore and aft to regulate the distance from the device being measured.

This antenna tower is a totally non-metallic structure.

Varian Awarded $5.5M

The Solid State Microwave Division (SSMD) of Varian Associates, Inc. has won a $5.5M contract from Eaton Corporation's AIL Division for amplifiers used in airborne radar jamming systems. The contract calls for the delivery of 2000 FET amplifiers over the next two years.

Rohde & Schwarz Contracted for EMC Project

Rohde & Schwarz of Munich has been awarded a contract for the equipment of an EMC test center for the Federal Armed Forces in Greding. The company's share of the project entails the supply of signal generators and broadband amplifiers for frequencies from 20 Hz to 18 GHz and power ratings up to 10 kW as well as receiver test assemblies from 20 Hz to 40 GHz. The project is scheduled to be completed by the end of 1988.

EPSCO Receives Contract For High Power Test Equipment

EPSCO, Inc. of Westwood, MA, announced the receipt of a $2.0M follow on order from Grumman Aerospace Corporation in Bethpage, Long Island, NY. The order is for high power RF source drawers for Radcom interface units (RIU) used as support equipment for the Navy's A-6E and other aircraft programs.

Listening to Short Wave

Shortwave Listening Handbook by Harry Helms is a reference guide providing amateur and professional shortwave radio enthusiasts with an introduction to and reference for the shortwave communication field. The book guides beginners from equipment selection and use to applications for special private, commercial and professional use. Special attention is given to the frequencies used by the U.S. and foreign embassies, the US Military and the CIA as well as chapters on illegal private broadcasting throughout the world. The book is published by Prentice Hall, Englewood Cliffs, NJ 07632. It is priced at $17.95.

Watkins-Johnson Wins Space Amplifier Contract

Watkins-Johnson Company announced that it has received a contract from the G.E. Astro Space Division for nearly $2 million to provide traveling-wave-tube amplifier (TWTAs) on the Mars Observer spacecraft. The Mars Observer is scheduled to be launched into Mars orbit in the early 1990s. TWTAs will be used in the spacecraft's X-band radio link to earth.

AEL Awarded Army Radar Contract

AEL Industries, Inc. announced that its American Electronic Laboratories, Inc. subsidiary has been awarded a $2.8 million contract by the U.S. Army's Armament, Munitions and Chemical Command (AMCCOM), Rock Island, IL, to produce 68 receiver-transmitters for the AN/VPS-2 Radar. The AN/VPS-2 Radar is a subsystem in the Vulcan Air Defense System (VADS) which provides tactical air defense against lowflying aircraft.

R & D Spending Jumped 9.4% in 1986

Company-funded research and development spending by the top 100 U.S. industrial performers of R & D rose to a record $41.3 billion in 1986, a gain of 9.4 percent from 1985. The amount the top 100 companies spent on R & D represents approximately 70 percent of all such company-funded expenditures for 1986. Those are some of the findings of the annual survey of R & D spending conducted by *Inside R & D. Boeing's R & D spending* shot up 85.1 percent in 1986, Cray Research's rose 78.3 percent and Apple Computer's R & D spending increase was 76.2 percent. Pharmaceutical companies funded R & D generously, as usual, while oil companies' R & D spending continued to slump.

Among the top ten R & D spenders there was little significant change. Ford hopped over AT&T to claim third place. General Electric rose from seventh to fifth on the strength of its acquisition of RCA. Hewlett-Packard broke into the top ten for the first time. And ITT, which has shed much of its high-tech interests, dropped out of the top ten altogether. More information can be obtained from Richard Consolas at (207) 568-4744.

Scientific-Atlanta Awarded $2.4M

Scientific-Atlanta, Inc., has received a $2.4 million order from the Jet Propulsion Laboratory for a satellite tracking and receiving ground station to be installed at the University of Alaska in Fairbanks, Alaska.

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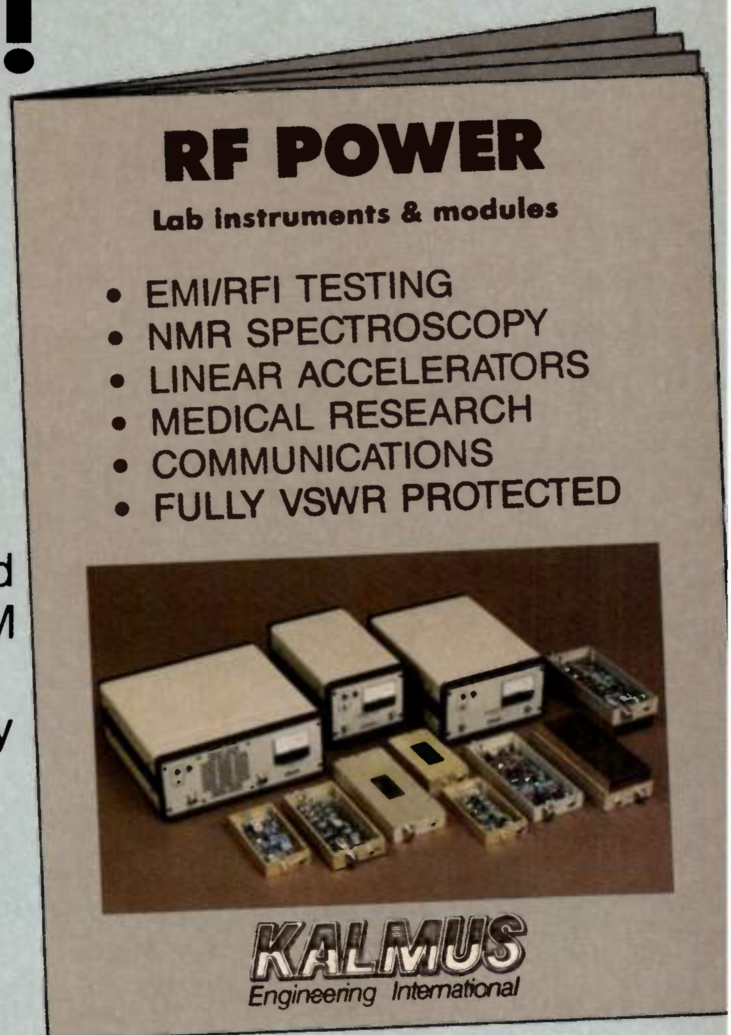

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rf calendar

July 27-30, 1987
1987 International Microwave Symposium/Brazil
Rio Palace Hotel, Rio de Janiero, Brazil
Information: Alvaro Augusto de Salles, CETUC-PUC/RJ, Rua Marques de Sao Vicente 225, Gavea, CEP22453, Rio de Janiero, Brazil

August 9-14, 1987
Intersociety Energy Conversion Engineering Conference Set
Wyndham Franklin Plaza Hotel, Philadelphia, PA
Information: Cathy Joyce, SAE Headquarters, Dept. 935, 400 Commonwealth Drive, Warrendale, PA 15096; Tel: (412) 776-4841

August 25-27, 1987
9th Quartz Devices Conference
Westin Crown Center, Kansas City, MO
Information: Components Group, Electronic Industries Association, 2001 Eye Street, N.W., Washington, DC 20006; Tel: (202) 457-4930

September 7-10, 1987
17th European Microwave Conference
Ergife Palace Hotel, Rome, Italy
Information: Microwave Exhibitors of Publishers Ltd., 90 Calverly Road, Tunbridge Wells, Kent TN12UN, England

September 15-17, 1987
Midcon/87
The Ohara Center, Chicago, IL
Information: Midcon/87, 8110 Airport Boulevard, Los Angeles, CA 90045-3194; Tel: (213) 772-2965, (800) 421-6816, inside California (800) 262-4208

September 22-24, 1987
Northcon/87
Portland Memorial Coliseum, Portland, OR
Information: Show Manager, Northcon/87, 8110 Airport Boulevard, Los Angeles, CA 90045-3194; Tel: (213) 772-2965

September 29-October 1, 1987
1987 OEM Design and Integrated Manufacturing Exposition
McCormick Place East, Chicago, IL
Information: Bill Little, Penton Exposition, 122 East 42nd St., New York, NY 10168; Tel: (800) 634-4639, in NY call (212) 867-9191

September 29-October 1, 1987
Ninth Annual Meeting and Symposium, Antenna Measurement Techniques Association
The Stouffer Madison Hotel, Seattle, WA
Information: James R. Otley, 1987 AMTA Symposium, 6682 South 191st Place, Suite E-105, Kent, WA 98023; Tel: (206) 655-7780

September 29-October 1, 1987
Fall National Design Engineering Show and Conference
Jarvits Convention Center, New York, NY
Information: Monica Viladegutt, Cahners Exposition Group, 999 Summer St., P.O. Box 3833, Stamford, CT 06905; Tel: (203) 964-0000

October 13-15, 1987
Scan-Tech 87
Bartle Hall, Kansas City, MO
Information: Don Anderson, AIM, Inc., 1326 Freeport Rd., Pittsburgh, PA 15238. Tel: (412) 963-8588

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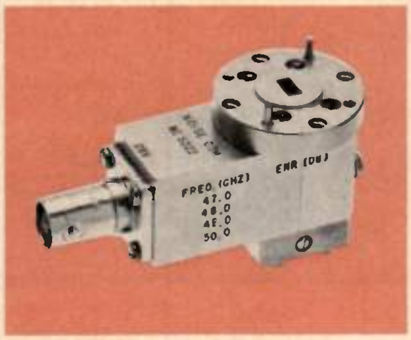

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NC 6108	up to 500 MHz
NC 6109	up to 1 GHz
NC 6110	up to 1.5 GHz
NC 6111	up to 2 GHz

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NC 7108	up to 500 MHz
NC 7109	up to 1 GHz
NC 7110	up to 1.5 GHz
NC 7111	up to 2 GHz

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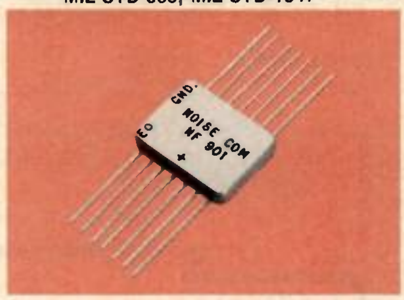

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INFO/CARD 16

The George Washington University

Frequency Synthesis
August 3-5, 1987, Washington, DC

Frequency Hopping Signals and Systems
September 9-11, 1987, Washington, DC

HF Communications Technology
September 14-18, 1987, Orlando, FL
November 16-20, 1987, Washington, DC

Spread Spectrum Communication Systems
September 21-25, 1987, Washington, DC

Fiber Optics Technology for Communication
September 22-24, 1987, Washington, DC

Introduction to Modulators and Transmitters
October 5-6, 1987, Washington, DC

High Frequency Spectrum: New concepts and technologies
October 5-9, 1987, Washington, DC

Introduction to Receivers
October 19-20, 1897, Washington, DC

Modern Receiver Design
October 21-23, 1987, Washington, DC

Information: Shirley Forlenzo, Continuing Education Program, George Washington University, Washington, DC 20052; Tel: (800) 424-9773, (202) 994-6106

UCLA Extension

Kalman Filtering
August 31-September 4, 1987, Los Angeles, CA

Information: UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024; Tel: (213) 825-1901; (213) 825-1047; (213) 825-3344

Interference Control Technologies, Inc

EMP Design and Testing
July 21-24, 1987, Washington, DC

Tempest Facilities
July 28-31, 1987, Mountain View, CA

Grounding and Shielding
July 28-31, 1987, San Diego, CA
August 11-14, 1987, Denver, CO
August 18-21, 1987, Ocean City, MD
September 15-18, 1987, Washington, DC

Tempest Design
August 4-7, 1987, Washington, DC

Practical EMI Fixes
August 25-28, 1987, Virginia Beach, VA
September 22-25, 1987, San Diego, CA

MIL-STD-461/462
September 29-October 2, 1987, Washington, DC

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

Integrated Computer Systems

Digital Signal Processing
July 21-24, 1987, Los Angeles, CA
July 23-26, 1987, San Diego, CA
August 18-21, 1987, Palo Alto, CA
September 22-25, 1987, San Diego, CA
October 27-30, 1987, Anaheim, CA

Machine Vision and Image Recognition
July 28-31, 1987, San Diego, CA
September 15-18, 1987, Los Angeles, CA
September 29-October 2, Washington, DC
October 20-23, 1987, Palo Alto, CA

Fiber Optic Communication
August 25-28, 1987, San Francisco, CA
September 15-18, 1987, Washington, DC
September 29-October 2, 1987, San Diego, CA

Hands-On Programming in C
July 28-31, Washington, DC
August 4-7, 1987, San Francisco
August 25-28, 1987, Los Angeles, CA
September 22-25, 1987, Washington, DC
September 29-October 2, 1987, San Diego, CA
October 27-30, 1987, Boston, MA

Information: Marilyn Martin, Integrated Computer Systems, 5800 Hannum Avenue, P.O. Box 3614, Culver City, CA 90321-3614; Tel: (800) 421-8166, (213) 417-8888

Norand Corporation

FCC, VDE, CISPR, and SAE Regulation and Design Criteria
September 1-2, 1987, Cedar Rapids, IA

Grounding, Bonding, Shielding and PCB Design for EMI/EMC
September 15-16, 1987, Cedar Rapids, IA

MIL-STD 461B/C and 462 Regulations and Design Criteria
October 13-14, 1987, Cedar Rapids, IA

Information: Bev Reynoldson, Norand Corporation, 550 2nd St. S.E., Cedar Rapids, IA 52401; Tel: (319) 846-2415

Georgia Institute of Technology

Millimeter and Microwave Ferrite Materials
July 27-29, 1987, Atlanta, GA

Modelling, Simulation and Gaming of Warfare
August 18-21, 1987, Atlanta, GA

Information: Deidre Mercer, Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385; Tel: (404) 894-2547

Compliance Engineering

Compliance Seminars: EMI, Safety, ESD, Telecom
August 25-28, 1987, Atlanta, GA

Information: Compliance Engineering, 593 Massachusetts Avenue, Boxborough, MA 01719. Tel: (617) 264-4208

INFO/CARD 18

SUPERSTAR

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Charles Wenzel Wins RF Design Awards Contest

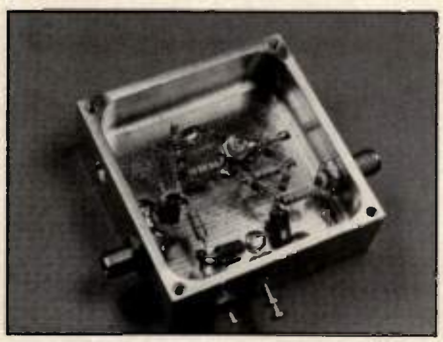
Frequency Multiplier Circuit Takes Grand Prize.

There is a very happy engineer in Austin, Texas these days — an entrepreneur with a small RF company who has just been awarded first place in the second annual RF Design Awards Contest. The disbelief was clearly evident in his voice as the contest results and prize presentation arrangements were made by telephone. But that uncertainty disappeared on May 21, 1987. After photographs had been taken and congratulations exchanged with RF Design *Editor Gary Breed and H-P Project Manager John Vink, Charles Wenzel finally realized that he actually got to keep a Hewlett-Packard 8590A Spectrum Analyzer!*

Charles Wenzel is president of Wenzel Associates, Inc., 1124-B Jollyville Road, Austin, TX 78759. He received his BSEE degree from the University of Texas at Austin and has been involved in oscillator design engineering for more than 10 years. He can be reached at (512) 345-2703.

Wenzel Associates is a small (12 employees) company in Austin, Texas which manufactures specialized oscillator products as their primary business. Its president is a 34-year-old engineer who, along with his partners, took a chance in 1979 and started in business. Since that beginning, the firm has grown to a modest size, producing precision reference oscillators, TCXOs, and other related standard and semi-custom products.

Charles Wenzel provides the primary engineering guidance to this company, and his creative talent was been rewarded with the Grand Prize in the RF Design Awards Contest. His winning circuit is an odd-order frequency multiplier using a diode bridge configuration to generate a square wave, with its inherent makeup of odd harmonics. The design and its key input and output matching configurations was developed for use in his company's products, and although the circuit was "semi-proprietary," he decided to take a chance and enter it in the contest. Obviously, the chance paid off. (Details of the circuit design are presented in this month's Featured Technology on page 31.)



The simplicity of the frequency multiplier and buffer amplifier circuit is apparent in this photo.

Presentation of the Grand Prize was made by Editor Gary Breed and the 8590A Project Manager, John Vink. John noted that small firms like Wenzel Associates were exactly the kind of businesses they hoped would be customers for the new low cost spectrum analyzer. It was especially fitting for the engineer with the primary responsibility for the development of the Grand Prize to be the one to present it to the winner.

Wenzel Associates will have moved to larger facilities by the time this issue is printed and mailed. Although the growth that requires such a move had no direct relationship to the prize-winning design, it is certainly an indication that Charles Wenzel is on the right track in more ways than with just one small circuit!

The Winners!

Results of the Second Annual RF Design Awards Contest.

By Gary A. Breed
Editor

Thirty engineers made the extra effort to define, document and deliver their proudest accomplishments to the judges in the second annual RF Design Awards Contest. Seven of them are now recognized as prize winners for their contributions to the art of engineering. Over the next six or eight months, these seven designs and several other entries will be published, sharing with all our readers a wealth of practical ideas.

Judging a group of more or less unrelated ideas was one heck of a tough job. At first, thirty entries seemed like only a modest response. After all, there were prizes worth nearly $20,000 and tens of thousands of engineers who would love to win one of them. However, once judging began, those thirty seemed like hundreds as it was discovered that each was a high-quality technical presentation.

Judge Andy Przedpelski noted the diversity of the topics. "Some of the entries were specific circuits, but others emphasized design techniques. It's hard to evaluate both in the same way," he commented. He also observed (as did all three judges) that the majority of the entries represented an engineer's unique solution to a typical engineering problem. Sharing these practical lessons can only help other engineers who may be confronted with similar tasks.

Charles Wenzel shows off winning prototype to Editor Gary Breed.

Dan Baker, last year's winner, was one of the trio of judges. He was impressed with the quality and variety as he remarked, "What a great collection of ideas! I put all the entries in a notebook as part of my reference library." Dan also was impressed by the prize list, considerably bigger than his winnings last year, but he says, "I can't decide whether to enter next year and go after a bigger prize or volunteer to be a judge and get to see all those good ideas again."

The Entrants

A more well-rounded representation of RF engineering could not have been planned! Large companies, small companies, consultants, government facilities and educational institutions were all represented in proportions similar to the RF industry as a whole. The circuits entered included the entire spectrum: oscillators, multipliers, switches, amplifiers, measuring instruments, power dividers and more. Frequencies ranged from 100 kHz through 2.5 GHz. There were digital, microstrip line, and passive lumped-element techniques as well as the expected transistor, diode and MMIC ideas.

Geographically, the entries came from traditional RF bastions as well as the "boonies." Eight entries were from California and another eight from the Northeast. Ten more came from all corners of the country. The only area of the U.S. not represented with at least one entry was the Southeast (y'all better enter next year). For the second year, there was significant interest from outside the U.S. Foreign countries represented were Canada, Poland, India and the United Kingdom.

One of the purposes of the contest is to encourage communications among as many different engineering points of view as possible. That goal appears to have been met.

The Winners and Their Designs

This year's Grand Prize, a Hewlett-Packard 8590A Spectrum Analyzer was awarded to Charles Wenzel for his diode bridge odd-order frequency multiplier. A profile of our winner is contained in this month's Cover Story (page 27), and his winning design is our Featured Technology article immediately following this report. The design is an excellent example of a "real world" engineering task and its successful solution.

Second place in the judging tabulation was a joint entry from Guy Love and Kevin Lindell, engineers at United Technologies' Norden Systems, Inc. in Norwalk, CT. As first runners-up, they had their choice of the two runner-up prizes and selected Touchstone RF™ from EEsof, Inc. Their design falls into the category of *techniques;* a method for calibrating phase noise measurement systems. The method uses switched lengths of transmission line to achieve a known phase modulation with predictable sideband characteristics. This entry will be published next month in *RF Design*.

Peter Vizmuller of Motorola Ltd. in North York, Ontario, is next on the winners list. For his space-saving broadband power splitter circuit, he won the Bird Digital Power Meter system. His microstrip circuit design takes up only 2/3 the board space of a conventional two-section broadband power divider with very nearly the same performance. Peter was one of only three entrants who had also entered last year's contest. Look for this design next month, too.

Four engineers are receiving the latest version of SuperStar circuit analysis software from Circuit Busters. First in this group is David Tharp, an RF engineer at Colorado Data Systems, Englewood, CO. One of several entrants who used low cost MMIC amplifiers in unusual roles, Dave designed a feedback network to provide flat frequency response up to 2.5 GHz.

Wes Hayward contributed oscillator circuits using MMIC amplifiers.

David Tharp's MMIC amplifier application earned him a place among the winners.

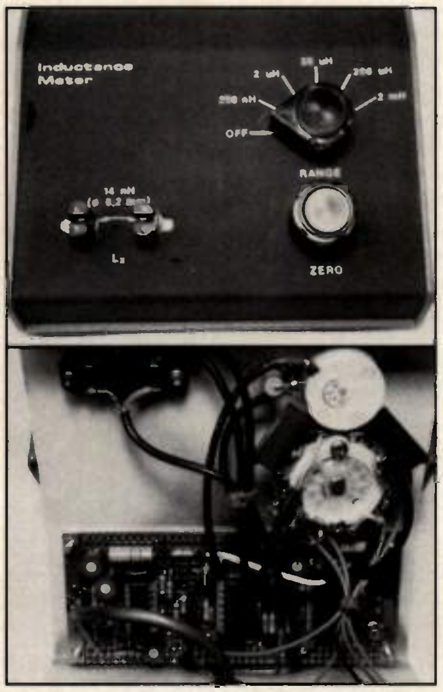
The amplifier design was developed for a smart frequency counter board which will soon be available as a component in CDS' line of automatic test systems.

Wes Hayward of Beaverton, OR, is another winner who used MMIC devices. His entry showed the development of feedback and amplitude limiting techniques to use these inexpensive gain blocks as VHF and UHF oscillators, solving the problem of low input and output port impedances. Wes is a well-known RF engineer at Tektronix, Inc., and through his own company, Hayward Electronic Systems, Inc.

An inductance measuring instrument was the entry of Roger Williams, Senior Engineer at LTX Corporation of Westwood, MA. His design measures the quadrature voltage across an inductor, then scales it for direct inductance readout on a digital voltmeter or DMM. Roger's circuit is relatively simple, using three ICs and a single JFET as active components, yet it achieves better than 2 per cent accuracy.

The final name on the winners list is Paul Shuch, who describes an application with public safety implications. He has developed a low power, dual-antenna doppler radar system intended as an aircraft anti-collision warning. The information from the two antennas is presented to the pilot in binaural audio form, providing the same type of *apparent position* information we get listening to stereo sound. Paul's company is Microcomm, and he teaches at San Jose City College and San Jose State University.

It is unfortunate that we can't award a prize to every entry. All were worthy contributions to engineering knowledge. It is possible, however, to publish three or four entries in addition to the prize winners. Readers can look forward to seeing as many of these great ideas as the publishing schedule allows. rf



This inductance meter earned designer Roger Williams a prize.

