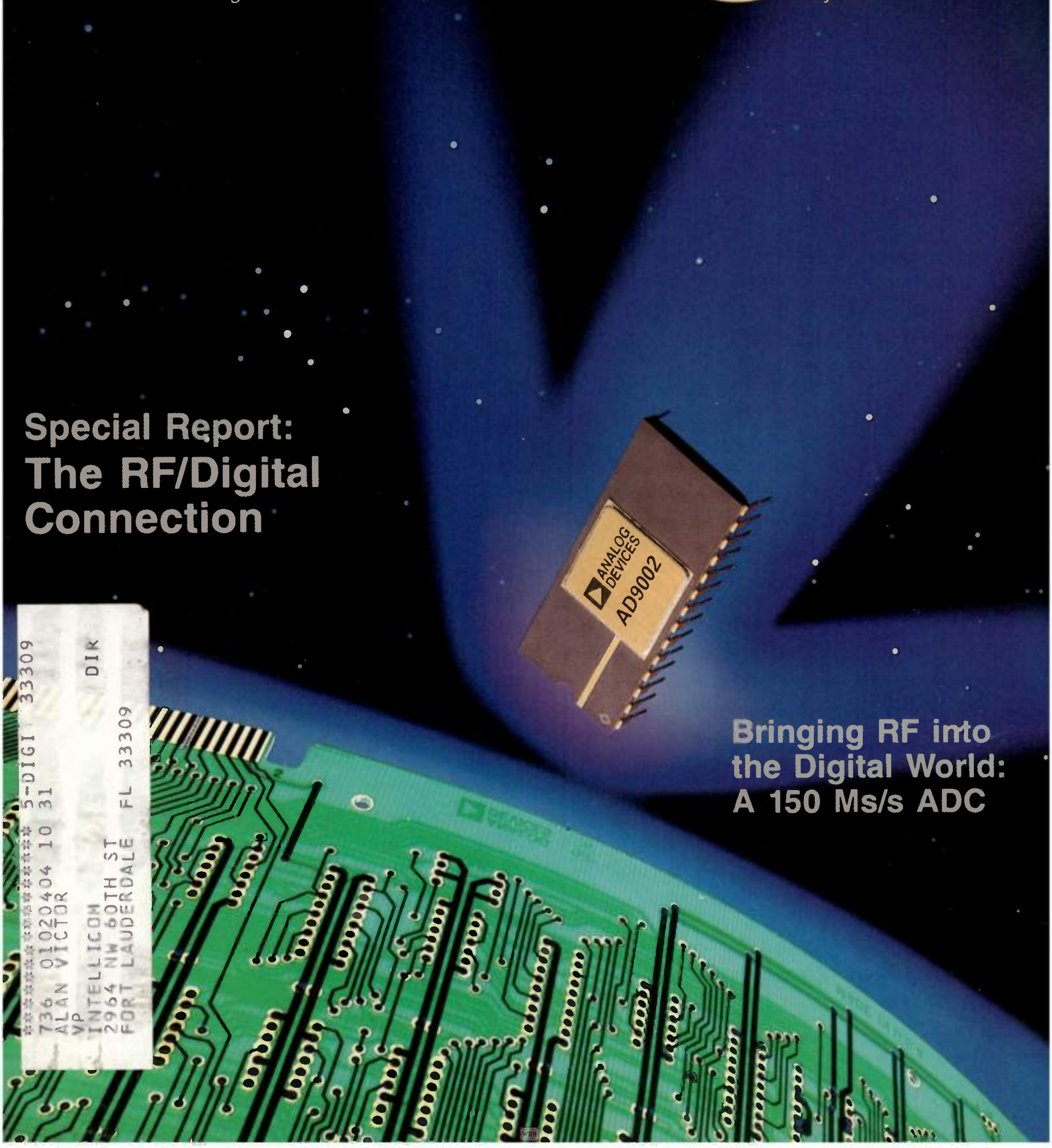
rf design

ideas for engineers

May 1987



Special Report: The RF/Digital Connection

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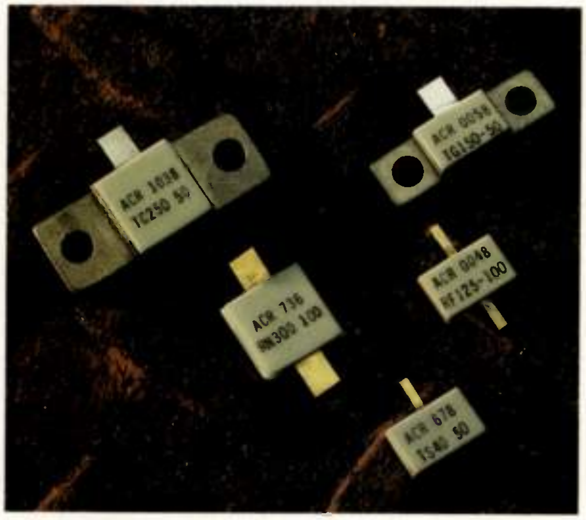

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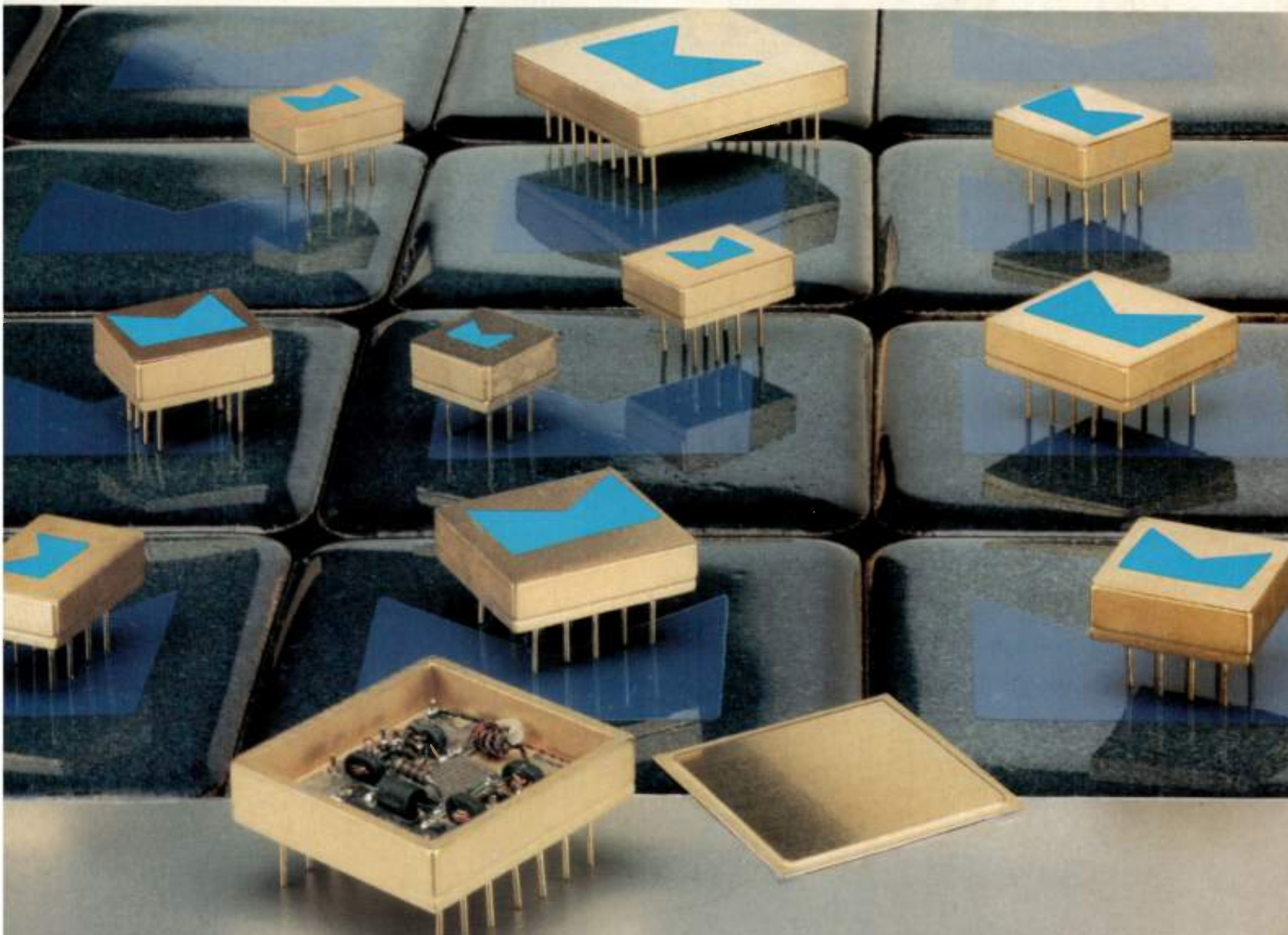

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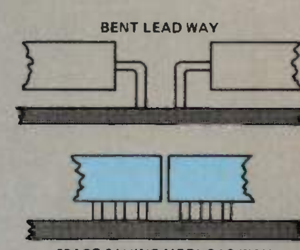

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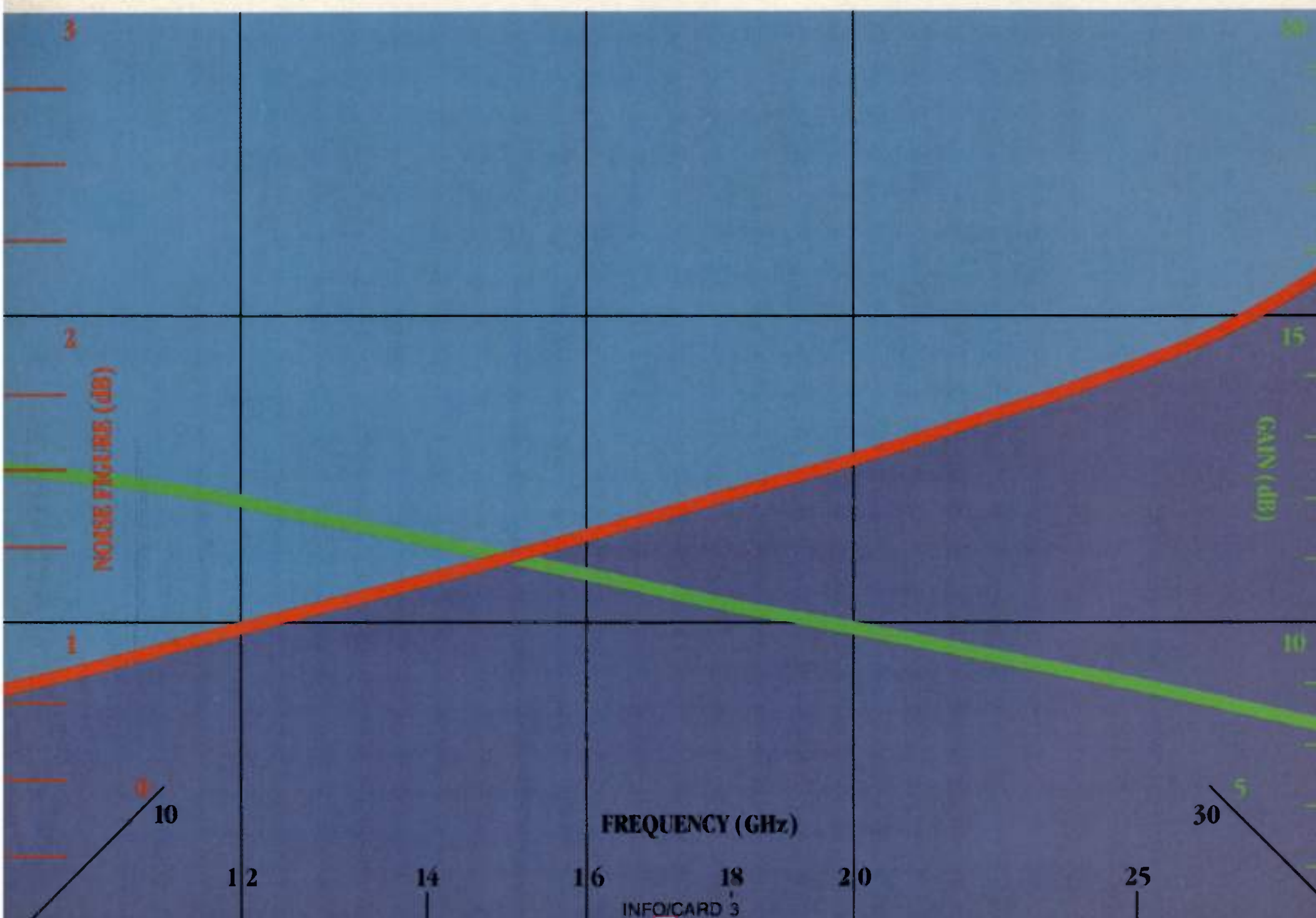
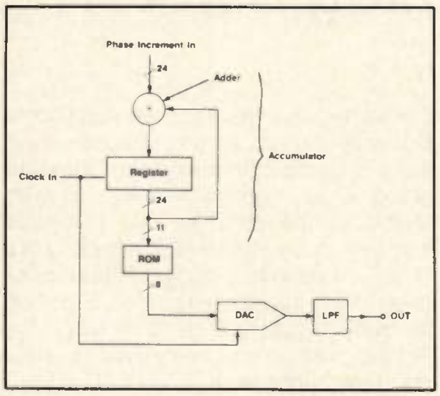


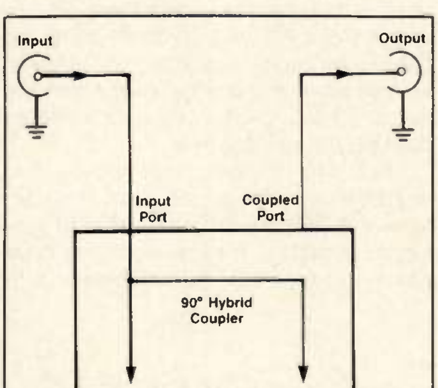
INFO/CARD 3



Page 30 — Direct Digital Synthesis

Class	Description
A	Equipment and subsystems v patibly when installed in critica ing platforms and installations
A1	Aircraft (including associated g
A2	Spacecraft and launch vehic ground support equipment)
A3	Ground facilities (fixed and mo wheeled vehicles)
A4	Surface ships
A5	Submarines

Page 35 — MIL-STD 461 B/C



Page 49 — Variable Phase Shifter

Cover Story

Features

Departments

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rf editorial

The World is Analog, Isn't It?

By Gary A. Breed
Editor

Why all the hoopla over digital? Digital oscilloscopes, digital TV, digital watches . . . what's the excitement? Why disguise a perfectly good sine wave as a bunch of bits; don't people like a nice smooth curve any more? My digital watch only changes its readout every minute, but I thought time was a constantly moving continuum. The concept of digital TV reminds me of the transporter beam on *Star Trek,* reducing Mr. Spock to a perfectly logical data stream, to be re-constructed in my living room.

Many of us in the world of RF only think in analog terms. I had enough trouble grasping the concept of a sine wave as a succession of 8-bit wide digital words, clocked at the Nyquist rate or higher. It takes some re-thinking to consider a mixer or balanced modulator in terms of cal-culator-style multiplication. For a long time, my sole exposure to a true RF/digital combination was the phase-locked loop. Digital circuits in RF equipment were used for mundane jobs that mechanical relays used to perform.

Well, fellow engineers, get ready for a digital revolution. Analog circuits will be more important than ever, but they are going to be working side-by-side with digital components. As our computer engineer counterparts discovered in the 1950s, computation and manipulation of information can be performed a lot better using digital circuits, not analog. The PC this column was composed at is not an analog computer!

Digitized information can be transformed, analyzed and rearranged according to the mathematical functions we learned in school. It's pretty tough to perform a Fourier transform by analog methods, but we are beginning to get digital components with enough speed to perform such mathematical functions at RF frequencies. We will soon have direct digital waveform synthesis in the hundreds of MHz, digitization of signals in a similar range, and processing of that digital information at real-time RF rates. Right now, some of the manufacturers developing these devices are having a tough time deciding which applications are most important: super computers or RF-speed signal processing.

Yes, the world we live in is analog. As we perceive it through our unaided senses, matter, time and space are continuous, uninterrupted and three-dimensional. But underlying our perceptions are the proven concepts of quantum physics, where matter and energy exist in discrete steps ("bits" of reality), and multiple dimensions are possible.

Thus, the world is both analog and digital; it depends on the point of observation. In RF, now is the time to start seeing the digital world as clearly as we have grown to understand the analog world.

Gary A. Breed

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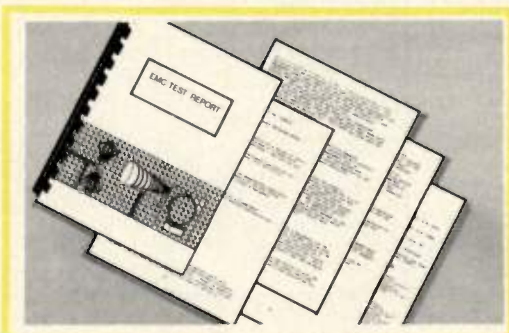

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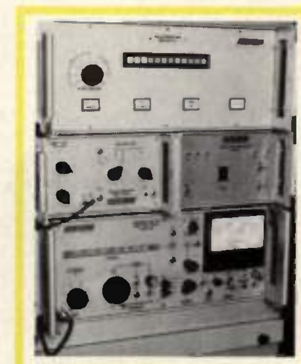

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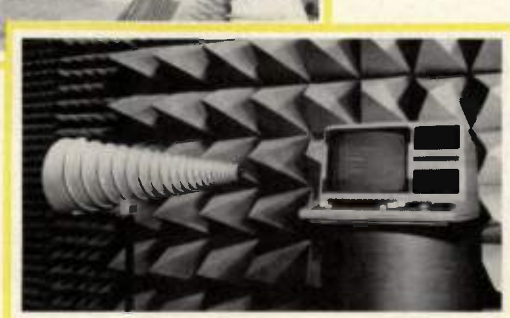

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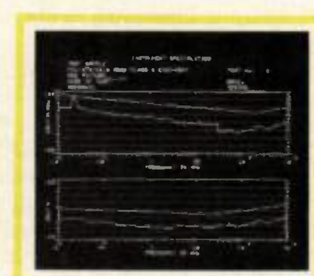

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CAD Is Here To Stay

By Mark Gomez
Assistant Editor

There is perhaps unanimous agreement among members of the NBE (new breed of engineers — see April "Viewpoint") that CAD is an essential part of RF engineering. I believe in it and certainly identify myself as a NBE.

The traditional method of designing is fine except for one major factor — time. Why spend three days on a design that can be done in three minutes with CAD? I always take the long way when I design a system for the first and occasionally the second time, to understand the principle behind the design. However, it is always a good idea to check a design on CAD after the first few manual attempts. After that, I believe a wise engineer will resort to computer aided design whenever a similar situation arises.

The time involved in designing a system with CAD as opposed to manual-plug-and chug is reduced by a large margin. For example, impedance matching for a certain circuit could take many hours of routine calculations and manipulation before practical results are obtained. The time factor is reduced by at least 75 percent when CAD is employed.

Engineers are only human. If you give them a tedious task, they'll get bored. If you give them a lot of time consuming calculations they will find short cuts that lead to a lower standard of accuracy.

Another human weakness is making mistakes that more often than not are hard to catch. Calculations done manually are often truncated sooner than those done on computer, resulting in less accuracy. Also, assumptions are often made to ease the design process when it is accomplished with pen, paper, and calculator. With CAD the assumptions can be minimized, leading to a design that is more closely related to the real world.

CAD and the OBE

"After all those years of avoidance of engineering math, using it when I absolutely needed to, I have taken a renewed interest in the really important concepts and have started to relearn it mostly because of the drudgery having been eliminated by . . . computer programs . . ." This is a statement made by one of the older breed of RF engineers (OBE). Most of the OBEs have been using tables, charts, and other means to simplify their calculations. As this engineer notes, OBEs are using CAD to strengthen their already substantial understanding of RF circuit design.

CAD is a design tool that is only as good as its creator. There is nothing incredible about it except the people that create and nurse it to the point where it is usable by people other than the creator himself. I feel that with the OBEs taking part in the CAD revolution that is currently occurring, CAD can only get better. The experienced engineers will help find the bugs that the less experienced NBEs do not see or even suspect.

The RF design process is definitely enhanced by CAD. The time-saving and reduction in human error is more than enough to justify the investment in a computing system. The next step is for CAD to become as common as the calculator in the RF world.

rf design

a Cardiff publication — Established 1978
Main Office:
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111 • (303) 220-0600

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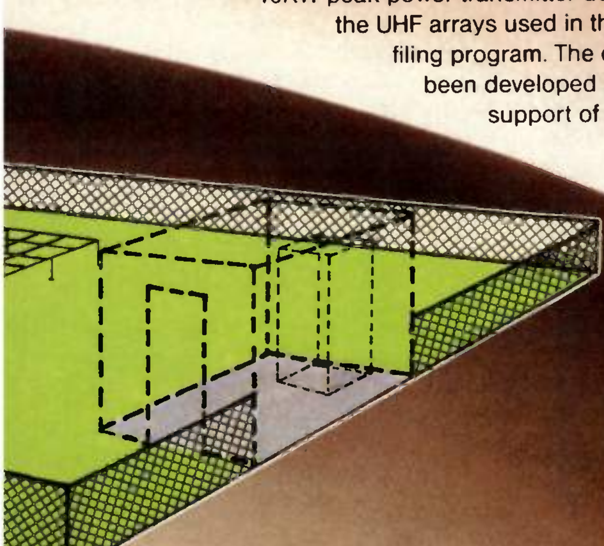

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INFO/CARD 7 DEMO
INFO/CARD 53 LITERATURE

Computer Commentary

Editor:

Please send me the program listing for "A Ladder Network Analysis Program." I would like to add that I really do appreciate your publication. It definitely keeps RF communications in the personal sense alive and well. Thanks!

Your tendency to publish analytic programs for the IBM-PC/XT as one extreme and for the Commodore-C64/128 as the other is very astute whether a conscious policy or not. I suspect that engineers, like me, are inclined to use the IBM Cadillac at the shop and our Commodore Ford at home.

After all those years of avoidance of engineering math, using it only when I absolutely needed to, I have taken a renewed interest in the really important concepts and have started to relearn it mostly because of the drudgery having been eliminated by publication of computer programs such as subject of this letter. It definitely is a liberating experience.

Again thanks and keep 'em coming.

J. J. Wormser
General Instrument — Tocom
Dallas, TX

German/English Glossary Help

Editor:

In case Michael Waters cannot locate the glossary of German electronic terms he is looking for, I would be glad to copy one I acquired about 15 years ago. It is 47 pages long, and goes both from English to German and vice versa. I don't remember the source, but it seems to have come from a German technical book originally.

Rudy Tietze
Altadena, CA

Editor:

Regarding reader Michael F. Waters' question in your March 1987 issue about a glossary of electronic terms, the December 1965 issue of *Microwaves,* pp. 48-76, published a Microwave Dictionary/French-English, German-English. It does not contain the Russian he mentioned and the date is much older, but perhaps it can help him.

