rf design

ideas for engineers

June 1986

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INFO/CARD 2

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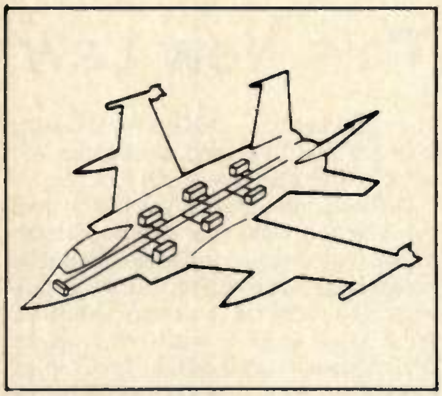

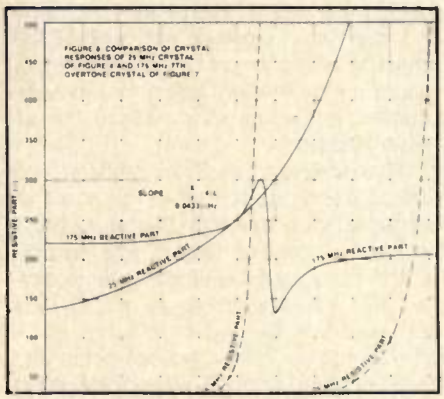

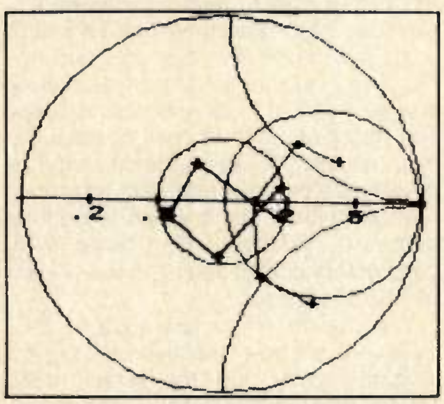

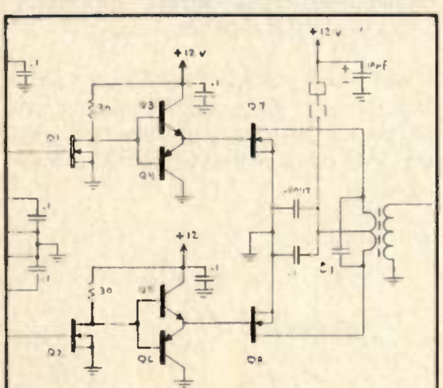

Cover

This month's cover features A/D devices manufactured by ILC Data Device Corporation, Bohemia, New York. In the foreground is the BUS-65112, a MIL-STD-1553 Dual Redundant Remote Terminal Unit. Packaged in a 1.9" x 2.1" hybrid, it includes two transceivers, two encoder/decoders, an RTU protocol, data buffers and timing control logic. In the center is the BUS-65505 Controller/RTU/BUS Monitor for complete intelligent interfacing to the DEC UNIBUS.® At the top is the BUS-68003 Data Bus Exerciser for testing, exercising and troubleshooting 1553 systems.

Features

Departments

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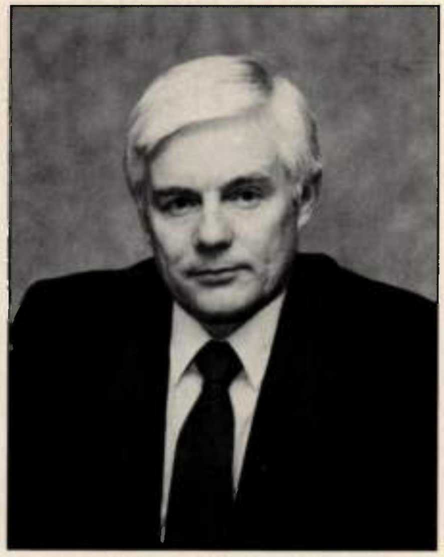
Be Careful With This New Law



A recent meeting of the International Society for Optical Engineering, formerly the Society of Photo-Optical Instrumentation Engineers (SPIE), was thrown into chaos when meeting organizers learned at the last minute that many unclassified papers scheduled for presentation would have to be given in closed session. The society was the first scientific organization to feel the effect of a new law.

The law, P.L. 98-94, allows the Secretary of Defense to "withold from public disclosure any technical data with military or space application in the possession of, or under the control of, the Department of Defense." Defense Department officials say the law was passed because of a discrepancy between export control acts and the Freedom of Information Act that allowed certain sensitive technical information to fall through the cracks.

The Export Administration Act of 1979 and the Arms Export Control Act prohibited the export of information with which weapons on the Munitions Control List could be made. These laws were administered by the Departments of Commerce and State. Using the Freedom of Information Act, however, anyone could obtain some of this information from unclassified projects funded by the DOD. The new law allows DOD to withold such information if State and Commerce can withold it, regardless of the FOI act.

Defense contractors know that papers resulting from DOD sponsored work must be submitted for approval before public presentation, and expect classified projects to be restricted to cleared personnel. What surprised SPIE, apparently, was the DOD stipulation that certain unclassified projects could not be discussed before foreign nationals. Fortunately, a compromise was worked out with DOD whereby only proof of U.S. citizenship or clearance by friendly foreign nation embassies was required to attend the affected sessions.

What now worries SPIE officers, and should worry the rest of us, is how this new law will be applied in the future. Such regulatory acts are seldom applied only for the purpose for which they were written. Most of us would agree that there is little sense in making information available to hostile foreign governments that could be used to make weapons against us, but who is to decide whether unclassified information meets this criterion?

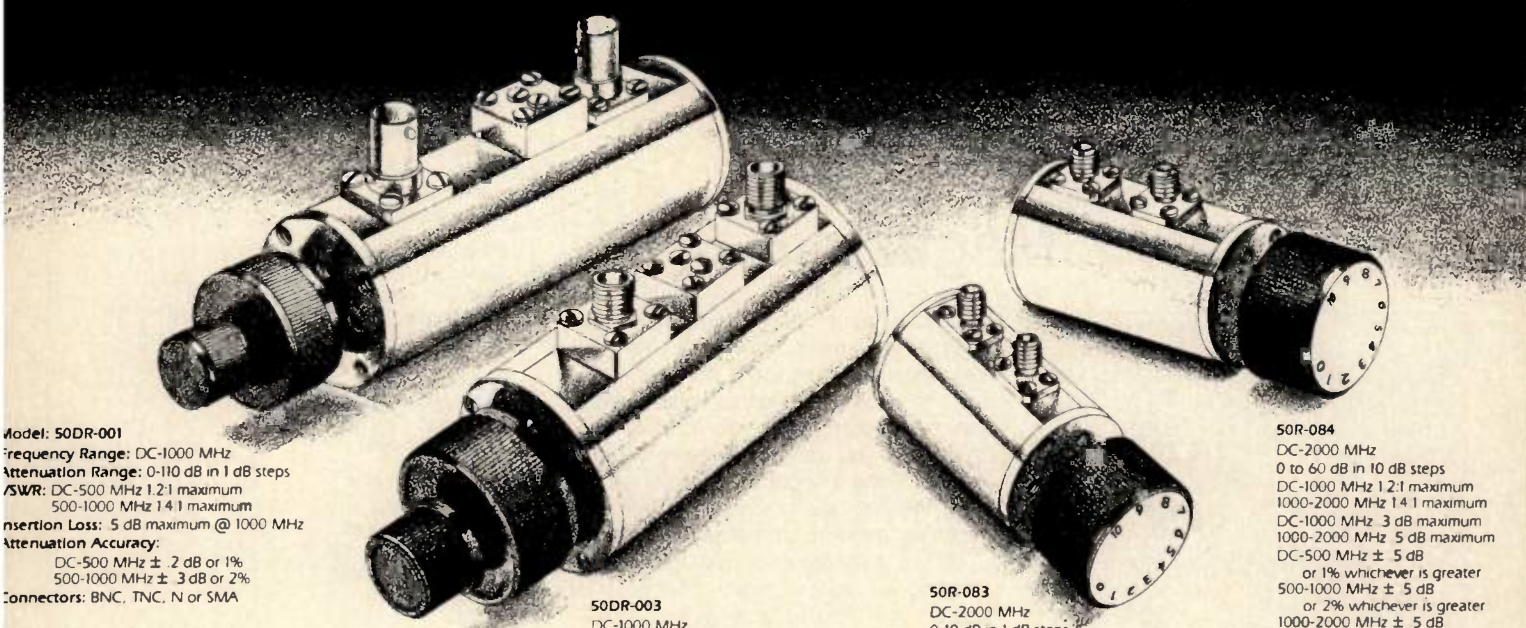
We may suffer from that behavior pattern known as the "cover your rear" syndrome. Asked to judge whether information might be used to design, produce, etc., military or space technology, a government official is most likely to restrict any information about which there is a question. Have you ever heard of a government official getting in trouble for being too cautious?