The Prizes

Grand Prize: Hewlett-Packard 8590A Spectrum Analyzer. Hewlett-Packard Company supplied this year's grand prize, an instrument introduced on the cover of last November's *RF Design*. The 8590A represents an effort on the part of H-P to develop low cost test equipment that retains a high performance level. John Vink, manager of the 8590A design team, expressed H-P's pleasure with the fact that the winner of their instrument represented a small company, the type of customer that they hope to reach with lower cost instruments.

Runner-up Prize: Bird Digital Power Meter. Introduced on the December 1986 *RF Design* cover, the model 4421 digital power meter from Bird Electronics goes to one runner-up. The prize includes the digital instrument, its accompanying sampling heads for 1.8 MHz - 1 GHz measurements, IEEE-488 interface and battery pack. With the award of this prize, Bird is pleased to have their newest product in the hands of an active RF engineer.

Runner-up Prize: EEsof's Touchstone RF™. PC-based RF software is one of the hottest topics of discussion among engineers, and the latest version of EEsof's design and analysis package has been awarded to another runner-up. The winners note that receiving the smaller PC-based software will make it easy to assess its value, with possible future plans of "trading up" to a full-feature version.

Honorable Mentions: SuperStar 3.0 from Circuit Busters. One of the leaders in low cost RF software, Circuit Busters has provided four copies of the latest revision of SuperStar. The 3.0 version, released just in time to be awarded to the contest prize winners, has been rewritten in C language and includes an internal editor for stand-alone operation.

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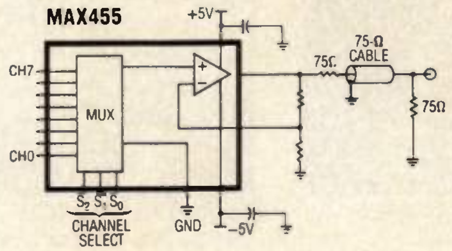

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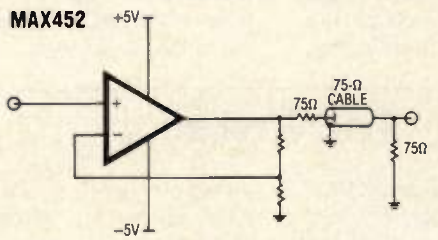

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New Topology Multiplier Generates Odd Harmonics

Contest Winner is a Classic Example of Engineering Problem-Solving.

By Charles Wenzel
Wenzel Associates, Inc.

The winning design in this year's RF Design Awards contest is not a physically or mathematically complex circuit. Like nearly all "everyday" engineering tasks, the author has taken a small, well-defined problem (efficient odd-order multiplication) and developed an acceptable solution. That solution may not be especially difficult or even completely unique. What makes it a winner, however, is the combination of an innovative "twist" to a known phenomena, a good theoretical analysis of its function, and a clear explanation of the design, construction and testing process.

The purpose of the circuit is to take advantage of the superior noise and switching characteristics of Schottky barrier diodes to make a high performance odd-order frequency multiplier. Modern quartz oscillators have reached a level of performance where it has become difficult to multiply the fundamental frequency without degrading the phase noise by more than the unavoidable 20 dB per decade of multiplication. Thanks to the Schottky barrier diode's extremely low flicker noise, this circuit adds little excess noise to even the best sources. In addition, the upper frequency limit of this configuration should be quite high: Schottky diodes are not slowed by minority carriers in the junction region and exhibit switching speeds measured in the picoseconds.

This particular application performs the difficult first stage multiplication after an ultra-low noise 10 MHz reference oscillator. Such low noise multiplication is necessary in constructing state-of-the-art synthesizers, radars and microwave communications equipment that rely on the reference oscillator for spectral purity near the carrier. The multipliers are also used to make the job of measuring phase noise easier.

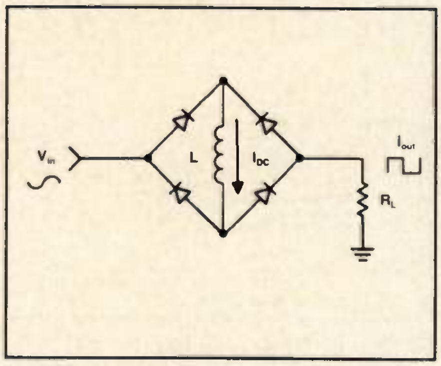


Figure 1. Sinewave to squarewave converter circuit.

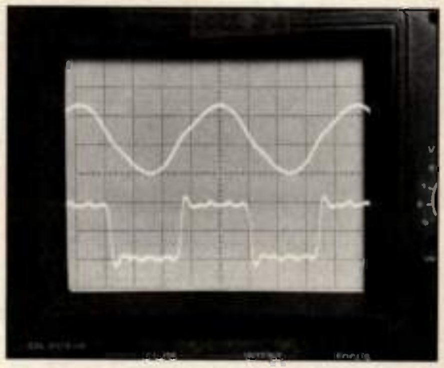


Figure 2. Top trace is signal into diode bridge (2V/div). Bottom trace is current in load resistor (10mA/div).

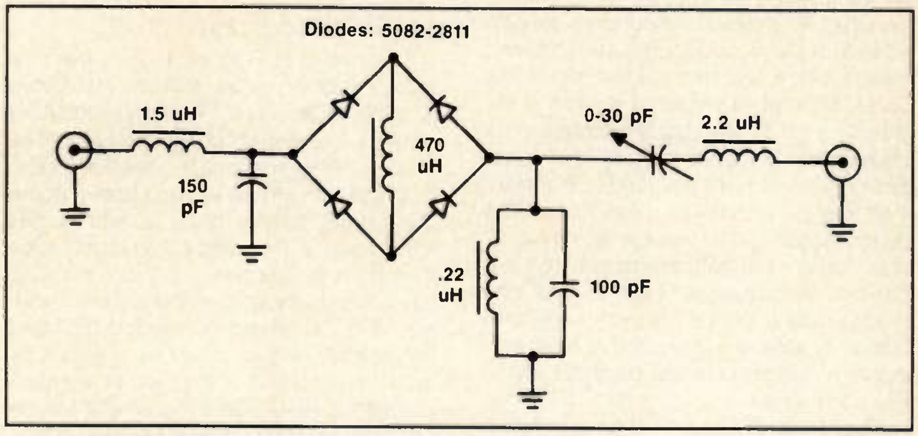


Figure 3. 10 MHz to 30 MHz multiplier circuit.

Topology

Figure 1 shows the voltage sinewave to current squarewave converter which forms the heart of the multiplier. This unique converter is simply a full-wave bridge with an inductor short-circuiting the DC terminals! The inductor is chosen to have a high impedance as the operating frequency so that an AC input results in DC in the inductor. This DC flows through

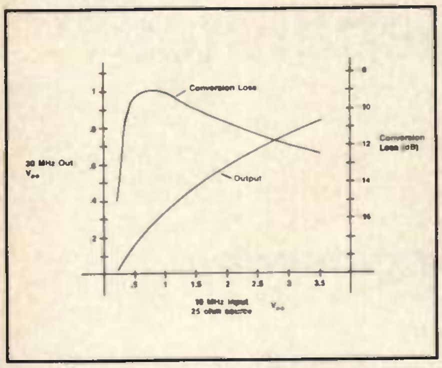


Figure 4. Prototype test results.

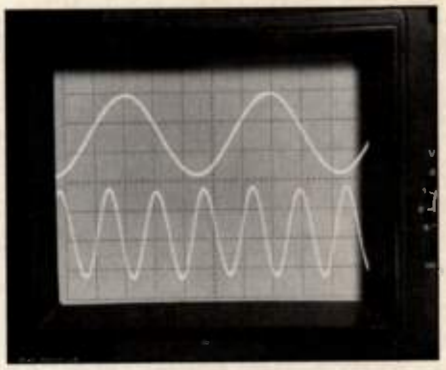


Figure 5. Top trace is input (1V/div) and bottom trace is output (.5V/div).

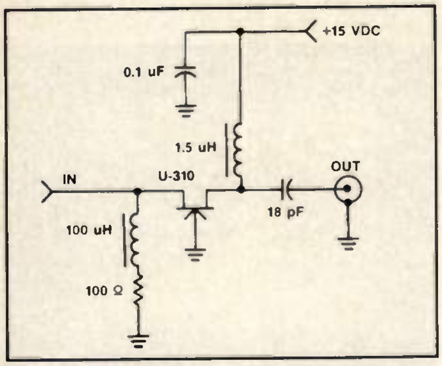


Figure 6. 30 MHz amplifier added to multipliers.

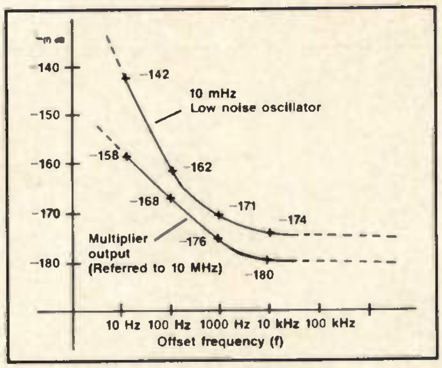


Figure 7. Phase noise measurement.

alternate pairs of diodes due to the commutating action of the input voltage. Therefore, if one AC terminal of the bridge is driven with a low impedance sinewave, the other AC terminal will supply a squarewave to a low impedance load. The load must have a low impedance since the compliance of this current source is exactly equal to the input voltage. The photograph in Figure 2 shows the waveform obtained from the circuit in Figure 1 at 10 MHz with a 470 uH inductor. The bottom trace is the voltage across a 10 ohm resistor and represents a 10 mA p-p current squarewave. Notice that the diodes switch as the input signal's zero crossing. Consequently, this circuit produces a minimum of troublesome AM to PM conversion.

The Fourier expansion of a squarewave is:

$$f(x) = A \times \frac{4}{\pi} \sum_{n = 1, 3, 5 \ldots} \frac{\sin(n \omega x)}{n}$$

Notice that only odd harmonics are present with an amplitude inversely proportional to the harmonic number. All that is necessary to make a frequency multiplier is to design input and output circuits to select and enhance the desired harmonic without disturbing the sine to square conversion.

Circuit Description

The circuit of Figure 3 meets these requirements, providing multiplication from 10 MHz to 30 MHz. The input matching network consisting of the 1.5 uH choke and the 150 pF capacitor does three jobs: it steps up the input voltage to overcome the diodes' barrier potential with series resonance; it provides a low impedance to ground for the switching current; and it isolates the input from the switching current. It is interesting to note that the input impedance of this series tank would be quite low except that the diodes' conduction spoils the Q with a resulting input impedance near 50 ohms for a 2 V_{p-p} input. For smaller input signals the input impedance drops, which explains the conversion efficiency peak near 0.5 V_{p-p} for the 25 ohm source (Fig. 4). This variable Q provides a degree of feedback to help ensure that the multiplier has a usable output over a wide range of input voltage.

The output network presents the required low impedance to the bridge while directing the desired harmonic to the output. The 0.22 uH choke and the 100 pF capacitor provide the low impedance away from 30 MHz and the series tank formed by the 2.2 uH choke and the 30 pF trimmer provide a low impedance path to the load at 30 MHz. Either higher Q or additional filtering may be used here if harmonic rejection better than about 30 dB is required.

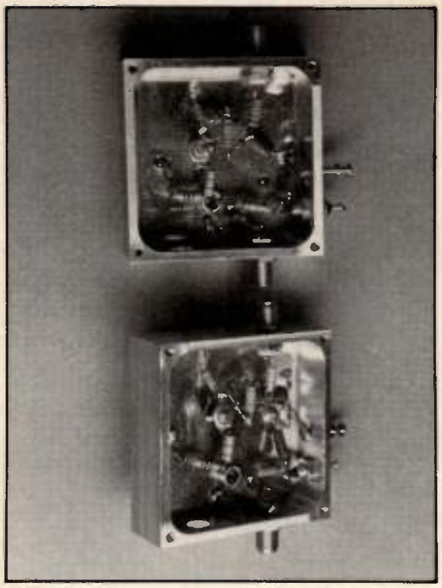
Schottky diodes are mandatory for best performance. Passivated diodes without the p-n guard ring like the H-P 5082-2835 are good for higher frequencies but reverse voltage breakdown must be avoided. Hybrid diodes which include a guard ring are desirable due to the higher breakdown voltage, but they do exhibit more capacitance (about 1 pF at 0 V). The 5082-2811 has a reverse breakdown of 15 V and exhibits 1.2 pF at 0 V. The 5082-2813 is a matched quad version.

The load inductor should exhibit a high impedance at the input and output frequencies. At low frequencies almost any large choke will suffice, but at higher frequencies a slight improvement is obtained by selecting an inductor to resonate with the diode capacitance at the input frequency.

Test Results

Figure 5 shows the input and output waveforms and Figure 4 shows the performance over a range of input voltage. The conversion gain is good over a wide range considering that no active gain stages are employed. The conversion efficiency is as high as diode frequency doublers even though the multiplication factor is higher.

In order to check the phase noise, a second multiplier was constructed and grounded-gate amplifiers were added to boost the output level (Figure 6). Figure 7 shows the measured phase noise of the multipliers and of the oscillator used to make the measurement. The Appendix describes the phase noise measurement technique. The multipliers' noise is significantly better than the oscillator so this test relies on noise cancellation in the mixer which should occur since both multipliers receive the same noise. Substituting a noisier oscillator increased the measured noise, suggesting that the measured noise may be in part due to dispersion in the signal paths. Such a measurement error would make the multipliers appear noisier than they actually are, but the in-



dicated noise is already below most "ultra-low noise" oscillators.

The cost of this multiplier is quite low since the component count is low and no exotic parts are used. The trimmer capacitor should be high quality since the rivet-like connection to the rotor of cheap trimmers can become noisy. The prototype used molded chokes and NPO dielectric capacitors.

Applications

A half-wave version is easily constructed by eliminating the bottom two diodes and connecting the inductor to ground. This configuration is convenient for high frequency layout and has been used to multiply 100 MHz to 500 MHz with about 20 dB of loss. Add a $0.98 MMIC amplifier for a cost effective high performance multiplier. Stripline techniques would prove interesting above 500 MHz.

For high order multiplication the constant current inductor can be reduced so the output becomes a short pulse instead of a square wave, reducing the power in the lower harmonics. This change also makes a nice bipolar pulse generator.

Conclusion

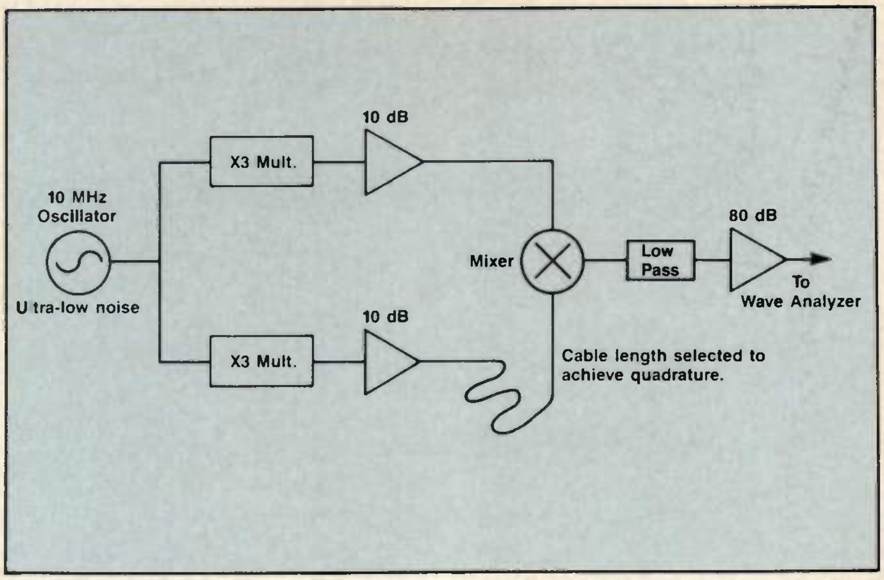
A high performance, low cost frequency multiplier of uncomplicated design has been described. The phase noise performance is sufficiently low to avoid serious degradation of the best commercially available oscillators and the conversion loss is good even for low level inputs. The new topology will provide state-of-the-art odd-order frequency multiplication over a wide range of frequencies. rf

For information about the author, see this month's Cover Story on page 27.

Appendix: Phase Noise Measurement

Phase noise is usually expressed as either a phase or frequency spectral density, $S_\phi(f)$ or $S_y(f)$ where f is the frequency offset from the carrier (Fourier frequency). The commonly used L (f) is the single-sideband phase noise-to-signal ratio and is one half of $S_\phi(f)$ for the low modulation index associated with low noise signals. Frequency multiplication causes sideband power (including phase noise) to increase by 20 dB per decade (i.e. the sideband power increases by n). Thus, an ideal 3x multiplier will increase the noise by 9.5 dB (20 log 3 = 9.5).

The key to ultra-low phase noise measurements is the Schottky diode double balanced mixer (see Figure 8). When two quadrature signals are applied to the RF ports, slight variations in the relative phase of these signals are converted into voltage variations in the DC component of the IF port signal. The mixer then has a characteristic conversion sensitivity expressed in volts per radian. For low noise work the IF signal is filtered, amplified, and applied to a spectrum or wave analyzer. This noise voltage measurement is converted to phase noise as follows:



$$(f) = 10 \log[(V/K)^2/BW] - 3\text{ dB} - 3\text{ dB}$$

where: V is the measured voltage
K is the conversion gain (volts/radian)
BW is the measurement bandwidth

The first 3 dB correction assumes that the two devices under test contribute equal noise. The second 3 dB is removed because this hetrodyne technique detects both sidebands and since these are uncorrelated noise signals one sideband will have half the power.

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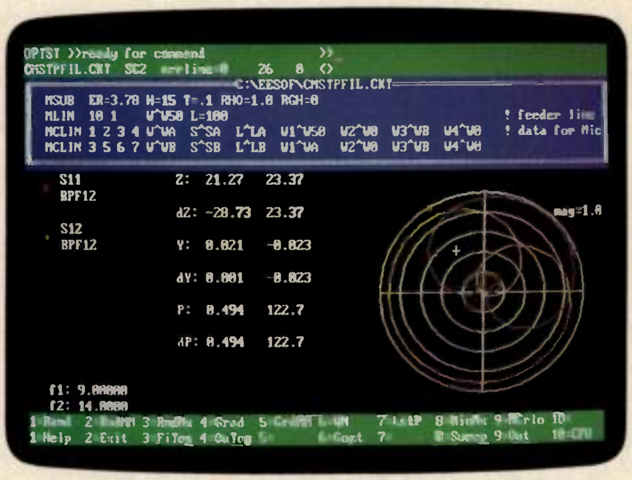

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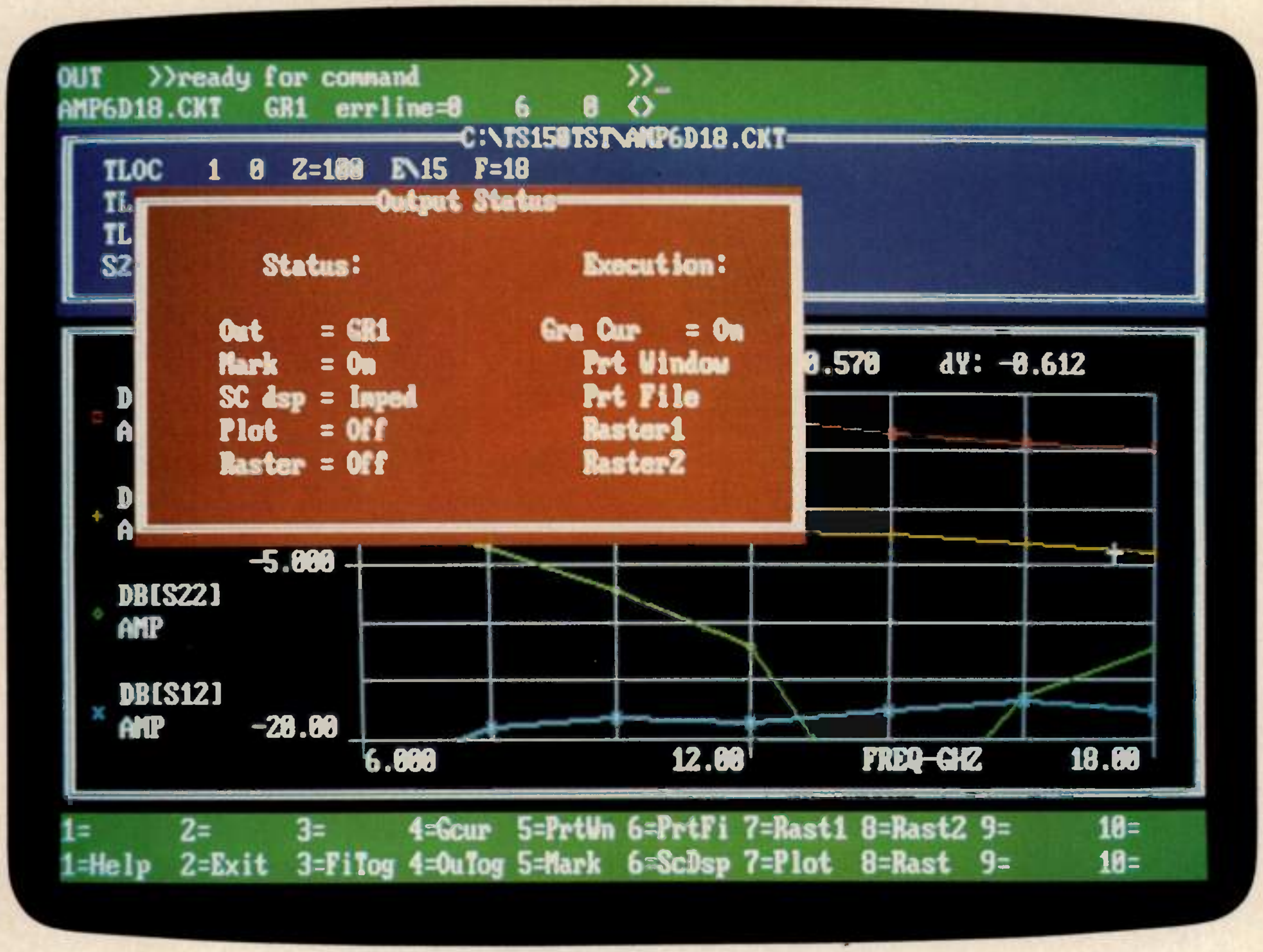

You see above how Touchstone's graphics output gives you control of the interactive cursor. And you get an idea of the many advanced kinds of plots that 1.5 lets you generate — with hard copies of everything you see on the screen.

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Opposite page (Left): Polar display with optimization activated: (Right): Admittance chart with tune mode activated.