Allen L. Davidson
Motorola Inc.
Schaumburg, IL

An Author's Reaction

Editor:

I was excited to see my article in the March issue of *RF Design*. It is refreshing to publish in a magazine that doesn't chop the text into incoherent jibber, as is commonly the case with several competitive trade journals.

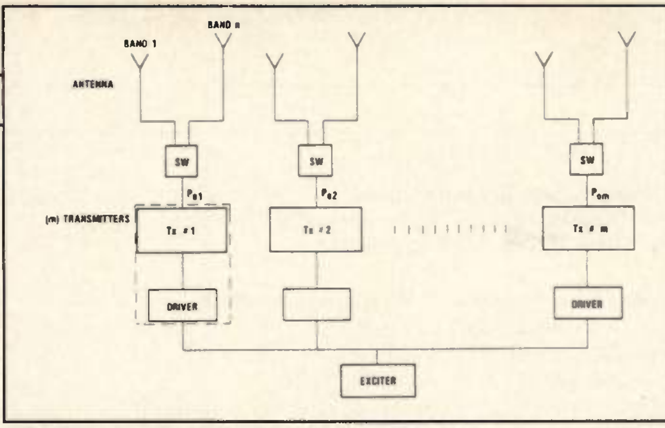
In the future, *RF Design* will be at the top of my list when I have an article ready for publication.

Mitchell Lee
National Semiconductor
Santa Clara, CA

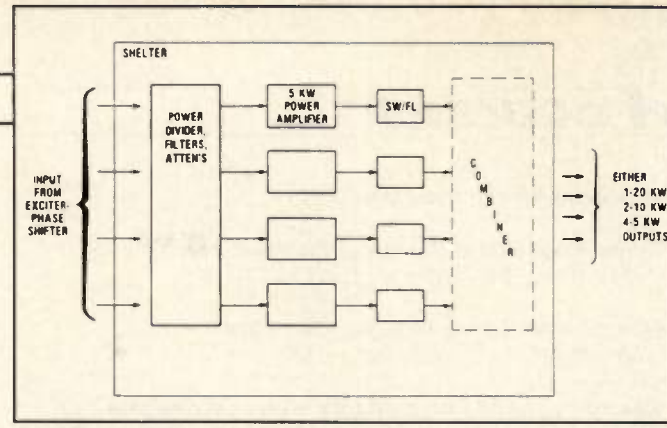
RF Power — More Information

Editor:

I noticed, with great interest, your article on new techniques and components to boost RF power. On page 37 of the February 1987 RF Technology Expo 87 Special Show issue of *RF Design* you



Typical antenna/transmitter configuration.



20 kW transmitter shelter.

mentioned the Over-The-Horizon-Radar from the point of view of a combiner but with no reference to the solid state amplifier that drives it. We thought that your article was remiss in not mentioning the solid state 20 kW amplifier built by M/A-COM MPD that utilizes this 20 kW combiner made by Werlatone. We will have a booth at both the East and West Coast RF Expos and plan to have some of this equipment on display.

I have taken the liberty of including a description of the system from concept to final photograph, including specifications. In addition, we have an in-house article entitled "Solid State Transmitters for Modern Radar Applications" that you may want to use in conjunction with the information that I am enclosing in order to inform your readership of these technologies.

Daniel R. Mazziota, President
M/A-Com Microwave Power Devices, Inc.
Hauppauge, NY

Block diagrams of the basic OTH-B radar transmission system and the 20 kW M/A-COM MPD transmitter subsystem assembly are included above — Editor

Photonic Communications

Editor:

Having read your April *RF Design* editorial, I thought that you might be interested in a look at the state of the Amateur Radio Service use of photonics.

As you may know, Part 97 allocates "all above 300 GHz" to the Amateur Radio Service. Several two-way laser QSOs have been made by hams in recent years.

Enclosed is a manual I wrote for hams on the subject. The techniques illustrated are rather crude, but quite effective and inexpensive.

Steve J. Noll
TiC Scientific
1288 Winford Avenue
Ventura, CA 93004-2504

"Amateur Lightwave Communications" is available for $13.95 (postpaid) from TiC Scientific. — Editor

rf courses

The George Washington University

Global Positioning System: Principles and Practice
May 18-20, 1987, Washington, DC

Fiber Optics Technology for Communication
May 19-21, 1987, Washington, DC

Electromagnetic Pulse and its effect on systems
June 15-17, 1987, Washington, DC

Information: Shirley Forlenzo, Continuing Education Program, George Washington University, Washington, DC 20052; Tel:(800) 424-9773, (202) 994-8530

UCLA Extension

Techniques and Technology of the Application of the Kalman Filters and Nonlinear Filters
May 18-22, 1987, Westwood, CA

Microwave Circuit Design 1
June 1-5, 1987, Westwood, CA

Navstar Global Positioning System (GPS-
June 15-19, 1987, El Segundo, CA

Pave Pillar Avionic Systems and Related Technologies
June 23-24, 1987, El Segundo, CA

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

Interference Control Technologies, Inc

ESD Control
May 18-19, 1987, San Jose, CA

Intro to EMI/RFI/EMC
May 20-22, 1987, San Diego, CA

Practical EMI Fixes
June 2-5, 1987, Ottawa, Canada
July 14-17, 1987, Denver, CO

Grounding and Shielding
June 9-12, 1987, San Jose, CA
July 21-24, 1987

Tempest Design
June 16-19, 1987, Mountain View, CA

Tempest Facilities
July 28-31, 1987

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
June 9-12, 1987, Ottawa, Canada
June 21-24, 1987, Los Angeles, CA
July 23-26, 1987, San Diego, CA

Fiber Optic Communication
May 19-22, 1987, San Diego, CA
June 23-26, 1987, Boston, MA

Machine Vision and Image Recognition
June 9-12, 1987, Los Angeles, CA
June 16-19, 1987, Washington, DC
July 28-31, 1987, San Diego, CA

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

Norand Corporation

RF Susceptibility and ESD Testing
May 19-20, 1987, Cedar Rapids, IA

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

Besser Associates, Inc.

Microwave Circuit Design
July 1-5, 1987, Los Angeles, CA

Principles of RF Circuits
July 6-9, 1987, Santa Clara, CA

Information: Les Besser, Besser Associates, Inc., 3975 East Bayshore Road, Palo Alto, CA 94303; Tel: (415) 969-3400

R & B Enterprises

EMI/EMC in the Automotive System
June 1-3, 1987, Dearborn, MI

Understanding & Applying MIL-STD-461C
June 2-3, 1987, Washington, DC
June 23-24, 1987, Philadelphia, PA

The Identification and Control of Microwave/RF Hazards
June 8-10, 1987, Philadelphia, PA

Electromagnetic Pulse Design and Test
June 11-12, 1987, Washington, DC

FCC Requirements & Test Methods per parts 2, 15 & 68
June 15-16, 1987, Boston, MA

Printed Circuit Board & Wiring Design for EMI & ESD Control
June 17-18, 1987, Boston, MA

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

Anadigics, Inc.

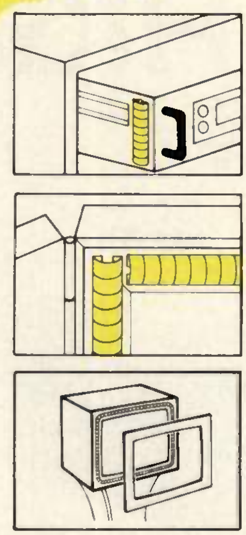
GaAs IC Design
May 12-15, 1987, Warren, NJ

Information: Michael P. Gagnon, Anadigics, Inc., 35 Technology Drive, Warren, NJ 07060

Want to save $10,000?

Heat is on computer manufacturers to comply with FCC emission standards. At stake are amounts of electromagnetic radiation that disrupt communications. Recent FCC test showed that half of 29 models examined failed to meet limits. Agency plans to ask Justice to crack down on offenders with fines of $10,000 for those who fail to comply, and that includes fixing machines already sold.

— as reported by Research Institute of America



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INFO/CARD 10

rf calendar

May 18-22
National Aerospace and Electronics Conference (NAECON)
Dayton Convention Center, Dayton, OH
Information: Cathy Joyce, SAE Headquarters, Dept. 935, 400 Commonwealth Drive, Warrendale, PA 15096; Tel:(412) 776-4841

May 19-21
EMC Expo 1987
Town and Country Hotel, San Diego, CA
Information: Sandra Hamilton, EMC Expo 87, P.O.Box D, Gainsville, VA 22065; Tel:(703) 347-0030

May 27-29
41st Annual Frequency Control Symposium
Dunfey City Line Hotel, Philadelphia, PA
Information: Dr. R.L. Filler, US Army Electronics Technology and Devices Laboratory, SLCET-EQ, Fort Monmouth, NJ 07703-5000; Tel:(201) 544-2467

June 1-5, 1987
EFOC/LAN-87, Fifth European Fibre Optic Communications and Local Area Networks Exposition.
European World Trade and Convention Center, Basel, Switzerland
Information: Renee Farrington, Information Gate Keepers, Inc., 214 Harvard Avenue, Boston, MA 02134; Tel:(617) 232-3111

June 9-11, 1987
IEEE MTT-S International Microwave Symposium
Bally's Grand Hotel, Las Vegas, NV
Information: Steve March, Maury Microwave Corporation, 8610 Helms Ave., Cucamonga, CA 91730; Tel:(714) 987-4715

June 9-11, 1987
NEPCON East '87
Bayside Exposition Center, Boston, MA
Information: Show Manger, Nepcon East, Cahners Exposition Group, 1350 East Touhy Ave., P.O. Box 5060, Des Plaines, IL 60017-5060; Tel:(312) 299-9311

June 12-13, 1987
29th Automatic RF Techniques Group (ARFTG) Conference
Bally's Grand Hotel, Las Vegas, NV
Information: Richard Irving, Systems For Automatic Test, 1292 Reamwood Avenue, Sunnyvale, CA 94089; Tel:(408) 734-9227

June 22-26, 1987
Laser '87 Optoelectronics Microwaves
Munich Trade Fair Center, Munich, West Germany
Information: Munchener Messe-und Ausstellungsgesellschaft mbH, Messegelande, Postfach 121009, D-8000 Munchen 12, West Germany; Tel: (89) 5107-0

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

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INFO/CARD 12

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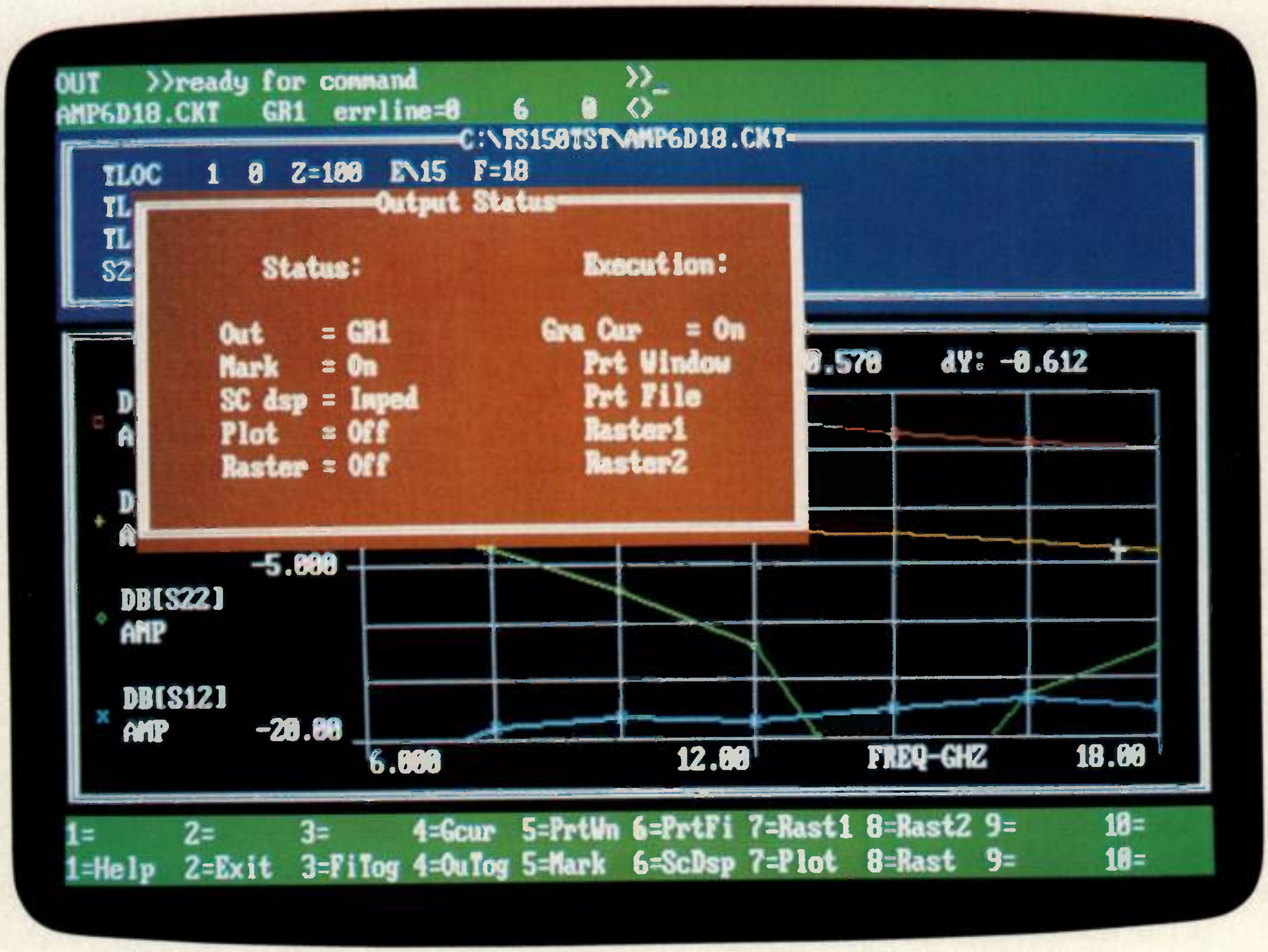

You see above how Touchstone's graphics output gives you control of the interactive cursor. And you get an idea of the many advanced kinds of plots that 1.5 lets you generate — with hard copies of everything you see on the screen.

Also note the windowing, another feature of Touchstone 1.5. This one displays the output status, and you invoke it at the touch of a single function key.

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

EEsof

INFO/CARD 13

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(Performance @ 1.0 GHz)

Model	Max. Useable Frequency (GHz)	Gain (dB, typ.)	Noise Figure (db,typ.)	P_{1dB} (dBm, typ.)	Package Type	1000 Piece Price $$$
MSA-0185	4.5	15.5	5.5	1.5	A	1.60
MSA-0204	4.0	11.0	6.5	4.0	B	1.90
MSA-0370	4.5	12.5	5.5	10.0	C	16.10
MSA-0420	3.5	8.5	7.0	15.0	D	18.45
MSA-0635	4.0	16.5	3.0	1.5	E	4.85
MSA-0835	6.0	23.5	3.0	12.5	E	7.80
MSF-8870	8.0	20.0	N/A	9.0	C	29.75

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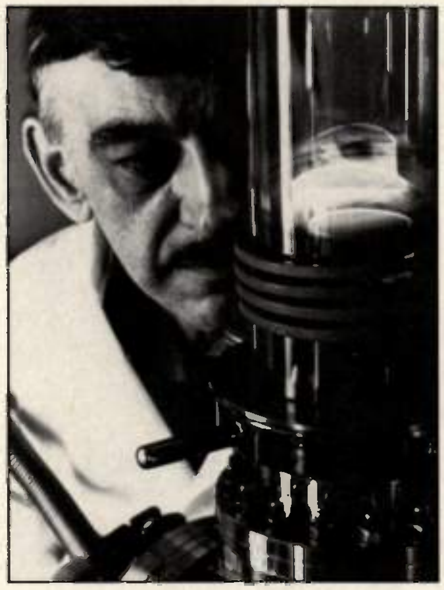
INFO/CARD 14

GTE Produces Pure GaAs Films

GTE Laboratories has announced an achievement in gallium arsenide materials research. GTE scientists have produced high purity gallium arsenide films using a method adaptable to commercial production.

The process is known as Metalorganic Vapor Phase Epitaxy, or MOVPE. The GTE Labs films were found to contain as little as one impurity atom for every 10 billion gallium or arsenic atoms. As a result, the gallium arsenide films exhibited a peak mobility nearly twice that which as previously has been achieved through this fabrication technique. High purity GaAs materials are required for maximum performance by devices such as the high electron mobility transistor (HEMT).

The inherent speed advantages of GaAs over silicon have not been fully utilized, due in part to impurities in thin films of the materials. This new development is part of GTE's continuing GaAs research. The firm has been prominent in GaAs technology since their 1984 development of the High Electron Mobility Transistor (HEMT).



High temperature chamber for GTE's Metalorganic Vapor Phase Epitaxy (MOVPE) process.

Zenith Petitions Supreme Court

Zenith Electronics has petitioned the U.S. Supreme Court to review a lower court decision which dismissed Zenith's long standing antidumping case against Japanese television manufacturers.

A year ago, the U.S. Supreme Court in a 5-4 decision remanded the antitrust portion of the case to the U.S. Court of Appeals to evaluate the evidence of whether a conspiracy existed among the defendants. The Court did not rule on the antidumping issues at that time.

Optoelectronics Research Center Funded

The University of Colorado at Boulder will become a national center for optoelectronics research. Colorado State University and the University of Colorado at Denver were also included in the grant of $14.5 million from the National Science Foundation.

A major portion of the research center's work will be toward the development of photonic logic, technology that many consider to be the "next generation" of computer architecture.

Electronics Market Growth Projected at Nearly 7 Percent

The world electronics market is forecast to expand at 6.9 percent in real terms in 1987 according to Benn Electronics in their Year Book of Electronic Data. The total market for the electronic equipment and components is forecast to reach $413 billion (US) in 1987 compared to $387 billion in 1986. The U.S. market growth was only 0.9 percent in 1986 but is expected to increase to 5.7 percent in 1987.

The market for telecommunications equipment will continue to grow at around 6 percent per annum overall but at a higher rate of 8 to 10 percent per annum in the less industrialized countries as equipment is updated and systems extended. Growth in the communication and military sector will average around 4.5 percent per annum for 1987-1990, being depressed by limited defense and space expenditure in the U.S.

The Yearbook of World Electronics data is available from Benn Electronics Publications Ltd., P.O. Box 28, Luton, LU2 OED, England for $1,295 (U.S.).

NBS Reports: Out-of-Band Response for Antenna Arrays; Semiconductor Bibliography

The response of antennas to unwanted frequencies plays an important role in interference and jamming problems. An NBS report analyzes antenna arrays at out-of-band frequencies; with effective aperture directivity and impedance mismatch treated in detail. Near-field measurements made on two large arrays of slotted waveguides are reported, and the subject of sampling in frequency and space is considered. The report continues earlier NBS studies of reflector antennas.

NBS has also produced a report that lists 23 years of semiconductor publications. It catalogs publications on semiconductor measurement technology produced between 1962 and 1985. The cataloged material includes subjects on Raman backscattering, Schottky barriers and other semiconductor related topics.

Both publications can be obtained from National Technical Information Service, Springfield, VA 22161. Out-of-Band Response of Antenna Arrays (NBSIR 86-3047) is $11.95, order by PB #87-125746/AS. Semiconductor Measurement Technology: A Bibliography of NBS Publications for the Years 1962-1985 (NBSIR 86-3464) is $16.95, order by PB #87-112298.

EEsof Users' Group to Meet at MTT-S

The fourth meeting of the EEsof Users' Group will be held Tuesday, June 9 from 7:00 to 10:00 p.m., in conjunction with the 1987 IEEE MTT-S International Microwave Symposium at Bally's Grand Hotel in Las Vegas. The meeting offers a forum to discuss and exchange applications and ideas relating to engineering and design using EEsof's CAE/CAD/CAT products. It is intended to address questions and topics of interest to all users of EEsof products, and will provide the opportunity for users to express their ideas about program enhancements and future product developments.

Specific topics and activities to be covered at this meeting include election of new officers, formation of local chapters, technical presentations delivered by users, new product demonstrations and computers and programs set up for hands-on use. For further information about the meeting contact Michele Bush-Weller at EEsof, Inc., (818) 991-7530.

Varian Receives Contract for OTH-B

Varian Associates Inc. has received a $19 million subcontract to provide transmitters for the Air Force Over-the-Horizon Backscatter (OTH-B) radar system, designation AN/FPS-118.

Varian's Continental Electronics division in Dallas will supply 36 100-kilowatt transmitters to primary contractor General Electric, which has been building the first OTH-B system in Maine, and recently received a contract to build and integrate three West Coast facilities.

Attention: WWV, WWVH, WWVB and GOES Users

The National Bureau of Standards is conducting a survey of users of all of its time and frequency services, such as WWV and WWVH shortwave broadcasts, WWVB 60 kHz broadcasts, GOES satellite broadcasts, and telephone time-of-day service. NBS requests users to participate in the Time and Frequency Services Users Survey.

The survey results will help NBS provide the best mix of services and levels of service to the broad spectrum of users who depend on them. Feedback from all kinds of users is needed to assure that the Bureau's finite resources for these services are allocated in the most effective way.

The Survey form is available from: Time & Frequency Survey, Div. 524.00, National Bureau of Standards, Boulder, CO 80303, or call (303) 497-3294 between 8 a.m. and 5 p.m. MDT to request a copy. *RF Design* readers may receive a Survey simply by circling INFO/CARD #185.

David Sarnoff Research Center Donated to SRI

General Electric announced that SRI International, a non-profit research organization founded by Stanford University, will receive RCA's David Sarnoff Research Center in a donation expected to have been completed by this date.

GE will move only a few specific commercial development projects from the Sarnoff Lab to its own facilities. In addition, the announcement stated GE's intention to spend perhaps a quarter-billion dollars in the next five years for research at the facility. SRI indicated that the workforce will be reduced under its management, but that no particular area of research is scheduled for elimination.

The donation will give SRI major research facilities on both coasts, and solves GE's dilemma over what to do with the Sarnoff Center, since the company already has comparable research capabilities. GE received the Sarnoff Center as part of its acquisition of RCA in 1986.

KDI and Triangle Microwave Announce Merger

KDI Corporation and Triangle Microwave, Inc. have reached an agreement in principle to merge a subsidiary of KDI Electronics, Inc. into Triangle Microwave. Following the merger, Triangle would be a wholly-owned subsidiary of KDI.

The merger, involving cash and contingent payment by KDI to Triangle common stock shareholders, is valued in excess of $35 million.

AEL Awarded APR-43A Contract

American Electronic Laboratories, Inc. has been awarded a $21,555,790 contract to produce the APR-43A radar warning receiver system for the U.S. Navy. The contract has options that could increase its value to $28,458,776. The initial award calls for AEL to produce 210 receiver interface units and 159 antenna interface units. Deliveries are expected to begin in the fall of 1988.