The trouble with a law such as P.L. 98-94 is that it takes the responsibility for judgment away from the person most familiar with the information — the expert who prepared the paper.

We thank William Griffith, Senior Engineer at Ad-Vance Magnetics, for bringing this matter to our attention, and we invite other readers to send us their opinions.

James N. MacDonald

ROTARY ATTENUATORS



HIGH POWERED!

rf publisher's note

A Dedicated Magazine

Keith Aldrich
Publisher

Since many of our readers are relatively new to the RF field, having grown up with the digital computer instead, they are familiar with the word "dedicated" as it applies to that ubiquitous instrument. It means that the computer is programmed and wired to do one task out of the many that might be accomplished with the same collection of processors.

RF Design is a magazine that is dedicated in a similar way. It is devoted to serving design engineers, as many electronics magazines are. However, it is the only such magazine that concentrates exclusively on the design of RF equipment using frequencies from DC up to about 3 or 4 GHz.

While other magazines write about work in the RF frequencies from time to time — especially now that RF is such a flourishing field — it is for them a part-time task. Their coverage of the subject tends to be of the kind that informs your associates over in the purchasing department what those guys in RF are up to now. It isn't always that much help to you.

Our dedication to the subject of RF design has the advantages that are sometimes offered by a dedicated computer. It deals with more aspects of the task to be accomplished, in more detail, with more familiarity. We can afford to devote time and space to some topic that isn't an exciting breakthrough, for example, but is something you need to know to do a job you weren't necessarily trained for in college. We concern ourselves with your training, as well as with your more dazzling accomplishments.

Why are we bringing this up? Perhaps to save you time in looking for practical help in your RF design engineering task. There just isn't much help to be found. Walk into the engineering section of any bookstore and look for topics similar to those covered in a typical issue of *RF Design*. You'll find row after row of books on computers, control systems, even a few on microwave topics — and probably nothing related to RF but a ham radio handbook.

In a recent interview, published in this issue, Bruno Weinschel, president-elect of IEEE, voices his concern about the current training of electronics engineers. We have printed it because we share the same concern, especially as it applies to RF design engineers. RF has become the forgotten technology in engineering colleges.

This situation will change, of course. RF has emerged as the bright shining "place to be" in an electronics industry that until recently has been dominated by digital technology. In the years immediately ahead we will surely see a wave of books, courses and curricula dealing with various aspects of RF technology, and we welcome them all. In the meantime, you can depend on our dedication to lead the way — and in fact to inspire much of the increased recognition that RF technology deserves.

Keith Aldrich

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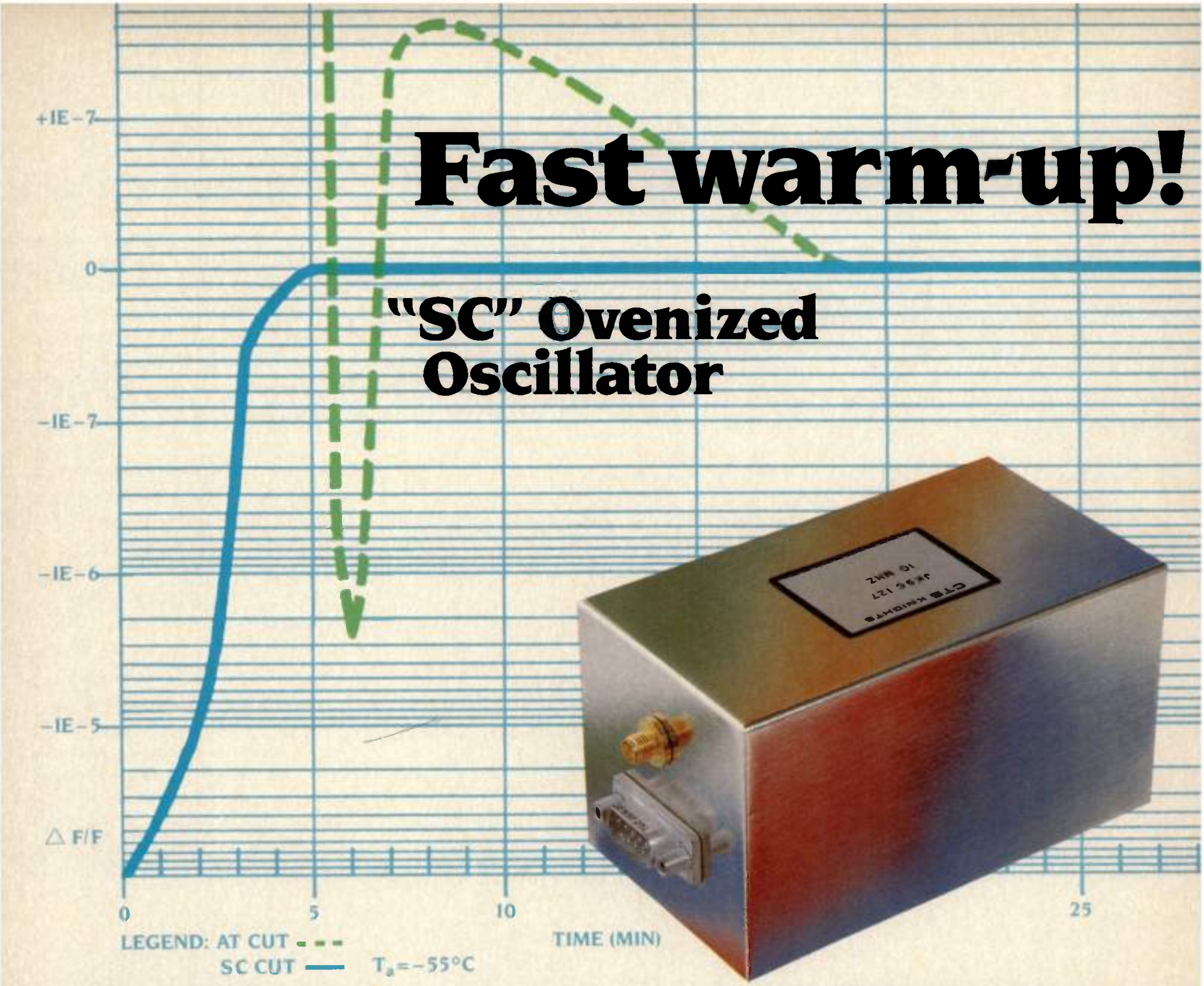