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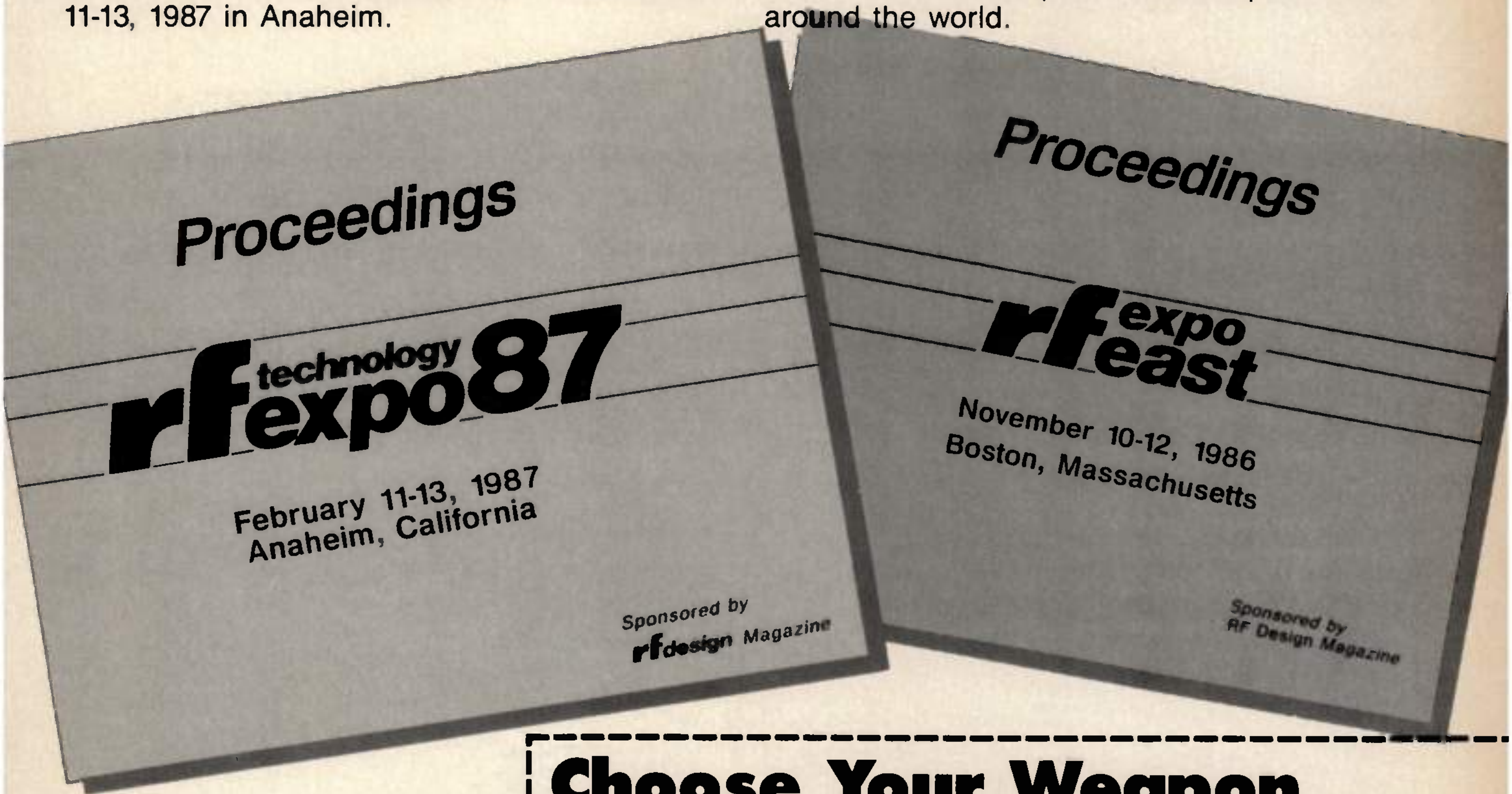

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Microstrip and Lumped Element Ladder Network Analysis Program

By R.K. Feeney and D.R. Hertling
Georgia Institute of Technology

Most RF amplifiers are terminated with ladder configuration networks made from lumped elements, microstrip, or a combination of the two. This article presents an analysis program written in BASIC that determines the driving-point impedance of such networks. The program will accept either microstrip material parameters or normalized dimensions. Driving point impedance, driving point reflection coefficient, and transducer gain calculations are made as a function of frequency. The program was written for the IBM PC, however, it can easily be adapted to other computers with sufficient memory. The program was kept as short as possible so that it can be adapted to run on portable machines with BASIC capability. A version for the HP-41CV is also available.

The program facilitates the calculation of the driving-point impedance, driving point reflection coefficient, and transducer gain of any terminated lossless ladder-configuration network. A maximum of 50 element groups or branches can be included in the network. If more than 50 branches need to be analyzed, the DIM statement in line 20 should be altered. At appropriate points in the calculation, the program prompts the user for all required data. The program writes all outputs to the screen and, if requested, a summary of the input data and the calculated output is printed.

Using the Program

When the program is initially executed, a menu of network elements and their code numbers is displayed. These codes, which are used to specify the geometry of the network, are:

Code Number	Description
1	A series microstrip transmission line.
2	A shunt-connected open-circuited transmission line.
3	A shunt-connected short-circuited transmission line.
4	A series connected capacitor.
5	A shunt-connected capacitor.
6	A series-connected inductor.
7	A shunt-connected inductor.
8	A series-connected parallel LC combination.
9	A parallel-connected series LC combination.

After displaying the menu of element codes, the computer requests the circuit configuration. The digits describing the circuit are entered together as one number starting from the end of the network opposite that where the driving-point impedance is to be calculated. In the usual amplifier design situation, one would start with the 50 ohm load or source impedance. If the network contains microstrip elements, the program requests how the microstrip transmission lines are to be specified. If specified as normalized values, the characteristic impedance and the length in fractions of a wavelength or in degrees at the design frequency will be requested for each microstrip section. If the choice of actual dimensions is selected, the microstrip material parameters and the dimensions of each microstrip in inches or centimeters will be requested at the appropriate time. Once the choice of the microstrip data entry mode is selected, the program will prompt for either the design frequency or the microstrip material parameters.

The information then requested by the program is the value of the complex termination of the network. Often, this will be the 50-ohm source or load impedance. When the load impedance has been entered, the program will prompt for all necessary data for each circuit branch. The element number is given and all applicable quantities are requested. Next the reference impedance in ohms for the reflection coefficient is requested. The number of points and the frequency range for the analysis are specified. For convenience, capacitor, inductor and frequency data are entered in pF, nH, and MHz, respectively. The last input needed by the computer is whether or not printed output is desired. Once data has been entered, the program will calculate and display the driving-point impedance, the driving-point reflection coefficient, and the transducer gain in dB. Upon completion of the calculations, the program will display the menu in Figure 1.

1 — Edit the ladder network
2 — Repeat calculations over a new frequency range
3 — Enter a new configuration
4 — Quit

Figure 1. Program menu.

Examples of Program Use

Three examples of program use are presented. The first example is a lumped element PI-network, the second example is a lumped element and microstrip network, while the last example is an all-microstrip filter. Both actual and normalized modes of strip specification are demonstrated in the examples.

Example One

Consider the Pi-network shown in Figure 2, which has been designed to match 500-j200 ohms to 50 ohms at 150 MHz. The design value of the right-hand capacitor is 212 pF. It has been replaced by the equivalent circuit of an actual chip capacitor having the same value of effective capacitance. This illustrates how the program can handle a series branch connected in shunt. Using the program, the match at 150 MHz is verified and the transducer power gain of the network is calculated from 140 to 160 MHz.

Begin the analysis by running MSTRIP. BAS. The program displays the menu of the element configurations with their code numbers and requests the configuration of the network under investigation. Starting from the 500-j200 ohm load, the network contains a shunt capacitor, a series inductor, and a parallel-connected series capacitor and inductor. The configuration number, 569, for this network should be entered. Next the user is prompted for the terminations. Enter 500 ohms for the real part and −200 ohms for the imaginary part.

Next, the elements in the network are entered. The program prompts all the element values for each branch starting with the left-hand shunt capacitor. Enter 61.9 pF, 23.2 nH, 192 pF and .55 nH when prompted. After all the network data have been entered, the 50 ohm reference resistance for gamma is entered. Next, data relating to the desired frequency range for the calculation must be entered. Three points, covering the 140 to 160 MHz range are used. Finally, enter NO to the print request prompt and the computer displays the results in Figure 3. Note that the match at the design frequency, 150 MHz, is close to perfect.

The monitor displays only the calculated output. However, the printer summarizes all data entered. It is often useful not to print output the first time the program is run. The editing features allow the operator to make several runs until the output is exactly what is desired. Then an additional run is made selecting option two, entering the same frequency parameters, and requesting the output be printed.

The program calculates the transducer gain from the reflection coefficient using the relation $G_T = 1 - |\Gamma^2|$ where Γ is the reflection coefficient at the port which the driving point impedance is calculated. The calculated transducer gain assumes that a source with a pure real impedance equal to the reference impedance drives this port. If a source with a complex impedance drives this port, the imaginary part of the source impedance should be entered as a branch of the ladder network. This makes the calculation of the transducer gain calculation correct. However, it does include the imaginary part of the source impedance in the driving point impedance. Calculation of the transducer gain using this expression is only valid for a lossless network.

Example Two

Figure 4 shows a simple matching circuit that finds wide application in UHF design, a capacitor followed by a quarter-wave transformer. This particular circuit matches 3.3 + j3.5 ohms to 50 ohms at 900 MHz. Since the example contains microstrip, we must specify how the microstrip parameters are to be entered. The user may specify transmission line relative lengths in terms of either degrees or wavelengths and actual transmission line dimensions in units of either inches or centimeters. Flags F2 and F3 control these choices. By setting F2 equal to zero in line 60, the program will expect actual microstrip dimensions in inches. If F2 is set to one, the program expects actual microstrip dimensions in centimeters. Similarly, by setting F3 to zero or one in

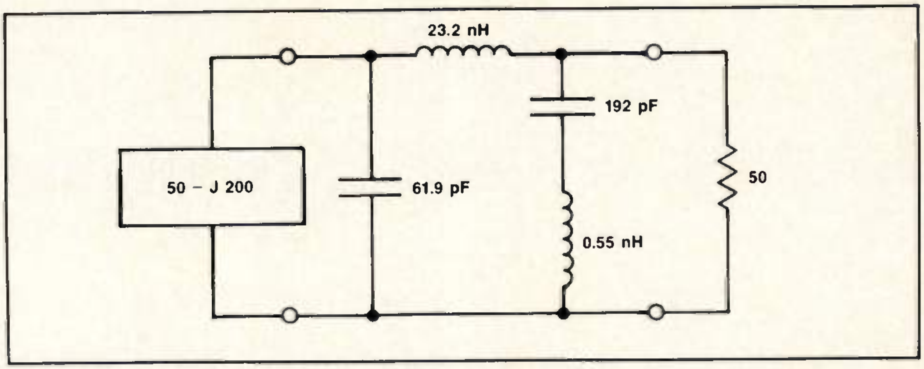

Figure 2. Lumped element matching network.

```
TERMINATIONS (OHMS):  RL= 5.000E+02  XL=-2.000E+02

                                              GAMMA (REF-  50.00 OHMS)
   F(MHz)       R(OHMS)        X(OHMS)          MAG          ANG        GT(dB)
 1.400E+02     1.638E+00     3.661E+00         0.937       171.62       -9.13
 1.500E+02     4.976E+01     1.911E+00         0.019        95.93       -0.00
 1.600E+02     1.150E+00    -1.206E+01         0.957      -152.86      -10.79
```

Figure 3. Results of Example 1.

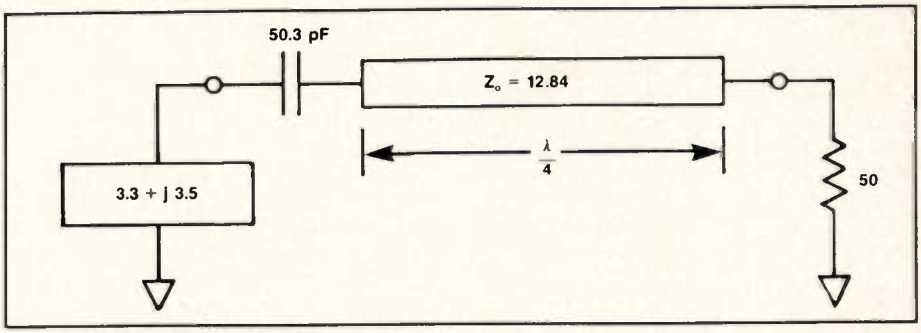

Figure 4. Hybrid matching network.

```
CONFIGURATION #:  14

NORMALIZED MSTRIP LENGTHS IN WAVELENGTHS

DESIGN FREQ:    900.000 MHZ

BRANCH #  1
ZO=   12.84 OHMS
LENGTH= 2.500E-01

BRANCH #  2
C(pF)=    50.30

TERMINATIONS (OHMS):  RL= 5.000E+01  XL= 0.000E+00

                                              GAMMA (REF-  50.00 OHMS)
   F(MHz)       R(OHMS)        X(OHMS)          MAG          ANG        GT(dB)
 6.000E+02     4.302E+00    -1.205E+01         0.850      -152.72       -5.56
 9.000E+02     3.297E+00    -3.516E+00         0.877      -171.92       -6.36
 1.200E+03     4.302E+00     4.139E+00         0.843       170.47       -5.37
```

Figure 5. Printout of Example 2 with print option selected.

line 70, normalized microstrip dimensions in wavelengths or degrees respectively are expected by the program. Since most of the time these two options do not need to be changed, it was decided to change these flags by editing the program. To avoid data entry errors, a statement is displayed indicating what units are expected by the computer each time the program is run. If the user prefers specifying the units to be used each time the program is run, appropriate program code can be easily entered to the program. The code given in the text is set for inches (F2=0) and wavelengths (F3=0). For this example, enter line lengths in wavelengths.

Select option 3 to enter a new configuration and the program prompts for a configuration number. For this network, enter 14 for the configuration number. The program next requests the microstrip dimensioning mode. We are using the normalized mode and therefore enter zero. The computer displays "Enter normalized MSTRIP dimensions in wavelengths" to verify which dimensioning mode has been selected. When normalized dimensions are used, the design frequency is required so that the dimensions can be scaled to other frequencies. The design frequency for this example is 900 MHz. We next need to enter the termination. This time start with the 50-ohm load as one would do when calculating Γ_S and Γ_L for substitutions into S-parameter amplifier design equations. The network element values are then requested. The characteristic impedance, 12.84 ohms, and the normalized dimensions of the microstrip at the design frequency, .25 wavelengths, should now be entered followed by the 50.3 pF capacitor value. The reference load is 50 ohms in this example. Finally, enter a frequency range of 600 to 1200 MHz with three points calculated. Assuming that the network data has been correctly entered and the frequency range is what is desired, request that the output be printed. The computer displays the results in Figure 5.

Example Three

This example illustrates use of the program with an all-microstrip network. Figure 6 shows a low pass filter composed of cascaded transmission line sections. The cutoff frequency of the filter is 600 MHz. It is desired to calculate the transducer gain of this network as a function of frequency.

First select option three so that the computer requests a new configuration. Begin the analysis by entering the configuration number into the calculator. The configuration 1111111 represents the seven cascaded transmission line sections. The first data needed by the program set the microstrip dimensioning convention. This example uses actual dimensions in inches, so select option number one. The computer displays "Enter normalized MSTRIP dimensions in inches" to verify what units the computer is expecting.

When actual dimensions are employed, the user must input the microstrip material parameters. These parameters need be entered only once during the execution of the program. The program next requests the termination. Enter 50 ohms since we desire to calculate the 50-ohm reflection coefficient and from that the transducer power gain. After the terminations, the program requests the dimensions of each microstrip element. In this example, calculate the driving-point impedance from 300 to 1200 MHz in four steps. Again, as in the previous example, select the printed output option. After completing the calculations, the computer displays and prints the results shown in Figure 7.

To demonstrate the editing features of the program, select option two to repeat the calculations over a new frequency range. This time calculate 10 points from

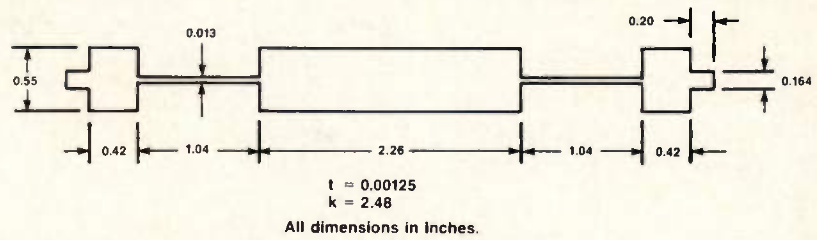

Figure 6. All-microstrip low pass filter.

```
CONFIGURATION #:  1111111

ACTUAL MSTRIP DIMENSIONS IN INCHES

DIELECTRIC THICKNESS=  6.000E-02
METAL THICKNESS=  1.250E-03
RELATIVE DIELECTRIC CONSTANT=    2.480

BRANCH #  1
WIDTH= 1.640E-01
LENGTH= 2.000E-01

BRANCH #  2
WIDTH= 5.500E-01
LENGTH= 4.200E-01

BRANCH #  3
WIDTH= 1.300E-02
LENGTH= 1.040E+00

BRANCH #  4
WIDTH= 5.500E-01
LENGTH= 2.260E+00

BRANCH #  5
WIDTH= 1.300E-02
LENGTH= 1.040E+00

BRANCH #  6
WIDTH= 5.500E-01
LENGTH= 4.200E-01

BRANCH #  7
WIDTH= 1.640E-01
LENGTH= 2.000E-01

TERMINATIONS (OHMS):   RL= 5.000E+01   XL= 0.000E+00

                                              GAMMA (REF-   50.00 OHMS)
  F(MHz)       R(OHMS)          X(OHMS)          MAG          ANG        GT(dB)
 3.000E+02    3.274E+01        5.920E+00        0.220       156.97        -0.22
 6.000E+02    6.032E+01        1.557E+02        0.818        31.53        -4.80
 9.000E+02    2.853E+00       -1.067E+02        0.980       -50.17       -13.96
 1.200E+03    2.428E-01       -4.499E+01        0.995       -96.04       -19.72
```

Figure 7. Printout for Example 3.

300 to 1200 MHz and request that the output be printed. The output is shown in Figure 8.

Branch editing can be demonstrated by selecting option one. Let us see what will happen if the length of the microstrip in branch four is lengthened to 2.5 inches. When prompted for the branch number to be edited, enter 4. The computer prompts for the width and length of the microstrip in branch 4. Enter .44 and 2.5 inches respectively. Even though only the length of this line is to be changed, the computer prompts for all the data for the branch to be edited. Next the computer again asks for the branch to be edited but this time enter Q to quit editing. Request that the output be printed and the output is shown in Figure 9.

This example was also analyzed by the programs COMPACT and TOUCHSTONE. In both cases, exact agreement was obtained. A measurement of the filter with a network analyzer also showed excellent agreement with the calculations.

In order to keep the program small, only lossless circuit elements are considered. However, for critical applications the code could be changed to request a resistive element or Q with each capacitor or inductor and loss information for the transmission lines. In addition to providing for the non-ideal inductors and capacitors, the transmission line subroutines would have to be modified to include the resistive elements. As mentioned previously, the method used for calculating the transducer gain is only valid for lossless networks and therefore, this part of the program would also need to be modified. The program calculates microstrip impedance and velocity factor using expressions developed by Sobol (1). Several other expressions (2, 3) are in common use and could be substituted.

As previously mentioned, a version of this program is available for the HP-41CV. This version is compatible with the BASIC version, however, it does not perform the transducer gain calculations and does not have the editing capabilities. A program listing and directions for use are available upon request. rf

About the Authors

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CONFIGURATION #: 1111111

ACTUAL MSTRIP DIMENSIONS IN INCHES

DIELECTRIC THICKNESS= 6.000E-02
METAL THICKNESS= 1.250E-03
RELATIVE DIELECTRIC CONSTANT= 2.480

BRANCH # 1 WIDTH= 1.640E-01 LENGTH= 2.000E-01	BRANCH # 5 WIDTH= 1.300E-02 LENGTH= 1.040E+00
BRANCH # 2 WIDTH= 5.500E-01 LENGTH= 4.200E-01	BRANCH # 6 WIDTH= 5.500E-01 LENGTH= 4.200E-01
BRANCH # 3 WIDTH= 1.300E-02 LENGTH= 1.040E+00	BRANCH # 7 WIDTH= 1.640E-01 LENGTH= 2.000E-01
BRANCH # 4 WIDTH= 5.500E-01 LENGTH= 2.260E+00	

TERMINATIONS (OHMS): RL= 5.000E+01 XL= 0.000E+00

			GAMMA (REF-	50.00 OHMS)	
F(MHz)	R(OHMS)	X(OHMS)	MAG	ANG	GT(dB)
3.000E+02	3.274E+01	5.920E+00	0.220	156.97	-0.22
4.000E+02	2.758E+01	2.438E+01	0.407	115.15	-0.79
5.000E+02	2.955E+01	5.995E+01	0.636	71.83	-2.25
6.000E+02	6.032E+01	1.557E+02	0.818	31.53	-4.80
7.000E+02	9.898E+02	-3.916E+02	0.916	-1.98	-7.95
8.000E+02	1.632E+01	-1.943E+02	0.960	-28.69	-11.11
9.000E+02	2.853E+00	-1.067E+02	0.980	-50.17	-13.96
1.000E+03	9.350E-01	-7.423E+01	0.988	-67.92	-16.37
1.100E+03	4.245E-01	-5.654E+01	0.993	-82.97	-18.30
1.200E+03	2.428E-01	-4.499E+01	0.995	-96.04	-19.72

Figure 8. Printout for Example 3 with frequency range edited.

CONFIGURATION #: 1111111

ACTUAL MSTRIP DIMENSIONS IN INCHES

DIELECTRIC THICKNESS= 6.000E-02
METAL THICKNESS= 1.250E-03
RELATIVE DIELECTRIC CONSTANT= 2.480

BRANCH # 1 WIDTH= 1.640E-01 LENGTH= 2.000E-01	BRANCH # 5 WIDTH= 1.300E-02 LENGTH= 1.040E+00
BRANCH # 2 WIDTH= 5.500E-01 LENGTH= 4.200E-01	BRANCH # 6 WIDTH= 5.500E-01 LENGTH= 4.200E-01
BRANCH # 3 WIDTH= 1.300E-02 LENGTH= 1.040E+00	BRANCH # 7 WIDTH= 1.640E-01 LENGTH= 2.000E-01
BRANCH # 4 WIDTH= 5.500E-01 LENGTH= 2.500E+00	

TERMINATIONS (OHMS): RL= 5.000E+01 XL= 0.000E+00

			GAMMA (REF-	50.00 OHMS)	
F(MHz)	R(OHMS)	X(OHMS)	MAG	ANG	GT(dB)
3.000E+02	2.897E+01	8.461E+00	0.285	151.97	-0.37
4.000E+02	2.460E+01	2.977E+01	0.487	108.71	-1.18
5.000E+02	2.797E+01	7.038E+01	0.702	65.31	-2.95
6.000E+02	6.831E+01	1.906E+02	0.854	26.34	-5.66
7.000E+02	4.825E+02	-6.645E+02	0.931	-5.65	-8.76
8.000E+02	1.191E+01	-1.778E+02	0.966	-31.29	-11.73
9.000E+02	2.445E+00	-1.021E+02	0.981	-52.16	-14.31
1.000E+03	8.924E-01	-7.196E+01	0.988	-69.58	-16.39
1.100E+03	4.514E-01	-5.505E+01	0.992	-84.50	-17.91
1.200E+03	2.937E-01	-4.376E+01	0.993	-97.62	-18.79

Figure 9. Printout for Example 3 with branch 4 edited.

References

1. H. Sobol, "Extending IC Technology to Microwave Equipment," *Electronics*, pp. 112-124, March 20, 1967.

2. E.O. Hammerstad, "Equations for Microstrip Circuit Design," *Proc. European Microwave Conference*, Hamburg, pp. 268-271, Sept. 1975.