The APR-43A is installed on A-4, A-7 and F-4 and is the third major radar warning receiver contract awarded to AEL. The company is the developer and producer of the APR-44 and is a subcontractor on the APR-39A.

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5-87

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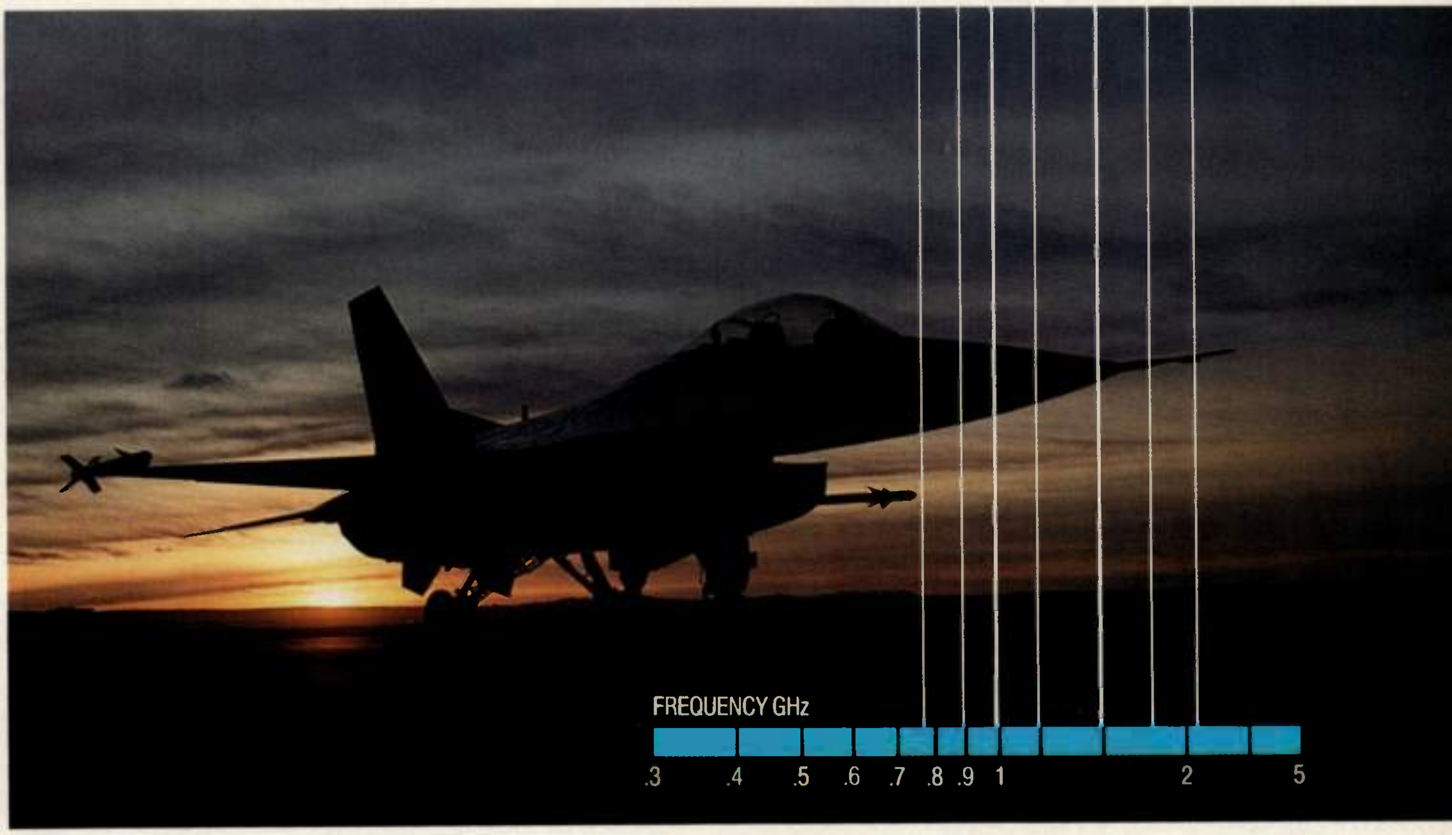

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INFO/CARD 17

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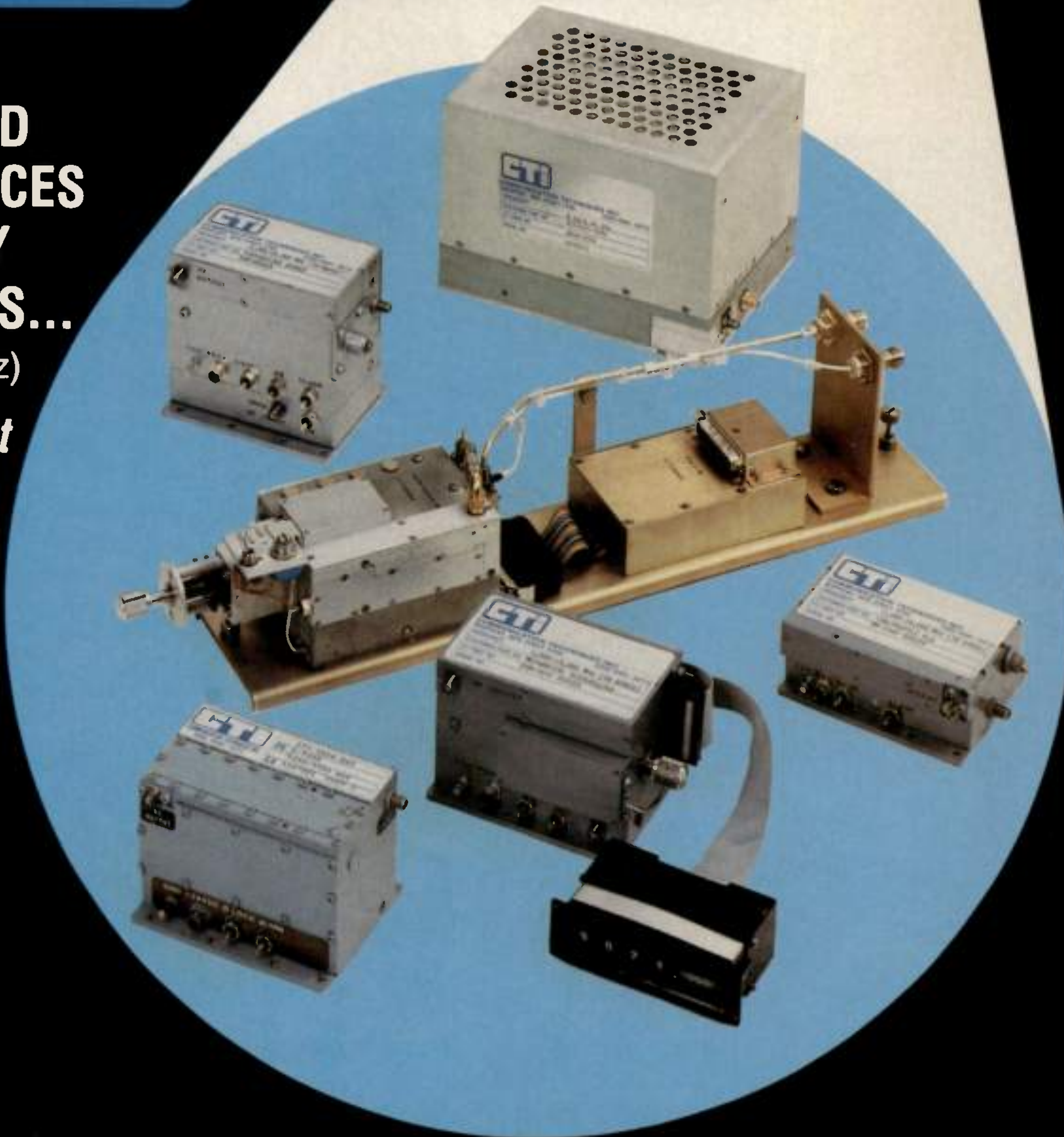

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INFO/CARD 18

See us at the MTT-S, Booth #418.

Flash ADC Achieves High Speed at Low Power

By Mark Logan
Analog Devices

The AD9002 from Analog Devices is an ultra-high speed 8-bit flash analog-to-digital converter (ADC). A new high-density bipolar fabrication process has been incorporated that allows operation at sampling rates in excess of 150 Msamples/s. These high sampling rates are necessary for applications requiring high speed digitization of analog and pulse signals. For applications requiring military qualified components, the AD9002TE/883 offers full screening to MIL-STD-883 Rev. C, operating over the −55C to +125C temperature range.

The device is considerably smaller than most competitive devices. Typical 8-bit flash ADCs are packaged in 40-pin DIPs while the AD9002 features packaging is a small 28-pin DIP or leadless chip carrier (LCC). Small size is another requisite of military applications.

Functionally, the AD9002 comprises 256 parallel comparators with outputs decoded to drive the ECL-compatible output latches. With 256 comparator stages on-chip, standard for 8-bit flash-type converters, one would expect the converter to be very power hungry. Not so; the AD9002 dissipates only 750 mW of power. Its straightforward design requires only a voltage reference and an encode signal to function. Additional key specifications include a low input capacitance of 17 pF and a high analog signal bandwidth of 115 MHz (−3 dB). The wide analog bandwidth is due to a new comparator design, a by-product of the extremely dense bipolar process technique.

Applications

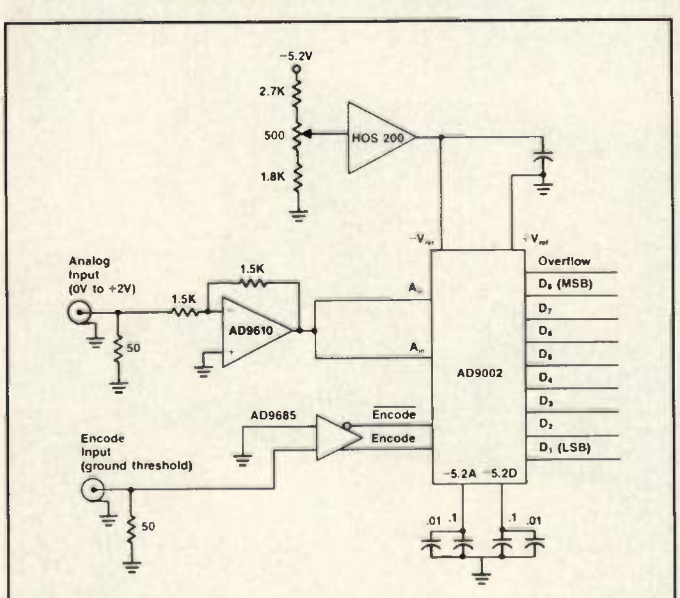
The AD9002 qualifies for a wide range of military applications because of its high speed, low power, small size and MIL-STD-883 Rev. C screening. Uses in military radar systems include active missile guidance, smart munitions, and anti-radiation guidance. Military electronics and communications that need fast sampling ADCs are laser/radar warning receivers, direction finding receivers, and communications jammers. Additional uses in the C³I segment of the military include troposcatter systems, military LAN and satellites. Industrial uses for the converter are found in nuclear research, ATE, digitizing oscilloscopes and spectrum analyzers.

Additional Features

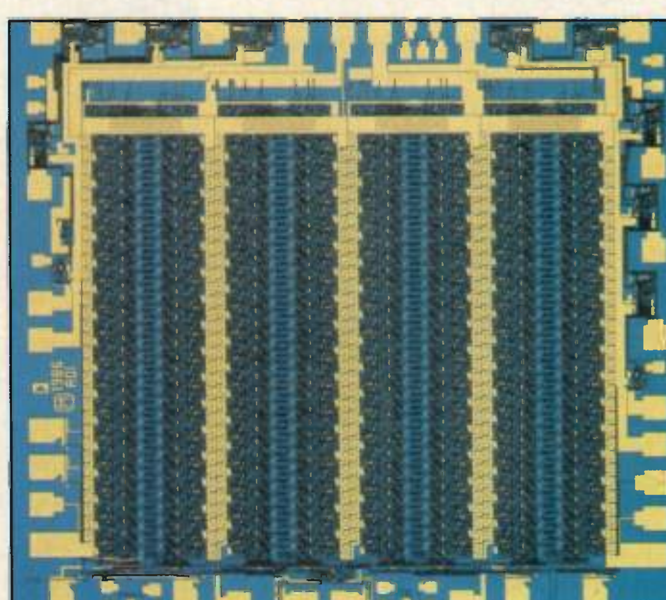
The converter provides an external hysteresis control pin, which can be used to optimize comparator sensitivity to further improve performance. An overflow bit signals over-range inputs. The overflow output feature can be easily disabled by the overflow inhibit pin. Two versions of the AD9002 will be available, with linearities of 1/2 LSB and 3/4 LSB. Both versions will be offered in a −25C to +85C industrial grade and a military grade, in both LCC or DIP packages.

Pricing for the AD9002AD (3/4 LSB version), and the AD9002BD (1/2 LSB version) starts at $112 and $168, respectively in quantities of 25.

Analog Devices, Norwood, MA. For more information, circle Info/Card #186.



AD9002 typical application circuit.



Chip uses high-density bipolar process.

The RF/Digital Connection

Part Two in a Series: The Integration of RF and Other Technologies

By Gary A. Breed
Editor

The second part of our series on the inter-dependence of different technologies explores applications involving both digital and RF techniques. We all are familiar with the phase-locked loop frequency synthesizers that include both digital and analog components, but beyond well-known circuits like this are many more applications that have been used to solve design problems through innovative combination of analog and digital components and concepts.

Easily the most familiar digital technique used by RF designers is phase-locked loop frequency synthesis. Almost every piece of communications equipment seems to have a PLL somewhere in its design. PLLs offer designers two advantages: stability in a tunable signal source; and a means of stabilizing a high frequency oscillator.

Tunable applications include everything from a public-service band scanner to high precision test instrumentation; from car radios to encrypted frequency-hopping communications systems. Single-frequency use of PLLs allows FM and TV broadcast transmitter designers to operate a modulated oscillator at the final output frequency, simplifying transmitter design while maintaining the required frequency stability.

In tunable PLL synthesizer design, instruments available from Hewlett-Packard, Programmed Test Sources, Eaton, Comstron and Wavetek all approach the state-of-the-art in spectral purity, phase noise, frequency range and switching characteristics. As an example, Comstron has a production unit which covers 10 MHz to 4.6 GHz in 0.1 Hz steps, and can switch between any two frequencies in less than a microsecond.

A less well known means of RF signal generation is direct digital synthesis (DDS), described in the article following this Special Report. By constructing a waveform from a series of digital words, using a high-speed digital-to-analog converter (DAC), sine waves (or any other desired waveform) can be created. The principle advantages of the method include virtually instantaneous switching between frequencies and a low level of "glitch" energy, since the frequency shift is phase-continuous.

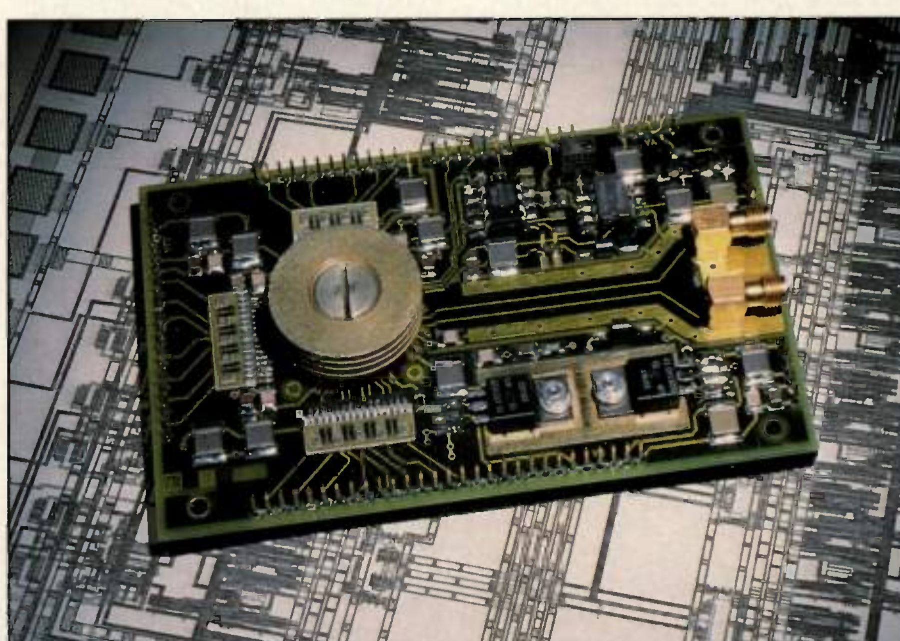
The most active company in DDS is Sciteq, which has a standard product offering 0-32 MHz output, and has just announced their VDS-3125 with 125 MHz range. Wavetek has had a DDS product for a number of years operating in the low MHz range. Currently, they have products using a derivative of this design in combined DDS/PLL synthesized instruments. Other companies are involved in DDS development as part of in-house requirements, such as fast switching military communications, EW and ECM systems. H-P has made use of this technique in its Arbitrary Waveform Synthesizer, a 50 MHz test instrument which allows the user to define the output waveform.

Before long, high-speed GaAs and enhanced silicon devices will allow designers to reach higher frequencies with DDS techniques. At present, there are 1 GHz DACs, but the other logic functions, particularly the memories needed for DDS, are not available to match their capabilities.

Digital Signal Processing

Digital information can be transformed and manipulated quite readily using today's computer technology. One of the fastest growing areas of RF/digital cooperation is digital signal processing. The analog-to-digital converter (ADC) on this issue's cover, along with similar devices from many other manufacturers, are reaching useful RF speeds. The Analog Devices unit will operate a 150 Megasamples/second. Just before our printing deadline, Sony announced a 300 Ms/s device. The Nyquist criteria tells us that RF signals up to nearly 150 MHz can now be directly digitized by these monolithic chips.

With digitized RF, the possibilities for digital manipulation are nearly endless. With this in mind, the government has sponsored the Very High Speed Integrated Circuit (VHSIC) program to develop signal processing components to operate at RF speeds. Military applications include digitally-encrypted voice and



Eight-bit DAC module uses TriQuint's 1 GHz GaAs TQ6112.

data communications, sonar and radar image processing, electronic warfare (EW) and countermeasures (ECM), plus guidance and targeting systems. Another important application is real-time processing of data from several inputs. An example is combined radar, infrafed and visual inputs in a single "heads up" visual display for combat pilots.

Digital signal processing is already used in instrumentation. Waveform storage and GHz-speed sampling oscilloscopes are nearly real-time, but more sophisticated digital data analysis currently requires processing time. Among the capabilities of today's instruments are computation of Fourier transforms for time-domain analysis, and analysis of relative harmonic levels for distortion measurement.

Control Circuitry

The oldest use of digital circuitry in RF applications is for control, particularly if you consider relay-based logic to be digital. The simple on-off or sequencing controls of the "old days" have been replaced by microprocessor-based system monitor and control systems, with accompanying digitally interfaced RF components.

One of the benefits of digital signal processing is the presence of a digitized output, which can provide data for operation of a control system capable of monitoring and adjusting signal levels, operating frequency, power output, antenna steering, and virtually every other possible variable parameter. Such an integrated system can make maximum use of available spectrum and operate at maximum performance at all times. Military communication systems often require this kind of control to maintain reliable communications in adverse operating conditions.

Components are continually being tailored for digital control. Programmable attenuators allow control of signal levels and switching systems route signals where desired. These devices are now available with internal decoding logic to simplify interface requirements. Add programmable synthesizers and filters, and an RF system can have complete digital control. As has been happening with consumer and industrial equipment, RF has a growing number of "smart" components and subsystems.

Component Technology

The state-of-the-art in component technology for digital/RF applications changes on a daily basis. The demand for digital circuits operating at these speeds is driven by several forces other than RF. First, the search for faster and faster computers has fueled both silicon and GaAs digital circuit research. High-resolution, real-time graphic displays require DACs operating in the hundreds of MHz. Optical communications needs RF-speed digital drivers for laser diodes and equal performance in demodulators. Measuring instruments may require digitization of waveforms with RF-like transition times.

All of these non-RF applications need digital circuits operating at speeds that can only be considered RF. These components often find uses in RF applications. For instance, the first direct digital synthesis circuits used high-speed DACs intended for graphics use and flip-flops for computer circuits have been used as prescalers in GHz-speed PLLs.

Performance of some of these components is astounding, when compared to that of five years ago! Analog-to-digital converters (monolithic ICs) are now available that can sample 300 million times per second. Standard logic functions can operate at over 1 GHz in silicon, and over 3 GHz in GaAs. Proponents of both Si and GaAs say that the limits of performance haven't yet been approached. Complex devices like multiplier/accumulators and memory devices are capable of operation in the hundreds of MHz.

Digital-to-analog converters have been given a lot of design attention, since they are the output interface between the digital and analog domains. It takes over 300 MHz update rate to drive a 1024 × 1024 pixel graphic display. The same speed DAC can reproduce RF waveforms up to about 125 MHz. Silicon DACs are available to 300 MHz (8 bits), with 10 and 12-bit devices close behind.

Just introduced by TriQuint Semiconductor is a GaAs 8-bit DAC that operates at 1 GHz update rate (see photo). Their new TQ6112 series offers performance intended for high resolution displays, waveform synthesis, fast-hop frequency synthesis, or as part of a high-speed analog-to-digital conversion system. In the rapidly developing area of high-speed digital technology, this device has performance exceeding that of almost every circuit that might be used to drive it. However, it will undoubtedly be leapfrogged by some other component.

Digital RF Amplifiers

In the mixed-technology area of RF and digital, new language and concepts are required. This is particularly true in switching-mode RF amplifiers, where rise and fall times replace the concept of bandwidth and "harmonics" become "Fourier coefficients." Operating a power amplifier tube or transistor as a switch (remember the digital 1's and 0's concept) improves the efficiency of a power amplifier markedly. 80 percent and higher efficiencies are to be expected from the Class D, E and other classes of switch-mode amplification. The drive circuits for these power amplifiers are also switching, or digital, circuits. In fact, most designs use some type of logic (typically ECL) at the low-level stages.

The tradeoff for efficiency is linearity. Switch-mode amplifiers can replace any Class C design, but not Class A or B. It is possible to take advantage of the high efficiency by modulating only the final amplifier stage. This may be a simple amplitude modulation or a more complex envelope stripping and restoration scheme. The other limitation is frequency range. Since the square wave signals that represent a digital pulse train contain many harmonics (Fourier coefficients) of the fundamental, the basic amplifier is required to pass at least five times the carrier frequency. Thus, an amplifier made up of 100 MHz power transistors is usable only to about 20 MHz.