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Warm-Up	@ −55°C ±5 x 10^{-9} in 7 minutes @ −32°C ±5 x 10^{-9} in 5 minutes @ +25°C ±5 x 10^{-9} in 3 minutes
Input Power	Oven @ turn-on 1.2 A maximum @ +28 V Oven @ 25°C 125 mA typical @ +28 V Oven @ −55°C 240 mA typical @ +28 V Oscillator 20 mA maximum @ +15 V
Frequency Stability Vs. Temperature	±5 x 10^{-9} from −55°C to +71°C
Phase Noise	(1 Hz BW) @ 10 Hz offset −120 dbc @ 100 Hz offset −140 dbc @ 1 KHz offset −150 dbc @ 100 KHz offset −150 dbc

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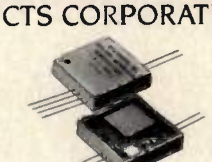

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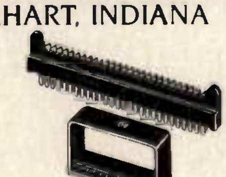

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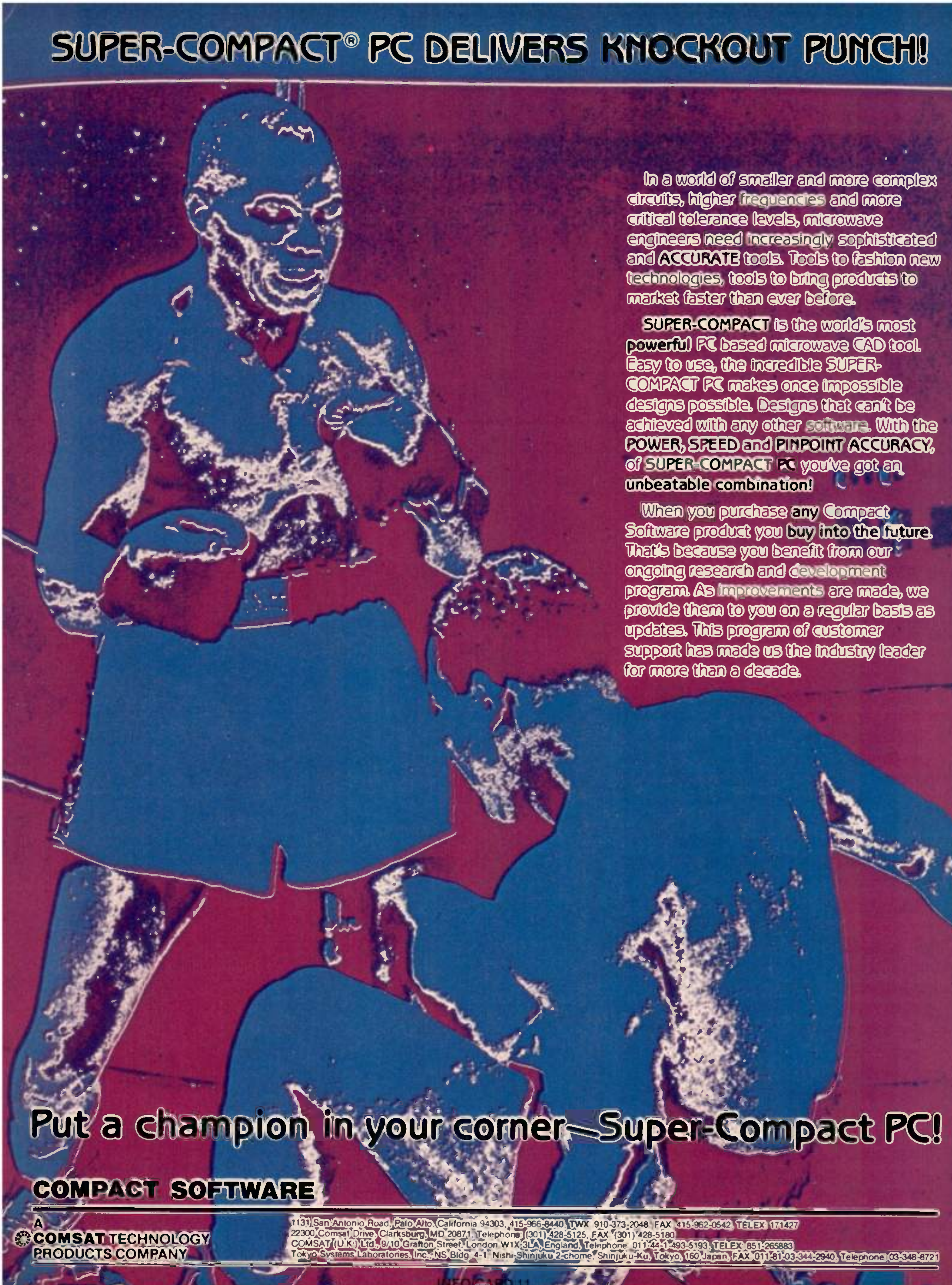
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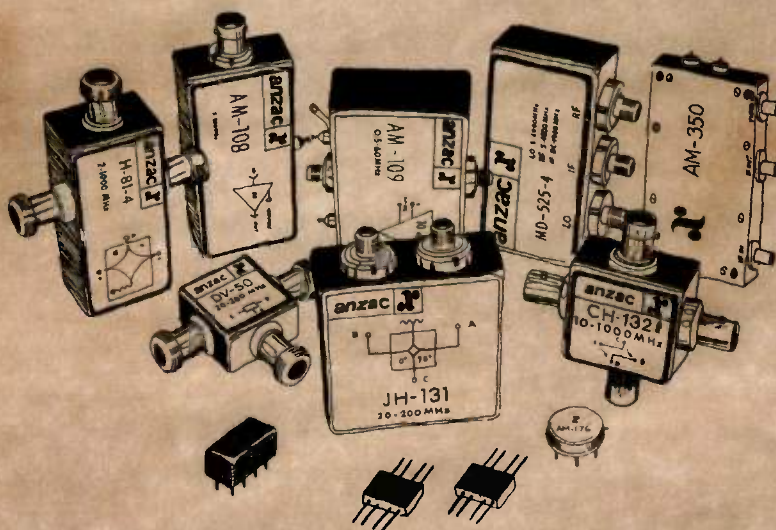

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INFO/CARD 12

See us at the MTT-S, June 4-6, Booth #528.

Editor:

Congratulations on your well written and informative comments. It is regrettable that since most of its readers have experiences of their own, this message is probably wasted on *RF Design* magazine readers. Most will merely read it and agree!

I have no interest in detailing my own experience or that of others, and you will undoubtedly have altogether too many letters to select from for the "RF Letters" column.

I would appreciate permission to reprint your editorial and send it to our local newspapers, the amateur radio newsletter and our Arizona Representatives and Senators as well as a few others to be determined later. . .

Serg Ticknor
President, Wide Band Engineering Co., Inc.

Editor:

In the April '85 editorial, "About That $600 Toilet Seat. . .," Mr. MacDonald forgot the essential and very expensive legal staff.

Jerry Goff
Hewlett-Packard

Editor:

Good editorial on qualification, but perhaps you can mention the qualification process relating to *a toilet seat*. Is this the potential cause of a ship sinking?

How do we relate the $400 coffee pot to the reliability of an aircraft?

The clincher concerning the toilet seat is that it's not even human engineered.

F. DeFelice

P.S. Enjoy your magazine!

Editor:

I very much enjoyed the program run by Alan J. LaPenn in your magazine, I would, however, like to point out two typographical errors which I have found. The first one is line 270 f3 = (1/(6.28*fo*x2))* –1. In the place of x2 should be x3. The second error is in line 410 x1 = rs*(sqr((rl/rs)/(q 2 + 1 – (rl/rs)))* –1. The set of three parentheses at the end of the equation should instead be a set of four. One parenthesis was omitted.