3. J.J. Lev, "Synthesize and Analyze Microstrip Lines," *Microwaves and RF*, Vo. 24, No. 1, pp. 111-116, Jan. 1985.

```
10 REM ***LADDER ANALYSIS PROGRAM  D. R. HERTLING  R. K. FEENEY  9/5/86***
20 DIM B(50),L(50),F(50),ZO(50),LM(50),WM(50),W(50)
30 PI=4*ATN(1)
40 PI2=2*PI
50 MZ=1000000!
60 F2=0   'REM F2=0  DIMENSIONS IN INCHES ; F2=1 DIMENSIONS IN CM'S
70 F3=0   'REM F3=0 LENGTHS IN WAVELENGTHS ; F3=1 LENGTHS IN DEGREES
80 PRINT
90 FO=0
100 PRINT "********************************************************"
110 PRINT
120 PRINT "CONFIGURATION"
130 PRINT "1 - SERIES MSTRIP TRANSMISSION LINE"
140 PRINT "2 - SHUNT-CONNECTED OPEN-CIRCUITED TRANSMISSION LINE"
150 PRINT "3 - SHUNT-CONNECTED SHORT-CIRCUITED TRANSMISSION LINE"
160 PRINT "4 - SERIES-CONNECTED CAPACITOR"
170 PRINT "5 - SHUNT-CONNECTED CAPACITOR"
180 PRINT "6 - SERIES-CONNECTED INDUCTOR"
190 PRINT "7 - SHUNT-CONNECTED INDUCTOR"
200 PRINT "8 - SERIES-CONNECTED PARALLEL LC"
210 PRINT "9 - SHUNT-CONNECTED SERIES LC"
220 PRINT
230 PRINT "********************************************************"
240 PRINT
250 INPUT "ENTER CONFIGURATION # ",CF$
260 PRINT
270 PRINT "********************************************************"
280 PRINT
290 NB=LEN(CF$)
300 FOR I=1 TO NB
310 B(I)=VAL(MID$(CF$,I,1))
320 IF B(I)<4 THEN FO=1
330 NEXT I
340 IF FO<>1 THEN GOTO 510
350 PRINT "MSTRIP DIMENSIONS"
360 PRINT
370 INPUT "0 = NORMALIZED ; 1= ACTUAL ",F1
380 PRINT
390 IF F1=0 AND F3=0 THEN UN$= "NORMALIZED MSTRIP LENGTHS IN WAVELENGTHS"
400 IF F1=0 AND F3=1 THEN UN$= "NORMALIZED MSTRIP LENGTHS IN DEGREES"
410 IF F1=1 AND F2=0 THEN UN$= "ACTUAL MSTRIP DIMENSIONS IN INCHES"
420 IF F1=1 AND F2=1 THEN UN$= "ACTUAL MSTRIP DIMENSIONS IN CM'S"
430 PRINT "ENTER "+UN$
440 PRINT
450 IF F1=0 THEN INPUT "DESIGN FREQUENCY (MHz)=? ",FM:FD=FM*MZ:GOTO 500
460 PRINT "MATERIAL"
470 INPUT "DIELECTRIC THICKNESS=? ",DT
480 INPUT "METAL THICKNESS=? ",MT
490 INPUT "RELATIVE DIELECTRIC CONSTANT=? ",ER
500 PRINT "********************************************************"
510 PRINT
520 PRINT "TERMINATIONS (OHMS) "
530 INPUT "RL=? ",RL
540 INPUT "XL=? ",XL
550 PRINT
560 PRINT "********************************************************"
570 PRINT
580 REM ENTER NETWORK DATA
590 PRINT "NETWORK"
600 FOR J=1 TO NB
610 PRINT
620 PRINT "BRANCH # ";J
630 ON B(J) GOSUB 2090,2090,2090,2130,2130,2150,2150,2170,2170
640 NEXT J
650 PRINT "********************************************************"
660 PRINT
670 GOSUB 2200
680 PRINT
690 PRINT "********************************************************"
700 PRINT
710 REM ENTER FREQUENCY DATA
720 INPUT "NUMBER OF POINTS? ",NP
730 IF NP=1 THEN INPUT "FREQUENCY (MHz)=? ",FL:FL=FL*MZ:PRINT :GOTO 820
740 INPUT "LOWER FREQUENCY (MHz)=? ",FL:FL=FL*MZ
750 INPUT "UPPER FREQUENCY (MHz)=? ",FU:FU=FU*MZ
760 REM IMPEDANCE VERSUS FREQUENCY CALCULATIONS
770 DF=(FU-FL)/(NP-1)
780 REM CALCULATIONS
790 PRINT
800 PRINT "********************************************************"
810 PRINT
820 INPUT "OUTPUT PRINTED ? (Y/N) ";P$
830 PRINT
840 PRINT "********************************************************"
850 IF P$="Y" OR P$="y" THEN F4=1 ELSE F4=0
860 IF F4=1 THEN GOSUB 2210
870 PRINT:PRINT:PRINT
880 PRINT "                                                  GAMMA (REF-";
890 PRINT USING "####.## OHMS)";RR
900 PRINT "   F(MHz)       R(OHMS)           X(OHMS)           MAG";
910 PRINT"        ANG            GT(dB)"
920 IF F4=0 THEN GOTO 970
930 LPRINT "                                                   GAMMA (REF-";
940 LPRINT USING "####.## OHMS)";RR
950 LPRINT "   F(MHz)       R(OHMS)           X(OHMS)           MAG";
960 LPRINT"        ANG            GT(dB)"
970 FOR I=1 TO NP         'FREQUENCY LOOP
980 RT=RL:XT=XL
990 F(I)=FL+(I-1)*DF
1000 W(I)=PI2*F(I)
1010 FOR J=1 TO NB        'CIRCUIT BRANCH LOOP
1020 ON B(J) GOSUB 1480,1480,1480,1760,1760,1820,1820,1880,1930
1030 NEXT J
1040 REM RECTANGULAR TO POLAR CONVERSION
1050 A=RT-RR:B=XT:C=RT+RR:D=XT
1060 DM=C^2+D^2
1070 RG=(A*C+B*D)/DM
1080 IG=(B*C-A*D)/DM
1090 MG=SQR(RG^2+IG^2)
1100 IF RG=0 THEN GOTO 1120
1110 GOTO 1140
1120 IF IG=0 THEN AG=0:GOTO 1200
1130 TH=90:GOTO 1150
1140 TH=(180/PI)*ATN(ABS(IG/RG))
1150 IF RG>=0 THEN GOTO 1180
1160 IF IG>=0 THEN AG=180-TH:GOTO 1200
1170 AG=-180+TH:GOTO 1200
1180 IF IG>=0 THEN AG=TH:GOTO 1200
1190 AG=-TH
1200 GT=10*LOG(1-(MG)^2)/LOG(10)
1210 PRINT USING "##.###^^^^   ##.###^^^^      ##.###^^^^";F(I)/MZ;RT;XT;
1220 PRINT USING "      ##.###     ####.##       ###.##";MG;AG;GT
1230 IF F4=0 THEN GOTO 1260
1240 LPRINT USING "##.###^^^^   ##.###^^^^      ##.###^^^^";F(I)/MZ;RT;XT;
1250 LPRINT USING "      ##.###     ####.##       ###.##";MG;AG;GT
1260 NEXT I
1270 PRINT:PRINT:PRINT
1280 PRINT "********************************************************"
1290 PRINT
1300 PRINT "1 - EDIT THE LADDER NETWORK"
1310 PRINT "2 - REPEAT CALCULATIONS OVER A NEW FREQUENCY RANGE"
1320 PRINT "3 - ENTER A NEW CONFIGURATION"
1330 PRINT "4 - QUIT"
1340 PRINT
1350 INPUT "ENTER 1 - 4 ";N2
1360 PRINT
1370 PRINT "********************************************************"
1380 IF N2=4 THEN STOP
1390 IF N2=3 THEN GOTO 80
1400 IF N2=2 THEN PRINT:GOTO 710
1410 PRINT
1420 INPUT "ENTER THE BRANCH # TO BE EDITED OR Q TO QUIT EDITING ";N3$
1430 IF N3$="Q" OR N3$="q" THEN GOTO 790 ELSE N3=VAL(N3$)
1440 J=N3
1450 PRINT
1460 ON B(N3) GOSUB 2090,2090,2090,2130,2130,2150,2150,2170,2170
1470 GOTO 1410
1480 REM R AND X MICROSTRIP SUBROUTINE
1490 IF F1=0 AND F3=0 THEN BL=TAN(PI2*LM(J)*F(I)/FD):RO=ZO(J):GOTO 1650
1500 IF F1=0 AND F3=1 THEN BL=TAN(LM(J)*PI/180*F(I)/FD):RO=ZO(J):GOTO 1650
1510 WE=WM(J)+(MT/PI)*(LOG(2*DT/MT)+1)
1520 S=WE/DT
1530 P=377/S/SQR(ER)
1540 Q=(1+1.735*ER^(-7.240001E-02)*S^(-.836))
1550 RO=P/Q
1560 S=WE/DT
1570 IF S>=.6 THEN GOTO 1590
1580 Y=(1+.6*(ER-1)*S^(.0297)) :GOTO 1600
1590 Y=(1+.63*(ER-1)*S^(.1255))
1600 VF=SQR(1/Y)
1610 IF F2=0 THEN IC=2.54 ELSE IC=1
1620 CO=3E+10/IC
1630 LD=VF*CO/F(I)   'LD=WAVELENGTH
1640 BL=TAN(PI2*LM(J)/LD) 'TAN BL
1650 IF B(J)<> 1 THEN GOTO 1710
1660 A=RT:B=XT+RO*BL:C=RO-XT*BL:D=RT*BL
1670 DN=C^2+D^2
1680 RT=RO*(A*C-B*D)/DN
1690 XT=RO*(B*C-A*D)/DN
1700 RETURN
1710 R=0
1720 IF B(J)=2 THEN X=-RO/BL :GOTO 1740
1730 X=RO*BL ' S.C. LINE
1740 GOSUB 2020
1750 RETURN
1760 REM R AND X FOR A CAPACITOR
1770 R=0
1780 X=-1/W(I)/C(J)
1790 IF B(J)=4 THEN GOSUB 1980:RETURN
1800 GOSUB 2020
1810 RETURN
1820 REM R AND X FOR INDUCTORS
1830 R=0
1840 X=W(I)*L(J)
1850 IF B(J)=6 THEN GOSUB 1980:RETURN
1860 GOSUB 2020
1870 RETURN
1880 REM R AND X FOR SERIES-PARALLEL LC
1890 R=0
1900 X=-(L(J)/C(J))/(W(I)*L(J)-1/W(I)/C(J))
1910 GOSUB 1980
1920 RETURN
1930 REM R AND X FOR PARALLEL-SERIES LC
1940 R=0
1950 X=(W(I)*L(J)-1/W(I)/C(J))
1960 GOSUB 2020
1970 RETURN
1980 REM SERIES COMBINATION OF IMPEDANCE
1990 RT=R+RT
2000 XT=X+XT
2010 RETURN
2020 REM PARALLEL COMBINATION OF IMPEDANCES
2030 DP=(R+RT)^2+(X+XT)^2
2040 RZ=((R*RT-X*XT)*(R+RT)+(X*RT+R*XT)*(X+XT))/DP
2050 XT=((R*RT-X*XT)*(-(X+XT))+(X*RT+R*XT)*(R+RT))/DP
2060 RT=RZ
2070 RETURN
2080 END
2090 REM MSTRIP NORMALIZED
2100 IF F1=0 THEN INPUT "ZO=? ",ZO(J):INPUT "LENGTH=? ",LM(J):RETURN
2110 REM MSTRIP ACTUAL
2120 INPUT "WIDTH=? ",WM(J):INPUT "LENGTH=? ",LM(J):RETURN
2130 REM CAPACITOR
2140 INPUT "C(pF)=? ",C(J):C(J)=C(J)*1E-12:RETURN
2150 REM INDUCTOR
2160 INPUT "L(nH)=? ",L(J):L(J)=L(J)*1E-09:RETURN
2170 REM RESONANT CIRCUIT
2180 INPUT "C(pF)=? ",C(J):C(J)=C(J)*1E-12
2190 INPUT "L(nH)=? ",L(J):L(J)=L(J)*1E-09:RETURN
2200 INPUT "ENTER REFERENCE FOR GAMMA (OHMS) ",RR:RETURN
2210 REM PRINT SUBROUTINE
2220 LPRINT:LPRINT:LPRINT
2230 LPRINT "CONFIGURATION #: ";CF$
2240 LPRINT
2250 IF F4=1 THEN LPRINT UN$:LPRINT
2260 IF FO=1 AND F1=1 THEN GOSUB 2500
2270 IF FO=1 AND F1=0 THEN GOSUB 2530
2280 FOR J=1 TO NB
2290 LPRINT "BRANCH # ";J
2300 ON B(J) GOSUB 2360,2360,2360,2430,2430,2450,2450,2470,2470
2310 LPRINT
2320 NEXT J
2330 LPRINT USING "TERMINATIONS (OHMS):  RL=##.###^^^^  XL=##.###^^^^ "
2340 LPRINT
2350 RETURN
2360 REM MSTRIP NORMALIZED
2370 IF F1=1 THEN GOTO 2400
2380 LPRINT USING "ZO=#####.## OHMS";ZO(J)
2390 LPRINT USING "LENGTH=##.###^^^^^";LM(J):RETURN
2400 REM MSTRIP ACTUAL
2410 LPRINT USING "WIDTH=##.###^^^^^";WM(J)
2420 LPRINT USING "LENGTH=##.###^^^^^";LM(J):RETURN
2430 REM CAPACITOR
2440 CP=C(J)*1E+12:LPRINT USING "C(pF)=#####.##";CP:RETURN
2450 REM INDUCTOR
2460 LN=L(J)*1E+09:LPRINT USING "L(nH)=#####.##";LN:RETURN
2470 REM RESONANT CIRCUIT
2480 CP=C(J)*1E+12:LPRINT USING "C(pF)=#####.##";CP
2490 LN=L(J)*1E+09:LPRINT USING "L(nH)=#####.##";LN:RETURN
2500 LPRINT USING "DIELECTRIC THICKNESS= ##.###^^^^^";DT
2510 LPRINT USING "METAL THICKNESS= ##.###^^^^^";MT
2520 LPRINT USING "RELATIVE DIELECTRIC CONSTANT= ###.###";ER:LPRINT:RETU
2530 LPRINT USING "DESIGN FREQ: #####.### MHZ";FM:LPRINT:RETURN
2540 END
```

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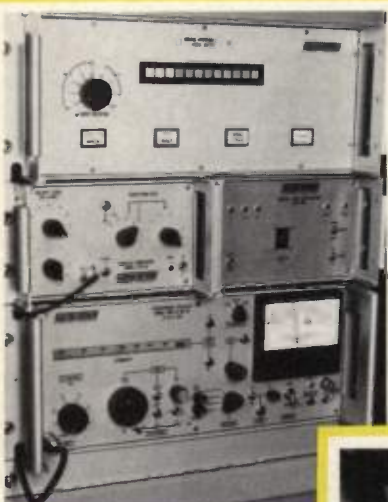

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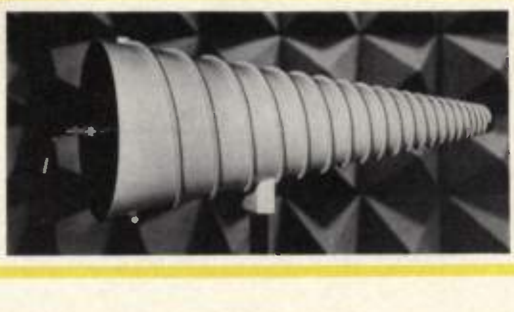

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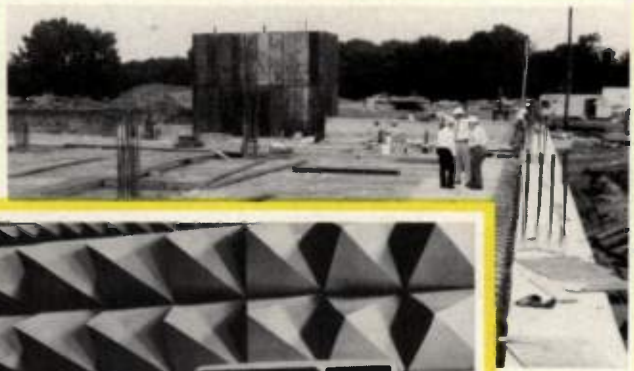

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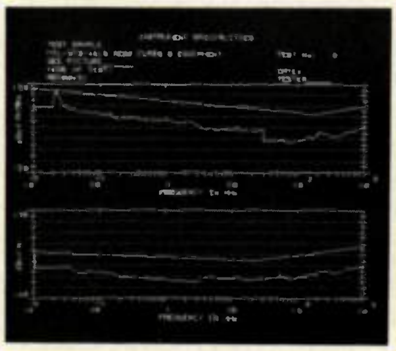

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INFO/CARD 31

An HF Dynamic Range Amplifier Using Feedforward Techniques

By Jean Yamas
Locus, Inc.

Feedforward is a distortion cancellation technique in which a sample of the distortion generated in an amplifier is coupled off, isolated, amplified, and recombined 180 degrees out of phase to cancel the remaining distortion in the output signal. This paper describes how feedforward was successfully applied to a three decade bandwidth amplifier (100 kHz to 100 MHz) to achieve a second-order output intercept point greater than +100 dBm, a third order output intercept point greater than +55 dBm, and a noise figure less than 7 dB.

A feedforward block diagram is shown in Figure 1. The main signal path is through the main amplifier and delay line 2 to the output. The distortion generated in the main amplifier is the source of the signal degradation and is the distortion which is cancelled by the feedforward circuit.

Feedforward utilizes a two loop system to accomplish the distortion cancellation. Loop 1, shown in Figure 2A, can be recognized as the first half of the feedforward block diagram of Figure 1. Loop 2, shown in Figure 2B, is the second half. Directional couplers are used to sample and recombine the signal and distortion to achieve the desired results.

To cancel the distortion generated in the main amplifier, it is necessary to isolate the distortion. This is the function of Loop 1. At the input, the clean signal is coupled off following one path through the main amplifier and the other through delay line 1. At the output of the main amplifier, a sample of the distorted signal is coupled down to DC3 where it is recombined 180 degrees out of phase with the clean signal from delay line 1. By proper choice of circuit gain and attentuation elements in both paths, the two signals will have equal amplitudes and when combined 180 degrees out of phase the signals will cancel, thereby isolating the distortion. Maximum signal cancellation is desirable not only to obtain a "clean" distortion sample, but also to minimize the input level to the error amplifier so that it

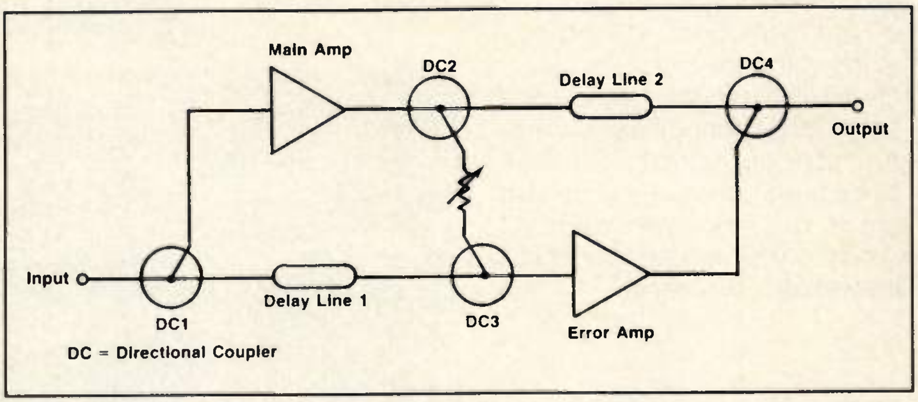

Figure 1. Feedforward block diagram.

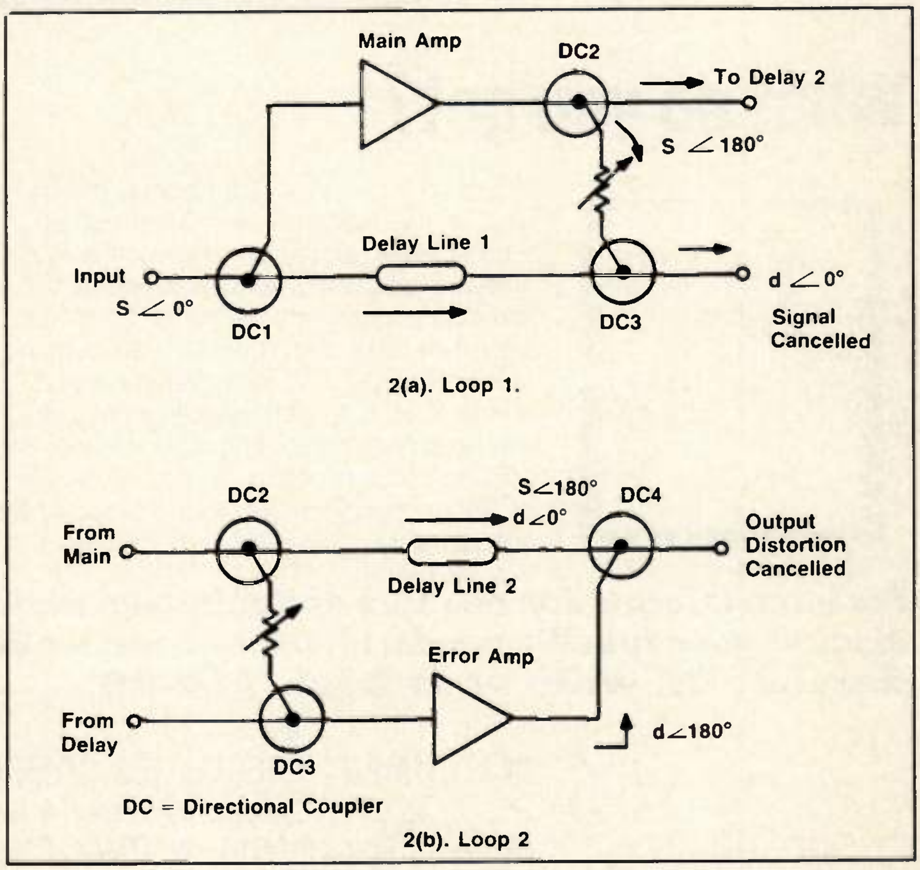

Figure 2. Feedforward loops.

does not generate distortion. In addition to strict level control and phase requirements, the time delay of both paths must be equal for cancellation to occur. The delay line is designed to obtain this match.

The distortion cancellation is a function of loop 2. The isolated distortion at the output of DC3 is amplified by the error amplifier and coupled to the output to recombine with the distorted signal from the main path of the feedforward circuit. As with the cancellation requirements of loop 1, the distortion from both paths must have good amplitude and delay match, and must be 180 degrees out of phase. Note that the distortion contributed by the error amplifier is insignificant due to the low signal level.

Design Considerations

Amplitude

To obtain the amplitude match required from both paths of loop 1 and loop 2, the losses of the directional couplers and gain of the amplifiers are calculated. For loop 1, equal levels from both paths occur at the output of DC3 when the following equation is satisfied (all gains and losses in dB)

$$S-D1+G1-D2-D3=S-L1-DL1-L3$$

where L# = absolute loss of thru path of DC#;
D# = absolute loss of coupled port of DC#;
DL1 = absolute loss of delay line 1;
G1 = gain of main amplifier.