An interesting new application combining high-efficiency Class D amplifiers with analog-to-digital conversion is the new DX-10 medium wave broadcast transmitter from Harris Corporation's Broadcast Division. In simplest terms, the transmitter is a 10 kW DAC. Input audio is converted to a 12-bit wide digital data stream, which is encoded by a PROM into a format suitable for driving the output amplifiers.

The digital signals turn on the proper number of series-connected power amplifiers so their sum is the proper output signal level. The amplifier section consists of 44 equal-voltage amplifiers and six binary-weighted amplifiers for full 12-bit resolution. The audio performance offers better than 1 per cent distortion (both THD and IMD) at 95 per cent modulation. Overall efficiency from AC power input to RF output is better than 80 per cent.

Future Outlook

All that can be said about the future of the digital/RF connection is that everything we expect to happen probably will. In addition, many new ideas will come up that serve to answer an RF design challenge with a digital technique.

Some of these applications will be noted next month, with the third and last part of our series on the integration of technologies: The RF/Aerospace Alliance. rf

Direct Numerical Synthesis of Sine Waves

By Fred Williams
TRW LSI Products

RF designers have been challenged to generate stable sine wave signals of controllable frequency since the earliest days of radio. Until recently, the techniques used came from the following list:

1) Tunable free-running LC or RC oscillator.

2) Switchable crystal oscillator.

3) Frequency-domain synthesis (addition and subtraction) based on a stable set of references.

4) PLL using VCXO, LC, or RC oscillator and variable divider.

5) Harmonic selection.

6) Combinations of the above 5 techniques.

Most RF designers are familiar with the techniques listed above. What they all have in common is synthesis in the frequency domain. With the development of high-speed digital circuits, it is now possible to consider the synthesis of waveforms directly in the time domain (that is, as waveforms), rather than the frequency domain. The necessary background was developed by Bell Labs engineer Harry Nyquist in the 1930s and '40s, when he defined the relationship beween the frequency domain and samples in the time domain.

Consider that relationship more closely. One of the problems which must be faced before digital circuitry can be used for time-domain signal synthesis is how to generate a continuous waveform from a limited set of sample values. Without going into great detail, Nyquist's contribution was the discovery that a (ideal) lowpass filter will perfectly reconstruct a waveform from its samples if there are more than two samples for every cycle of waveform bandwidth. If that condition is not met, there will be no way of perfectly reconstructing the waveform. Given that we know how to generate a signal from its samples, we now need to generate a sequence of numbers which will yield a pure sine wave of the desired frequency when converted into analog form. If absolutely ideal analog-to-digital converters were available, a sequence of numbers could be obtained by taking a pure sine wave at the desired frequency, and converting it to digital form. The limited and non-ideal perfomance of converters (not to mention storage requirements) rule out this approach, but it does provide a theoretical standard against which any other technique can be compared.

How can such a series of numbers be generated? Drawing a parallel to analog techniques would suggest a feedback system. Because the output would depend on previous values, this approach is called a recursive technique by digital designers. However, recall that the sine function takes on irrational values. That means that any finite-precision representation (such as used by actual digital-to-analog converters) will have rounding errors.

Unfortunately, since any given output affects all those which follow, these unavoidable errors will accumulate. That makes the recursive approach an unsatisfactory technique.

One of the ironic aspects of digital signal processing is that sometimes techniques which are poor design practice in analog technology become excellent in digital technology, and vice versa. An example of this is the relaxation oscillator, followed by a waveshaping circuit, to generate a stable, pure signal.

It is easy to create an extremely stable repetitive ramp digitally. (A digital ramp is actually a staircase-appearing signal, if examined closely enough.) A repeated ramp can, with little imagination, be transformed into a sinewave. The most

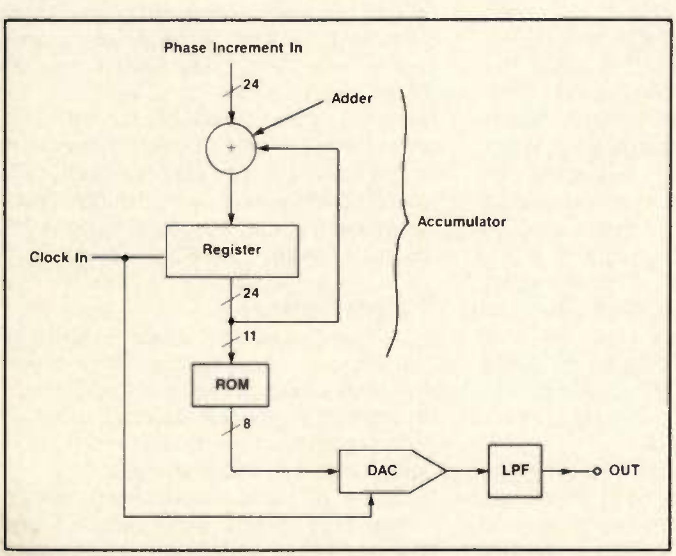


Figure 1. Block diagram of a direct numerical frequency synthesizer.

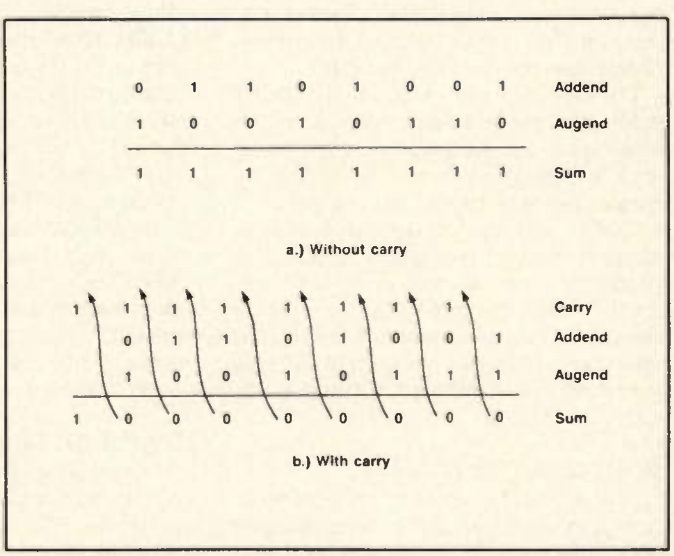


Figure 2. A worst-case carry can propagate from the LSB to the MSB.

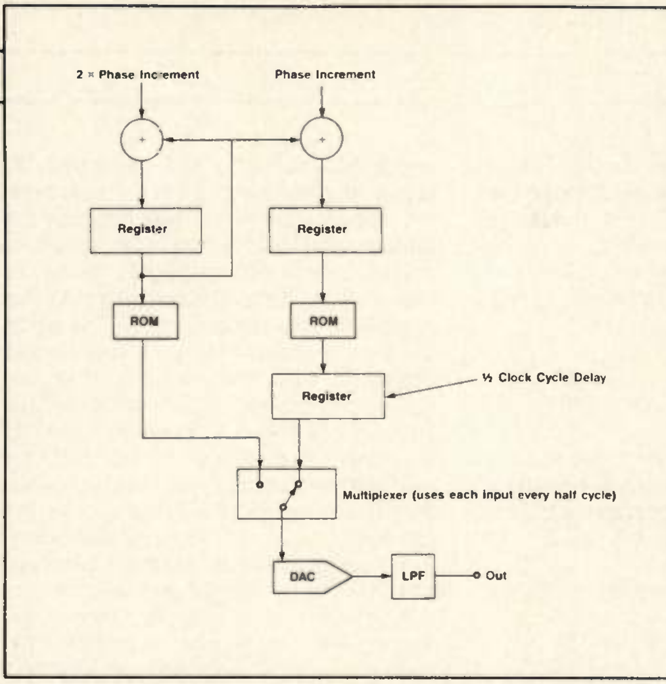


Figure 3. Parallelism can double the sampling rate.

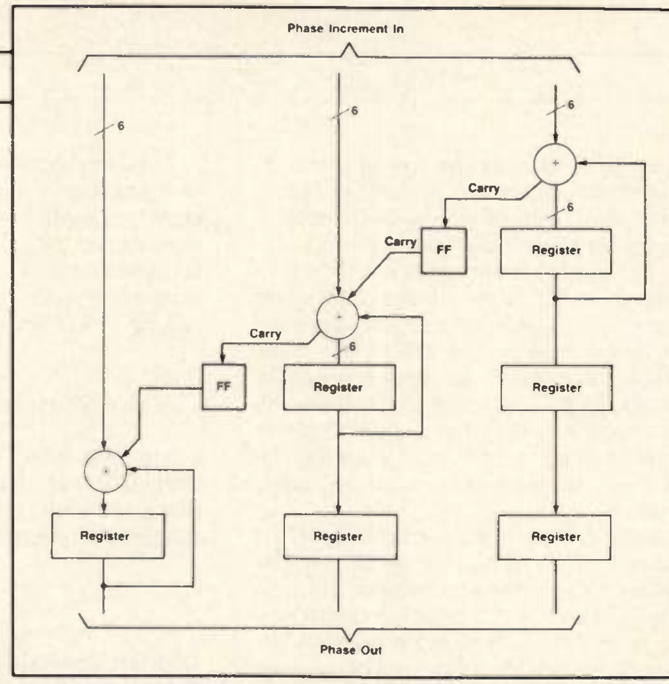


Figure 4. A pipelined accumulator operates in the T_{PD} of a single adder chip.

direct approach is to use a look-up table, which could be a read-only memory (ROM). Alternatively, a shaping circuit can be used after the D/A converter, much as with low-frequency analog function generators. This is the approach which this article will discuss.

First, a digital ramp must be generated. This can be done by repeatedly adding a phase increment to a phase, to get a sequence of phase values. For the particular configuration under discussion, an n-bit wide register is used to store the phase. At regular clock intervals of $1/F_c$ seconds, the value stored in the register is incremented by a quantity delta, which is proportional to the phase change of the desired sine wave result during the sampling period. The new value is then placed back in the register.

This value is then interpreted to be a binary fraction of the phase angle of the output sine wave at the sampling instant. This phase value is then used to address a look-up table (usually implemented with a ROM) circuit which gives the sine of the phase angle. A block diagram of this configuration is shown in Figure 1.

Design Equations

The output frequency is a function of the clock frequency, the length of the accumulator, and the phase increment delta. Obviously, the lowest frequency that can be generated comes from the lowest phase increment that can be used: 1 LSB in the digital word. Coincidentally, this frequency is also the frequency step that the synthesizer can provide. The basic relationship is therefore:

$$F_{out} = F_c \text{ Delta}/2^{(\text{Number of Bits})} \quad (1)$$

The Nyquist limit can be stated:

$$F_c > 2 * F_{max} \quad (2)$$

While (2) is given, the value actually used will depend on the allowable level for the spurious signal which is the image of the desired signal around half the sampling frequency. This signal is close to the amplitude of the desired signal, and must be adequately filtered out by the reconstruction filter.

The number of bits required in the accumulator is:

$$\text{Number of Bits} = \text{ceil}(\log_2 (F_{max}/F_{step})) \quad (3)$$

where ceil is the smallest-integer-larger-than function, and $\log_2$ denotes binary logarithm.

The clock rate can be derived as:

$$F_c = F_{step} - 2^{(\text{Number of Accumulator Bits})} \quad (4)$$

Performance Equations

The output amplitude varies as a function of the synthesized frequency:

$$A = \sin(2\,\pi\,F_{out}/F_c)/(2\,\pi\,F_{out}/F_c) \quad (5)$$

Note that the signal is −3.92 dB at the Nyquist limit with respect to the low frequency value. Because the signal is quantized, there will be harmonics present. The signal-to-noise-and-distortion (SINAD) is approximately:

$$\text{SINAD} = 6n + 3.02 \text{ dB} \quad (6)$$

where n is the number of bits applied to the DAC, and an ideal DAC is assumed.

Benefits and Limitations

This circuit is simple, and can give fine-grain frequency resolution. Depending on the size of the sine look-up table ROM, the output phase noise can be extremely low, approaching that of the reference clock. The amplitude is quite stable.

This circuit has five basic limitations:

1.) Since the circuit is a sampled-data system, the Nyquist criterion applies (but note that aliasing can be used intentionally to increase the output frequency range)

2.) The output reconstruction filter affects the precision (SINAD) of the signal

3.) There are practical limitations on the size of the table look-up ROM (and thus phase noise)

4.) Spectral purity is affected by the performance of the digital-to-analog converter (DAC) in areas of digital feedthrough and "glitches"

5.) The amplitude of the output has a sin x/x response shape

The applicability of the Nyquist criterion to a digital frequency synthesizer has several implications. The first is that the output frequency is constrained to be less than half of the internal sample generation rate. While the image component can, in fact, be used for the output signal, it will be lower in amplitude than the baseband signal, and will not be quite as pure. The second implication follows from this need to generate samples at a rate greater than twice the output frequency, and that is that high output frequencies place rather stringent requirements on the operating speed of the digital components. Thus, technologies like ECL and circuit design techniques such as pipelining and parallelism may have to be applied to obtain a functional circuit.

The sampled-data nature of a digital frequency synthesizer means that a reconstruction filter will generally be used at the output of the DAC. This filter, because it must be implemented in analog form, will impose limits on the output frequency range (because of its transition band) and on the accuracy of the output amplitude (because of its passband ripple).

Ideally, there is a specific value in the table look-up ROM for each possible phase angle in the accumulator. This can easily result in the need for extremely large ROMs. To implement practical accumulator with table look-up synthesizers, the size of the table is often limited. This limitation adds angle quantization to amplitude quantization. The effects of this truncation have not been explored in depth in the technical literature, and is the subject of ongoing work. Two of the references (the papers by Tierney et al. and Sunderland) in the Bibliography address this issue.

While the signal, in its digital form, can be of extreme purity, the analog version comes from a DAC. These parts suffer from non-ideal linearity, and finite and variable timings, which degrade the signal. Thus, choice and proper use of a DAC is critical.

Some Comments on Phase Noise

There are two contributors to phase noise in the accumulator-based direct numerical synthesizer:

1.) Restriction of the number of bits to the DAC

2.) Restriction of the number of bits to the ROM

The first contributor is not particularly obvious. Quantization of the sine wave results in harmonics. However, since the quantization occurs in the digital (sampled-data) domain, the harmonics are all aliased down into the range from DC to the Nyquist limit. These harmonics are all on possible channel frequencies of the synthesizer. Since the amplitudes of these harmonics are not all equal, the amplitudes of the spurious signals at a given distance from the carrier are unequal; this will be demodulated as phase noise. If the output frequency is not relatively prime to the clock frequency, then there will be fewer possible output frequencies, and so spurious modulation can be increased. The use of a prime number for the accumulator modulus will avoid this effect.

The second contributor does not affect all channel selections equally. If the phase increment delta has no "ones" below the truncation of the phase word, there will be no contribution at all to phase noise. The worst-case phase modulation and its rate can be calculated from

$$\text{Delta phi} = 2\pi\left(1 - 2^{[\text{Nbits} - \text{No. of Accumulator bits}]}\right) \quad (7)$$

where Nbits is the number of bits applied to the ROM, and Number of Accumulator Bits is the width of the accumulator. This deviation is a sawtooth at a rate of

$$F_{error} = F_{step} \times 2^{(\text{Nbits} - \text{No. of Accumulator bits})} \quad (8)$$

Digital-to-Analog Converter Considerations

DACs have a large number of parameters which affect their operation in frequency synthesis. The important ones are number of bits and linearity (which determine the spurious signal line content of the output signal), settling time and update (which together determine the highest sampling rate which can be used), glitch impulse and digital signal feedthrough (which determine the noise floor of the output). Unfortunately for RF designers, most high-speed DACs are manufactured with computer graphics in mind, not communications use. This means that not all devices are specified to make device selection easy. Competing devices must be checked in operational circuits. My personal experience has shown a wide variation in performance for apparently identical specifications.

TRW introduced the first monolithic video-speed DAC (the TDC1016) in 1980. Because it was a pioneering device, TRW considered uses other than graphics. This tradition of multiple use has continued, and so TRW's newer DACs (such as the TDC1018) often have the lowest level of spurious signals when used in waveform synthesis applications.

A specific example of the sort of specifications which can mislead the unsuspecting designer is the citing of an "update rate," independent of settling time. This is merely the speed at which data can be loaded into a converter, regardless of the changes at the output. The output spectrum of a direct numerical synthesizer will be very noisy unless the DAC output actually settles during a clock period.

Fast Accumulator Structures

One of the limitations on direct numerical synthesis is the speed with which two numbers can be added. In digital electronics, this depends on both the speed with which two bits can be added, and the speed with which a "carry" signal can propagate. (There is also a slight cost for the setup time for the register in the accumulator). The worst case carry comes when a carry must propagate from the least significant bit (LSB) up to the most significant bit (MSB). An example of this is shown in Figure 2. If ordinary ripple-carry adders (such as the 7483 and related devices) are used, that means that there will be a given delay for every bit in the accumulated word. This can be a serious limitation, because the time for a "carry" signal to move through a full adder stage can range from around 600 picoseconds (for 100K ECL devices) up to 50 nanoseconds (for 74C devices). For a 24-bit accumulator, this gives a cycle time ranging from 14.4 nanoseconds up to 1.2 microseconds. This means a Nyquist limit of only 10 MHz for 100K ECL, and a limit of around 40 kHz for 74C. This is not acceptable; something more must be done.

Integrated circuit vendors have already provided one form of acceleration: carry look-ahead. This is used both on-chip and between chips, to "short cut" the carry propagation process. The idea is to detect quickly whether a carry between stages will occur, and tell the next stage. A carry can only occur if it is generated in some stage, and can propagate through the stages between it and the stage in question. "Generate" and "propagate" signals are not difficult to generate. For example, a set of six 74F283s can run at 18 MHz clock, for a Nyquist limit of 9 MHz. Using an external carry look-ahead chip with these signals, a 100K ECL accumulate loop using 100179 and 100180 devices can operate at 100 MHz, for a Nyquist limit of 50 MHz.

Even this may not be enough for some applications. Digital designers use two techniques to improve speed: pipelining and parallelism.

Parallelism is simply using multiple circuits to perform computations overlapping in time. For example, two accumulator/ROM combinations could be used to generate alternate samples, as shown in Figure 3. Here, the top accumulator/ROM path holds its output constant while the bottom path is changing. The parts cost is greater than the number of multiples, as a multiplexer is required. In this application, parallelism is a brute-force approach.

Pipelining is a way of dividing up signal flow so that each element is operating as fast as it can, without holding data constant for another section of the circuitry to use. This is accomplished by using registers to hold intermediate values. A specific example of this is shown in Figure 4. Here, as soon as the results from the least significant adder are available, they are latched and a new addition begun. The next cycle, the following adder uses the carry from the least significant adder, and provides a register with its results. Here, the possible operating speed is merely the sum of the propagation delay through a single adder section plus the setup time of the register. With this approach, 100K ECL can reach sample rates of 250 MHz, or a Nyquist limit of 125 MHz. One note of caution, however: 4 nanosecond ROMs are not yet available, so some parallelism will be necessary for the table look-up.

Conclusion

Digital synthesis techniques are practical in the MF and low VHF ranges. They can provide a fast-switching, low noise sine signal.

A final word: While the author believes that all the circuits discussed in this article are matters of public knowledge, neither the author, TRW nor *RF Design* has done a patent search on the subject. That means that we cannot assume responsibility for patent infringement. Further, this article does not convey the right to use any patents of TRW or any other individual or organization. If you wish to use these circuits commercially, you should check for patent coverage. rf

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About the Author

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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
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MIL-STD 461 B/C

Test Requirements and Comparison Part I: Background of MIL-STD 461 and Associated Standards.

By Michael W. Howard
Norand Corporation EMC Test Lab

MIL-STD 461, entitled Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, was first issued in 1967.

Two revisions have occurred in MIL-STD 461 since 1967. The latest issue is MIL-STD 461C, which was released on August 4, 1986. This revision includes requirements for tests to simulate both conducted and radiated electromagnetic pulse (EMP) levels. MIL-STD 461 B/C covers a broad range of requirements and test limits for the measurement of radiated and conducted emission and susceptibility over a wide range of military electrical/electronic equipment and commercial off-the-shelf equipment procured for military usage.

MIL-STD 461A was issued on August 1, 1968 by the Department of Defense (DOD). It replaced earlier standards, such as MIL-I-6181D, MIL-E-55301, MIL-I-16910C, MIL-STD 826A and MIL-I-26600.

MIL-STD 461 consolidated the requirements of these standards into one standard for the Army, Navy and Air Force (i.e., Tri-Service Standard). Since then, the services which use MIL-STD 461 have amended it to where it is no longer a true tri-service, but three different documents having a single cover. MIL-STD 461 defines electromagnetic interference characteristics and requirements for equipment. Two other MIL-STD documents commonly used with 461 are MIL-STD 462 and MIL-STD 463. MIL-STD 462 deals with the test procedures required for MIL-STD 461. MIL-STD 463 contains a list of definitions and the system of units used in the 461 and 462 documents. MIL-STD 461 covers both conducted and radiated emission and susceptibility on power leads, control and signal leads, and overall equipment and systems. The total frequency span of the various test requirements of 461 cover a frequency range of 20 Hz to 40 GHz.

EMC Control Plan, EMC Test Plan and EMC Test Report are contract data items that must be satisfied under MIL-STD 461. The EMC Control Plan describes the overall approach, design procedures and techniques that will be used to meet the contractual EMI requirements based on those in MIL-STD 461. It is basically an EMC design guideline written for equipment being designed. The contractor has to include details such as management, spectrum utilization, EMI mechanical design, wiring and circuit design, grounding, cable shielding, circuit design, filter design, R & D testing required, deficiencies and problem areas anticipated, and revisions to the control plan in the guidelines for the design to ensure compliance with the required test limits of 461.

The EMC Test Plan describes the measurement program that will be employed to demonstrate that a piece of equipment or subsystem complies with its contractual EMI requirements based on those in MIL-STD 461. The test plan also describes how the general test methods in MIL-STD 462 will be applied on the specific equipment or systems. In the test plan, the contractor must show a list of applicable test requirements with a full description of the test item, applicable documents, type of facilities required, type of instrumentation, set up, test sample set up, test sample operation during test, and calibration requirements and measurement assurance. The results of all 461/462 tests must be supplied in a formal test report written in accordance with MIL-STD

Class	Description	Applicable Part
A	Equipment and subsystems which must operate compatibly when installed in critical areas, such as the following platforms and installations:	—
A1	Aircraft (including associated ground support equipment)	2
A2	Spacecraft and launch vehicles (including associated ground support equipment)	3
A3	Ground facilities (fixed and mobile, including tracked and wheeled vehicles)	4
A4	Surface ships	5
A5	Submarines	6
B	Equipment and subsystems which support the Class A equipment and subsystems, but which will not be physically located in critical ground areas. Examples are electronic shop maintenance and test equipment used in non-critical areas, theodolites, navaids, and similar equipment used in isolated areas.	—
C	Miscellaneous, general purpose equipment and subsystems not usually associated with a specific platform or installation. Specific items in this class are:	
C1	Tactical and special purpose vehicles and engine-driven equipment	8
C2	Engine generators and associated components, uninterruptible power sets (UPS) and mobile electric power (MEP) equipment supplying power to or used in critical areas.	9
C3	Commercial electrical and electromechanical equipment.	10

Table 1. Equipment and subsystem classes vs. applicable part of MIL-STD-461 for emission and susceptibility requirements and limits.