I would also like to point out that when the program was run with the corrections it was also compatible with the IBM PC.

Good work!! Keep it coming.

Vincent Onelli
Rochelle Park, N.J.

Editor:

The article by Mr. LaPenn on the BASIC program for 14 matching networks in the April 1985 *RF Design* is clearly an update of an earlier article on the same subject. Fortunately, the equations were given in the earlier article, and I reprogrammed them for my Sharp 1401 computer to solve the problem at that time.

Some apparent similarities among the equations caused me to suspect that some simplifications should be possible. I found that in fact to be true. There is no point in computing a given expression over and over in slightly different forms.

Since the program for the various TI and HP programmable calculators are far from interchangeable, I would suggest that a program in BASIC should always be provided for flexibility in applications. It isn't even possible to use a TI59 program on a TI57, let alone an HP, etc. One has to start from the basic equations if they are given. (They should be.)

The article is useful, but would have been more so if the various equations had been resolved as listed below.

Very truly yours,
Keats A. Pullen, Jr.

$$W = \sqrt{Y-1};\quad T = Q^2+1;\quad U = R_S R_L - R_S^2;\quad V = R_L / Q;\quad Y = \frac{R_S}{R_L}(Q^2+1);\quad Z = QR_L - \frac{R_S R_L}{X_1}$$

1,2
$$X_1 = \frac{-R_S}{\sqrt{Y-1}} = \frac{-R_S}{W}$$
$$X_2 = Z / T$$
$$X_3 = \frac{-R_L}{Q} = -V$$

3,4
$$X_1 = \frac{R_S}{\sqrt{Y-1}} = \frac{R_S}{W}$$
$$X_2 = Z / T$$
$$X_3 = \frac{-R_L}{Q} = -V$$

5,6
$$X_1 = QR_S$$
$$X_2 = \frac{-R_S T}{Q+\sqrt{Y-1}} = \frac{-R_S T}{Q+W}$$
$$X_3 = R_L\sqrt{Y}$$

7,8
$$X_1 = QR_S$$
$$X_2 = \frac{-R_S T}{Q-\sqrt{Y-1}} = \frac{-R_S T}{Q-W}$$
$$X_3 = -R_L\sqrt{Y-1} = -R_L W$$

9,10
$$X_1 = \sqrt{U - QR_S}$$
$$X_2 = QR_S$$
$$X_3 = -R_S R_L / (X_1 + X_2)$$

11,12
$$X_1 = \sqrt{U}$$
$$X_2 = -R_L / Q = -V$$
$$X_3 = \frac{X_2}{(X_1 / QR_S - 1)}$$

13,14
$$X_1 = \sqrt{U}$$
$$X_2 = \frac{-R_S R_L}{X_1}$$

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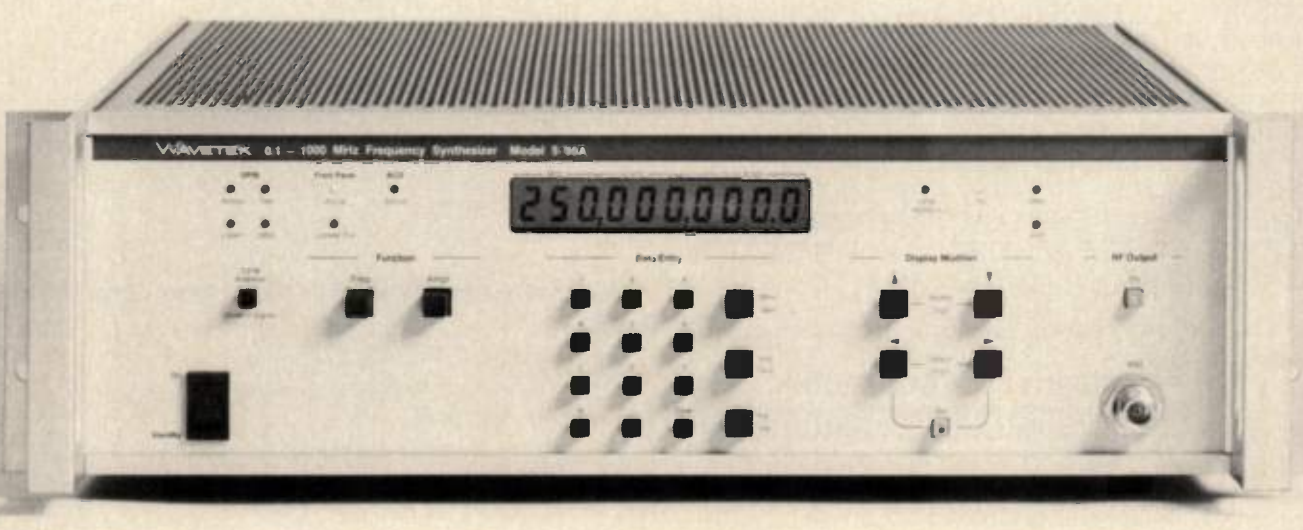

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rf calendar

June 4-6
MTT-S

St. Louis, MO

Information: Fred Rosenbaum, Central Microwave, 12180 Prichard Farm Rd., Maryland Heights, MO; Tel: (314) 291-5270.

June 19-21
Nepcon East 85

Bayside Exposition Center
Boston, MA

Information: Show Manager, Cahners Exposition Group, Des Plains, IL; Tel: (312) 299-9311.

August 27-29
Quartz Devices Conference & Exhibition

The Westin Crown Center
Kansas City, MO

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rf courses

June 3-4
Introduction to Receivers
2-day course

George Washington University
Washington, DC

Information: Stod Cortelyou, George Washington University, Washington, DC; Tel: (800) 424-9773.

June 17-21
Microwave Circuit Design — Linear Circuits

UCLA
Los Angeles, CA

Information: Les Besser, Microwave Educational Programs; Tel: (213) 825-3344.

June 24-28
Microwave Circuit Design — Non Linear Circuits

UCLA
Los Angeles, CA

Information: Les Besser, Microwave Educational Programs; Tel: (213) 825-3344.

Interview with Bruno Weinschel, President-Elect, IEEE

RF Design *recently spoke with Dr. Bruno Weinschel, President-elect of the IEEE, about the lack of analog training in our Engineering schools. Part of the interview, dealing with Engineering education in general, is reproduced here. Dr. Weinschel speaks of changes he would like to see in U.S. Engineering colleges.*

RF: I suppose you have heard the criticism that the papers presented at IEEE symposiums and published in IEEE Transactions are too scholarly and concerned with theoretical fine points rather than practical matters. As President-elect of the IEEE, are you concerned about this?

Weinschel: The award system in the IEEE mirrors academia, and of course tenure in academia in Engineering results from publishing the results of basic research. You don't obtain tenure because you have solved some very important practical problem. You don't get tenure because you helped engineer a Boeing 747 or a complete satellite system or digital telephone system. You have to publish something which is on basic research, which expands our knowledge of science or nature. And this is reflected in our awards system. Lately we have become painfully aware that we are awarding Engineering science more than Engineering practice.

But what makes a country strong is a balance between Engineering science and Engineering practice, because you have to transform the fruits of science into useful products and services which can be supplied competitively, in quality as well as cost. So we have become aware that we have to emphasize more Engineering practice.

I am on a task force of the American Society of Engineering Education, headed by John Kemper of the University of California at Davis, which is concerned with the requirements of an Engineering educator. They have, to my joy and pleasant surprise, agreed that the conditions for granting tenure should not be based only on published results of basic research, as it has been historically, but excellence in teaching should be of equal importance.