Rearranged, this equation is one of three required for feedforward circuit design.

For signal cancellation:

$$G1=D1+D2+D3-L1-L3-DL1 \quad (1)$$

For loop 2, the equation for amplitude match is:

$$S-L2-DL2-L4=S-D2-D3+G2-D4$$

where L# = absolute loss of thru path of DC#;
D# = absolute loss of coupled port of DC#;
DL2 = absolute loss of delay line 2;
G2 = gain of error amplifier.

For distortion cancellation:

$$G2=D2+D3+D4-L2-L4-DL2 \quad (2)$$

An additional consideration is the desired gain of the feedforward circuit.

For gain requirements:

$$GAIN=G1-D1-L2-L4-DL2 \quad (3)$$

The solution to these equations is simplified by several design considerations. For minimum noise figure, DC1 and DC3 should have minimal thru path losses. Minimal loss in the thru paths of DC2 and DC4 is necessary for the highest intercept point. To simplify circuit design, G1 can be set equal to G2 which forces DC1 = DC4 and DC2 = DC3.

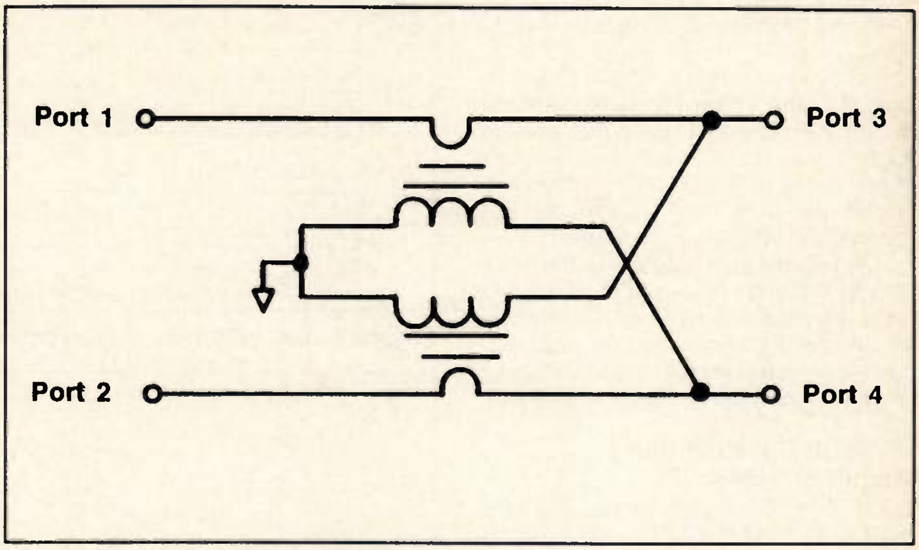

Figure 3. Directional Coupler.

Phase

The phase of the signals can be controlled by choosing appropriate paths through the directional couplers. The circuit diagram of a directional coupler is shown in Figure 3. When a signal enters port 1, the output at port 2 is 180 degrees out of phase with the input, whereas if the signal enters port 3, the output at port 4 is in-phase with the input. By directing the signal in the feedforward circuit through the appropriate port, the required phase is obtained.

Delay

Once the gain of the main and error amplifiers and the coupling coefficients of the directional couplers are chosen, the delay of the main amplifier path of loop 1 is measured and matched by designing delay line 1 accordingly. Efforts should be made to minimize the delay variation vs. frequency of the main amplifier path to simplify the delay line design. Similarly, delay line 2 should be designed to match the delay of the delay line path to the error amplifier path of loop 2.

Cancellation Requirements

Figure 4 shows the amplitude and phase match requirements to obtain the desired amount of cancellation. As the chart indicates, 20 dB of cancellation can be obtained with 1 degree of phase match and about 0.9 dB amplitude match. The circuit should have a gain adjustment to adjust the amplitude for a good match and a phase adjustment in the delay lines to attain the delay match. Equalizers and temperature compensation networks are sometimes necessary to obtain more stringent amplitude and phase match requirements.

Feedforward Architecture

Figure 5 shows a configuration commonly used for power amplifiers. It requires less gain in the main amplifier than that of Figure 1. The disadvantage of the circuit in Figure 5 is that it has a much higher noise figure. This is because feedforward not only cancels the distortion contributed from the main amplifier, but also cancels its noise contribution. This leaves only the error amplifier as the noise source. Since the noise contributed by the error amplifier is the sum of its noise figure and the losses incurred before it, the higher input losses of DC1 in Figure 5 will result in a much higher noise figure.

HF High Dynamic Range Amplifier Design

An HF multicoupler is used at receiver sites to provide multiple outputs from a single receiving antenna and consists of an amplifier driving an n-way splitter. Because of the high concentration of both desired and undesired signals in the antenna environment, a high performance amplifier is required. It must not add excessive noise to weak desired signals nor produce intermodulation products from strong signals. The demands placed on such an amplifier are severe.

Preliminary specifications were established based on these demands and what was considered theoretically possible. A gain of around 11 dB was determined to be necessary to offset the less of an 8-way split. The goals set for the second and third order output intercept points (OIP2 and OIP3, respectively) were based on the performance of a typical 1 watt bipolar transistor and the estimated distortion cancellation capabilities of push-pull and feedforward techniques. In particular, it was estimated that the OIP2 could be improved 20 dB from push-pull and 20 dB from feedforward and the OIP3 could be improved 3 dB from push-pull and 10 dB from feedforward. From this, the goal of +100 dBm for OIP2 and +57 dBm for OIP3 was established. The noise figure was estimated to be 7 dB: 5 dB from the error amplifier and 2 dB from input losses.

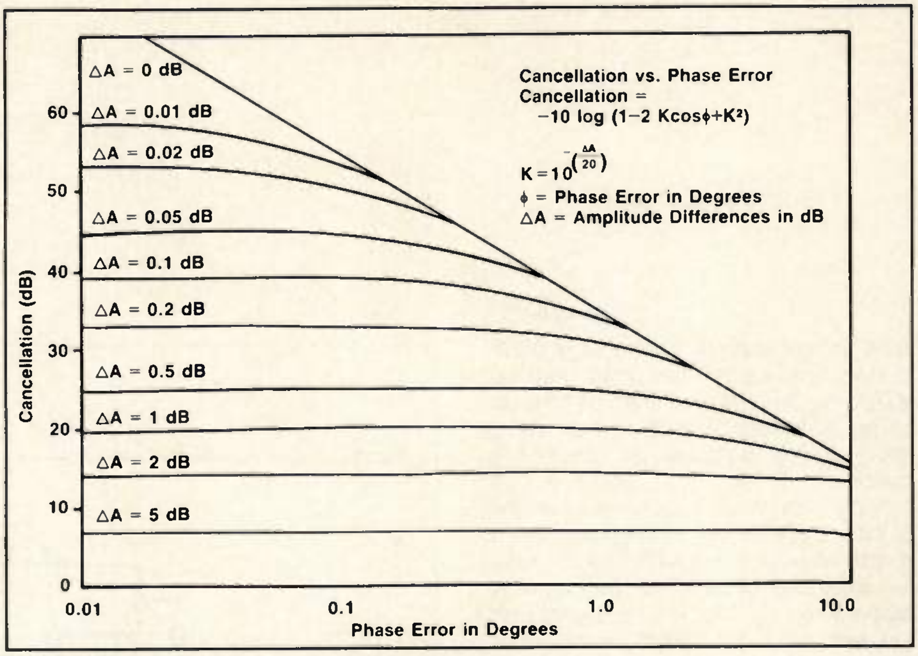

Figure 4. Cancellation Requirements.

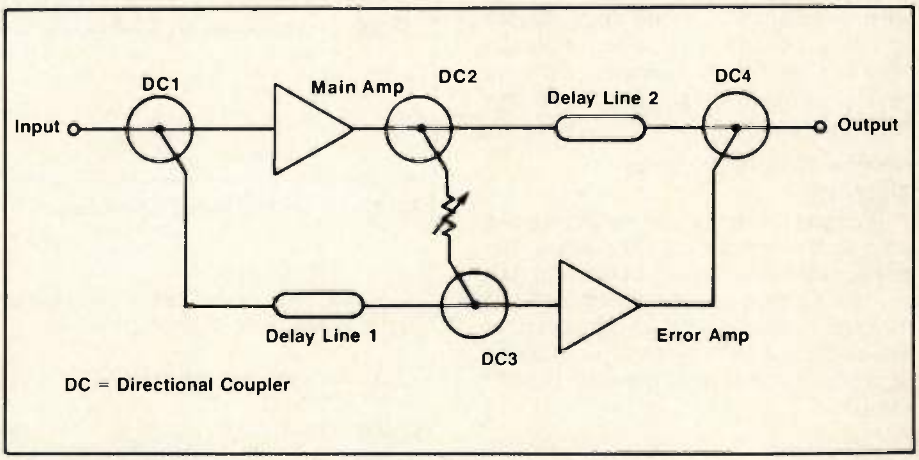

Figure 5. Feedforward power configuration.

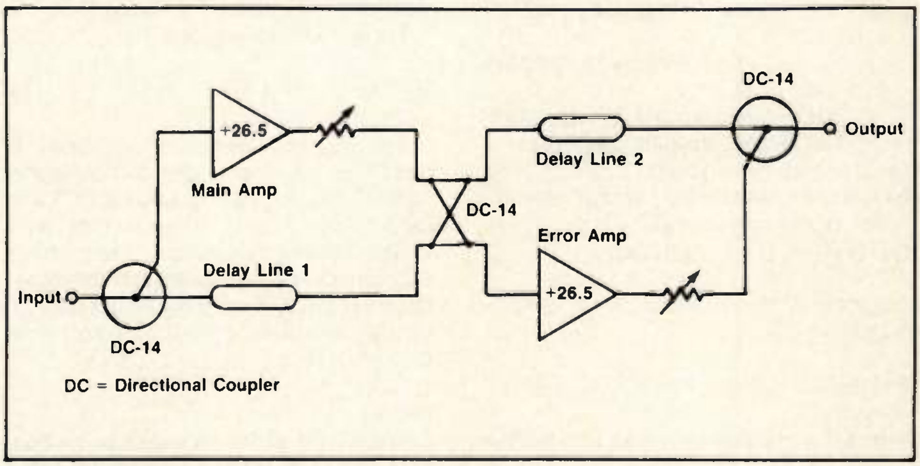

Figure 6. Feedforward circuit.

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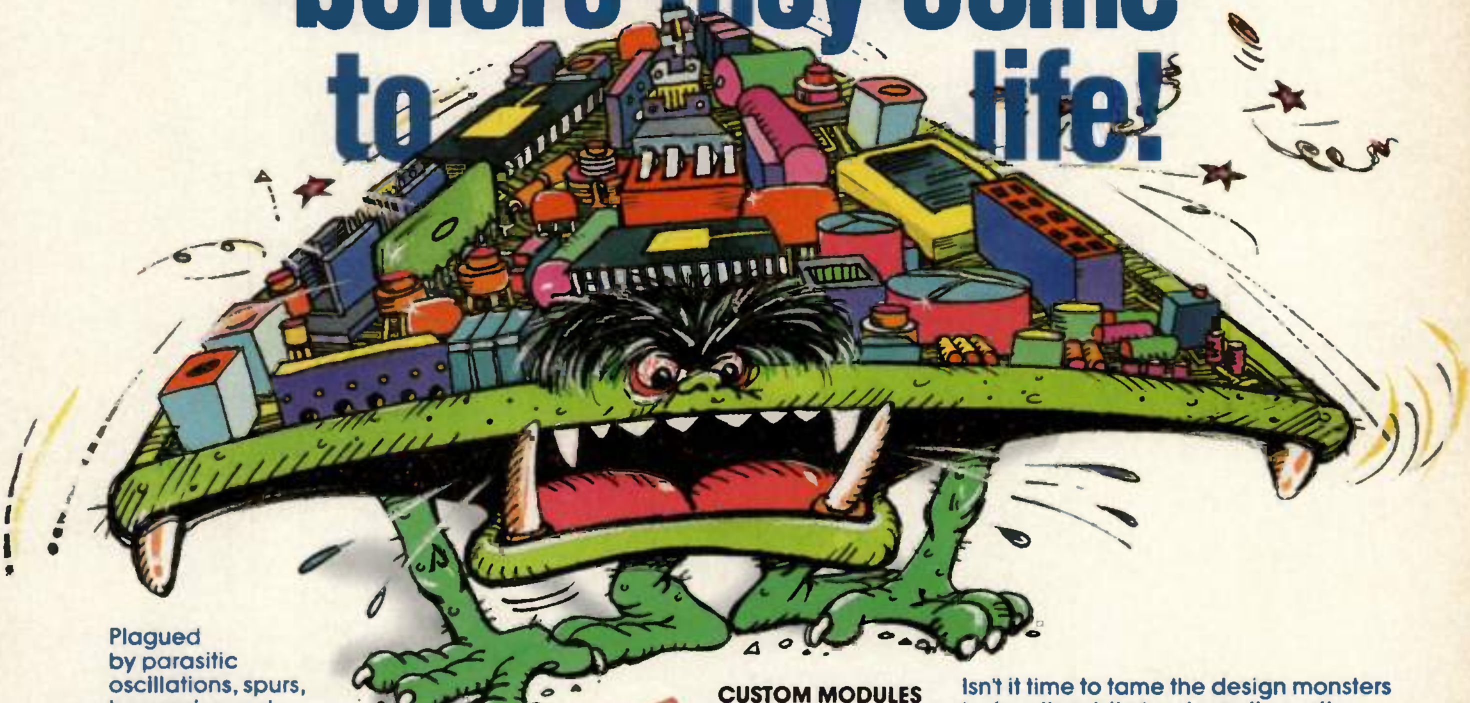

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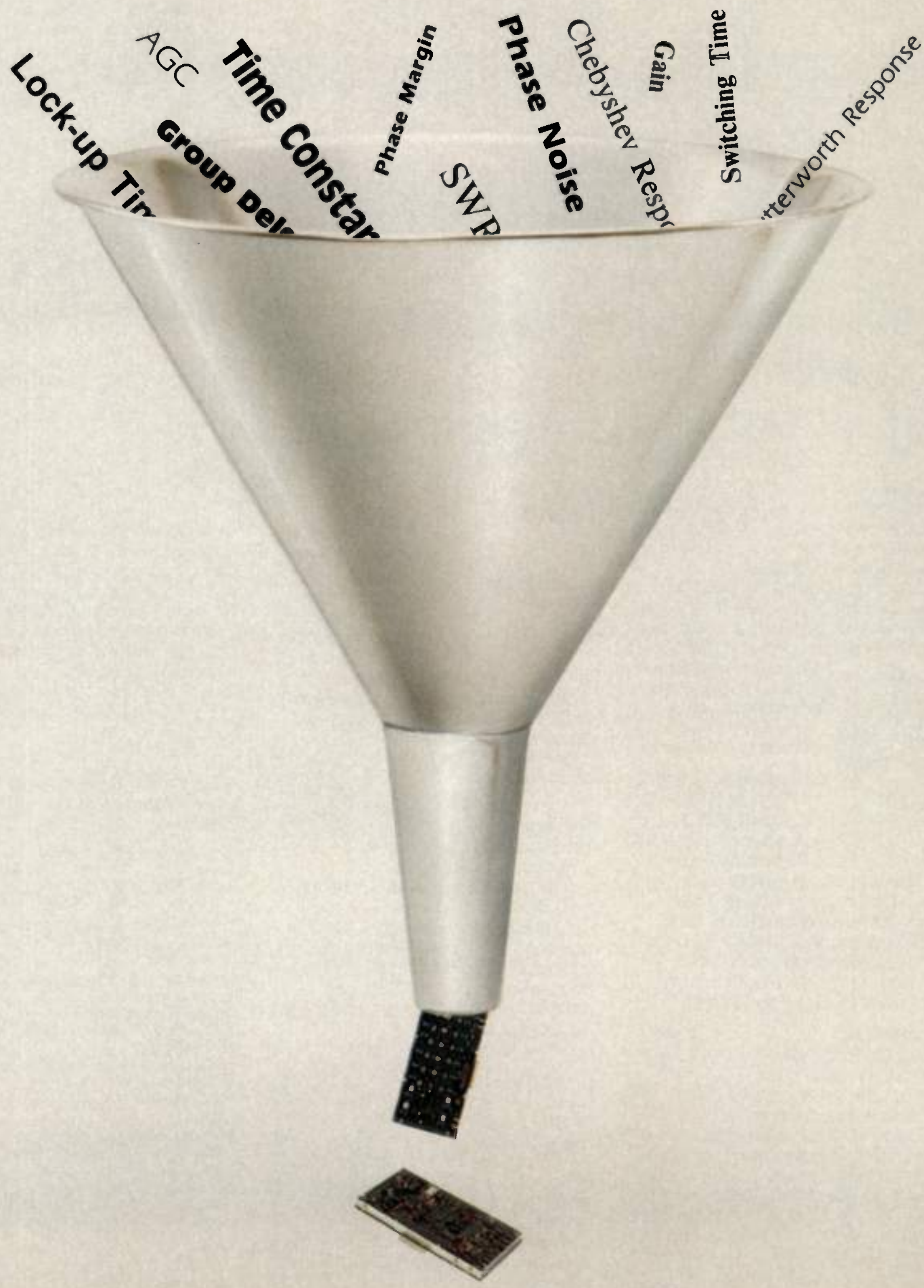

With these preliminary specifications, a circuit was built, tuned and tested as described below.

Feedforward

The feedforward configuration used in the HF high dynamic range amplifier was a modification of that shown in Figure 1 and is shown in Figure 6. Directional couplers DC2 and DC3 are replaced with a single directional coupler to achieve the desired results with fewer parts. A gain adjustment is placed within each loop for independent control of signal levels. With this design, three 14 dB directional couplers are used with main and error amplifier gains of 26.5 dB. This achieves the necessary cancellation in both loops and the desired gain of 11.5 dB.

Push-Pull

Feedforward is used to cancel distortion generated in the main amplifier by 20 dB and more. However, second order output intercept points greater than +100 dBm and third order output intercept points greater than +57 dBm require a high performance main amplifier. A push-pull arrangement shown in Figure 7 is used to obtain an additional 20 dB of cancellation of the second order intermodulation product and an additional 6 dB of reduction of the third order intermodulation product. Flatness and phase linearity is improved by using 3 dB directional couplers instead of push-pull transformers. In addition, noise figure and intermodulation products are minimized by biasing amps 1 and 2 with I_C = 50 mA and amps 3 and 4 with I_C = 100 mA at +15 V. This design is used for both the main and error amplifiers bringing the total power consumption to 9 W.

Resistive Feedback

The amplifiers in the push-pull arrangement use Motorola's MRF587 1W bipolar transistors in a resistive feedback network. Negative feedback techniques are beneficial because they produce flatter gain, lower distortion, better impedance match and temperature stability. Although resistive feedback results in a higher noise figure (5 dB vs. 1.5 dB) and a lower intercept point (by 1-2 dB) than a lossless or coupler feedback network, this compromise was accepted in return for the extended bandwidth that it provided. The resistive feedback amplifier circuits are designed based on a desired gain of +14 dB per stage to bring the total gain in the push-pull arrangement to 26.5 dB. Gain flatness of the push-pull configuration with resistive feedback amplifiers is ±0.1 dB from 100 kHz to 100 MHz with a return loss greater than 20 dB.

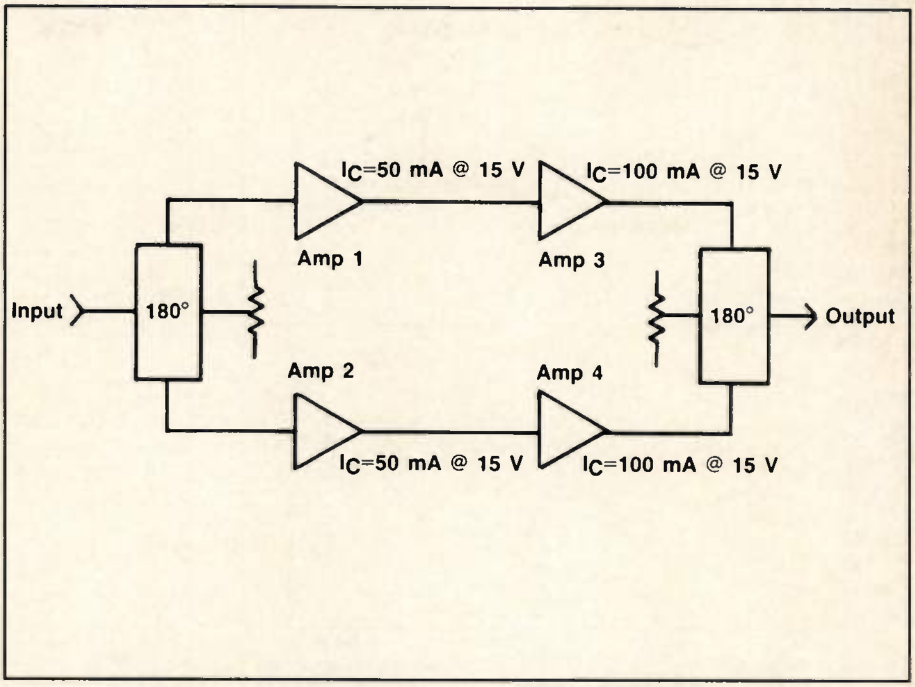

Figure 7. Push-Pull arrangement for main and error amplifiers.

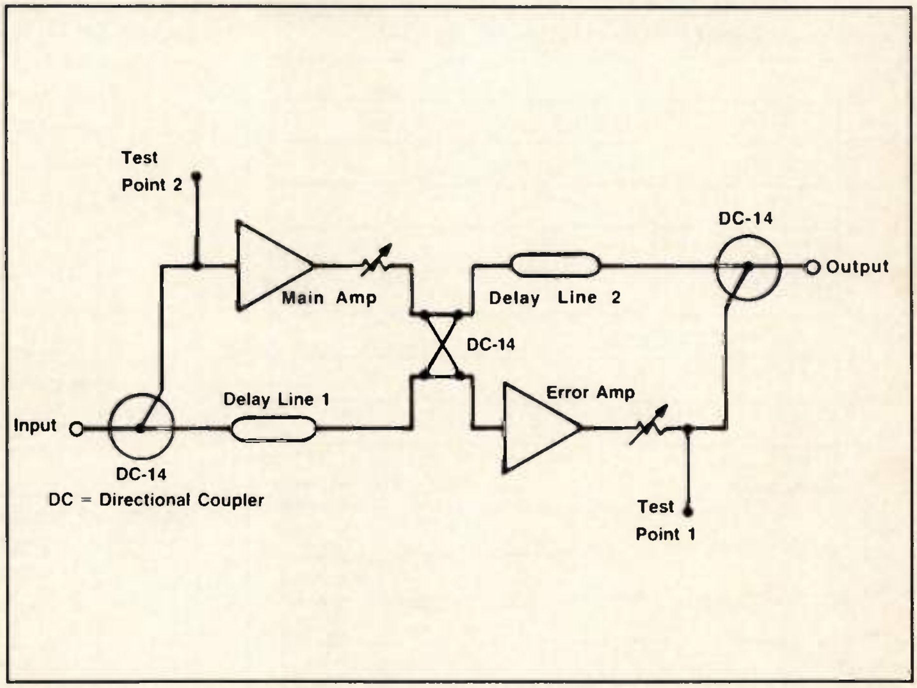

Figure 8. Feedforward with test points.