Requirement	Description
CE01	Conducted Emissions, Power and Interconnecting Leads, Low Frequency (up to 15 kHz)
CE02	Conducted Emissions, Power and Interconnecting Leads, 0.015 to 50 MHz
CE06	Conducted Emissions, Antenna Terminals 10 kHz to 26 GHz
CE07	Conducted Emissions, Power Leads, Spikes, Time Domain
CS01	Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz
CS02	Conducted Susceptibility, Power and Interconnecting Control Leads, 0.05 to 400 MHz
CS03	Intermodulation, 15 kHz to 10 GHz
CS04	Rejection of Undesired Signals, 30 Hz to 20 GHz
CS05	Cross-modulation, 30 Hz to 20 GHz
CS06	Conducted Susceptibility, Spikes, Power Leads
CS07	Conducted Susceptibility, Squelch Circuits
CS09	Conducted Susceptibility, Structure (Common Mode) Current, 60 Hz to 100 kHz
CS10	Conducted Susceptibility, Damped Sinusoidal Transients, Pins and Terminals, 10 kHz to 100 MHz
CS11	Conducted Susceptibility, Damped Sinusoidal Transients, Cables, 10 kHz to 100 MHz
RE01	Radiated Emissions, Magnetic Field, 0.03 to 50 kHz
RE02	Radiated Emissions, Electric Field, 14 kHz to 10 GHz
RE03	Radiated Emissions, Spurious and Harmonics, Radiated Technique
RS01	Radiated Susceptibility, Magnetic Field, 0.03 to 50 kHz
RS02	Radiated Susceptibility, Magnetic and Electric Fields, Spikes and Power Frequencies
RS03	Radiated Susceptibility, Electric Field, 14 kHz to 40 GHz
RS05	Radiated Susceptibility Electromagnetic Pulse Field Transient
UM03	Radiated Emissions and Susceptibility, Tactical and Special Purpose Vehicles and Engine-Driven Equipment
UM04	Conducted Emissions and Radiated Emissions and Susceptibility, Engine Generators and Associated Components UPS and MEP Equipment
UM05	Conducted and Radiated Emissions, Commercial Electrical and Electromechanical Equipment

Table 2. Emission and susceptibility reqûirements.

831.

MIL-STD specifies test procedures to be performed as a function of classification by use of equipment. It has been structured into ten parts for ease of application. These equipment classes versus applicable parts of MIL-STD 461 can be seen in Table 1. Part 1 applies to all procurements and serves as a general requirement for all equipment. Parts 2 through 6 require additional interpretation depending upon the procuring activity. In some parts, the Air Force and Navy may agree on a specific test limit whereas the Army requires a totally different test limit and vise versa. So, one must pay careful attention if supplying products to more than one DOD agency to ensure the product complies with the agency or agencies being supplied to.

Each part is then broken down to various conducted and radiated emission and susceptibility requirements. The first two letters of the test requirement identify the type of test required. For example, conducted emission tests are identified as CE01, CE03, and so forth. A complete breakdown of the various test requirements for 461 can be seen in Table 2.

The main intent of MIL-STD 461 is to provide assurance that the equipment or subsystem will be compatible with the electromagnetic environment that it will be operated within and with adjacent equipment and systems. The end environment must be considered in order to properly apply MIL-STD 461.

MIL-HDBK 235 is a handbook that should be used concurrently with 461. It defines specific EMI environments and is used to tailor the radiated susceptibility requirement RS03 of MIL-STD 461B/C and MIL-E-6051. By using MIL-HDBK 235, the contractor can more accurately determine what the actual environment is in which his equipment will be used for by the military.

All of the MIL-STD's listed herein can be obtained from the following organization: Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. Next month will feature Part II which covers MIL-STD 461C in detail and the test methods used in MIL-STD 462. Differences between 461B & 461C will also be covered.

About the Author

Mike Howard is the Supervisor in charge of the Norand EMC Test Lab. He has over 15 years experience in commercial and military EMI/EMC test & design. He can be reached at Norand EMC Test Lab, 550 2nd St. SE, Cedar Rapids, Iowa 52401. Tel: (319)-846-2415.

References:

1. MIL-STD 461A/B/C,MIL-STD 462,MIL-STD 463,MIL-STD 831
2. Ron Brewer,Frank Rock, "International Conference on Electromagnetic Compatibility," *EMC Expo Record,* June 1986.
3. Robert D. Goldblum, "MIL-STD 461B," *ITEM* 1984 & 1985.
4. Frederick L. Helene, "MIL-STD 461C," EMC Science Center, *ITEM* 1986
5. Data Item Descriptions, DOD, DI-R-7061, DI-R-7062, DI-R-7063
6. MIL-HDBK 235
7. Air Force AFSC Design Handbook DH 1-4
8. Department of the Navy EMC Design Guide NAVAIR AD 1115
9. Hewlett Packard Application Note 330-1

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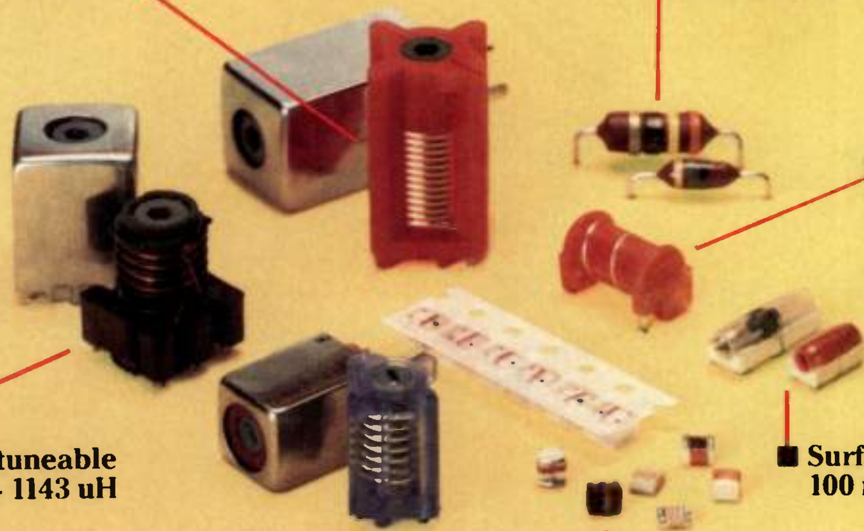

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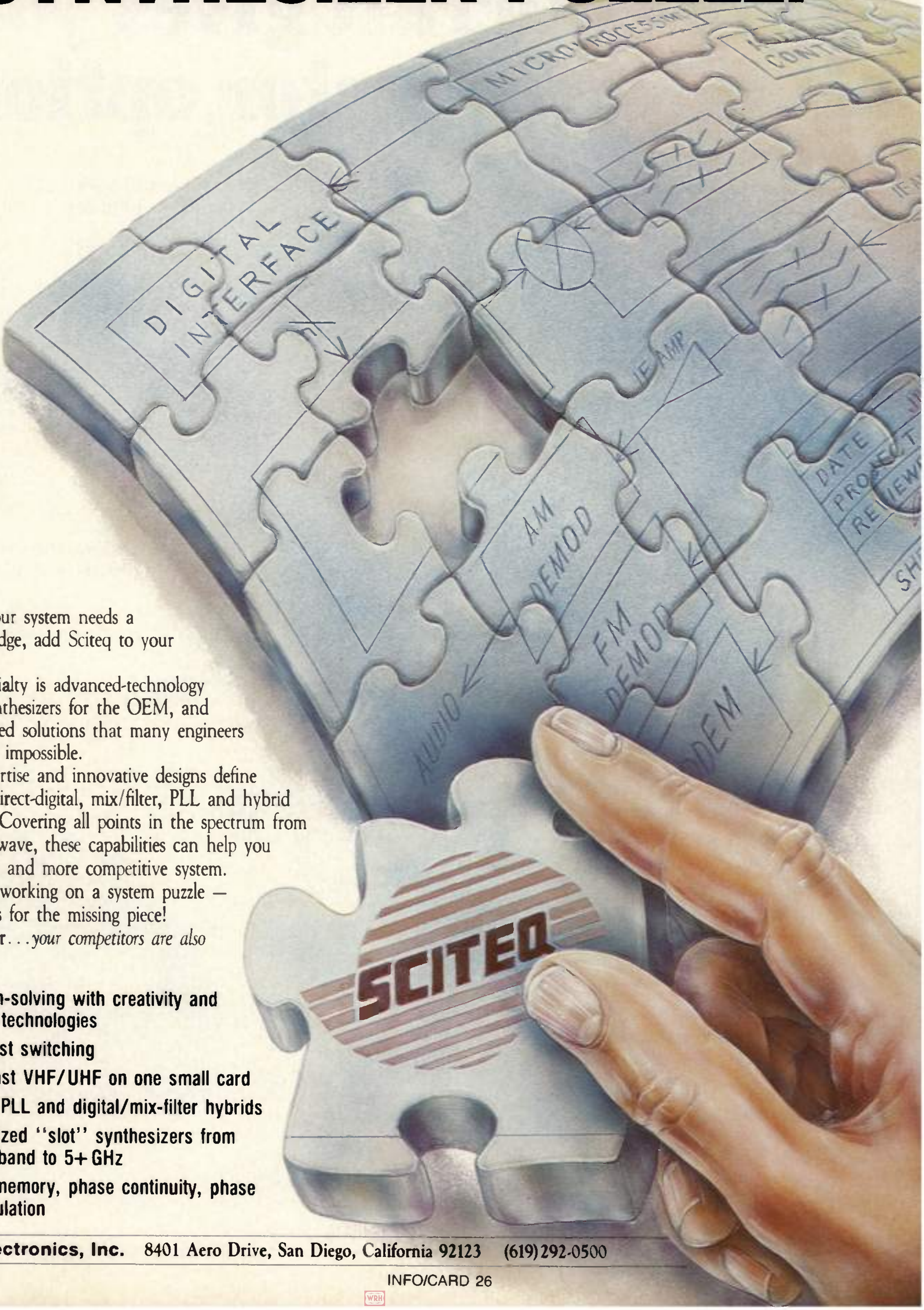

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INFO/CARD 26

An RF Engineer's Guide to the MTT-S Technical Program

Annual Microwave Symposium Offers 234 Papers

The 1987 MTT-S International Microwave Symposium will be held June 9-11 at Bally's Grand Hotel in Las Vegas. A primary feature of the Symposium is the collection of technical papers, panel sessions and workshops covering nearly every aspect of microwave engineering. A listing of the scheduled sessions and workshops can be found below.

Many RF engineers will be attending the Symposium because a portion of their work involves microwaves. Others will be there to learn and observe areas of common techniques involving microwaves and lower frequency RF.

The editors of *RF Design* have identified those papers covering topics of interest to a large number of RF engineers. Of course, many other papers will find interested RF engineers in the audience. This evaluation of papers for RF applicability is intended to be used as a guide; an individual engineer should have his or her own needs and interests in mind.

PLENERY SESSION
Tuesday — June 9, 1987 —
8:30 to 10:00 a.m.
Welcoming Remarks
Keynote Address: Les Besser, President, Besser Associates

TECHNICAL SESSIONS (With RF-related papers noted)

TUESDAY — JUNE 9, 1987
Nonlinear and Powercircuits
10:30 a.m. to Noon

Computer-Aided Design
10:30 a.m. to Noon

1) *Simple Analytical Modeling of GaAs FET Linear Behavior*
2) *Large-Signal Modeling of GaAs Power FET Amplifiers*
3) *Optimum Design of Non Linear Power FET Amplifiers*

Microwave Filters and Multiplexers
10:30 a.m. to Noon

1) *Quasi Low Pass, Quasi Elliptic Symmetric Filter*
2) *Dielectric High-Power Bandpass Filter Using Quarter-Cut Tedi q Image Resonators for Cellular Base Stations*

Low Noise Techniques
1:30 to 3:00 p.m.
3) *A Low Noise Distributed Amplifier with Gain Control*
4) *Wide-Band Monolithic GaAs Phase Detection for Homodyne Reception*

MIC
1:30 to 3:00 p.m.
1) *High Q Dielectric Resonator Frequency Discriminator*
6) *A Low Noise L-Band Dielectric Resonator Stabilized Microstrip Oscillator*

Couplers and Power Dividers
1:30 to 3:00 p.m.

1) *Multiple-Port Power Dividers/Combiner Circuits Using Circular Microstrip Disc Configuration*
4) *Analysis and Synthesis of T Triplate Branch-Line 3 dB Coupler Based on the Planar Circuit Theory*
5) *Impedance Transforming Coupled-Line 3 dB Hybrids*

MMIC Manufacturability
3:30 to 5:00 p.m.

Biomedical Aspects of Microwaves
3:30 to 5:00 p.m.

1) A New Type of Lightweight Low Frequency Electromagnetic Hyperthermia Applicator
2) Regional Heating of Tissue with Control of Applicated Power and with Minimized Leakage Radiation
3) Optimal Source Distribution for Maximum Power Dissipation at the Center of a Lossy Square
4) Measurement of Dielectric Properties of Biological Substances Using Improved Open-Ended Coaxial Line Resonator Method
5) Dielectric Measurements on DNA Solutions Using the HP-8510 Network Analyzer

Open Forum I
3:30 to 5:30 p.m.
3) *A Rigorous Field Analysis of Multilayered SAW Devices*
4) *Ferrite Phase Shifter Finite-Element Analysis Including Losses*
9) *Design Techniques for GaAs Logic Boards*
18) *A 0.5 — 4.0 GHz Tunable Bandpass Filter Using YIG Film Grown by LPE*
21) *Wideband Measurement of Nonstandard Transmission Paths*
22) *Linearization of Diode Detector Characteristics*
23) *Statistical Analysis of Simulated ANA (Automatic Network Analyzer) Measured Errors*
25) *Radial Line Stubs Improve Performance of Microstrip Impedance Matching Network*
26) *Steady-State, Quasi-Steady-State and Transient-State Analysis of Delay Line Discriminators for FM Noise Measurement*
37) *An Efficient Electromagnetic Analysis of Arbitrary Microstrip Circuits*
40) *Precise Measurement Method for Temperature Coefficient of Microwave Dielectric Resonator Materials*
41) *Numerical Spectral Matrix Method for Propagation in Anisotropic Layered Media*

WEDNESDAY — JUNE 10, 1987
Advances in Millimeter Wave Technology and Systems —
8:30 a.m. to Noon

Microwave Measurements
8:30 to 10:00 a.m.

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INFO/CARD 27

2) A Measurement and Calibration Technique for the Accurate Measurement of Amplifier S-Parameters
4) Dielectric Constant Evaluation of Insulating Materials: An Accurate, Practical Measurement System
5) Method for Determining Dielectric Properties of Solids From Measurements on Pulverized Materials

Communications Systems
8:30 to 10:00 a.m.

2) Control of Phase Transients in Digital Radio Local Oscillators
4) Power Amplifier for Microwave Digital Radios with Inherent Phase Compensation
5) GHz Band Monolithic Modem ICs

Noise Measurement
10:30 a.m. to Noon

1) A New Automated Noise and Gain Parameter Measurement System
2) The Evaluation of Phase Noise in Low Noise Oscillators
3) A New Measurement System for Oscillator Noise Characterization

Radar Systems
10:30 a.m. to Noon

1) Solid State Transmitter/Modulator for the Mode Select Airport Beacon System Sensor
3) Self Adaptive Bandpass Filters with Applications to "Frequency Set-On" Oscillators
4) Noise In Pulsed Microwave Systems

Guided Waves
1:30 to 3:00 p.m.

European Microwaves Session
1:30 to 3:00 p.m.

Millimeter Wave Component Technology
1:30 to 3:00 p.m.

Waveguide Discontinuity Structures
3:30 to 5:00 p.m.

Microwave Acoustics
3:30 to 5:00 p.m.
1) Applications of Custom SAW Devices
2) Evolution of SAW Technology from Discrete Devices to Functional RF Building Blocks
3) Miniature SAW Antenna Duplexer for Portable Telephone
4) Design and Evaluation of UHF Monolithic Film Resonator-Stabilized Oscillators and Bandpass Filters
5) Performance of Acoustic Charge Transport Chirp Filters

THURSDAY — JUNE 11, 1987

Optical Techniques For Microwave Applications
8:30 to 10:00 a.m.

3) A High-Speed Phase Shifter Based on Optical Injection

Optical Techniques For Microwave Applications II
10:30 a.m. to Noon

1) Microwave Measurements of GaAs Integrated Circuits Using Electro-Optic Sampling

FET Amplifiers
8:30 to 10:00 a.m.

Solid State Circuits (Non-FET)
8:30 to 10:00 a.m.

2) Frequency Stability of L-Band, Two-Port Dielectric Resonator Oscillators

Non-Linear FET Applications
10:30 a.m. to Noon

2) A Balanced Double Balanced Single Sideband Modulator

Solid State Devices/Circuits II
10:30 a.m. to Noon

Phased Array Systems
1:30 to 3:00 p.m.

1) A 2 Watt GaAs TX/RX Module With Integral Control Circuitry, for S-Band Phased Array Radars
5) Low Cost Cartop Phased Array Steering

HEMT/MESFET Applications
1:30 to 3:00 p.m.

2) FET's and HEMT's at Cryogenic Temperatures — Their Properties and Use in Low-Noise Amplifiers
5) High Efficiency Reaction Amplifier for Microwave Land Mobile Radio Systems

Solid State Devices III
1:30 to 3:00 p.m.

Microwave Ferrites
3:30 to 5:00 p.m.

HEMT Amplifiers and Devices
3:30 to 5:00 p.m.

Open Forum II
3:30 to 5:30 p.m.

1) The Effectiveness of Four Direct Search Optimization Algorithms
4) Puff, an Interactive Microwave Computer Aided Design Program for Personal Computers
8) Optical Stability Analysis of Microwave Circuits by a Frequency-Domain Approach
10) An Almost-Periodic Fourier Transform for Use With Harmonic Balance
13) Absorbed Power Distribution in Heart Lung System Due to Microwave Irradiation at 750 MHz
24) Microwave Resistance of Gallium Arsenide and Silicon PIN Diodes

30) *A Refractory Self-Aligned Gate Process for Monolithically Combined Microwave and Digital GaAs ICs*
32) *Load-Line Analysis in the Frequency Domain With Distributed Amplifier Design Examples*
45) *Centering and Tolerancing the Components of Microwave Amplifiers*

PANEL SESSIONS

GaAs Microwave Monolithic Integrated Circuits — MMICs
Tuesday — June 9, 1987 — Noon to 1:30 p.m.

Financial Planning for Engineers
Tuesday — June 9, 1987 — Noon to 1:30 p.m.

Applications of HEMT Devices and Circuits
Wednesday — June 10, 1987 —
Noon to 1:30 p.m.

Solutions to Problems Existing in Educating Microwave Engineers
Thursday — June 11, 1987 — Noon to 1:30 p.m.

WORKSHOPS

Numerical Techniques for Microwave Field Problems and Their Implementation on Personal Computers
Monday — June 8, 1987 —
8:30 a.m. to 5:00 p.m.

Amplification in High Power Systems
Monday — June 8, 1987 —
8:30 a.m. to 5:00 p.m.

Noninvasive Microwave Sensing of Physiological Signatures
Monday — June 8, 1987 —
8:30 a.m. to 5:00 p.m.

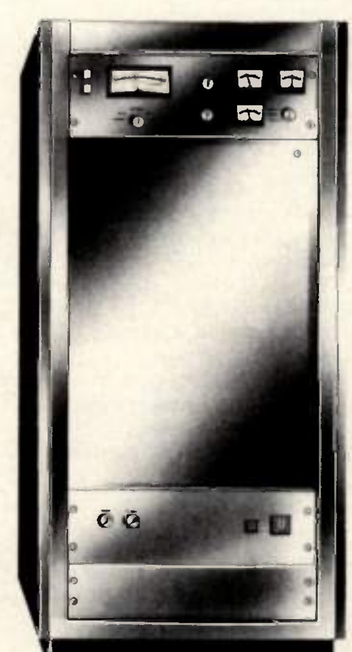
Optical-Microwave Interactions
Friday — June 12, 1987 —
8:30 a.m. to 5:00 p.m.

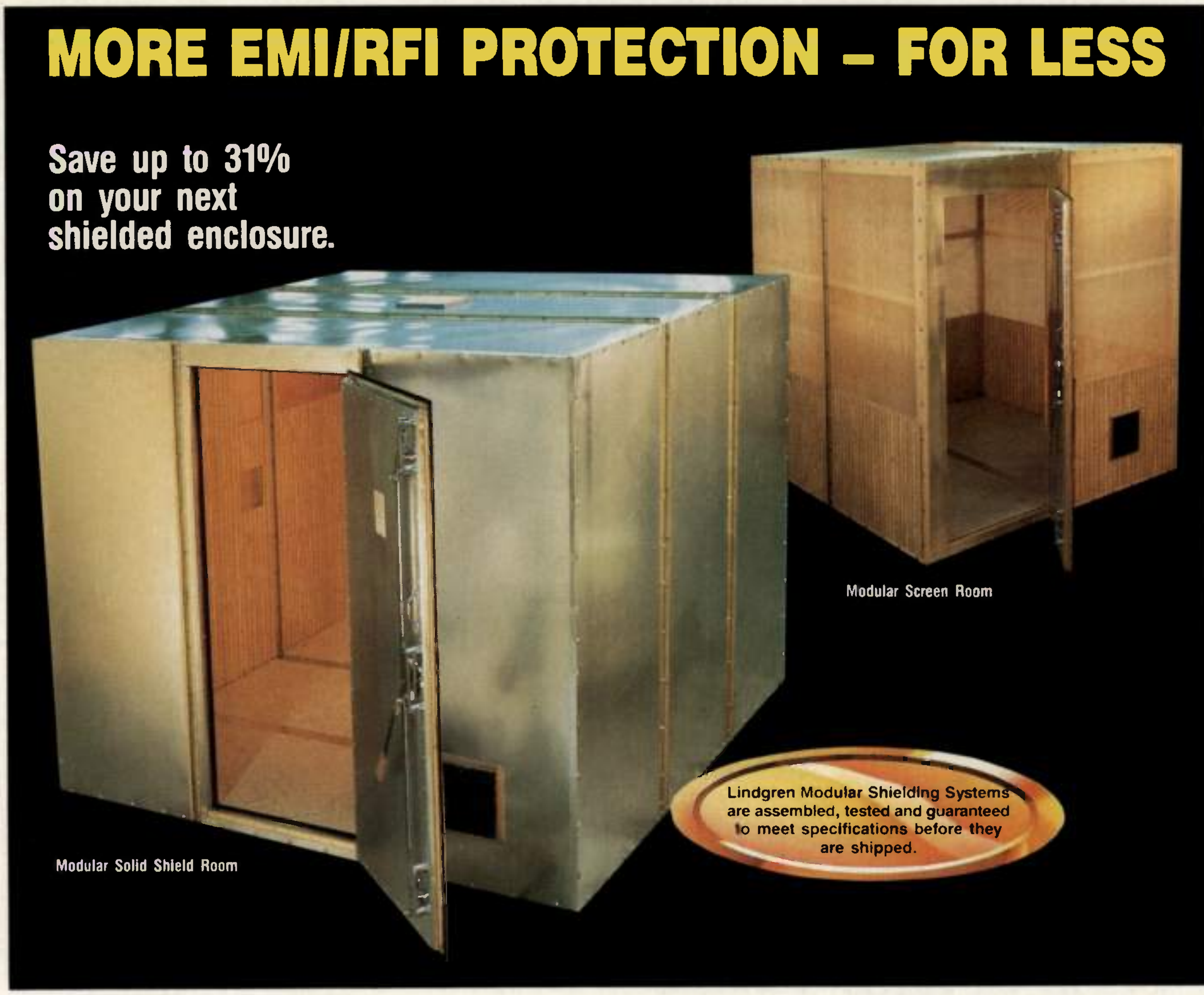
Nonlinear CAD and Modeling
Friday — June 12, 1987 —
8:30 a.m. to 5:00 p.m.