Historically, we have slipped into a very interesting position. In the Second World War a lot of advances in microwaves were actually accomplished by physicists at MIT and Harvard. It became apparent that the engineer at that time could not really contribute much to new things. Therefore, there was a movement afoot to change the contents of the Engineering curriculum to put in much more basic science. Then, in 1957 we had Sputnik, which really got this thing going, and we bent over backwards to emphasize Engineering science at the expense of Engineering practice and manufacturing technology.

The federal goverment probably was one of the major contributors to this change by giving the universities a lot of funding in basic research. By doing this for about 30 years we were breeding out the teachers and we were breeding in the researchers. The majority of Engineering professors today, especially in Ph.D. granting universities, are researchers, not teachers. They love to do research and some of them consider teaching not as interesting as the research.

So, the American Society of Engineering Educators, which includes all the 280 or so deans of Engineering schools in the U.S., by agreeing at the highest level that teaching must be at least of the same importance in granting tenure as publications or research, is taking a tremendous step.

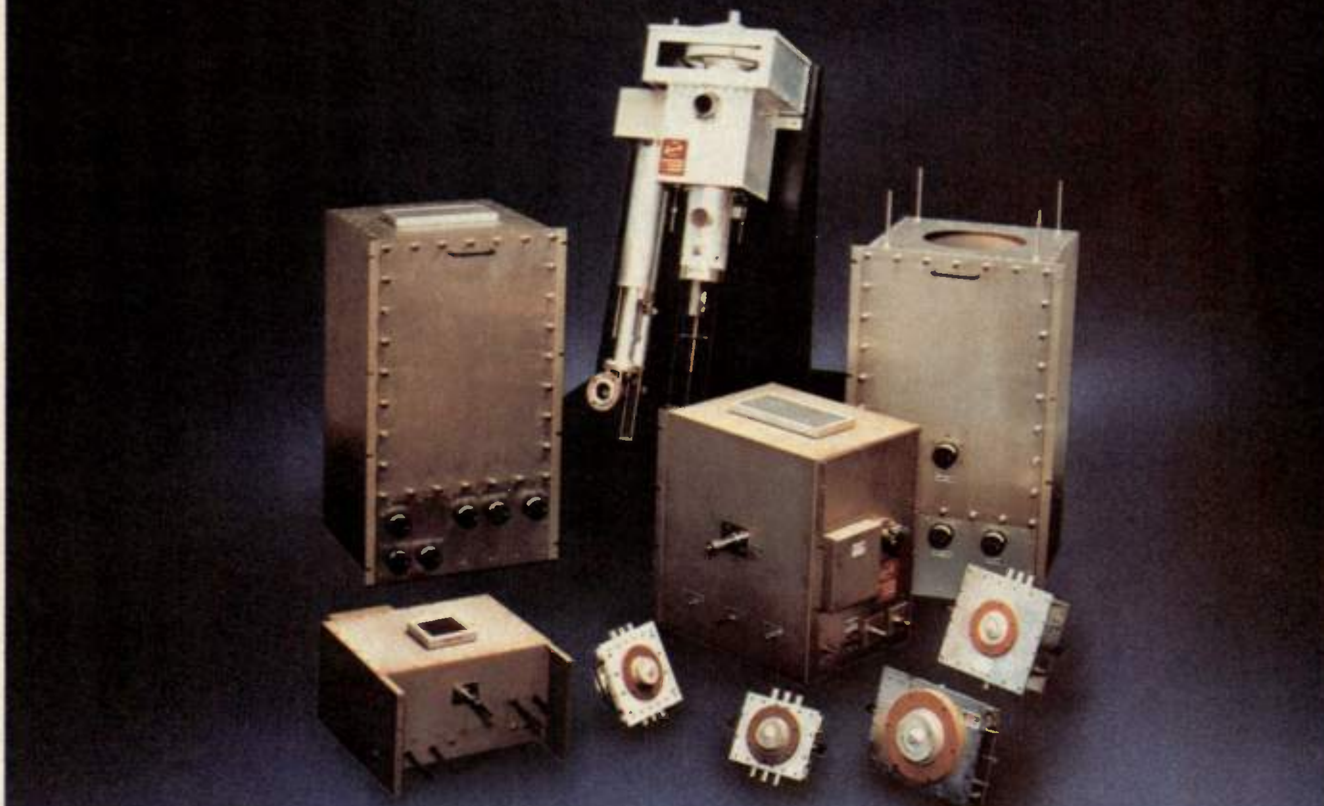
Another thing I'm arguing for in this committee, and it seems I am making some headway, is that there are three legs to granting tenure. There is research and there is teaching, but I'll add something else: being involved in a meaningful way in Engineering practice and industrial activities. Most of the graduates of our schools are employed by industry, but somehow we are focusing our best and brightest Engineering graduates into research, while some of our very successful trading partners, such as Japan and West Germany, are channeling their brightest Engineering graduates onto the manufacturing floor.

Both the British and the U.S. excel in basic research; we have the majority of the Nobel Prizes. But look at our trade balances. You take away the North Sea oil from Britain and it is going to be a sad trade balance. Last year our merchandise trade balance was about minus $123 billion, and I think with Japan alone it was somewhere over minus $20 or $30 billion. 1984 was the first year we imported more electronic devices than we exported.

It doesn't speak well for the future. And, of course, the IEEE is concerned with this — for several reasons. One is the basic health of the industry. Another is the job security of its members. We cannot compete in the world market unless we improve our manufacturing technology. So this whole thing about how you give people tenure and how you award them in the IEEE, in Fellow awards and other awards, relates to what kind of articles you emphasize in your transactions. It is all one stream, and I hope I can make some impact on it.

RF: Sounds like a large task. A lot of people will be wishing you luck.

Weinschel: Another impact I would like to make is to reduce this hemorrhage of



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CV-2250	3CX10,000U7	170–227	10 kW†
CV-2400	8874	420–450	300/1250 W*
CV-2800	3CX400U7	850–970	225 W
CV-2810	3CX400U7	910–970	190 W

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INFO/CARD 20

about 2 percent of our engineering population a year completely leaving the Engineering field, including technical management. This puts an undue pressure on the colleges and universities to produce more people, which could cause a reduction in the quality of the graduates. Up to now we have not seen a reduction of the quality of the graduates because we are using the absolute best Freshmen with excellent SAT scores. Our Engineering schools are so highly selective. Some of our schools have established a limitation of enrollment resulting in extremely high entrance requirements. At Davis, for instance, you have to have a 4.0 average for Electrical Engineering! At Maryland University you need a 3.9. Now with that kind of requirement you have to have good graduates, even if the teaching might not be of the same quality today that it was five years ago.

RF: Why do 2% of our engineers drop out of the field each year?

Weinschel: They probably see a better future somewhere else. Perhaps they find more psychological satisfaction or they can get more money. There isn't any good research on that subject. It is a very important subject and good research is needed. Not keeping up-to-date technically and/or underutilization are probably two more reasons. The resulting salary compression is another cause.

Besser To Teach Fundamentals of RF Design Course for RF Technology Expo 86

Les Besser, president of Microwave Educational Programs, Los Altos, Calif., will be instructor and supervisor of the *Fundamentals of RF Design* course at RF Technology Expo 86. Besser taught a half-day course on Small-Signal Amplifier Design at the 1985 Expo.

Besser met recently with *RF Design* publisher Keith Aldrich and editor James MacDonald to plan the course content for the 1986 conference. The course will begin at a more basic level this year, Besser said. He plans to devote the morning session to such concepts as basic design techniques, component functions, measurements and the changes in inductor and capacitor characteristics that occur at high frequencies. During the afternoon he will discuss low-level signal amplification principles, a subject which was well received at the 1985 Expo.