Tuning Procedure

Loop 1 and loop 2 are designed independently and fine-tuned after integrating into the final feedforward circuit. The final circuit is tested using resistive coupler test points as shown in Figure 8.

Tuning the feedforward circuit is performed by using a test signal to simulate the signal that is to be cancelled in loop 1 and to simulate the distortion that is to be cancelled in loop 2. Cancellation of each loop is measured separately and requires a reference. For loop 1, a reference

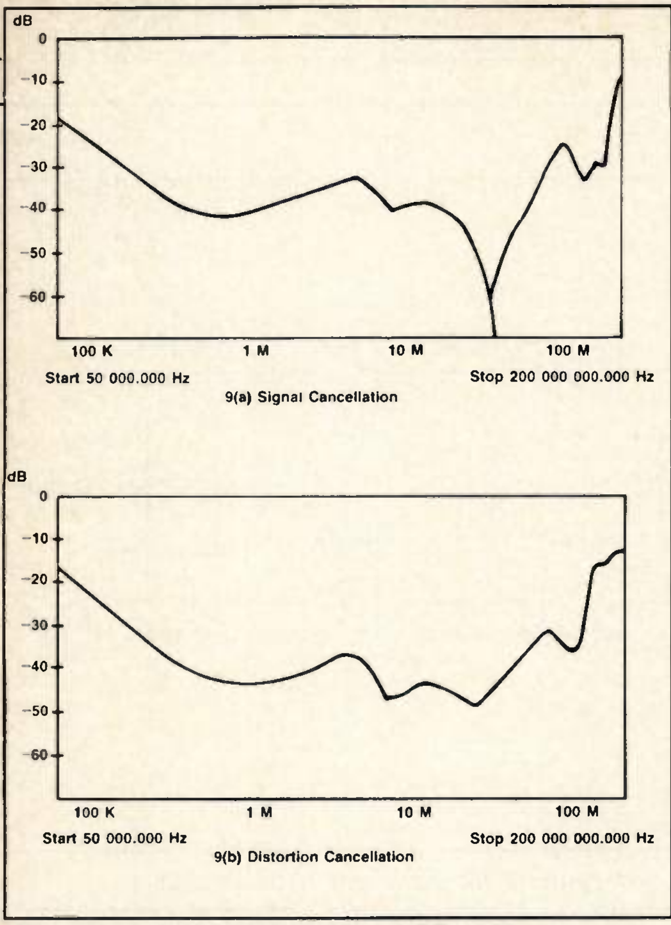

Figure 9 — Cancellation (Model RF 1960A)

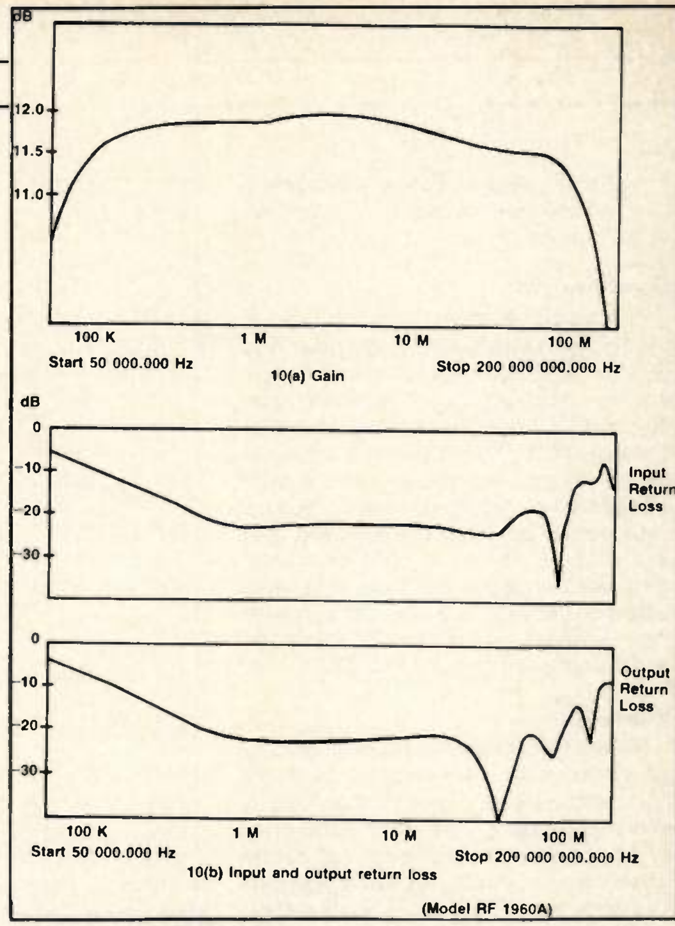

Figure 10 — Response

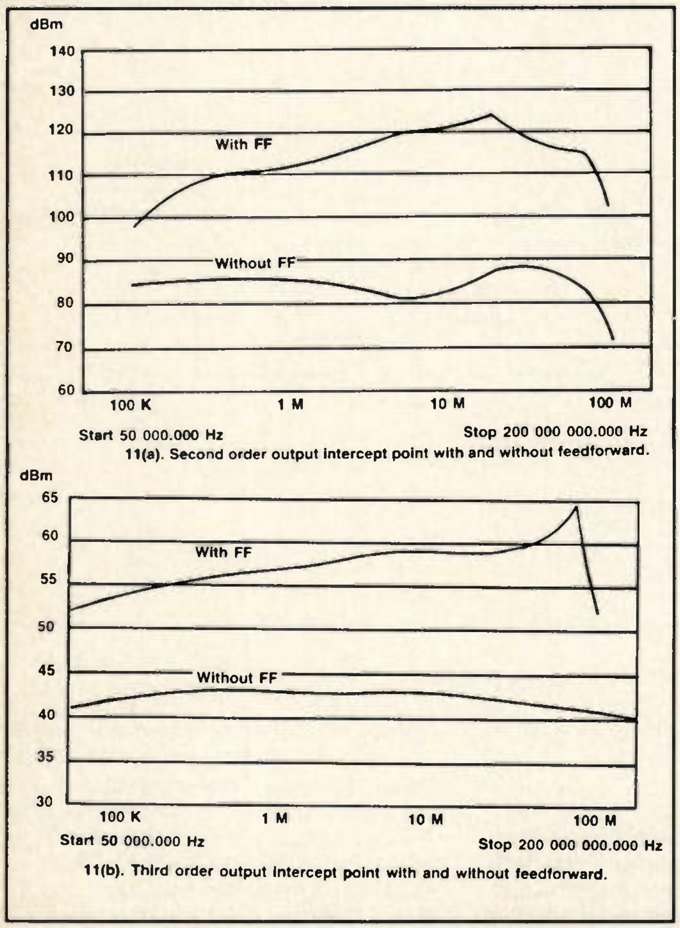

Figure 11. Output intercept points (Model RF 1960A)

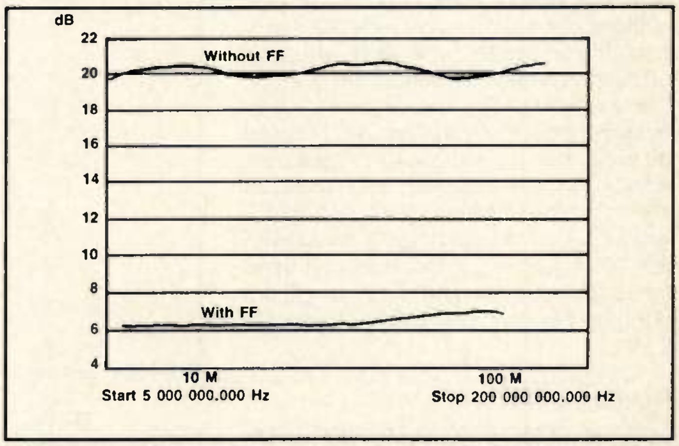

Figure 12. Noise figure with and without feedforward

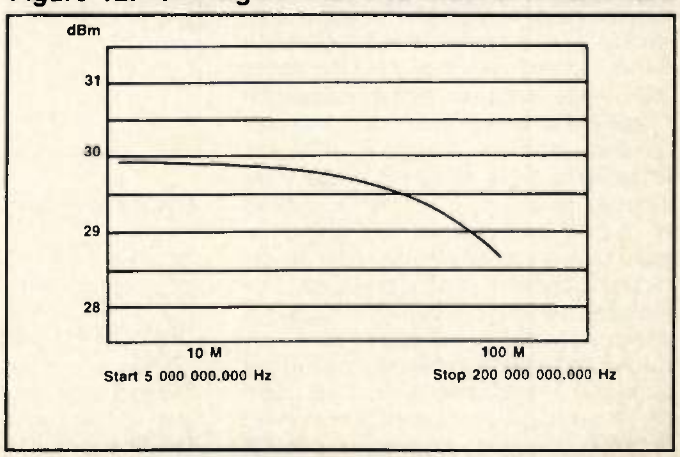

Figure 13. 1 dB compression point (Model RF1960A)

is set up by disconnecting the main amplifier and sweeping from the input through the delay line 1 path to test point 1. Then, with the main amplifier in the circuit, the cancellation is measured by sweeping across loop 1 from the input to test point 1. Amplitude and delay adjustments should be made to improve the match for maximum cancellation. Similarly, the cancellation of loop 2 is measured by disconnecting the error amplifier and injecting a test signal into test point 2 through the delay line 2 path to the output to obtain the reference.

Then, with the error amplifier in the circuit, the response of loop 2 from test point 2 to the output is measured and tuned for maximum cancellation.

Results

Test results of the specified HF high dynamic range amplifier indicate success in attaining the specifications ser forth. Figure 9 shows the cancellation curves of loop 1 and loop 2. As can be seen, better than 30 dB of cancellation of both signal and distortion was attained across most of the three decade bandwidth from 100 kHz to 100 MHz. The gain and return loss curves, shown in Figure 10, indicate a flat response with 11.5 ±0.5 dB of gain and return loss better than 18 dB across most of the band. Figure 11 is a plot of the calculated intercept points with and without feedforward based on the intermodulation measurements of a two-tone test. The OIPs was 10 dB higher than the expected +100 dBm due to the 30 dB of cancellation obtained from feedforward rather than the anticipated 20 dB. The OIP3 was better than the expected +57 dBm across most of the band. The noise cancellation effects are presented in Figure 12. With feedforward, the noise figure was below the 7 dB specification. rf

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1. H. Seidel, "A Microwave Feed-Forward Experiment," Bell System Technical Journal, Vol. 50 Nov. 1971, pp. 2879-2916.

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About the Author

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Voluntary EMI Susceptibility Standards

By Mark Gomez
Assistant Editor

Public Law 97-259, passed in 1982, gave the Federal Communications Commission (FCC) authority to regulate the RF interference susceptibility of home electronic equipment and systems. This report takes a look at the voluntary RFI susceptibility standard and the progress that has been brought about since its implementation.

The presence of *authorized* RF radiation created the need for the implementation of standards. The ANSI C63 Ad Hoc committee was formed to study the TV/VCR immunity problem. Members of the committee represent manufacturers, testing laboratories, the Electronic Industries Association (EIA) and the American Radio Relay League (ARRL). The initial step was to study television receivers and video cassette receivers. Later a group was formed to study susceptibility problems associated with cordless phones.

Interference

One common source of interference to television reception is from CB transmitters, due to harmonics of 27 MHz transmission. This is usually identified between telecommunication channels 2 and 5 and occasionally on channels 6 and 9. The interference occurs at or close to the frequencies corresponding to the undesired responses of superheterodyne receivers. The interference generates products that appear as signals within the desired channel.

Interference can also cause front-end overload, and its resulting generation of spurious signals. Receiver susceptibility is particularly high at IF and co-channel frequencies. IF interference occurs due to pickup in the chassis of the receiver. Co-channel occurs on a cable TV system when the radiated TV signal is picked up directly due to insufficient shielding of the tuner or coaxial cable between the antenna and receiver.

ANSI has proposed 1 V/m as the minimum susceptibility guideline for electronic devices for interference coupled by direct radiation into the chassis. More stringent requirements have been adopted in countries like West Germany where the requirement is 3 V/m. Below 30 MHz, the direct radiation guideline is 1 V/m. This is considered sufficient for CB radios.

Compliance

The Ad Hoc committee considers compliance with the voluntary standard to be satisfactory, that the immunity standards for TV receivers and VCRs are proceeding in a timely manner. There also is a significant increase in awareness on the manufacturers' part. The new TVs and VCRs have immunity built in to them wherever the manufacturer finds that it is cost effective.

The Electronic Industries Association (EIA) conducted a survey in Summer 1986 to determine the extent of voluntary compliance with EIA Interim Standards No. 10 and 16. EIA Interim Standard No. 10 is for interference from 0.54 to 30 MHz at antenna input of −7 dBm (.25 V at 75 ohms) referenced by a desired video carrier of −65 dBm or greater on channel 2. EIA Interim Standard No.16 is for the compliance of an undesired RF field of 1 V/m for broadcast, amateur and CB bands; 0.3 V/m for other frequencies. For TVs, the frequency range of concern is from .54 to 30 MHz and for VCRs it is 7.5 to 30 MHz with the desired video carrier being −65 dBm and −25 dBm on channel 2.

The survey showed that 93 percent of the color television sets (5" or over), 77 percent of the monochrome television sets (9" or over) and 100 percent of the VCRs produced by the companies that responded complied with EIA Interim Standard No. 10. For EIA Interim Standard No. 16, 82 percent of color TVs (9" to 25"), 0 (zero) percent of monochrome TVs (9" to 25") and 95 percent of non-portable VCRs complied. Note that the percentages quoted are the mean values of the tabulated results.

Mr. Don Heirman, chairman of the C63 Ad Hoc committee feels that the standards seem to be headed in the right direction but he states that it is too early to be certain if the voluntary standards will work.

"The voluntary standards eliminate the need for legislation by the FCC," said Mr. Frank Rose, an FCC representative on the C63 Ad Hoc committee. He mentions that the object is to make the manufacturers understand why they should comply rather than impose legislation that forces compliance.

However, in the future, manufacturers

	Sources											
Phenomena	CB	Amateur	Radar*	Pagers (40-60 MHz)	Cnsmr. ISM	Ind. ISM*	Land Mobile Radio	Maritime Mobile Radio 216-220 MHz	AM	Cordless Phone*	FM	TV
Front End Overload	a	a	x	c			x	x			c	c
Spurious Response	b	b	x	c			x				c	c
IF Susceptibility			x	x				x		x		
Adjacent Channel		x	x	x			x	x		x	a	c
Image Response			x				x					
In Band Spurious Emissions	x	x										
CATV***		c	x			x	x				c	c

Legend: *Identified Interactions*
a = High
b = Moderate
c = Low
x = Interaction not established

* Low Priority
** Anything with a TV tuner exclusing a cable TV converter
*** Both a source and phenomena

Table 1. Interference coupled into antennas (TV/VCR).**

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MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/510	300 - 1800 MHz	Log Periodic
SAS-200/511	1000 - 12000 MHz	Log Periodic
SAS-200/512	200 - 1800 MHz	Log Periodic
SAS-200/518	1000 - 18000 MHz	Log Periodic
SAS-200/530	150 - 550 MHz	Broadband Dipole
SAS-200/540	20 - 300 MHz	Biconical
SAS-200/541	20 - 300 MHz	Bicon'l Collapsible

MODEL #	FREQ. RESP.	DESCRIPTION
SAS-200/542	20 - 300 MHz	Biconical, Folding
SAS-200/550	001 - 60 MHz	Active Monopole
SAS-200/560	per MIL-STD-461	Loop - Emission
SAS-200/561	per MIL-STD-461	Loop - Radiating
BCP-200/510	20 Hz - 1 MHz	LF Current Probe
BCP-200/511	100 KHz-100 MHz	HF/VHF Crnt. Probe

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may be faced with a competitive disadvantage if they do not comply. Also, devices that comply may be priced higher. Hugh Turnbull, ARRL Atlantic Division Director pointed out that a written statement regarding the immunity of the product should be included in the packaging. Since the standard is not regulated, manufacturers need not put a tag on the product itself. The statement is to fulfill the voluntary obligation between manufacturer, vendor and consumer.

Cordless Telephones

On April 16, 1984, a group was formed to study the susceptibility problems with cordless phones. The group consists of representatives from EIA, Uniden, AT&T Consumer Products and Bell Northern Research. According to Eric Shimmel of EIA, the reason for the study is that there is an amateur band from 50 to 54 MHz which can cause interference problems with cordless phones that operate at 49 MHz.

This problem is being phased out by technological advances in the cordless phone industry. The new devices being manufactured seem to be immune to the said interference.

Conclusion

Voluntary standards are ideal since they eliminate the need for regulation. Progress towards compliance with the voluntary standards seems to be proceeding in a timely manner. The C63 Ad Hoc committee has noted a significant increase in awareness by the manufacturers for building more immunity into *newly designed* TVs and VCRs.

However, if compliance is low, the FCC may have to step in and regulate susceptibility. Also, for the consumers benefit, regulation may have to be introduced to create uniformity in the market.

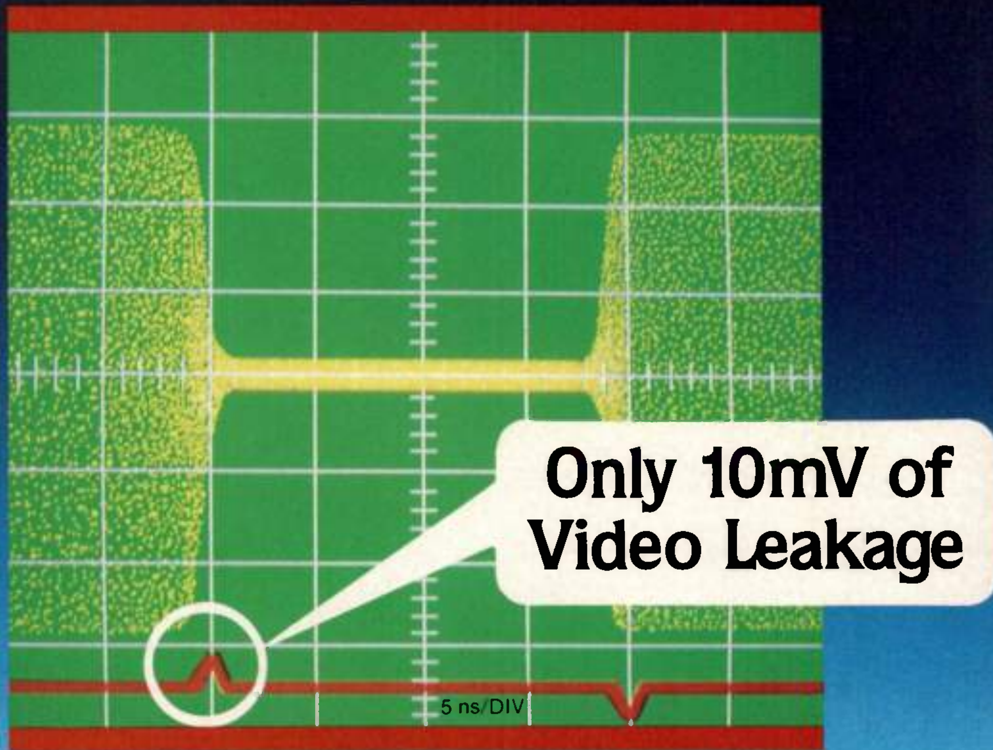
Progress towards international susceptibility standards is slow. This is due to the requirements of the different countries. For example, political situations govern the requirements in certain countries where the consumers are required to purchase a television license in order to use a television set. This license guarantees television reception and hence the susceptibility requirement has to be higher. rf

References

1. Gary A. Breed, "ANSI Committee Studying Voluntary EMI Susceptibility Standards," *RF Design*, November 1985, p. 36.

2. Ad Hoc Committee on Public Law 97-259, Initial Report; Immunity of Home Entertainment Devices, December 1985.

The MMIC switch from W-J



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- Very low video leakage (10 mV)
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Specifications (Measured in a 50-ohm system)

Characteristics	Frequency	Minimum	Typical	Maximum
Control Voltages –8V/0V or –5V/0V				
Insertion Loss	DC to 1 GHz		0.8 dB	1.2 dB
	1 to 2 GHz		1 dB	1.3 dB
	2 to 4 GHz		1.1 dB	1.5 dB
	4 to 5 GHz		1.4 dB	1.8 dB
Isolation	DC to 1 GHz	35 dB	40 dB	
	1 to 2 GHz	30 dB	35 dB	
	2 to 4 GHz	30 dB	35 dB	
	4 to 5 GHz	30 dB	35 dB	
VSWR	DC to 5 GHz		1.2:1	1.4:1
Control Voltages –8V/0V				
Input Power for 1 dB Compression	10 MHz		+19 dBm	
	100 MHz		+21 dBm	
	200 MHz		+25 dBm	
	500 MHz		+28 dBm	
	5 GHz		+30 dBm	

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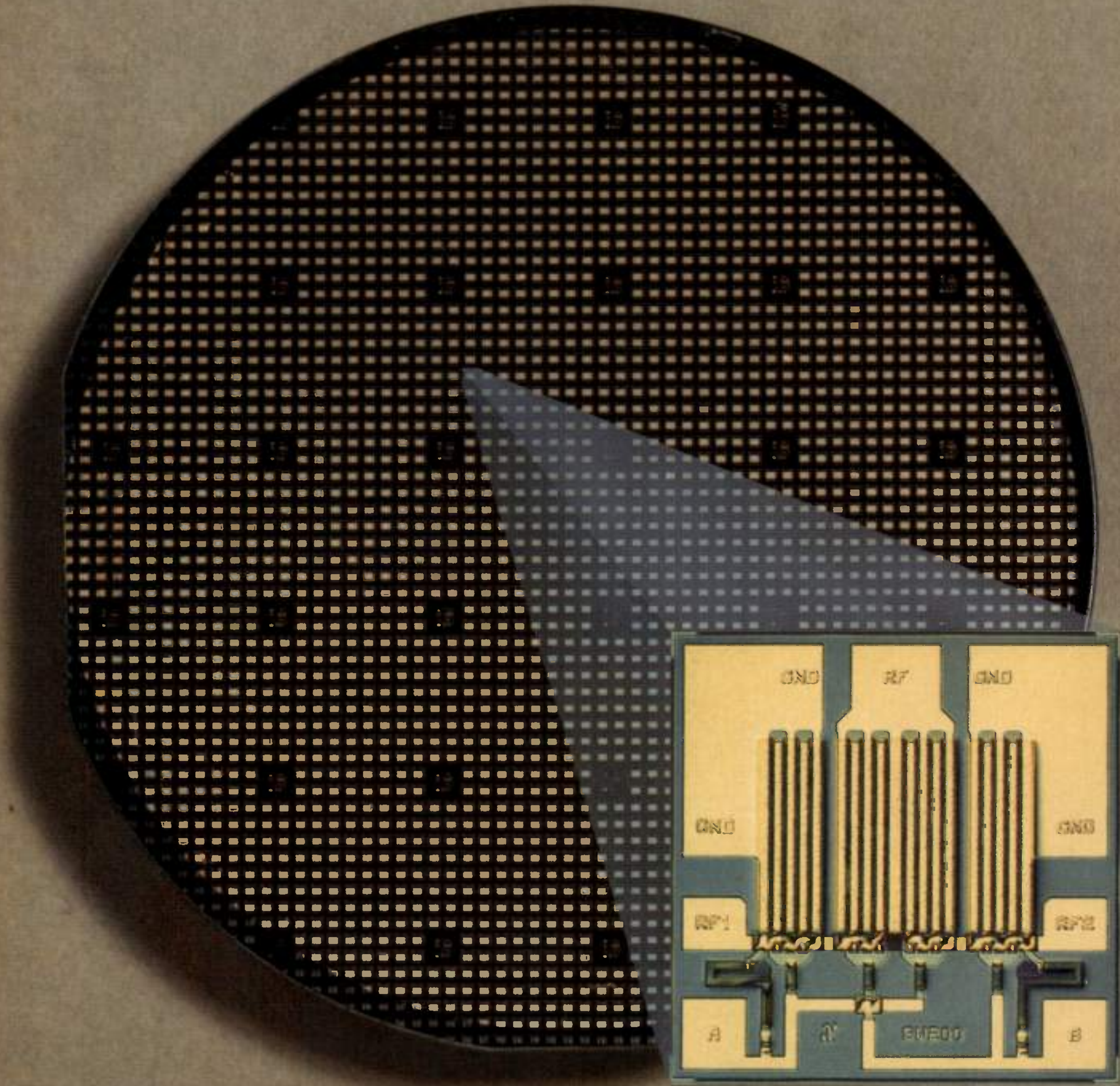

2 ns dc to 6 GHz GaAs MMIC!