Quasi-Planar Millimeter-Wave Components and Subsystems
Friday — June 12, 1987 —
8:30 a.m. to 5:00 p.m.

Dielectric Resonators in Microwave Oscillators
Friday — June 12, 1987 —
8:30 a.m. to 5:00 p.m.

Planning and Packaging for the Next Generation of Integrated Circuits
Friday — June 12, 1987 —
8:30 a.m. to 5:00 p.m.





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INFO/CARD 31

S Parameter to Input Impedance Conversion Program

By Thomas B. Mills
National Semiconductor Corporation

Although S parameters are becoming more readily available for high frequency devices with new measuring devices, the actual data obtained does not always leave the designer with an understanding of the device's input and output impedance. S11 and S22 provide all the data necessary to calculate the device's input and output impedance. The following relationship will do this for a device terminated in 50 ohms:

$$Z_{in} = 50 \frac{1 + S11}{1 - S11}$$

This expression gives the equivalent series input impedance of a one or two port network. Note that S11 is a complex number.

The accompanying Microsoft (PC) BASIC program solves the equation, calculates the equivalent parallel impedance and it also calculates the size of the series and parallel inductor or capacitor associated with the impedance as shown in Figure 1.

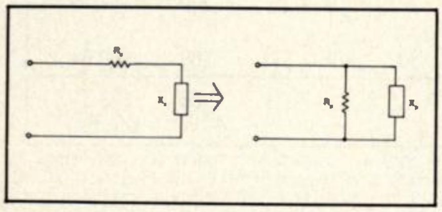

Figure 1. Equivalent Circuits.

As an example, consider a transistor with S11 at −3.4 dB with a phase of 47 degrees. As 100 MHz, the following results are obtained.

Equivalent series resistance (R_s)	=	51.71 ohms
Equivalent series resistance (X_s)	=	−j91.35 ohms
Equivalent series capacitance	=	17.92 pF
Equivalent parallel resistance (R_p)	=	213.11 ohms
Equivalent parallel reactance (X_p)	=	−j120.62 ohms
Equivalent parallel capacitance	=	13.19 pF

```
10 CLS
20 COLOR 6
30 REM THIS PROGRAM CONVERTS S11 TO AN INPUT IMPEDANCE
40 PRINT"THIS PROGRAM CONVERTS S11 TO SERIES AND PARALLEL IMPEDANCE AND ALSO"
50 PRINT"CALCULATES THE EQUIVALENT SERIES AND PARALLEL CAPACITOR OR INDUCTOR"
60 PRINT"S11 MAGNITUDE MAY BE ENTERED IN EITHER DB OR MAG."
70 INPUT"(D)B OR (M)AGNITUDE?",A$
80 IF A$<>"D" AND A$<>"d" AND A$<>"M" AND A$<>"m" THEN 70
90 PI=3.1415927#
100 PRINT
110 COLOR 6
120 INPUT"FREQUENCY IN MHZ ",F
130 PRINT
140 IF A$="D" OR A$="d" THEN INPUT"S11 IN DB,DEGREES",M,A
150 IF A$="M" OR A$="m" THEN INPUT "S11 IN MAGNITUDE,DEGREES",M ,A
160 IF A$="D" OR A$="d" THEN M=EXP(2.3025851#*M/20)
170 PRINT
180 GOSUB 610
190 R2=1-RE:I2=-IM
200 R1=RE+1:I1=IM
210 GOSUB 560
220 RE=50*RE:IM=50*IM
230 COLOR 3
240 PRINT "SERIES REAL PART: ";RE,
250 PRINT "SERIES IMAG. PART: ";IM
260 PRINT
270 COLOR 2
280 IF IM<0 GOTO 300
290 IF IM>0 GOTO 320
300 PRINT"THIS IS A SERIES CAPACITOR OF: ";-.000001/(2*PI*F*IM); "PF"
310 GOTO 340
320 PRINT "THIS IS A SERIES INDUCTOR OF: ";1000/(2*PI*F)*IM;"NH"
330 GOTO 340
340 PRINT
350 REM CONVERT SERIES TO PARALLEL
360 R1=1:I1=0
370 R2=RE : I2=IM
380 GOSUB 560
390 COLOR 3
400 PRINT "PARALLEL REAL PART: ";1/RE ,
410 PRINT"PARALLEL IMAG. PART: ";-1/IM
420 COLOR 2
430 PRINT
440 IF 1/IM>0  GOTO 470
450 IF 1/IM <0 GOTO 500
460 PRINT
470 PRINT"THIS IS A PARALLEL CAPACITOR OF: ";.000001 /(2*PI*F*(1/IM)) ; "PF"
480 PRINT
490 GOTO 110
500 PRINT "THIS IS A PARALLEL INDUCTOR OF: ";-1000/(2*PI*F)*(1/IM); "NH"
510 PRINT
520 GOTO 110
525 REM COMP NUMBER MULTIPLICATION
530 RE=R1*R2-I1*I2
540 IM=I1*R2+R1*I2
550 RETURN
560 REM COMP NUMBER DIVISION
570 X=R2*R2+I2*I2
580 RE=(R1*R2+I1*I2)/X
590 IM=(I1*R2-R1*I2)/X
600 RETURN
610 A=A*.017453
620 RE=M*COS(A)
630 IM=M*SIN(A)
640 R(K)=RE
650 I(K)=IM
660 RETURN
```

About the Author

Tom Mills is a MTS at National Semiconductor. He is involved in hybrid design and has been with NSC for 17 years. He can be reached at NSC, 2900 Semiconductor Drive, M/S 11-130, P.O. Box 58090, Santa Clara, CA 95052-80990. Tel: (408) 721-3400.

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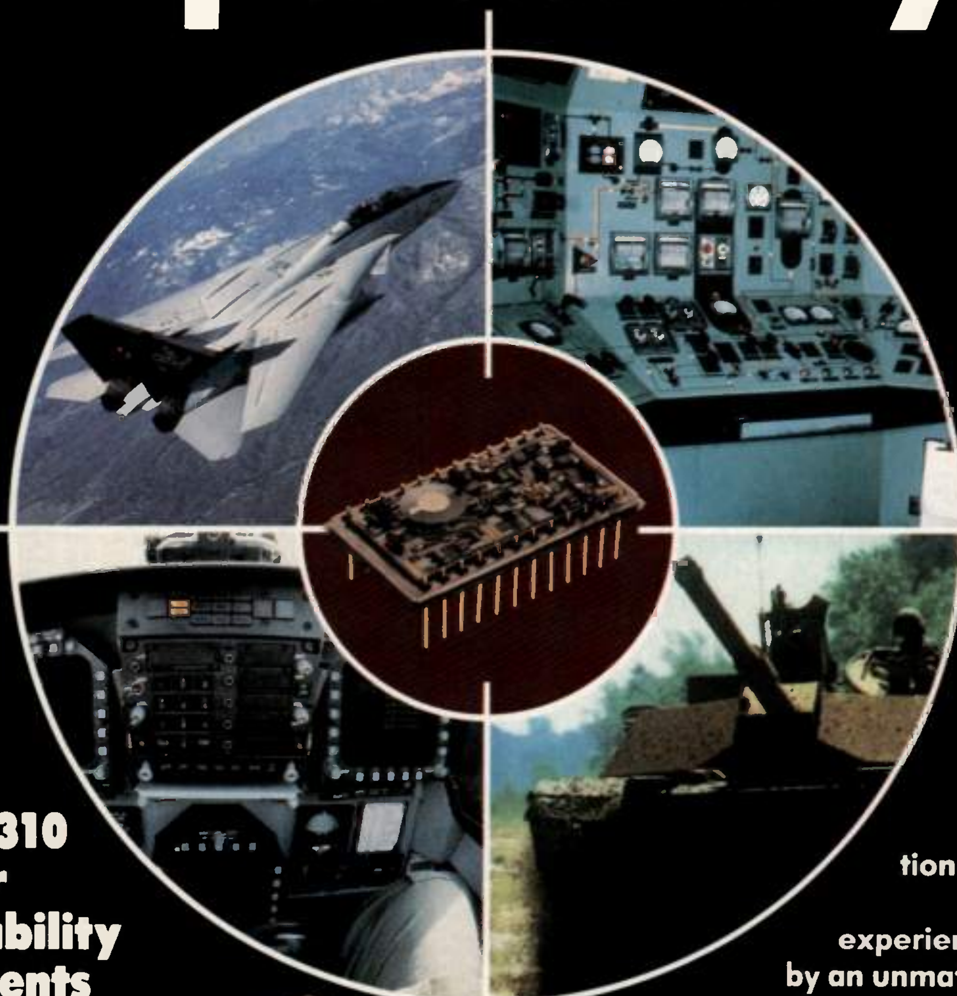

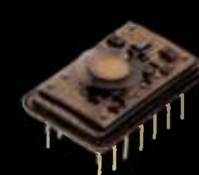

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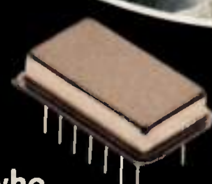

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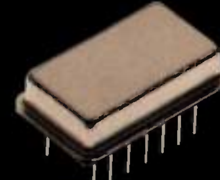

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INFO/CARD 33

A Variable Phase Shifter and BPSK Modulator

This 10.7 MHz IF Circuit Has Many Applications

By G. Abdul Latheef,
K.N. Suryanarayana Rao and S. Pal
ISRO Satellite Centre, India

Applications for variable phase shifters and BPSK modulators are wide and varied. This article takes a look at the design of a circuit centered at 10.7 MHz.

The circuit employs a 3 dB quadrature hybrid terminated in a reactance load. A junction varactor diode in a series with a fixed inductance is used as a voltage controlled reactance. Thus a voltage controlled phase shift is obtained between the input and the normally isolated ports of the quadrature hybrid. A continuously variable phase shift form +90° to −90° is realized. An asymmetry compensation technique has been developed to obtain minimum variation in the insertion loss over the entire range of phase variation.

The phase shifter is designed for application in an S-band coherent transponder for telemetry, tracking and command purposes in a spacecraft. The variable phase shifter is required for establishing the proper phase operating point for the PM demodulator and coherent AGC detector. Since the second IF is at 10.7 MHz in the transponder, the phase shifter has been designed for operation at that frequency. This principle can, however, be employed to realize a phase shifter at any other frequency. A low loss BPSK modulator has been developed using the variable phase shifter.

Basic Principle

A transmission line with characteristic impedance Z_o, terminated in a load Z_L has the reflection coefficient given by:

$$\varrho = \frac{Z_L - Z_o}{Z_L + Z_o} \qquad (1)$$

If Z_L is a reactance of $\pm jX$, then the reflection coefficient is:

$$\varrho = e^{j(\pi - 2\phi)}, \text{ for inductive reactance} \qquad (2)$$

$$\varrho = e^{j(\pi + 2\phi)}, \text{ for capacitive reactance} \qquad (3)$$

$$\text{Where } \phi = \tan^{-1} \frac{|x|}{Z_o}$$

From equations (2) and (3), when the termination is varied from $+jZ$ through zero to $-jZ_o$, the phase of the reflection coefficient will vary from +90° through 180° to −90°. The phase shift in the reflection coefficient, obtainable by variable load, can be obtained in the transmission made by utilizing a 90°, 3 dB hybrid as shown in Figure 1. The variable reactance load gives rise to the variation in the phase shift of the signal output, which is obtained from the isolated port.

To realize a varible phase shift from +90° to −90° the quadrature hybrid should see the reactance varying from $+jZ_o$ to $-jZ_o$. To get this range, an inductance is used in series with the varactor diode. The varactor diode should have appropriate capacitance and capacitance ratio to obtain the reactance variation of $2Z_o$.

Suppose the diode has a reactance of X_1 ohms (at the signal frequency) at a voltage V_1 and a reactance of $X_2 = (X_1 + 2Z_o)$ ohms at the voltage V_2, the series inductance should have reactance of $(X_1 + Z_o)$ ohms. X_1 is chosen so that the capacitance ratio is enough to provide variation from X_1 to X_2.

The V100E is used, providing a capacitance of 100 pF at 4 V, a capacitance ratio of 4 (0.5 VDC/20 VDC) and Q exceeding 100 at 10.7 MHz. The diode presents a reactance of X_1 = 100 ohms at V_1 = −0.8 V. The system characteristic impedance, Z_o, is 50 ohms. So X_2 should equal $(X_1 + 2Z_o)$, or 200 ohms. The voltage V_2 cor-

Table 1. Phase variation with respect to bias.

Bias Volts	Terminating Reactance ohms	Phase measured deg.	Theoretical Figure deg.	Error deg.
−0.82	j50.0	92.0	90.0	2.0
−1.50	j35.1	112.0	109.9	2.1
−2.00	j24.2	130.0	128.4	1.6
−2.50	j15.3	148.0	146.0	2.0
−3.62	j0.0	−178.0	180.0	2.0
−5.00	−j18.0	−143.0	−140.4	2.6
−6.00	−j28.2	−124.0	−121.2	2.8
−7.00	−j37.8	−109.0	−105.8	3.2
−8.35	−j50.0	− 94.0	− 90.0	4.0

responding to this reactance is −8.3 V. Thus the bias variation required is from 0.8 dB over the entire range of phase should have a reactance of $(X_1 + Z_0)$ = 150 ohms. This is provided at 10.7 MHz by an inductor with the value 2.23 uH. A 2.2 uH RFC has been used here in the circuit.

The finalized circuit is as shown in Figure 2. C_1 and C_2 are DC blocking capacitors. Resistance R_1 and R_2 isolate the signal from the biasing network. They are chosen to provide high resistance to RF signals and are low compared to the reverse resistance of the varactor diode. Resistance R_3, R_4 and potentiometer R_5 provide variable bias to obtain the required phase shift. C_3 and C_4 are compensating capacitors. C_5 is a feed through capacitor for RF bypass.

The theoretical and experimental values of phase shifts have been tabulated in Table 1.

When the bias is varied from 0.78 to 8.7 V a phase variation from +90° to −90° is observed.

Frequency:	10.7 MHz	
Phase shift:	+90° through 180° to −90°	over the temperature range of −20°C to +70°C
Maximum Insertion loss:	1 dB	
Maximum signal power:	+6 dBm	
DC Drain:	0.3 mA (max)	
Phase change for a fixed phase shift of 180° with respect to temperature:	±2.7%	

Table 2. Phase shifter characteristics.

Asymmetry Compensation:

The key to the good performance, particularly in respect of insertion loss, lies in maintaining symmetrical reactance in both the hybrid ports. It is difficult to obtain symmetry due to dissimilarity in the reactive elements and the diodes, nonideal characteristic of the hybrid, etc. It is possible to take care of the problem by having a compensating shunt capacitance. With the introduction of variable capacitors C_3 and C_4, the maximum insertion loss could be reduced from 1.8 dB to 0.8 dB over the entire range of phase variation. C_3 and C_4 are chosen to be much smaller than the diode capacitance since they are required only for trimming purposes.

The phase shifter was subjected to a temperature test in the range of −20° to +70°C. The temperature performance of the phase shifter is shown in Figure 3. A worst case phase variation of 2.7 percent is observed in the temperature range.

The performance characteristics of the phase shifter are summarized in Table 2.

BPSK Modulator

The variable phase shifter developed can provide a phase shift range exceeding 180° with appropriate terminations. By applying two discrete voltages V_1 and V_2, corresponding to phase shifts of Φ_1 and

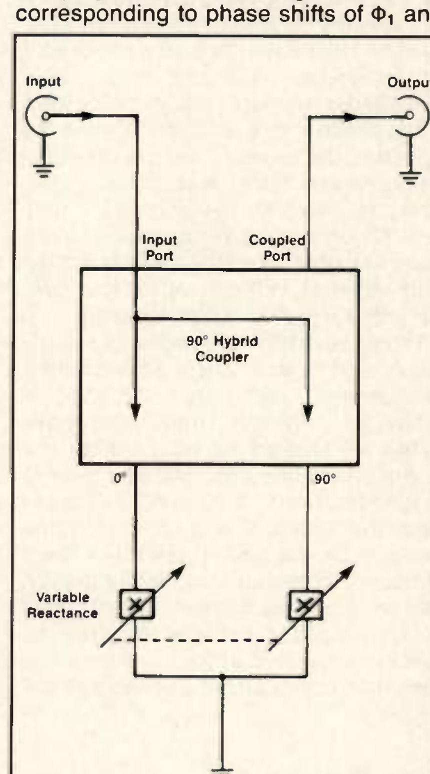

Figure 1. Basic phase shifter using 90° hybrid coupler.

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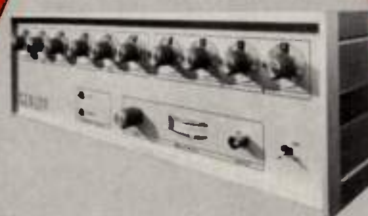

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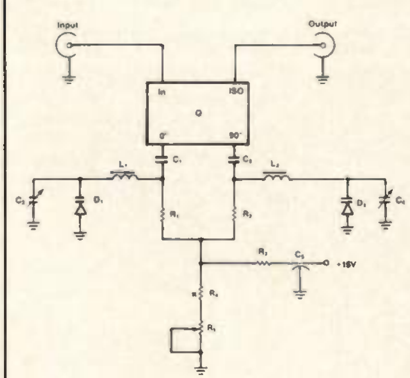
Φ_2, a fixed phase shift of $(\Phi_2 - \Phi_1)$ can be realized. This property can be utilized in designing a BPSK modulator. Here, the data should generate the two voltages V_1 and V_2 such that a phase shift, $(\Phi_2 - \Phi_1) = 180°$ is obtained.

The generation of two fixed analog voltages, controlled by digital data, can be realized by using an analog multiplexer. A CMOS multiplexer, CD 4025 B has been used here. It is a differential 4-channel multiplexer having two bit binary control. In the present application, it is used as a single 2-channel one bit controlled multiplexer.

The practical circuit of the BPSK modulator is shown in Figure 4. The voltages V_1 and V_2 are generated from precise potential dividers $R_1 - R_2$ and $R_3 - R_4$, respectively, from a temperature compensated Zener diode reference voltage (11.7 V). These voltages are applied as inputs to the multiplexer. The output is switched between V_1 and V_2 depending on the state of the data input. The multiplexer output is applied through the fast voltage-follower, buffer to the phase shifter input terminals.

The elements $R_8 - C_2$ compensate the capacitive load at the phase shifter input terminals. The RFCs $L_3 - L_4$ block the carrier signal while having low impedance for the highest data rate. C_3 and C_4 are chosen to provide high impedance to the data path while giving low impedance to RF.



Component List (Figure 2)

C_1, C_2	— Ceramic Capacitor, CKR 06, 10 nF
C_3, C_4	— Variable Capacitor, JMC 8053, 1.5-14 pF
C_5	— Feed through capacitors, Cambion, 3265-37, 1000 pF
L_1, L_2	— RF choke, 2.2 uH
R_1, R_2	— Resistor, 1/8 W, 10 K Ω, 5%
R_3	— Resistor, 1/8 W, 47 K Ω, 5%
R_4	— Resistor, 1/8 W, 3.3 K Ω, 5%
R_5	— Multi turn, Trimpot, RJR 26 FW, 100 K Ω
D_1, D_2	— Varactor Diode, TRW — V 100E
Q	— Quadrature hybrid, Merrimac — QHF — 2A — 10.7 B.

Figure 2. Variable phase shifter practical circuit.