The second day of the course will be given to a detailed explanation of fundamental RF circuit building blocks, such as oscillators and power amplifiers. Cardiff Publishing Company officials are discussing ways to schedule the courses so attendees will have ample opportunity to hear papers.

MacDonald is program chairman for the 1986 conference. He said the program will be similar to the previous Expo, with as many as five papers being presented simultaneously. The program will be divided into half-day sessions. Papers dealing with the same subject will be presented in the same room each session.

"This way attendees can go from room to room to hear particular papers on different subjects or stay in one room to hear all the papers on one subject," he said.

MacDonald said he anticipated as many as 75 papers at the 1986 Expo. He had received 18 responses to the call for papers by the May 1 meeting. The deadline for proposals for papers is July 26, he said, with selection being completed by August 30. He said the reason for the early selection of speakers is that the Proceedings will be printed before the Expo and will be available there. The early selection will allow speakers ample time to prepare their papers for the Proceedings, he said.

RF Technology Expo 86 will be held at the Anaheim Hilton Hotel and Towers, Jan. 30 through Feb. 1. The hotel has a large exhibit space and conference rooms are available close to the exhibit hall.

Les Besser

Yearbook Predicts Nearly 6% Annual Growth in World Electronics Industry

The world electronics market is expected to grow at a rate of 5.9 percent per annum over the period of 1985 to 1988, according to data recently published by Benn Electronics Publications, Ltd., Luton, England. The estimate is based on forecasts for 30 leading countries. The rate is the compound annual average growth rate for 30 countries at a constant 1984 exchange rate.

Growth for 1985 is expected to be approximately 7.8 percent at constant 1984 values and exchange rates. The lower rates predicted for the 1985-1988 period reflect a U.S. economic downturn projected by a consensus of leading economic forecasters for 1986, according to Benn, and its likely effect on economic activity in other nations.

Communications and military electronics equipment are expected to grow by more than 7 percent per annum by the yearbook publisher, which predicts a 6.4 percent growth rate for the components sector over the four-year period. The information is contained in the BEP Yearbook of International Electronics Data 1985 Second Edition.

The yearbook contains a review of prospects for the economy and the electronics industry in each country and a list of sources of the information.

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INFO/CARD 31

MIL-STD-1553: A Viable Interface Standard

By Steve Friedman
ILC Data Device Corporation

This article introduces the reader to the serial data bus known as MIL-STD-1553. A brief history and overview of the standard gives a better insight to why it is growing in popularity with the tri-services.

A discussion of some typical off-the-shelf products and how they support the RF engineer in integrating a system with that of MIL-STD-1553 is included. The special protocol and interface requirements of MIL-STD-1553 are described on a system level.

One serial bus structure adopted by the tri-services is called MIL-STD-1553. This military standard document establishes the requirements for a serial, digital, command/response, time-division multiplex communication bus for aircraft. The bus permits transmission of information among several sources connected by a single, twisted, shielded pair of wires. The data is transmitted at a 1 MHz bit rate, using a Manchester II coded trapezoidal-wave-shaped transmission.

The MIL-STD-1553 specification evolved through the efforts of the U.S. Air Force in conjunction with the Society of Automotive Engineers (SAE). Their goal was to develop some type of system integration to help reduce the overall complexity of avionic systems. In the mid-60s avionic systems required a maze of interconnecting cables in order to integrate each black box of the system. This complexity introduced excessive size and weight and proved to be a major expense when system updates were necessary. Figure 1 depicts the avionic interconnection prior to the data bus standard.

The tri-services have accepted MIL-STD-1553 because of its well defined protocol and electrical specification, supported by off-the-shelf hardware. The U.S. Air Force mandates using a dual redundant data bus for additional reliability. Figure 2 illustrates an avionic MIL-STD-1553 Dual Redundant MUX (multiplex) BUS aircraft.

The data bus functions asynchronously in command/response mode; remote terminals (RTs) receive and transmit data only when commanded to do so by the bus controller. Data moves in both directions but in only one direction at a time. This half duplex information transfer flow is the responsibility of the bus controller which issues the commands. The bus controller is the main element within the multiplex system. System modifications require software changes to the bus controller's normal polling routine, since it directs and monitors all data bus traffic. The simplified architecture of a typical 1553 MUX BUS is shown in Figure 3. The dotted lines represent optional redundant data bus cables.

Figure 1: Avionic Interconnection

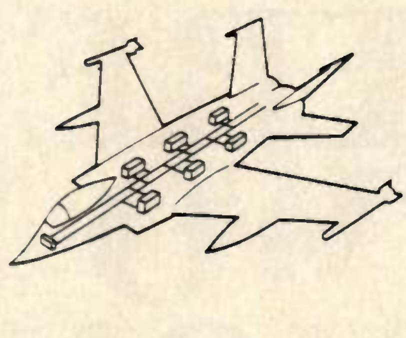

Figure 2: MIL-STD-1553 MUX BUS Aircraft

MIL-STD-1553 transfers data in a serial, digital, pulse code modulation (PCM) form at a 1 MHz transmission bit rate. The data is a Manchester II bi-phase code transmitted as a bipolar trapezoidal signal. The coding used provides both digital information and clock information transfers. Figure 4 shows the comparison between digital Non-Return to Zero (NRZ) data and Manchester II coded data. The information transfers, as initiated by the bus controller, are comprised of messages formed by three types of words. These are the command, data and status words (Fig. 5). Each word is 20 bits long, or 20 microseconds in time.

The first three bit times for all these word types is called the sync field (Fig. 5). The sync field distinguishes a command or status word from a data word. After the sync field come 16 bits that contain the information to be transmitted or received. The last (20th) bit is parity. MIL-STD-1553 uses odd parity to check validation of the 16 data bits. With the use of these words, transfers can be made from the bus controller to an RT, an RT to the bus controller, or an RT to an RT. The information transfer formats are shown in Figure 6.

In all cases the bus controller issues command words containing one unique RT address from a possibility of 32, or 31, should broadcast commands be allowed. Note that all message formats, with the exception of broadcast, generate a status word response with or without data, depending on the command issued. This closes the loop so the bus controller knows of any transmission problems. MIL-STD-1553 permits up to 32 data words per message transfer.

The MUX BUS is a twisted shielded two conductor cable terminated with a 70 ohm resistor at each end. MIL-STD-1553 permits two types of bus coupling, direct or transformer coupled configurations.

The direct coupled configuration (Fig. 7) connects to the MUX BUS through two 55 ohm fault-isolation resistors connected in series with an isolation transformer. The direct coupled configuration stub length is limited to one foot from the MUX BUS. The isolation resistors prevent an RT terminal fault from pulling the bus impedance down to a point where message transfers would cease.

The transformer coupled configuration in Figure 8 is the only type permitted in U.S. Air Force avionic applications. This configuration connects to the MUX BUS through two 55 ohm fault-isolation resistors connected in series with a coupling transformer with a required 1:1.4 turns ratio. The coupling transformer connects to an isolation transformer by a stub which must not exceed 20 feet. The defined coupling parameters provide a set of guidelines for any terminal which will be connected to the 1553 MUX BUS.

MIL-STD-1553, in summary, has many advantages which digital interfaces such as the RS-232 or Parallel IEEE 488 standards cannot provide.

1. **Noise Immunity** — The twisted shielded 1553 MUX BUS with transformer isolation from ground offers better than 40 dB Common Mode Rejection (CMR). The 6 to 9 Vp-p Manchester II Trapezoidal Bi-Polar Waveform was selected for noise immunity, good transfer characteristics and a minimum of channel crosstalk.