What more can we say? For one thing, this SPDT chip has unbelievably low DC power requirements — 200 μA! And low Insertion Loss — typically 0.5 dB at 2 GHz. And even integral static protection. That's a lot for a little chip that costs only $40.00! Six additional models, configured as TO-5, flatpack, and 14-pin DIP with integral drivers round out the line. Want more facts? Just ask. We'll send you our latest folder.

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Video Modulated Wideband FM Signal Source

By Robert A. Dennison
Channel Master®

Most satellite receivers operating in the 3.7 to 4.2 GHz band or 11.7 to 12.2 GHz band use a first IF of 950 to 1450 MHz if block conversion, or 70 MHz if single conversion. This article describes a test signal source which produces an FM modulated signal source tunable from 950 to 1450 MHz. A 70 MHz output is also included. The signal source output is combined with a noise source in order to permit receiver design work at low carrier to noise ratios. The modulating signal is from 30 Hz to 8 MHz, thus allowing video and many other modulation sources. The unit is designed around readily available building blocks and can be put together by a person with no microwave design skill for around $200.

A block diagram of the generator is shown in Figure 1. A schematic is shown in Figure 2. The modulation source input is loaded by 75 Ω (300 Ω and 100 Ω in parallel). The 100 Ω potentiometer sets the deviation level. U1 (MC 1733) provides a small amount of voltage gain, enough to comfortably achieve ±10.75 MHz from a 1 V video input. By switching the output of U1 from pin 7 to pin 8, normal or inverted video results. 12 GHz receivers generally have block down converters with low side LO, whereas 4 GHz signals use high side, which inverts the video, so in order to simulate both these signals the video inversion feature is necessary.

Q1 buffers U1 and is followed by a pre-emphasis network. This network has a frequency response which is the inverse of the de-emphasis network in TVRO receivers. The pre-emphasis and de-emphasis results in an improved signal to noise ratio and prevents excessive deviation by the sync pulses in a video signal. Q2 buffers the pre-emphasis network. The DC tuning voltage is applied to the base of Q2 through a 10 kΩ resistor, the pre-emphasized video modulates that voltage. The emitter feeds the modulated tuning voltage to the voltage tuned oscillator. The VTO is an Avantek model no. VTO-8090. 950 MHz needs approximately 3 V and 1450 MHz requires approximately 25 V.

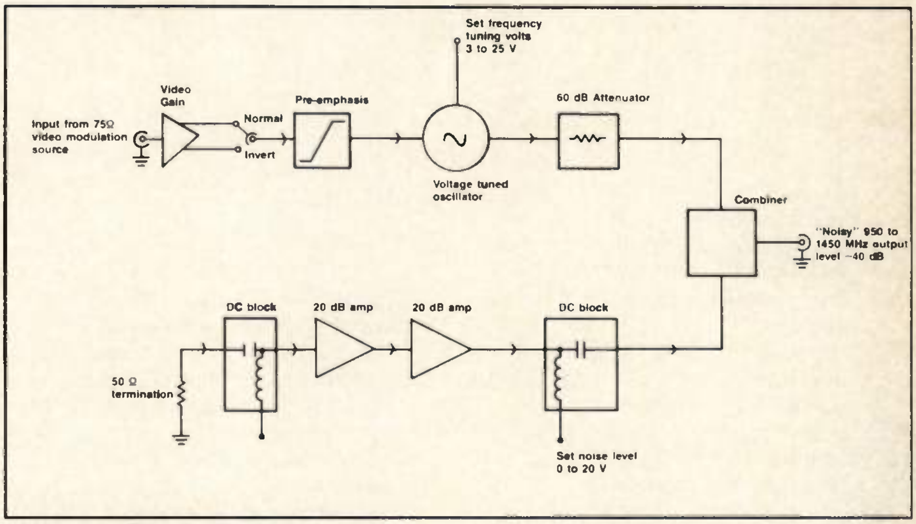
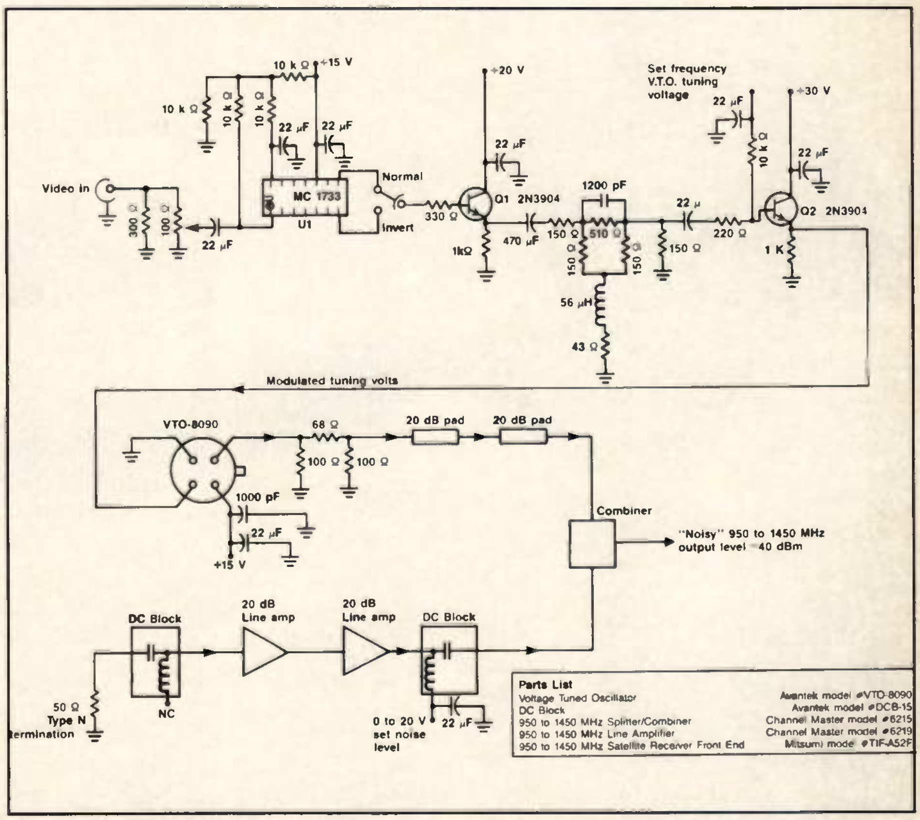


Figure 1. Block diagram.



Parts List	
Voltage Tuned Oscillator	Avantek model #VTO-8090
DC Block	Avantek model #DCB-15
950 to 1450 MHz Splitter/Combiner	Channel Master model #6215
950 to 1450 MHz Line Amplifier	Channel Master model #6219
950 to 1450 MHz Satellite Receiver Front End	Mitsumi mode #TIF-A52F

Figure 2. Schematic.

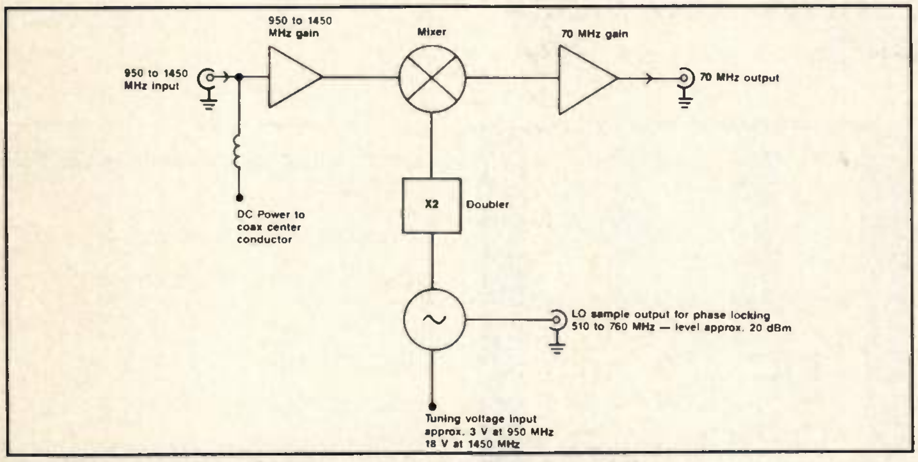


Figure 3. Satellite TVRO receiver front-end module.

It is essential that the VTO be mounted flush to a PC board in order to avoid spurious and unwanted sidebands in the oscillator output. A 10 dB PI pad prevents loading of the oscillator and drops the level to around 0 dBm. The level is further dropped to around −40 dBm with two series 20 dBm pads; these are the cheap CATV-type cylindrical pads with "F" connectors on each end.

Block conversion satellite receivers generally are specified for a 950 to 1450 MHz input between −30 and −60 dBm, so −40 dBm is a good level. The noise source is added at this point. The noise source is a 50 Ω type N termination. The noise is amplified by two 20 dB satellite TV receiver line amps. These line amplifiers are powered by 20 VDC on the center of the coax, so it is necessary to provide a DC block at the input to the first amp and the output of the last. One of the DC blocks is used for powering the line amps. Lowering the DC voltage to the line amps lowers the gain allowing the noise level to be adjusted.

The oscillator signal and noise signal are combined in a satellite TV receiver splitter connected in reverse. The noise source must be completely shielded and separate from the VTO, which should also be shielded in order to avoid picking up the VTO signal. Use a good quality 50 Ω type N termination and DC blocks. The output of the combiner is then connected to a 950 to 1450 MHz receiver. Start with the set noise voltage at zero volts (no added noise). A color bar generator is used as the video source. Viewing the receiver's output on a TV set with no added noise, perfect color bars will be seen. Increasing the set noise voltage from zero to 20 V the color bars will first become slightly grainy, then the characteristic

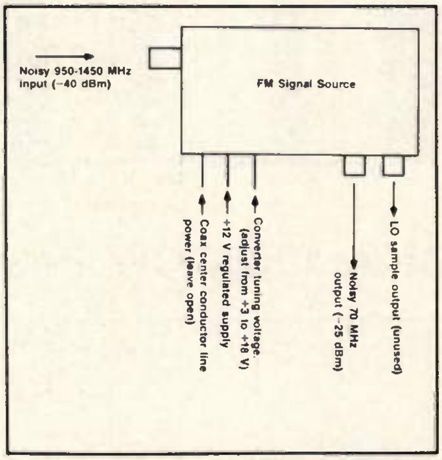


Figure 4. Noisy 70 MHz wideband RF signal source.

"sparklies" will start to appear and eventually wipe out the signal.

When a 70 MHz IF signal is required, we simply convert the 950 to 1450 MHz signal to 70 MHz using a satellite TV receiver front end module, Mitsumi model no. TIF-A52 F. A block diagram of this module is shown in Figure 3. 950 to 1450 MHz signals are mixed with a high side tunable local oscillator to produce 70 MHz. Figure 4 shows the satellite receiver front end connected to the 950 to 1450 MHz signal for a 70 MHz output. rf

About the Author

Robert Dennison is a senior project engineer for Channel Master, Avnet Inc., P.O. Box 1416, Industrial Park Drive, Smithfield, NC. He received his BS in electronic engineering in 1977 from the University of Manchester, England. He can be reached at (919) 934-9711.

Directed Energy Introduces New Class of Pulse-Power MOSFETs

The DE-275 Series from Directed Energy is a line of power MOSFETs designed specifically for high speed, high power switching and pulse applications. The first products from this young company, the DE-275 devices are intended to bridge the gap between RF-characterized power FETs and lower frequency switching transistors. By packing a switching MOSFET die in an RF-type package, its inherent nanosecond switching speed is not degraded by the inductance and capacitance associated with TO-3 and TO-220 cases. In addition, the package has a unique clamped mounting which allows direct thermal connection between the insulating ceramic and the heat sink for improved heat transfer.

Other features of note include: surface mount compatibility, low inductance (gate input is capacitive only), package thermal expansion closely matched to silicon, and a proven switching Power MOSFET die

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Switching Time	⩽1 ns
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Voltage V_{DS}	50 to 1000 V
Peak Current	to ⩾200 A
Average Current	5 to 50 A
Pulse Recurrence	⩾10 MHz

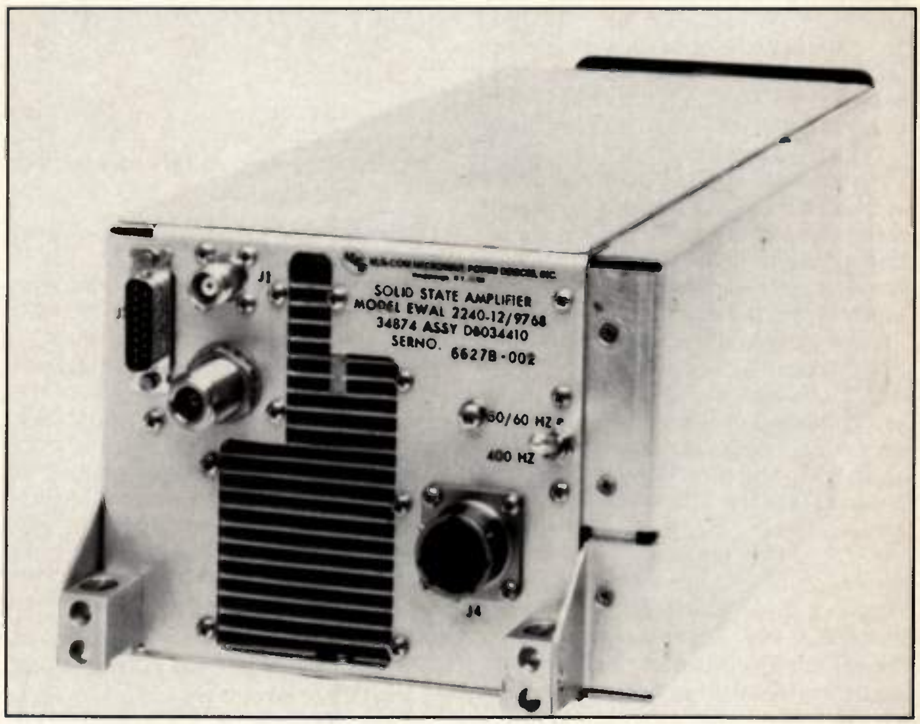
design. Applications include lasers, sonar, ultrasonics, particle accelerators, medical equipment and communications. The company plans to provide RF characterization of the device for Class C and linear applications in the near future. **Directed Energy, Ft. Collins, CO. Please circle INFO/CARD #204.**

M/A-COM MPD Unveils A 100W CW Power Amplifier

This class AB unit is a microprocessor controlled amplifier subsystem. The output power is 100 W CW between the ranges of 225 and 400 MHz. The subsystem has a volume of 0.21 cubic feet and this includes a built in power supply. The integral microprocessor provides control of subsystem power (ON/OFF) and control of RF output power levels from 0.1 to 100 W.

In addition, status outputs are provided from the integrated bit circuitry. These outputs include digitized readings of forward and reflected RF levels with 8-bit accuracy. The communication bus is implemented using RS422 synchronous data link control (SDLC), permitting multiple amplifier units to be operated individually as remote terminals from a single controller with a data transfer rate of 1 MHz. The input connectors are type TNC female and the output is transmitted via type N female connectors.

The amplifier subsystem is designed around an aluminum finned heat sink structure with integral forced air cooling to ensure maximum reliability.



Typical specifications include an input VSWR of 1.5:1, a spurious response of 90 dBc and harmonic response of −20 dBc (between 450-490 MHz). The amplifier measures 4.75" × 6.5" × 13". Output noise floor at 100 W measured less than −119 dBm/Hz. RF input power is 8 dBm ±3 dB.

The protection features for the device are thermal overload, power supply overcurrent, output power fault, and excessive load VSWR. **M/A-COM Microwave Power Devices, Inc., Hauppauge, NY. Please circle INFO/CARD #203.**

Programmable DIP Attenuator

The dual-in-line attenuator operates from DC to 1.1 GHz and is programmable in 0.5 dB steps from 0.5 to 24 dB. The Model EPIBOXXX (Xs denote attenuation value) provides an accuracy of 0.25 dB throughout its operating range with insertion loss of 0.3 dB maximum. It measures 1.26" × 0.48" × 41". The Model EPIBOXXX programmable attenuator is priced at $40 in 100 lot quantities. **EMC Technology, Inc., Cherry Hill, NJ. INFO/CARD #202.**

Log/Antilog Amplifier System

Solid State Micro Technology introduces the SSM 2100, a subsystem for realization of log, log ratio, and antilog transfer functions. The 16 pin device offers two operational amplifiers with low offset voltages of 4 mV as well as low input current (0.5 nA). Total dynamic range is 100 dB, and external trims are minimized. It is priced at $5.75 for 1000 pieces. **Solid State Micro Technology for Music, Inc., Santa Clara, CA. INFO/CARD #201.**

RGB Video Amplifier

The LM1203 is a monolithic integrated circuit consisting of three wideband video amplifiers with independent trim capability and the circuitry for DC contrast and brightness control. The three amplifiers operate at 70 MHz at -3 dB. Three attenuators for contrast control and three externally gated comparators for brightness control are provided. The LM1203 features independent gain control of each amplifier. **National Semiconductor Corporation, Santa Clara, CA. Please circle INFO/CARD #200.**

VHF/UHF Receiver

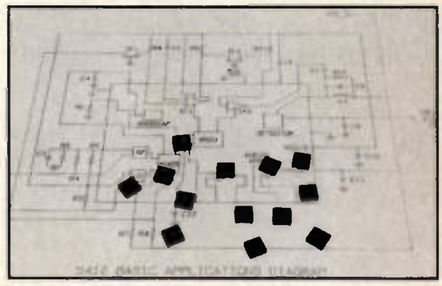
The Model 7516-1 is a VHF/UHF receiver with a frequency range of 20-1000 MHz. The features include a tuning resolution of 1 kHz, RF input VSWR of 50 ohms and a noise figure of 10.5 dB maximum. It is priced at $28000. **Interad Ltd., Gaithersburg, MD. INFO/CARD #198.**

High Power Thin Film Amplifier

Avantek introduces a high power thin film amplifier having minimum gain of 12 dB with a typical gain of 13 dB over the 10-1000 MHz range. Model UTO-1023 has a maximum noise figure of 8.5 dB; minimum 1 dB compressed output power of +24.5 dBm; and maximum input and output VSWR of 2:1. **Avantek, Inc., Santa Clara, CA. INFO/CARD #197.**

Cellular Radio IC

Siltronics' cellular radio IC, the S412, is a double conversion superheterodyne FM radio receiver with added features for



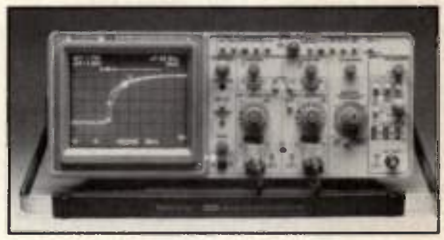
cellular radio. The device can be used with second IF frequencies of either 10.7 MHz or 455 kHz. The IC, with external components, provides the second mixer, IF amplifier-limiter, detector, and audio amplifier. The input frequency range to the mixer is up to 110 MHz. Sensitivity is better than 2 uV at 12 dB sinad. Also on the chip is an accurate and stable received signal strength indicator (RSSI) circuit. RSSI accuracy is ±2 dB from ideal over a temperature range of 0 to 60C. **Siltronix Ltd., Kanata, Ontario, Canada. INFO/CARD #196.**

Four-Pole Monolithic Crystal Filter

Piezo Technology unveils a four-pole 21.4 MHz monolithic crystal filter in a .45" × .45" × .06" leadless ceramic package. It offers a bandwidth of ±7.5 kHz at 3 dB attenuation and a ±25 kHz bandwidth at 35 dB attenuation. Ultimate attenuation is 70 dB minimum. The filter is designed to have less than 1.0 dB ripple and less than 35 dB spurs. The flat loss is 3.0 dB maximum. **Piezo Technology, Inc., Orlando, FL. INFO/CARD #195.**

Digital Storage Oscilloscope

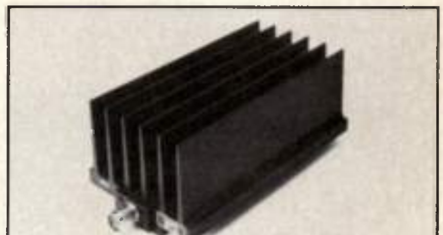
The Tektronix 2221 digital storage oscilloscope (DSO) has a storage bandwidth



of 60 MHz. It has measurement cursors and readout to the 4096 point record, averaging 100 nanosecond peak detect capabilities and accumulated peak detect (enveloping). Peak detection ensures at least one sample on noise or switching spikes as narrow as 100 nanoseconds. Waveform sampling is done at 20 Megasamples/sec. **Tektronix, Inc., Beaverton, OR. INFO/CARD #194.**

500 W Fixed Attenuators

Operating from DC to 2.5 GHz, the Weinschel Model 53 is rated for up to 500 W CW and up to 10 kW of peak power. It has a maximum deviation of ±0.5 dB and a VSWR of ≤1.10. The units are available



Model 53

with fixed values of 20, 30 or 40 dB. Calibration is done at DC, 1.5 and 2.5 GHz. The attenuators cost $595. **Weinschel Engineering, Gaithersburg, MD. INFO/CARD #193.**

2.5 to 6.5 GHz Amplifiers

Airtron introduces a series of hermetically sealed wide dynamic range amplifiers operating in the 2.5 to 6.5 GHz band. The ASA-2565 series offers gain options from 25 to 42 dB with power outputs of +22

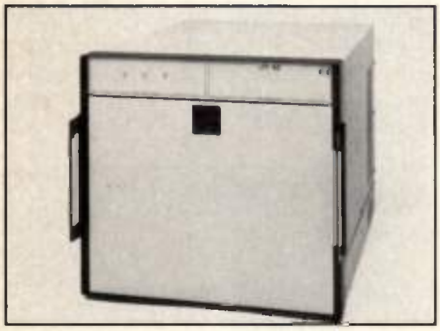
dBm at the 1 dB compression point. Other specifications include a VSWR of 2:1, noise figure of 5.5 dB and gain flatness of ±1 dB maximum. **Airtron Division, Litton Industries, Morris Plains, NJ. INFO/CARD #192.**

Microwave Network Analyzer

The 360 network analyzer phase locks the microwave source to the desired measurement frequency almost an order of magnitude faster than previous systems. It is compatible with the 6600B series of Wiltron microwave sweepers. The 360SS45 covers 10 MHz to 18 GHz and the 360SS69 covers 10 MHz to 40 GHz. The basic 360 analyzer costs $29800. **Wiltron Company, Morgan Hill, CA. INFO/CARD #183.**

4 kW Amplifier

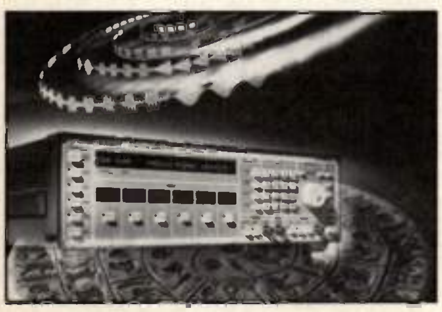
The LPI-40 provides 4 kW of linear pulse power from 10 to 86 MHz, with pulse widths up to 20 ms and 20 percent duty cycle. The amplifier is optimized for amplitude and phase linearity to ensure maximum transparency while increasing the power of the pulsed signal. This air cooled unit features output overpower protection and built in test equipment.