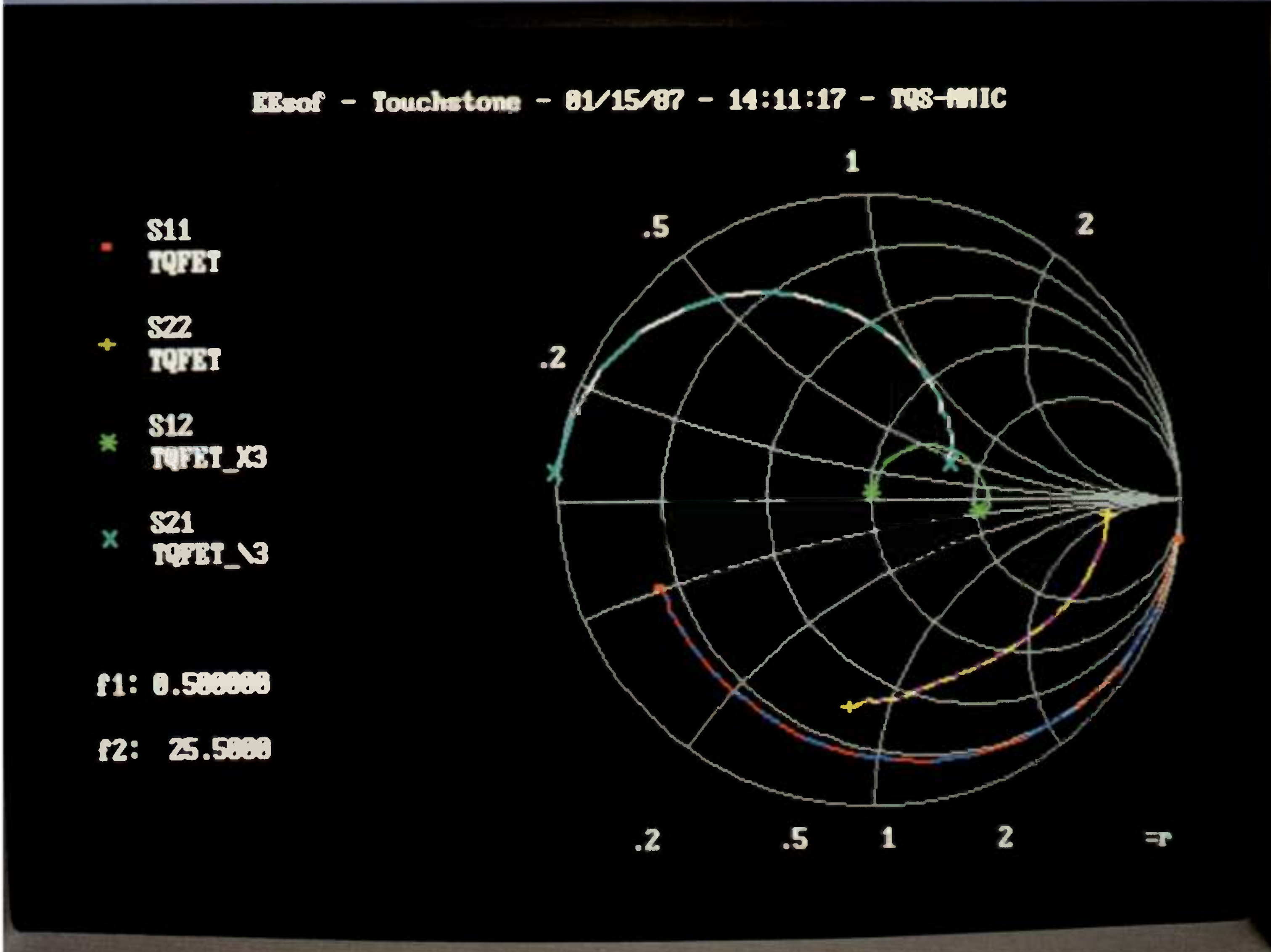
Test Results

The BPSK modulator was tested and was found to have performance up to 50 kBPS. The circuit performance was also evaluated in a temperature range of −20°C to +70°C. In that range the following specifications have been met:

Carrier suppression:
37 dB at 1 kBPS (min)
26 dB at 50 kBPS (min)

Insertion loss:
1.0 dB (max)

The main advantage of this modulator is that it has low insertion loss as compared to the normally used double-balanced-modulator scheme. It is possible



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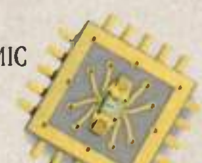

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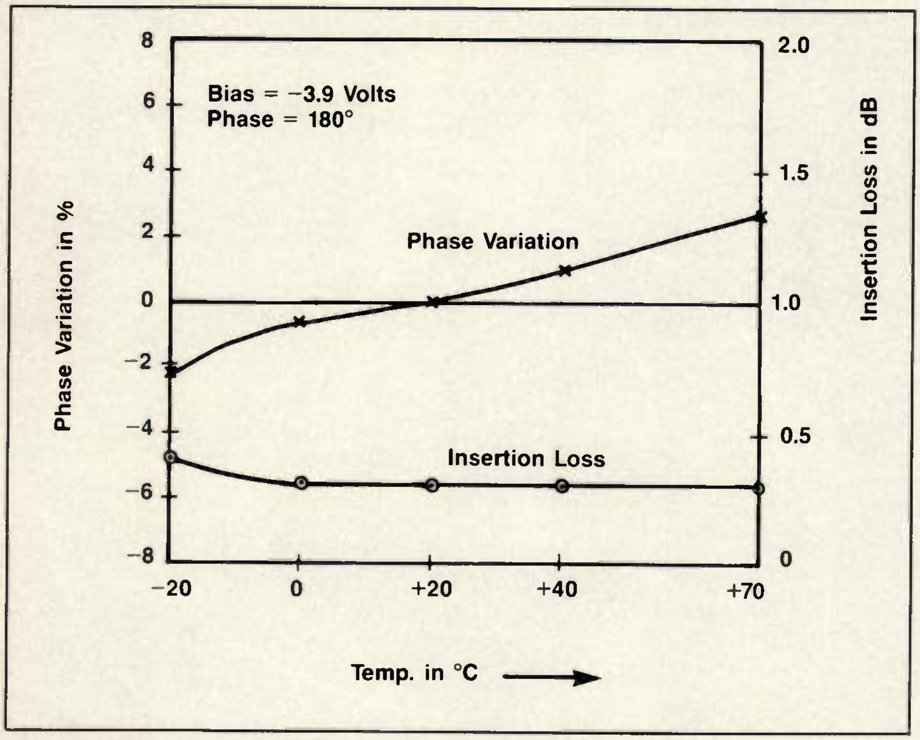

Figure 3. Phase shifter performance with temperature.

to precisely correct the phase imbalances and thus obtain improved performance. Such precision phase adjustment is not possible in the other scheme. Also the data input voltage levels for the logic can be fixed over a wide range, depending on the type of logic circuit used. Moreover, higher levels of modulation like QPSK is possible using the same principle.

The authors acknowledge the support given by Mr. N. Pant, director, ISRO Satellite Centre, in carrying out this work. ▣

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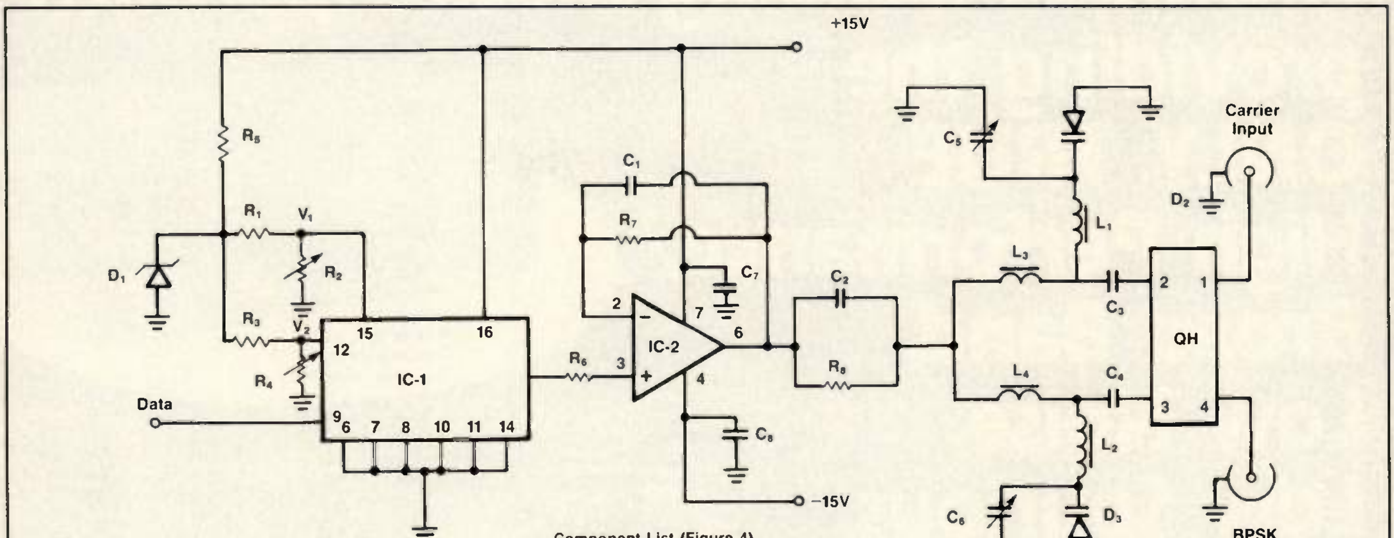

Component List (Figure 4)

R_1	— Metal film Resistor, 10 K Ω, 1%, 1/10 W
R_2	— Trimpot, RJR 26 FW, 100 K Ω
R_3	— Metal film Resistor, 10 K Ω, 1%, 1/10 W
R_4	— Trimpot, RJR 26 FW, 1 K Ω
R_5	— Resistor, 1 K Ω, 5%, 1/8 W
R_6, R_7, R_8	— Resistor, 10 K Ω, 5%, 1/8 W
C_1	— Silver Mica capacitor, CMR 04, 10 pF
C_2	— Ceramic Capacitor, CKR 06, 68 nF
C_3, C_4	— Ceramic Capacitor, CKR 06, 2.2 nF
C_5, C_6	— Variable Capacitor, JMC 8053, 1.5-14 pF
L_1, L_2	— RFC, 2.2 uH
L_3, L_4	— RFC, 22 uH
D_1	— TC Zener, 1N946
D_2, D_3	— Varactor Diode, TRW-V100E
IC-1	— CD 4052 B
IC-2	— LM 118
QH	— Quadrature Hybrid, Merrimac — QHF — 2A-10.7 B
C_7, C_8	— Ceramic Capacitor, CKR 06, 0.1 uF.

Figure 4. BPSK modulator.

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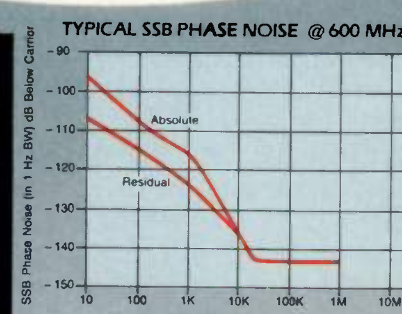

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RF Engineering Employment Expansion Continues

Wanted: RF Engineers — BSEE Required, RF Experience Desirable

By Keith Aldrich, Publisher, and Bonnie Ward, Research Manager

Nine out of ten of the largest U.S. employers of RF engineers now have openings for RF engineers or expect to have in the near future, according to a survey conducted in late March by RF Design. *Seven out of ten of the openings are new jobs, representing continued expansion of the RF industry. One out of four of the jobs are earmarked for new engineering graduates, and many of them will be treated by their employers to advanced training in RF and microwave techniques.*

Twenty companies were interviewed by telephone in the survey, mainly large defense and aerospace contractors where *RF Design* has at least 100 subscribers. Eighteen of the twenty (90 percent) said they now have or soon will have openings for RF engineers, ranging in number from two or three, to over 100 in the case of Sanders Associates, Nashua, N.H. The average number of openings was 24, and the median was 12.

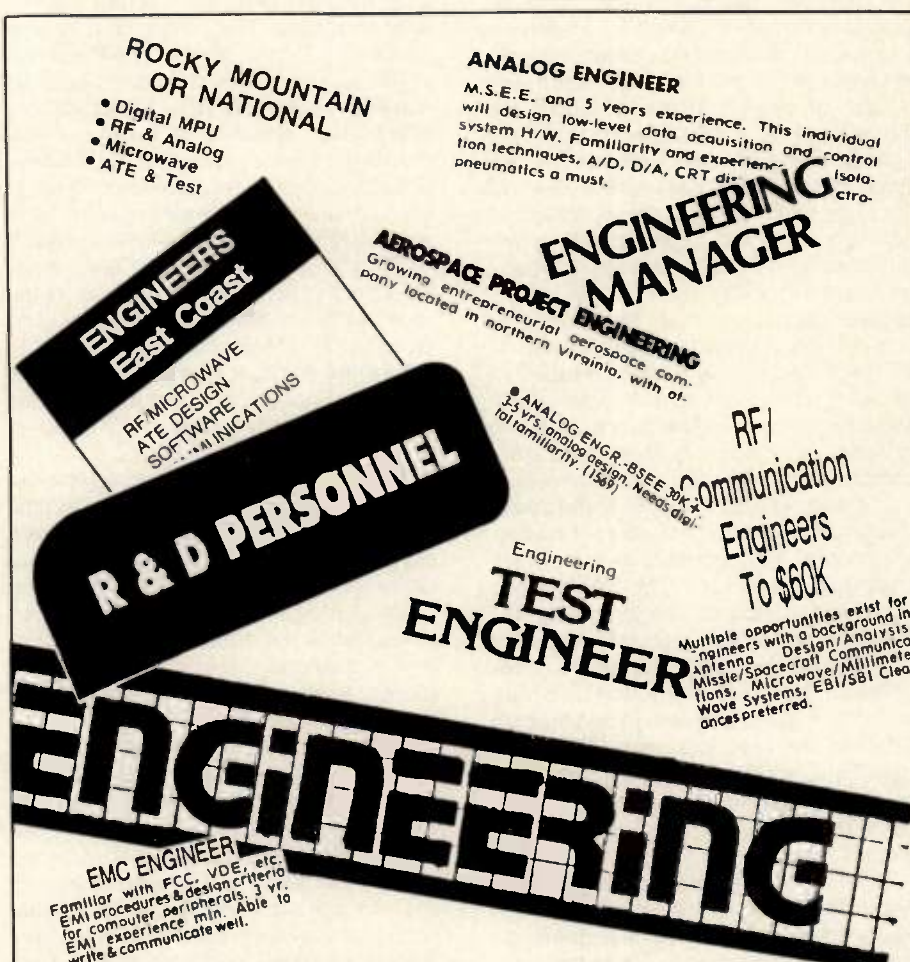
Almost half of the openings are for senior-level RF engineers with at least five years experience in some specific area of RF system or hardware design. For instance, TRW Space and Defense Communications in Redondo Beach, Calif., needs around 40 engineers with experience in GaAs and SAW circuit design and fabrication, to work on a new contract which funds the development of MMICs. Another hot area is radar and antenna systems: engineers with this experience are needed by General Electric, Syracuse, N.Y. (20 openings); Grumman Aircraft, in both Bethpage, N.Y. (4-6 openings) and in Melbourne, Fla. (10 openings); and Harris Government Communications Sys-

Do you have now or expect to have in the near future, job openings for RF Engineers?

Yes 90% No 10%

How many of the jobs to be filled are. . .
Entry level: 24%
Journeyman level: 32%
Senior level: 44%

Response to survey questions by 20 of the largest employers of RF engineers.



tems, Melbourne, Fla. (3 openings). Receiver/transmitter and RF communications design experience is needed by Magnavox in Fort Wayne, Ind. (5-10 openings); and by Rockwell Avionics, Cedar Rapids, Ia., (6 openings).

Employment Activity Reflects A Continuing Trend

While the survey indicates the RF engineering population will be growing, it also shows that this is nothing new. Roughly half the companies surveyed said they have been hiring RF engineers at an accelerated rate for the last couple of years, and that their hiring for the next couple of years will be at "about the same" rate as in the recent past.

At Grumman Aircraft Systems Div., RF Section Head Victor Albanese talks about "intense hiring activity" through 1986, in which a so-called "tiger team" of ten engineering recruiters from the company, including Albanese, toured trade shows, campuses, and other likely locales searching for the rare species known as RF engineers. While a hiring freeze had halted this activity at the time of *RF Design's* interview in March, a thaw is due in June. At Grumman, as at most other companies interviewed, government contract activity is behind the RF hiring boom. Grumman's Melbourne Systems Division, Melbourne, Fla., where 10 senior RF engineers are needed now to augment a work force already numbering nearly 600, has grown up largely since the awarding of a JSTARS contract in September 1985. JSTARS is a joint Army/Air Force surveillance system program including both airborne and ground systems. The word "joint" also applies to suppliers in the program, as Grumman supplies the airborne portion while Motorola supplies the ground system.

While almost half the companies do not plan to hire new college graduates, the others (more than half) do have openings for "fresh-outs" ranging in number from one or two up to 60, in the case of Sanders. About 25 percent of all current openings are for new engineering graduates, encouraging news for students with an interest in RF careers.

In general, companies hiring new graduates seek a BSEE with as many courses as possible in electromagnetic theory, communications and other RF and microwave subjects, reflecting an analog rather than digital emphasis. Since some schools do not offer many of these courses, some hiring companies place a high priority on "interest" in RF techniques, and many have co-op programs in which students get practical work experience before graduation, while also earning academic credit.

Closing the RF Education Gap

Some RF companies offer training after the new graduate becomes a full-time employee. The programs take several forms. Roger Brown, Vice President of Human Resources at Sanders, says his company adds 60 new EE graduates every year, selected to have a "well-rounded" EE degree. After an apprenticeship, Sanders sends many of them to the University of Massachussetts for a year's training, concluding with an MSEE in RF and microwaves. The employees are actually relocated at the school for the year while receiving full salary and benefits. The Master's thesis project involves the solution to a problem on the boards at Sanders, and is researched and written by a team composed of Sanders graduate-student/employees.

A different approach is used at Motorola Government Electronics Group in Scottsdale, Ariz. Jerry Fiala, Manager of Staffing at Motorola GEG says recent graduates are given a 24 week engineering training program to help develop their skills. Unlike Sanders, however, the training is provided by Motorola. The employee receives full pay and benefits, but no college credit.

An innovative training program at Grumman matches newly hired graduates with a "mentor." The mentor is not necessarily in the same department and is not a supervisor. Instead, it is someone who can acquaint a new employee with the "ins and outs" of the company. Section Head Albanese says Grumman "very much wants June graduates year to year" and the mentor program works very successfully in acclimating new graduates to the work environment at Grumman.

A Bright Future for Young EEs

The RF engineering community is still booming and maturing. For recent graduates, the well-rounded EE courses they took in college are being augmented by more specific RF training provided by individual companies. Innovative training methods to enhance RF engineers' capabilities help make this discipline an attractive one for recent EE grads. As new government contracts are awarded, experienced RF engineers will be in high demand. The experience gained in the first years of employment will lead to greater opportunities as they expand their knowledge of RF engineering techniques. This all points to an optimistic outlook for RF engineers hoping to join the workforce in the next couple of years.

Listed below are the companies interviewed for the article who are hiring. Those marked with an asterisk (*) will be accepting new or recent college graduates:

General Electric, Syracuse, N.Y.
Mark Rideout, Manager of Professional Staffing: (315) 457-6007

*Grumman Aircraft Systems Div., Bethpage, N.Y.
Victor Albanese, Section Head RF Engineering: (516) 575-3999

*Harris Government Communications Systems, Melbourne, Fla.
Charley Hester, Manager of Personnel: (305) 727-4141

Magnavox, Fort Wayne, Ind.
Bill Blake, Senior Personnel Administrator — Tactical Systems Div.: (219) 429-7772

*Motorola Government Electronics Group, Scottsdale, Ariz.
Jerry Fiala, Manager of Staffing: (602) 949-3066

*Northrop Corp. Defense Systems, Rolling Meadows, Ill.
David Kornhauser, Employment Representative: (312) 259-9600

Rockwell Avionics, Cedar Rapids, Ia.
John Gorman, Staffing Specialist: (319) 395-2069

*Sanders Associates, Nashua, N.H.
Roger Brown, Vice President of Human Resources: (603) 885-4321

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ENGINEER
Broadband, Communications and Electronics System

Michigan State University has an advanced level opening for a seasoned, operations-oriented communications engineer. This position requires the application of extensive and diversified engineering principles and methods to the operational development of a large broadband LAN and various electronic systems.

Examples of typical tasks are the following. Plan, develop and coordinate large and vital broadband cable and electronic systems, as well as smaller complex projects. Develop preventative maintenance programs for broadband television and data networks, and other electronic systems. Design broadband cable trunks and distribution systems. Consult on maintenance and troubleshooting problems for broadband cable, general analog, digital and radio frequency communication systems. Assist with the development of improved and innovative operational procedures for high technology systems in a university environment. Develop, direct and implement technical training of personnel. Applicants must have a BSEE and reasonable progressive and responsible experience in planning/designing broadband and other electronic systems, installations and equipment. Some supervisory experience is also required. Registration as a PE in the State of Michigan is desired.

Contact Michigan State University Employment Office, 110 Nisbet Building, 1407 S. Harrison Road, East Lansing, MI 48824. Refer to Position A654.

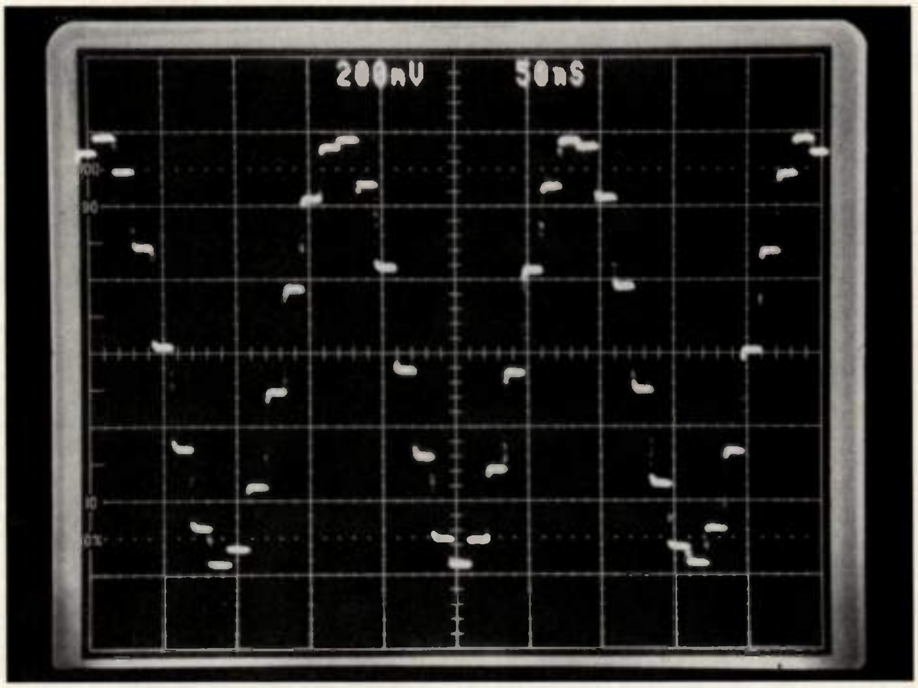
MSU is an Affirmative Action/Equal Opportunity Institution.

TriQuint Introduces 1 Gs/s DAC

A family of 600 to 1000 megasample/second (Ms/s) digital to analog converters has been produced by TriQuint Semiconductor, Inc. The GIGA-DAC™ family of GaAs 8 bit DACs includes the TQ6100 series designed to meet high-speed applications in high resolution CAD/CAM displays, waveform synthesis, analog to digital conversions and military fast hop frequency synthesis.

The family is available in die, packaged part and daughter-board module formats. The TQ6111 and TQ6112 are suitable for megapixel graphics display applications. The devices offer an additional blanking input and IRE standard blanking interval. Since an 8-wide 2:1 input data multiplexer is included, the input data rate need only be half that of the DAC output.

On-chip temperature compensated ECL reference circuits enable these DACs to interface with 10K and 100K ECL families, making them useful for extension of current DAC subsystems using ECL circuitry. GIGA-DAC parts are also available in a daughter-board module that adds I/O line terminations, power supply regulation and filtering, and output voltage stabilization.



Power dissipation for the 600 and 1000 Ms/s ICs is typically 2.5 and 3.5 W, respectively. The price ranges from $159 to $895 depending on model, quantity and packaging. The photograph shows a digitally synthesized sinewave using the TQ6112-B1 daughter board module. **TriQuint Semiconductor, Inc., Beaverton, OR. INFO/CARD #220.**

WJ Unveils A Portable EMC/TEMPEST Test Receiver

The WJ-8999 is a portable EMC/TEMPEST test receiver designed for frequency coverage from 1 kHz to 1 GHz. It contains 18 IF bandwidths from 100 Hz to 50 MHz and provides AM, AM/AGC, FM, CW and LOG signal detection modes. Audio, video, IF and signal monitor outputs and an IEEE-488 interface are provided.