2. **System Reliability** — Dual Standby Redundancy used by the U.S. Air Force or five channel redundancy used by the space shuttle is a distinct advantage found in MIL-STD-1553.

3. **Flexibility** — The system's designer can adapt to system changes simply by updating the bus controller and the remote terminal's software packages.

The Black Box

Now that a MIL-STD-1553 interface has been selected, what does the system designer have to do?

First determine which version of MIL-STD-1553 is being specified. It could be 1553A, 1553B or the latest 1553B Notice I. Other specifications main airframe builders have imposed can greatly influence hardware requirements. Reference ILC Data Device Corporation's (DCC's) MIL-STD-1553 Designer's Guide Section I, for more details concerning various programs and their differences.

The system designer must then determine whether or not to implement a Remote Terminal (RT), Bus Controller (BC), Bus Monitor (BM) or any combination of these modes. It is also important to determine whether single, dual or a higher level of redundancy is required.

The system designer must select the direct or transformer coupled configuration, then carefully plan the placement of Ts along the MUX BUS to insure proper wave propagation. This must include future expansion and test point accessibility.

The last but most important aspect is knowing the Subsystem Interface Unit (SSIU) requirements. The system designer must have a general understanding of the 1553 terminal interface handshakes and how to interface with them.

Whether a Remote Terminal, Bus Controller or Bus Monitor function is required, the building block is the same. The protocol logic will differ, however, since each function has a different responsibility in its implementation of the protocol as defined by MIL-STD-1553. (See Fig. 9, General Terminal Block.)

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High Frequency beyond 18 GHz
Power (50 ohm matched, semi-matched)
Low Cost Packages

BIPOLARS—1945
Small Signal
Power
Pulse Power

DIODES—1930
IMPATT, GaAs Varactor
Si/GaAs Schottky
Beam Lead PIN and Schottky
Low Cost Packages

Testing

The U.S. Air Force, in an effort to control the quality of MIL-STD-1553 avionic systems, has set up a testing facility at Wright Patterson Air Force Base, Ohio, known as SEAFAC. This facility has been responsible for testing avionic remote terminals. The SEAFAC test plan insures that the terminal meets 1553 protocol and all of the electrical parameters. An ever-increasing number of tri-service programs requiring 1553 MUX BUS interfaces have requested SEAFAC verification in their contracts. As a result, there has been an increasing need for MIL-STD-1553 tester/exercisers.

The BUS-68003 (Fig. 10) and BUS-68010 (Fig. 11) are good examples of low cost off-the-shelf exercisers which support all the 1553 message formats shown in Figure 6. They permit ease of programming via the front panel keyboard or through a host computer (BUS-68003 only) via RS232, IEEE488 or a special 8-bit parallel microprocessor port for ease of implementing a fully automated test stand.

These exercisers allow very sophisticated error injection and detection capabilities and ease of setting up a variety of polling routines, which includes introducing 1553 format errors. The BUS-68003 allows the operator manual control over the output level supplied to the data bus for receiver threshold testing.

Conclusion

MIL-STD-1553 is a standard which defines all aspects of the data bus network to ensure the interchangeability of equipment from numerous suppliers and yet is flexible enough to allow creative system integration. The SAE, AE-9 (formerly A2K) Committee, with tri-service and other industrial representation, is constantly striving to promote and improve the standard so future applications can be met.

New technology and system concepts will certainly be the driving force for shaping new high-speed communication standards, but MIL-STD-1553 is here to stay for the foreseeable future due to its many attributes.

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2. MIL-STD-1553 Designer's Guide, Third Printing by ILC Data Device Corporation, 1982.

Steven N. Friedman is Applications Manager for Data Bus products with ILC Data Device Corporation, 105 Wilbur Place, Bohemia, N.Y. He was formerly Senior RF Staff Engineer with Fairchild Camera, Space and Defense, Chief Engineer with Modular Devices, Inc., and Vice President of the Professional Products Division of Robins Broadcast and Sound Equipment Corporation. Friedman also directed engineering programs at Robins Industries. He received his Masters of Science in Engineering Management from Long Island University in 1978, and Bachelors of Science in Electrical Engineering from the New York Institute of Technology in 1970.