Overvoltage, pulse width, and pulse duration trips maximize safety and eliminate the need to provide external circuitry. The external gating input on the LPI-40 allows the bias to be turned off on both the driver amplifier and output power amplifier stages, ensuring a noise floor of better than 20 dB above thermal noise. **ENI, Inc., Rochester, NY. INFO/CARD #190.**

Function Generator AFGU

The function generator AFGU from Rohde & Schwarz has a frequency range from 1 uHz to 20 MHz and produces sinewave, triangle, square, trapeze and pulse signals. User specific waveforms can be



generated using the arbitrary functions. A 4K parameter memory with a resolution of 10 bits is available. Start/stop addresses can be set to produce curve segments or individual curves. The XY coordinates can be entered via the keyboard or IEC/IEEE bus. Other features include internal and external FSK and pulse modulation, external AM,FM and VCO. **Rohde & Schwarz, Munich, West Germany. Please circle INFO/CARD #189.**

Chip Capacitors

AVX introduces a line of MLC chip capacitors. It is a combination of two low loss dielectric materials, either silicon dioxide or silicon nitride, with highly conductive electrode metals manufactured under class 100 clean room standards. The capacitors have a low ESR, high Q, and low capacitance change when operating up to 1 GHz. **AVX Corporation, Myrtle Beach, SC. INFO/CARD #188.**

Microwave Counters

EIP Microwave introduces MATE-compatible versions of two existing microwave counter families. Models 535 and 538 are CW counters with frequency coverage to 18 GHz and 26.5 GHz respectively. Models 585 and 588 are pulsed counters capable of counting CW, pulsed, and time varying signals. Both families incorporate a YIG preselector, allowing multiple selectivity and 10 W burnout protection. **EIP Microwave, Inc., San Jose, CA. INFO/CARD #150.**

RF Enclosures

The W series double electrically isolated (DEI) RF enclosure is essentially a shielded enclosure within a shielded enclosure. Two isolated layers of shielding material are mounted on opposite sides of frames that bolt together. **Lindgren RF Enclosures, Inc., Addison, IL. Please circle INFO/CARD #181.**

UHF High Power Amplifier

TRW RF Devices Division introduces a line of high power, class A UHF amplifier modules. The PAM-0810 series operates on a 24 VDC input with a 800 MHz to 1000

MHz frequency range and power outputs of 3 W, 5 W, 12 W, 25 W or 50 W. **TRW Electronic Components Group, Lawndale, CA. INFO/CARD #186.**

Video Amplifier

The PA19 video power amplifier from Apex Microtechnology has a gain bandwidth product of 100 MHz plus an output swing capability of 70 V p-p at currents up to 4 A peak. The slew rate is 900 V/us. Voltage offset maximums are 3 mV for the PA19 and 0.5 V for the PA19A. **Apex Microtechnology Corp., Tucson, AZ. INFO/CARD #185.**

SMT Ferrite Beads

A surface mount ferrite bead designed to increase line impedance at high frequencies for EMI/RFI reduction and the prevention of undesirable oscillation is available from Murata Erie. A 50 mA and 100 mA bead is offered. Typical impedance of these devices is 65 to 70 ohms at 100 MHz while DC resistance is 0.5 ohms maximum. **Murata Erie North America, Inc., Smyrna, GA. Please circle INFO/CARD #184.**

rf software

Ladder Filter Design

Ladfil is an LC filter design and evaluation software package. The features include a library of special designs, automatic application of Norton transformations to all pole direct scaled designs and the capability to analyze up to 150 points in frequency for VSWR, forward attenuation, group delay, or absolute phase while holding the data for graphic display. Optimization functions are incorporated in the package. **ALK Engineering, Salisbury, MD. INFO/CARD #209.**

Filters Program

Filter synthesizes thirteen different topographies of lowpass, highpass, bandpass, bandstop, elliptic lowpass and elliptic bandpass filters. Filters up to 21st order including the elliptic may be designed. The filters are synthesized with response shapes of Chebyshev, Butterworth, Bessel, Gaussian to 6 dB, Gaussian to 12 dB, minimum phase with equal ripple error and elliptic Cauer-Chebyshev. Singly terminated Butterworth and Chebyshev types are included.

Also from Circuit Busters is version 3.0 of *Superstar.* This version includes an internal editor. Each variable independently adapts to appropriate step sizes during optimization. The circuit file has been increased to 75 lines. **Circuit Busters, Inc., Stone Mountain, GA. INFO/CARD #161.**

PCB Software

Bishop Graphics CAD introduces version 4.2 of its Quick Circuit CAD/CAM software package for printed circuit board design and manufacturing. PCB designers and drafters can create and select over 200 each of various pad sizes, square, round, and oval shapes, hole diameters, patterns and trace widths to create artworks for PC boards up to 32" × 32". Analog, digital, and SMT layouts for a single, double or multilayer boards can be created. This package is tailored for Apple systems. **Bishop Graphics, Westlake Village, CA. INFO/CARD #205.**

Analog Circuit Analysis

ECA-2 is an analog circuit simulator with AC, DC, transient, fourier, worst-case and Monte Carlo analysis. It can sweep voltage, time, temperature or frequency for a range of values of one or several components. The possible calculations include node or branch voltages (magnitude or phase), branch currents, power, and port impedance. The output may be obtained in the form of bode plots, DC transfer and transient timing diagrams. **Tatum Labs, Inc., Ann Arbor, MI. Please circle INFO/CARD #208.**

30 MHz to 21 GHz Catalog

CTI introduces a catalog that includes products, application notes, outline drawings and phase noise charts. It is called Phase-Locked Signal Sources and Frequency Synthesizers. **Communication Techniques, Inc., Whippany, NJ. INFO/CARD #162.**

1987 Data Book

1987 Data Converters and Voltage Reference is a data book from Maxim that features information on A/D converters, D/A converters and 11 voltage references. A product listing, converter selector guides and package information section is incorporated. **Maxim Integrated Products, Sunnyvale, CA. INFO/CARD #159.**

Filter Connector Catalog

Custom designed EMI/RFI Connector catalog No. 61-04 is available from Murata Erie. Filter connectors meeting all applicable MIL requirements are described. Testing procedures, design considerations, and specifications for BNC and TNC connectors are included. **Murata Erie North America, Inc., Symrna, GA. INFO/CARD #158.**

Amplifier and Oscillator Catalog

Alpha Industries has introduced an amplifier and oscillator catalog. It includes information on Gunn diodes, oscillators, custom designed microwave and millimeter wave subsystems and GaAs power amplifiers. **Alpha Industries, Inc., Woburn, MA. INFO/CARD #167.**

30th Anniversary Catalog

This catalog includes a line of miniature and subminiature anti-aliasing filters and programmable filters from TTE. The programmable units feature up to eight filters per unit. **TTE, Inc., Los Angeles, CA. INFO/CARD #166.**

Data Conversion System Digest

This digest is a compendium of tutorials and reference material on design problems often encounted by engineers. A/D conversion architecture, parametric definitions and design considerations, ground loops and interference are some of the topics that are examined. It is available at no charge to chief engineers and systems designers. **Analogic Corporation, Peabody, MA. INFO/CARD #165.**

Coaxial Switch Catalog

Switch categories described in this catalog include SPDT, SP3T to SP10T multiposition switches, 2P2T transfer switches and a series of matrix switches featuring up to 66 selectable RF paths. The switches cover a range from DC to 26.5 GHz. **Wavecom Division, Loral Corporation, Northridge, CA. INFO/CARD #164.**

Crystal Oscillators Catalog

The catalog covers oscillators ranging from 1 Hz through 1 GHz with stabilities from ±0.1% to 1×10^{-10}. It details clock oscillators, low phase noise oven control crystal oscillators, TCXOs, VCXOs, VCOs and frequency standards. **Vectron Laboratories, Inc., Norwalk, CT. INFO/CARD #218.**

Electronic Materials Catalog

25 Years Of Electronic Materials Technology is a catalog that describes ESL's complete line of electronic material systems including applications in surface mount technology, thick film, multilayer and flexible circuits, packages, hybrids, photovoltaic cells, etc. **Electro-Science Laboratories, Inc., King of Prussia, PA. INFO/CARD #217.**

Antenna Systems Catalog

This catalog consists of electrical and mechanical specifications, radiation patterns, and application notes for more than 300 base stations and mobile antennas and accessories. Also included is information on transmitter combiners, receiver multicouplers and other RF site management products. The products featured lie in the frequency range from 30-1000 MHz. **The Antenna Specialists Co., Cleveland, OH. INFO/CARD #216.**

Military Products Brochure

CTS Corporation introduces a military products brochure detailing its line of electronic components available for MIL applications. The components featured include hybrid microcircuits, quartz crystal oscillators and variable resistors. **CTS Corporation, Elkhart, IN. INFO/CARD #215.**

Signal Generators Application Note

HP AN 283-3, "Low Phase Noise Applications of the HP 8662A and HP 8663A Synthesized Signal Generators" explains how the two signal generators achieve low close in phase noise. It presents techniques of applying this phase noise performance to solve problems that commonly arise in RF and microwave phase noise measurements, receiver testing and local oscillator substitution. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #214.**

Short Form Catalog

A short form catalog, #61-05, is available from Murata Erie. Included are specifications on monolithic and disc ceramic capacitors, resistors and piezoelectric products, surface mount devices and EMI/RFI filters. **Murata Erie North America, Inc., Smyrna, GA. INFO/CARD #211.**

Surface Mount IC Brochure

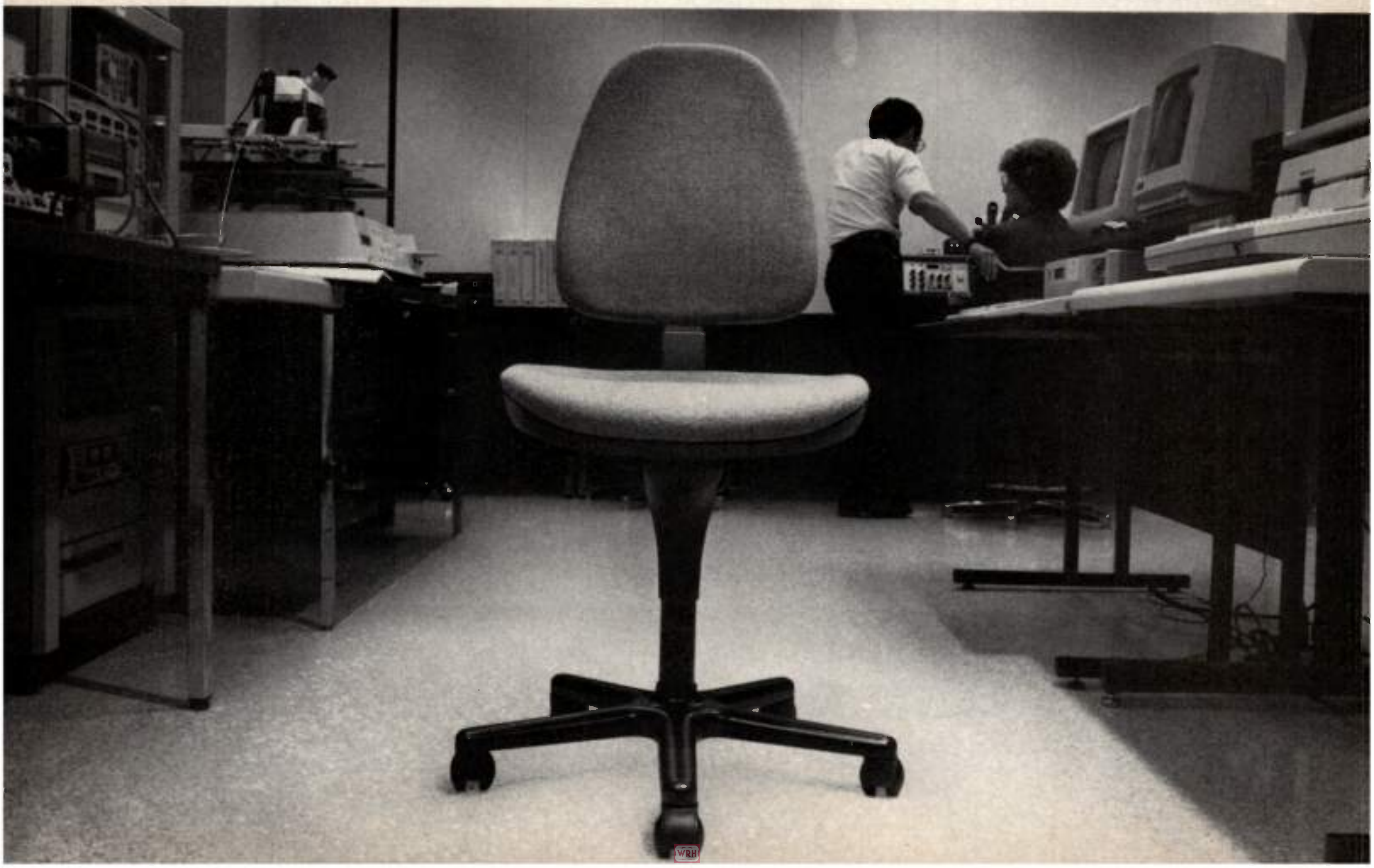
The brochure reviews 46 products available in plastic surface mount packaging. Functional block diagrams, specification and pin out information are provided for each product. The guide is divided into nine sections: op amps, D/A converters, A/D converters, voltage to frequency converters and more. **Analog Devices, Norwood, MA. INFO/CARD #210.**

EMI/EMS Accessories Brochure

A brochure which describes Eaton's line of accessories for electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) testing is introduced. Detailed description and photographs are provided for current probes, absorbing clamps (CISPR), dipole kits, tuned dipoles, antennas and related accessories (20 Hz to 40 GHz), and impulse generators. Tables and graphs are included. **Eaton Corporation, Electronic Instrumentation Division, Los Angeles, CA. INFO/CARD #220.**

Power Monitor Data Sheet

Thermocouple RF power monitors (20 and 30 dB) are the subject of a four page data sheet published by Narda. It features compact, lightweight power monitors for power monitoring and control systems in radars, jammers, satellite uplinks, and in test equipment designs. The data sheet provides descriptions, specifications, outline drawings, and interconnection diagrams for all models. **Narda Microwave Corporation, Hauppauge, NY. INFO/CARD #219.**



Engineering Opportunities

Scientific-Atlanta, a Fortune 500 manufacturer of products used in the cable television industry, has the following engineering positions available in our Atlanta based Broadband Communications Division.

PROJECT MANAGER—Responsibilities will include management of approximately 10 Engineers and Technicians. Will be responsible for successful execution of critical projects in regard to technical performance, schedule and budget. Experience in PC based software written in 'C', real time microprocessor software in assembly language and digital hardware design are required. Experience in broadband RF and computer based control systems is desirable. BSEE required. MSEE and MBA desirable. Three years technical management experience required.

HARDWARE DESIGN ENGINEER—This individual will be involved in the design and development of CATV equipment. Qualified applicants will have a BSEE with 2-5 years experience in RF circuit and video systems design.

DIGITAL DESIGN ENGINEERS—Design of standard cell custom ICs, general digital hardware design, and microprocessor hardware design including peripheral hardware. Expertise in microprocessor software desirable. A BSEE with a minimum of 2 years experience is required.

MICROPROCESSOR ENGINEER—Design, coding and design verification of microprocessor based CATV subscriber products. Experience in real time microprocessor software written in assembly language is required. Expertise in digital hardware design is also desirable. A BSEE with a minimum of 2 years experience is required.

SOFTWARE ENGINEERS—Design, coding and design verification of PC based or HP1000 based computer control systems. Expertise in 'C', Fortran, OS/2, and RTE are highly desirable. Strong candidates should be able to write software for real time microprocessor based systems using 'C' and assembly language. Ability to work intimately with custom hardware is desirable. A BSEE with a minimum of 2 years experience is required.

PRODUCT QUALIFICATION ENGINEER—Evaluation and approval of components and assemblies for high volume products. Expertise to include qualification testing, interfacing with vendors, specification development and maintenance and familiarity with UL and FCC regulations and approval procedures. A BSEE with a minimum of 5 years of related experience is required.

CIRCUIT DESIGN ENGINEER—Design and development of analog and digital circuits which will perform over the outdoor environmental extremes. Will build, test, and analyze prototype circuits to prepare for manufacturing. A BSEE plus 2-5 years in related circuit design are required.

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Antenna Design

Northrop Corporation's Defense Systems Division, located in sprawling Rolling Meadows, IL just northwest of Chicago, continues to provide innovation and leadership in its role as a major force in the electronic countermeasures industry. Our professionals contribute to the state-of-the-art within a creative, well-managed environment in which individuals are encouraged to develop their capabilities to the fullest, and work in concert as part of winning team. **Positions below require a BSEE, Physics or equivalent, MS preferred.**

Manager: EW Antenna Design

We seek a seasoned professional to spearhead our EW Antenna Design activities. Will be responsible for the design, development and transition into production of Airborne Antenna Systems for ECM applications, and the supervision of a growing unit of design engineers and technicians. Position will have frequent interface with manufacturing and program management. Requirements include a minimum of 12 years experience in airborne antenna design with at least 4 years of project level experience involving budgetary/scheduling responsibilities. Strong management and interpersonal skills are also essential.

Antenna Design Engineers

Participate in the analysis, design, development and testing of Airborne ECM/EW antennas, and the preparation and debugging of a new, state-of-the-art antenna range facility. Positions require candidates with knowledge of phased arrays, monopulse D.F. systems and millimeter wave techniques.

Northrop offers a salary schedule commensurate with level of experience, and a full range benefits program. Interested persons should forward resume with salary specifics to: **James Frascona, Technical Recruiter, Dept. C76, Northorp Corporation, Defense Systems Division, 600 Hicks Road, Rolling Meadows, IL 60008.** An equal opportunity employer M/F/V/H. U.S. citizenship may be required for certain positions.

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Ad Index

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Series Resis. RS (Ohms) MAX	3.0	2.0	4.0	3.0
Capacitance Cj (pF) MAX	.03	.06	.02	.07
Lifetime TL (ns) TYP	50	50	150	150
Switching Time TS (ns) TYP	5	5	15	15

*Mesa **Planar

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INFO/CARD 49

SAW Questions and Andersens.

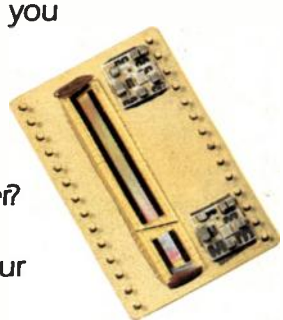
Bandpass filters:

QUESTION: I have an application that requires filters. Why should I consider SAW devices?

ANDERSEN: Want to eliminate tuning? Need very sharp passband skirts (i.e. low shape factor) with high close-in rejection? Low ripple? Phase that can be linear or non-linear, as you choose? Small size? Highly repeatable characteristics? These are the areas where SAW filters excel. If any of these factors are important, you should be looking at SAW's.

QUESTION: How expensive and how long will it take to get my filter?

ANDERSEN: That depends on your specs. But we have hundreds of stock designs to choose from (we're the oldest SAW manufacturer), so it's very possible we already have one that meets your specs. If not, with our recent major staff increase we offer one of the largest groups of SAW designers of any U. S. company to meet your needs fast and at aggressive pricing.



QUESTION: What about hybridizing?

ANDERSEN: This may be a very smart move. With our in-house hybrid facility, we can deliver maximum performance in a minimum space. Buying a zero-loss SAW filter module or an entire hybridized Andersen IF section may improve your system performance, reduce size, increase reliability and fully exploit the advantages of SAW technology.

QUESTION: How do I get started?

ANDERSEN: Just give us a call. We'll do everything we can to meet your needs.

Or, if you simply want more information, send for Volume I of our comprehensive handbook on Acoustic Signal Processing. In it, you'll find the right Andersen to most of your SAW questions—and specs on the latest models.

Write to Andersen Laboratories,
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Bloomfield, CT 06002.
Or phone (203) 242-0761/
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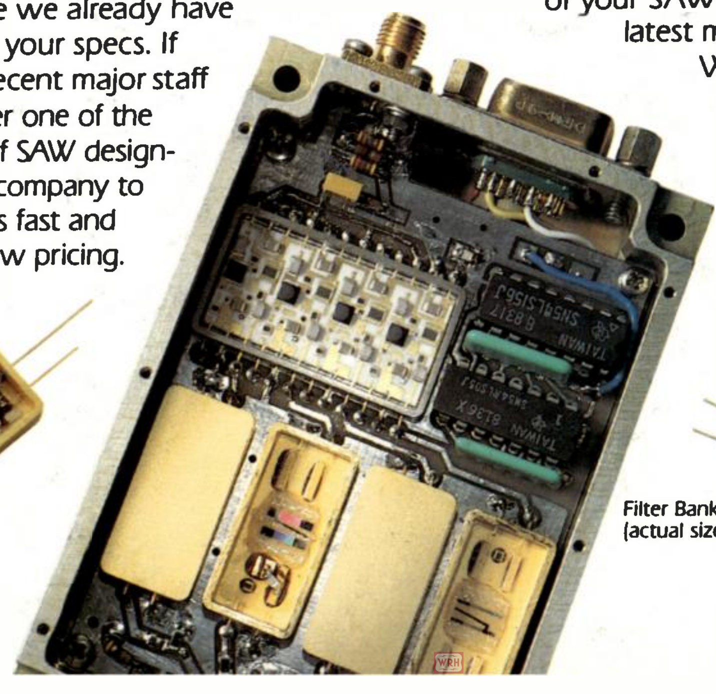

Filter Bank
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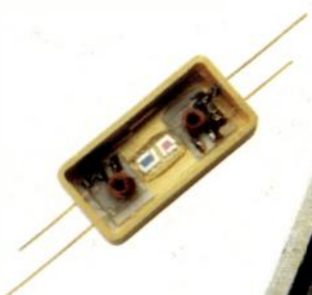

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