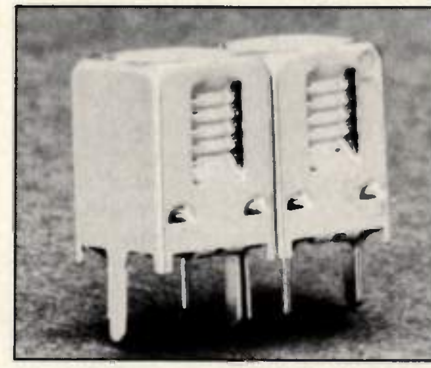
The receiver system is comprised of a digital control unit and a tuner/synthesizer unit. The units, interconnecting power, IF, fiber optic control cable assemblies and external limiter are housed in two carrying cases.

The WJ-8999 provides four operating modes: fixed frequency, sector scan/plot, sector scan/monitor and remote control. The fixed frequency mode provides the capability to manually tune the receiver using the tuning wheel or up/down keys on the front panel.

In the sector scan/plot mode, eight sectors may be programmed with start frequency, step size and other receiver parameters. The sector scan/monitor mode gives the operator the ability to scan multiple sectors. The number of sectors and the order in which they are scanned are operator selectable. Operation in the remote control mode allows the system to be customized to the needs of a particular application utilizing the IEEE-488 bus. All the functions accessible to the operator in the fixed frequency mode are available as remote control commands. **Watkins-Johnson Company, Palo Alto, CA. Please circle INFO/CARD #219.**

Helical Filter is Compact

An adjustable double tuned helical filter from Toko America has a 650 MHz to 1.5 GHz frequency range. The 5HW filter offers superior mechanical performance and resistance to temperature, humidity, shock and vibration, as well as high Q and low insertion loss. Bandwidth at 959 MHz is 18 MHz or 20 MHz depending on the model. The filter features an adjustable screw type core for tuning. **Toko America, Inc., Prospect, IL. INFO/CARD #191.**



Impedance Matching Pads

Wideband Engineering Company introduces two resistive minimum loss impedance matching pads for precision measurement and impedance matching applications. Model MLPV is a 50/75Ω pad covering the 1 to 500 MHz frequency range. Loss is 5.7 dB nominal. Loss flatness is ±0.1 dB max. and VSWR is 1.05:1 for either 50 or 75Ω port. Model MLPU covers the range of 1 to 900 MHz and has specifications similar to the MLPV. Loss flatness is ±0.2 dB. Price for the MLPV is $45 and the MLPU is $75. **Wideband Engineering Company, Inc., Phoenix, AZ. INFO/CARD #189.**

Automatic Modulation Meter

CT Systems introduces Model 4101, a fully automatic Modulation Meter. Automatic measurements can be made from 1.5 MHz to 2.0 GHz of FM deviation to 100 kHz and AM modulation to 100 percent. Priced at $1,395, the 4101 Modulation Meter has a large, easy-to-read meter, three selectable filters and is available with a rechargeable battery option. **CT Systems, Inc., Beech Grove, IN. Please circle INFO/CARD #190.**

Long Delay Line

Sawtek introduces a SAW long delay line. Designed for non-dispersive delay line applications in which long delays exceeding 30 us and small size are required, the long delay line center in frequencies operate in the range of 20 MHz to over 600 MHz. It allows for a non-dispersive delay from 20 to 200 us. The fractional bandwidths obtainable vary from 4 to 30 percent of center frequency. Insertion losses range between 20 to 50 dB. Amplitude ripple varies from 0.5 to 1.5 dB. **Sawtek, Inc., Orlando, FL. Please circle INFO/CARD #218.**

Digital Prescalers for 0.5-2.8 GHz

NEC has developed a family of new digital high frequency prescalars that divide by 2 (UPB581) and divide by 4 (UPB582). Applications include frequency synthesis, division and prescaling. The devices operate from .5 to 2.2 GHz (package A) and from .5 to 2.8 GHz (package C). Both prescalars are available in two packages; an 8 pin can (package A) and an 8 pin DIP (package C). **California Eastern Laboratories, Santa Clara, CA. INFO/CARD #217.**

Cascadable Amplifiers Have Variable Gain

HP introduces the HAMP-4001 and HAMP-4002 variable gain controllable amplifiers for use in circuits requiring automatic gain control. The amplifiers provide a modular solution to system gain control requirements cascadable with other standard amplifiers in a 50 ohm system. The biasing and coupling is provided internally. The HAMP-4001 provides 22 dB gain and 30 dB gain control over the frequency range of 2 to 1250 MHz. The HAMP-4002 provides 17 dB gain and 29 dB gain control over the frequency range of 2 to 1600 MHz. In quantities of 100, the HAMP-4001 is $100 and the HAMP-4002 is $115 per piece. **Hewlett-Packard Company, Palo Alto, CA. Please circle INFO/CARD #216.**

Ferrite Circulator is High Power

Thomson Microwave Division has introduced a high power 225-400 MHz circulator. The Model BB3007-02 has an input power handling capability of 200 W CW, 1 kW peak. Isolation is 17 dB min., VSWR is 1.35 max. and insertion loss is 0.6 dB max. IM3 is −70 dBc$_1$ (P_1 = 200 W; P_2 = 2 W). **Thomson Components-Mostek Corp., Rutherford, NJ. Please circle INFO/CARD #198.**

Surface Mounted Crystals

Q-Tech introduces a line of surface mounted crystals in two standard 480 mil square 40 pad leadless chip carrier (LCC) packages: the QX64A (85 mil thick) and the QX64B (65 mil thick). Frequency ranges from 5 MHz to 125 MHz depending on the mode of operation. They are also available in swept quartz for radiation hardened aplications. **Q-Tech Corp., Los Angeles CA. INFO/CARD #188.**

NMR Amplifiers Offer 3 kW and Fast Blanking

Kalmus Engineering introduces a series of NMR amplifiers consisting of 8 new models which cover 10-500 MHz at power levels from 500 to 3000 W. Built in

blanking circuits permit ultra-fast RF pulse blanking better than 0.5 us. **Kalmus Engineering International, Ltd., Woodinville, WA. INFO/CARD #215.**

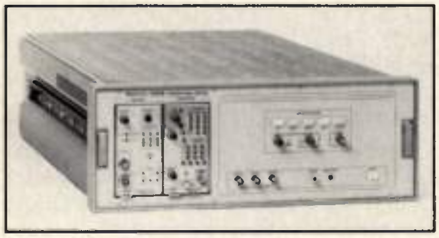
Digital LCR Meter

The Model TC200 will measure capacitance, inductance, resistance and the dissipation factor over a wide range. The measured values are displayed on a 3 1/2 digit LCD display with automatic

decimal point positioning. The display provides warning for low battery and overrange conditions. **Thandar Electronics Ltd., St. Ives, Cambs., England. Please circle INFO/CARD #214.**

750 MHz Transient Digitizer

The 7912HB Programmable Digitizer operates at 750 MHz for applications requiring the capture and analysis of fast single shot events. With 10 ps/point time resolution, it performs at the equivalent of 100 gigasamples per seconds. The unit accepts the 7000 series amplifier and time



base plug-ins. Plug in amplifiers include the 7A29 amplifier at 700 MHz bandwidth, 7A19 amplifier at 500 MHz and the 7A16P programmable amplifier at 200 MHz. The 7F10 optical amplifier is also supported. **Tektronix, Inc., Vancouver, WA. Please circle INFO/CARD #213.**

Environmentally Hardened Oscillator

FTS unveils the environmentally hardened FTS 2000A/019 crystal oscillator which features fast warm-up and operates over a temperature range of −55C to 71C. It reaches 2×10^{-7} of final frequency in 5 minutes after cold soak at −55C. Power consumption during warm up is 30 W. The phase noise characteristic is −150 dBc at 1000 Hz. Aging per day is 5×10^{-10}. The unit measures 2"× 2"× 5.4" and is available in frequencies of 4 to 16 MHz. **Frequency and Time Systems, Inc., Beverly, MA. INFO/CARD #210.**

HI-Q Crystal Products

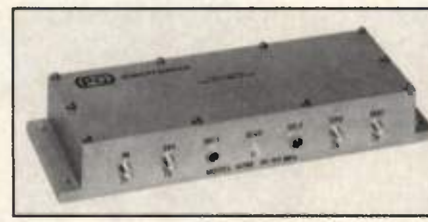
Hi-Q Crystals introduces a line of crystals covering surface mount custom packages, TO-5 round and HC-45 miniature packages. Frequency range covered is from 4 MHz to 200 MHz. **HI-Q Crystals, Hybrid International, Ltd., Olathe, KS. INFO/CARD #212.**

Miniature Noise Modules

Micronetics introduces a series of noise modules that offer broadband white Gaussian noise covering the 1 MHz to 6 GHz range. The NMU-2000 has a typical flatness of ±0.5 dB with the output ranging from 15.5 dB ENR to 30 dB ENR. The device is packaged in a 14 pin dip measuring .875"× .50"× .24". A list of options is available . Single piece units start at $89. **Micronetics, Inc., Norwood, NJ. INFO/CARD #211.**

Wideband Amplifiers are Linear

Linear wideband amplifiers are available for bands from 2 to 500 MHz. These modules utilize feedforward distortion cancellation to achieve typical third order intercept points of +57 dBm. The configuration also provides improved reliability as any transistor failure does not change the overall gain but results in a



reduction in dynamic range. **P.G. Electronics, Inc., Wilmington, DE. Please circle INFO/CARD #209.**

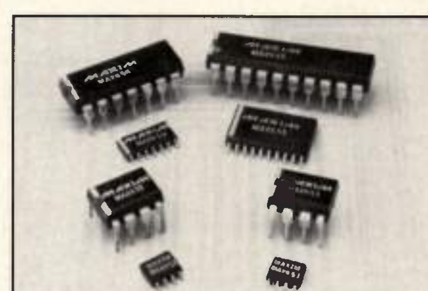
Fast Switching Synthesizer

Eaton Corporation introduces its Model 384M-255 Modulating Synthesizer System for use in multi-mode communications. It is a fast switching synthesizer that offers AM, FM, Phase and BPSK modulation. Rates up to 10 MHz

can be applied to the FM and phase modulator, while the BPSK modulator can be driven up to 5 MHz. A half frequency unmodulated carrier output is also provided. The 384M-255 operates from 1 MHz to 4 GHz with 20 us switching and low noise. **Eaton Corp., Electronic Instrumentation Div., Los Angeles, CA. INFO/CARD #208.**

Video/Mux Amplifier

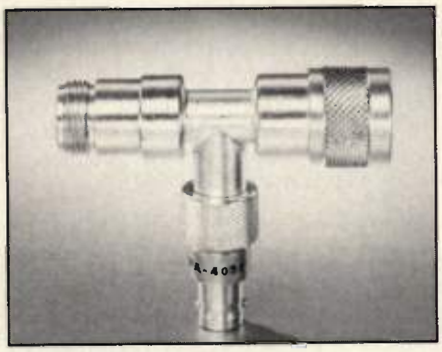
The MAX452 is a unity gain stable 50 MHz video amplifier capable of driving a 75 ohm load directly. The MAX453, MAX454 and the MAX455 combine the 50 MHz video amplifier of the MAX452 with



an on board multiplexer offering 2, 4, or 8 channels respectively. Optimized for video applications, these amplifiers will directly drive a 150 ohm load to ± 2 V. The devices are available in surface mount, standard cerdip and DIP packaging. **Maxim Integrated Products, Sunnyvale, CA. INFO/CARD #207.**

RF Signal Sampler

The RFA-4059 RF signal sampler is made of silver plated brass with gold



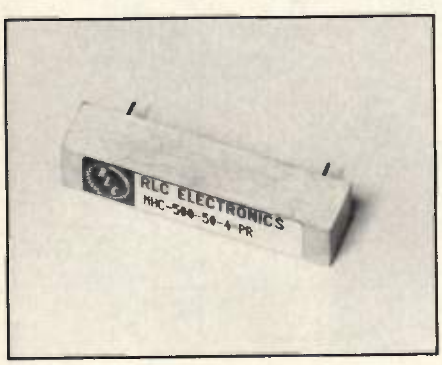
center pins and teflon insulation. It is a N female connected to a N male by a through line section. The vertical part of the T is terminated by a BNC female jack from which the RF sample is taken. Attenuation from 20 to 80 dB can be produced. The frequency range is from 50 MHz to 12 GHz and at powers up to 500 W continuous. **RF Industries, Hialeah, FL. INFO/CARD #206.**

125 MHz CMOS Video DAC

Integrated Devices introduces an 8-bit 125 MHz video analog to digital converter. The IDT75C18/28 can directly drive a 75 ohm load to standard video levels with a resolution of 1280 × 1024 pixels. For most applications, no additional registering, buffering or deglitching is required. Power dissipation is specified at 400 mW. **Integrated Device Technology, Inc., Santa Clara, CA. INFO/CARD #205.**

Bandpass Filters

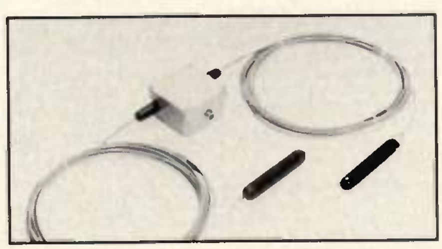
RLC Electronics announces the introduction of a series of bandpass filters. Standard units with center frequencies of



80 to 1200 MHz are offered in 2 to 8 sections with 3 dB bandwidths from 2 to 15 percent. A 1000 MHz center frequency, 20 MHz bandwidth, three section unit provides an insertion loss of 4 and 30 dB attenuation at 966 MHz and 1052 MHz. The filters are priced at $310 in unit quantities. **RLC Electronics, Inc., Mt. Kisco, NY. INFO/CARD #203.**

Wide Band Antennas

A family of wide band antennas for the high fractional bandwidth low HF bands which eliminate the need for antenna



tuners and special radiator networks are introduced by Poyntek. Snyder Full Band™ wide band antennas for the 160, 75/80 and 40 meter bands are designed to allow maximum use of broad frequency range, continuous or digital tuned transceivers and no tune power amplifiers to 1000 W. **Poyntek Associates, Placentia, CA. INFO/CARD #204.**

Low Phase Shift Limiter

Petrond's PLM limiters cover the frequency band of 10 to 160 MHz with a dynamic range from −5 to −70 dBm at −12 VDC and 150 mA typical. VSWR is 1.5. All unit have removable connectors in a 2.5" × 1.1" × 0.22" stainless steel package. **Petrond Microwave, Santa Clara, CA. INFO/CARD #202.**

Miniature Wire Wound Inductors

Toko America introduces four types of miniature wire wound inductors. Type 32CS coils are fixed type chip inductors for solder dipping. The inductances vary from 0.1 to 220 uH. **Toko America, Inc., Mt. Prospect, IL. INFO/CARD #201.**

Chip Capacitors Include Nickel Barrier Layer

American Precision includes the option of a nickel barrier layer to its line of multilayer ceramic chip capacitors. The nickel barrier layer minimizes termination leaching during solder cycles. Class I-COG(NPO) components are from 1 pF to 0.027 uF. Class II X7R parts are from 100 pF to 0.68 uF. **Delcap Division, API Electronic Components, East Aurora, NY. INFO/CARD #200.**

Shielding Cabinet

The Vent Rak TEMPEST cabinet from General Devices is an EMI/RFI high shielding cabinet designed for military, TEMPEST and EMP applications. The cabinet provides a minimum of 88 dB of shielding up to 10 GHz. Features include a double wall 10 gauge frame, 14 gauge side panels and doors plus elastomer gaskets to prevent leakage or interference. **General Devices Co., Indianapolis, IN. INFO/CARD #199.**

Crystal and Oscillator Catalog

Bliley Electric Company has published a 12-page color catalog which updates the specifications of its line of quartz crystals and crystal oscillators. Bliley's SMT crystals, OCXO and TCVCXO oscillators are covered in detail. The C/D5 catalog is available on request. **Bliley Electric Company, Lewiston, NY. Please circle INFO/CARD #187.**

High Power Microwave Sources

High power microwave sources suitable for survival and RF hardness against electronic jamming of electronic systems and components are described in this equipment guide from Cober Electronics. Typical microwave power generators include magnetron pulsers with 1 MW output, CW klystron sources with 10 kW output and 1 kW pulse/CW units. Frequency spectrum, power output and operating parameters for these power sources are determined by the microwave tubes utilized. **Cober Electronics, Inc., Stamford, CT. INFO/CARD #197.**

Attenuator and Coaxial Switch Catalog

JFW has released its Attenuator and Coaxial Switch catalog, presenting designs such as a 1P8T coaxial switch with a frequency range of 250 kHz to 1100 MHz. Also included are two new matrix switch models. **JFW Industries, Inc., Indianapolis, IN. INFO/CARD #196.**

TVRO Interference Filter Data Sheet

This TVRO data sheet identifies the T1 suppression, insertion loss, DC continuity and construction features. A frequency response chart illustrates a competitive comparison of signal protection. The filter is designed for in-line installation at existing antenna sites utilizing male and female type N connectors which provide built in DC continuity so jumper wires are not required for LNA power. **North Hills Electronics, Inc., Glen Cove, NY. INFO/CARD #195.**

Reconditioned Test Equipment Catalog

A catalog of reconditioned test equipment is available from Rubytron Instruments. It features RF and microwave instruments such as spectrum analyzers, power meters, counters, RF sweepers and signal sources. All the instruments are calibrated and guaranteed. **Rubytron Instruments, Port Chester, NY. INFO/CARD #194.**

Signal Processing Technical Journal

Analog Dialogue is a technical journal on circuits, systems and software for signal processing, prepared by Analog Devices. It highlights the AD569, a 16 bit monotonic DAC with applications including closed end process and high precision waveform generation. **Analog Devices, Norwood, MA. INFO/CARD #193.**

1987 Test Equipment Catalog

Sencore's Spring/Summer full line catalog features waveform analyzers, capacitor and inductor analyzers, and frequency counters. Also featured is a section on related accessories for the equipment. **Sencore, Sioux Falls, SD. INFO/CARD #192.**

INFO/CARD 47

Ad Index

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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

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INFO/CARD 51

SAW Questions and Andersens.

Dispersive devices:

QUESTION: I'm curious about dispersive devices. Where would I use them?

ANDERSEN: Our matched filters are widely used in digital communications and radar. With pulse expansion/compression you can increase dynamic range without increasing transmitter peak power or sacrificing resolution. They're also used in compressive receivers for real time spectrum analysis with 100% probability of intercept.

QUESTION: What range of bandwidth, dispersion and center frequencies are available?

ANDERSEN: SAW dispersive devices are used for wide bandwidth applications (up to 500 MHz) with dispersions up to 100 μs. IMCON dispersive devices have narrower bandwidths but provide dispersions up to 600 μs (IMCON's have been cascaded to produce dispersions of 10 ms). Center frequencies of Andersen dispersive devices range from 1 MHz to 750 MHz.

QUESTION: If I want to use dispersive devices in my system, what do I do?

ANDERSEN: We can help you specify the devices you need. Or we can supply the entire subsystem (compression/expansion module, compressive receiver, etc.). We've been supplying such systems for over 20 years. And with our in-house hybrid facility we can provide a compact, high performance unit tailored specifically for your system needs.

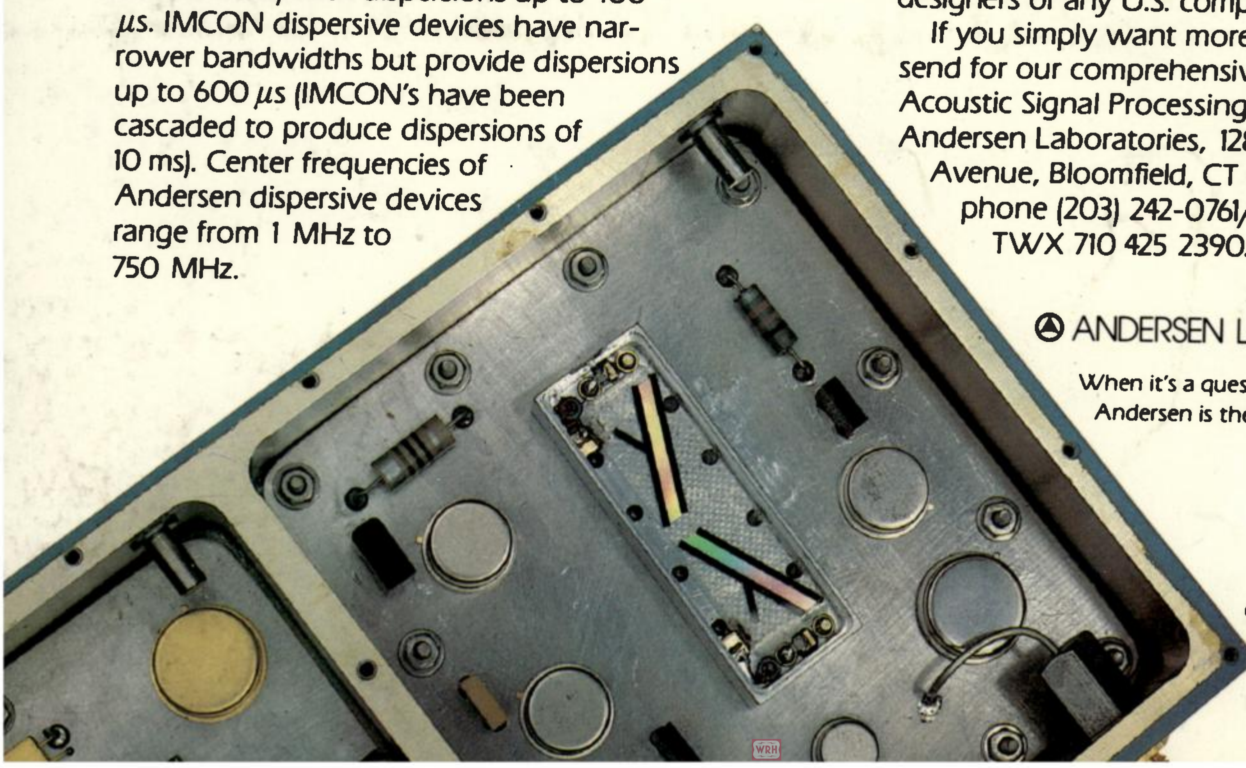
QUESTION: How do I get started?

ANDERSEN: Just give us a call. We'll do everything we can to meet your needs. With our recent major staff increase, we offer one of the largest groups of SAW designers of any U.S. company.

If you simply want more information, send for our comprehensive handbook on Acoustic Signal Processing. Write to Andersen Laboratories, 1280 Blue Hills Avenue, Bloomfield, CT 06002. Or phone (203) 242-0761/ TWX 710 425 2390.

ANDERSEN LABORATORIES

When it's a question of SAW, Andersen is the answer.



Compressive Receiver (actual size)

INFO/CARD 52