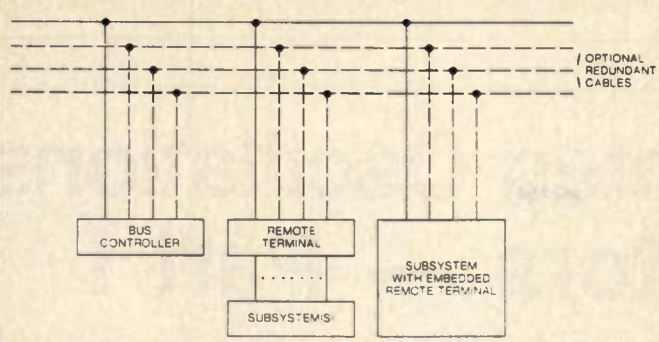


Figure 3: 1553 MUX BUS Architecture

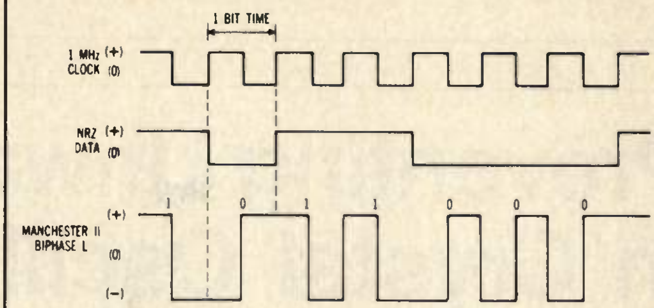


Figure 4: Manchester II Coding

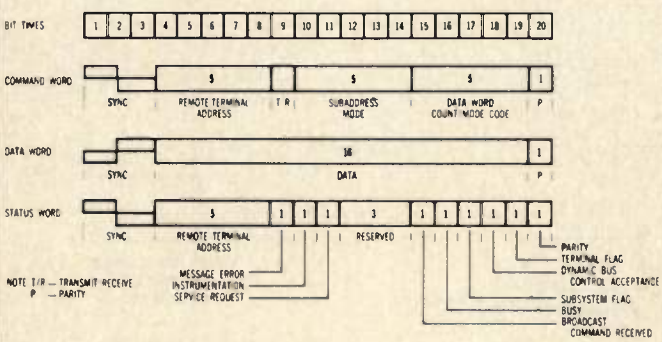


Figure 5: Word Formats

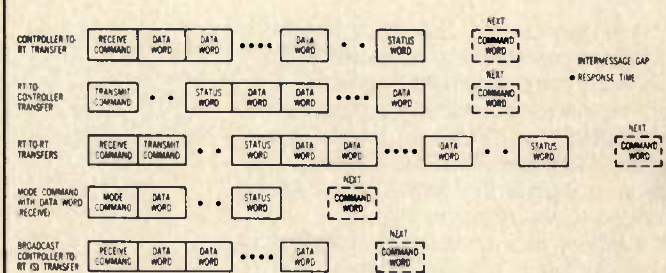


Figure 6: Transfer Formats

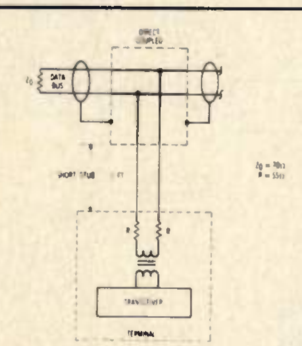


Figure 7: Direct Coupled

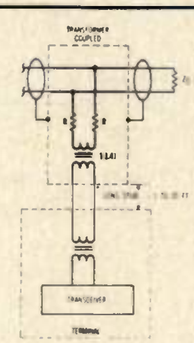


Figure 8: Transformer Coupled

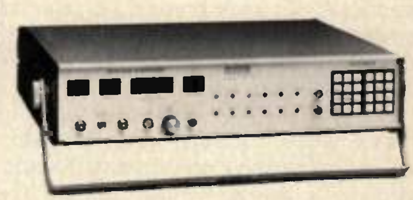


Figure 10: BUS-68003 Exerciser

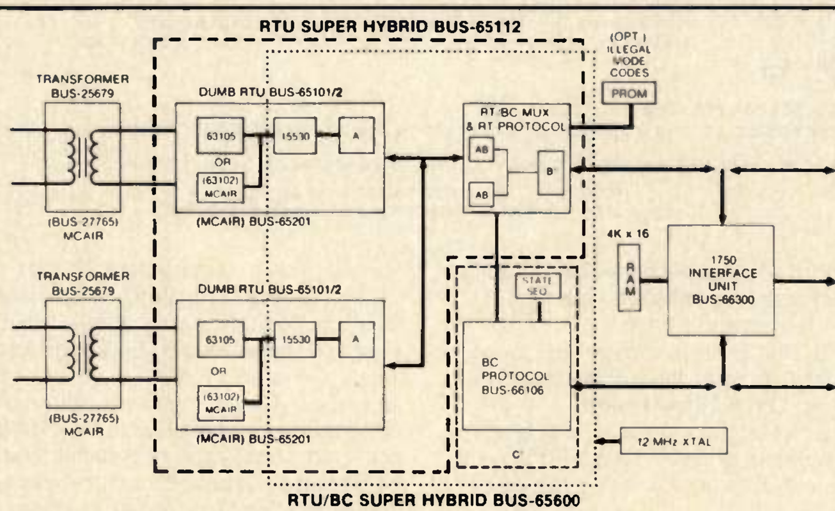


Figure 9: General Terminal Block Diagram

Figure 11: Hand-Held Exerciser

Preventing Unwanted Oscillations in Crystal Oscillators — Part I

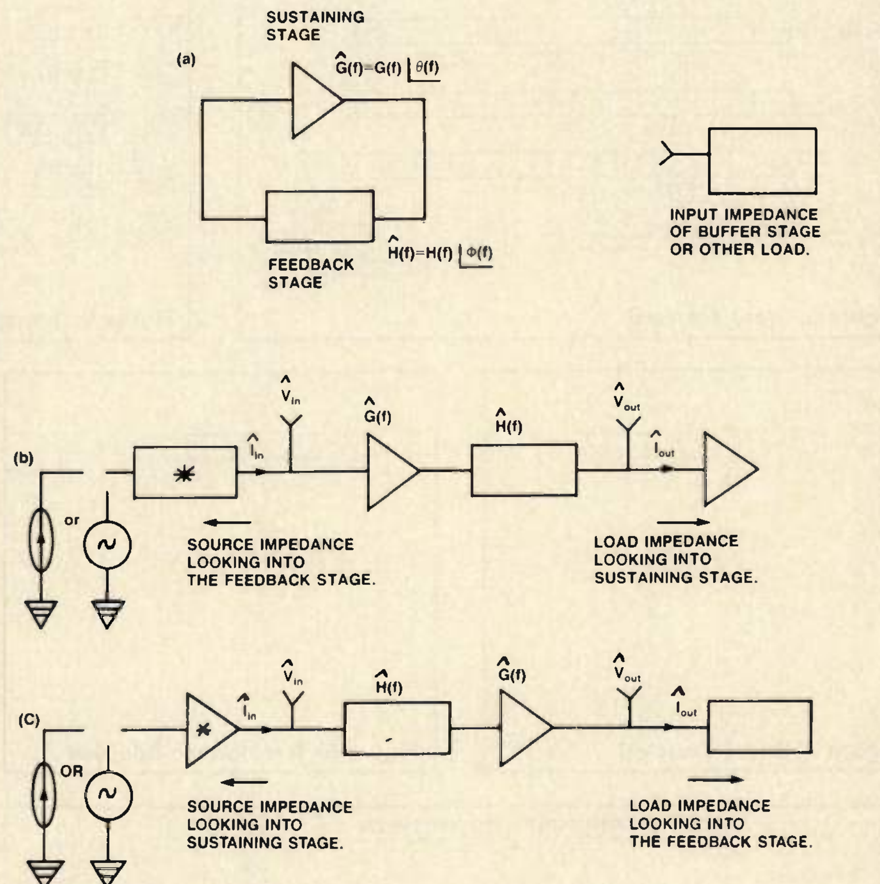
By James W. Wieder
Westinghouse Defense and Electronics Center

A fundamental concern of oscillator design is to ensure that oscillation will only occur at the desired frequency. This article discusses many of the causes of unwanted oscillations in crystal oscillators. Many are difficult to foresee in the paper design and in some instances are related to the physical layout.

Verifying that an oscillator will start-up and oscillate at the desired frequency is not a sufficient design test. During the development testing, the desired oscillation may dominate and suppress unwanted oscillations. Later in production, circuitry variations may cause an unwanted oscillation to dominate or interfere with the desired oscillation. This article discusses several verification tests which specifically uncover potential unwanted oscillations. These verification tests are considered an important part of the oscillator design process.

One way of considering an oscillator is as a closed loop with a sustaining stage and a feedback stage. As shown in Figure 1, the loop can be viewed in terms of voltage or current. The model of the sustaining stage may make one method preferable; however, both methods should give identical results. The sustaining stage contains an active device, such as a transistor, or amplifier or a logic gate biased at its threshold. A quartz crystal would be part of the feedback stage. The sustaining and feedback stages each have an amplitude and phase reponse which are functions of frequency. As shown in Figure 1, the loop can be opened and restructured for analysis and test purposes. It is significant to note that $\hat{G}$ (f) depends on the input impedance of the feedback stage and that $\hat{H}$ (f) depends on the input impedance of the sustaining stage.

In general, the oscillator is "tapped into" loaded at some point to provide a usable output. The input impedance of this load will affect $\hat{G}$ (f) or $\hat{H}$ (f) and hence the oscillator performance. Loading by any test probes should also be considered.



CLOSED LOOP RESPONSE = $\hat{V}_{out}/\hat{V}_{in}$ or $\hat{I}_{out}/\hat{I}_{in}$

*THE SOURCE IMPEDANCE/ADMITTANCE IS ONLY SIGNIFICANT TO THE SUSTAINING STAGE REVERSE GAIN.

IN SOME CASES, THE VOLTAGE OR CURRENT SOURCE CAN BE CONNECTED DIRECTLY TO $\hat{V}_{in}$ OR $\hat{I}_{in}$.

FIGURE 1. (a) OSCILLATOR VIEWED AS A CLOSED LOOP.
(b & c) OSCILLATOR RECONFIGURED FOR ANALYSIS AND TEST.

Figure 1 has positive feedback. The requirements for oscillation "start-up" at a given frequency (f_o) are:

a) a closed loop voltage (or current) gain at f_o greater than or equal to one. That is, $G(f_o) \bullet H(f_o) \geq 1$, and

b) a closed loop phase shift at f_o equal to a multiple of 360°. That is, $\Theta(f_o) + \Phi(f_o) = n\,360°$ where n = 0, 1, 2, 3 . . .

Both criteria must be met simultaneously at the frequency of oscillation f_o.

An additional requirement is that the criteria for oscillation shall be satisfied at only one frequency. Unwanted oscillation should be prevented by assuring that the loop gain is less than 1 at all other frequencies. Attempting to prevent oscillations by trying to prevent a n360° phase shift from occurring is not recommended.

Oscillation "start-up" commences with the application of the power supply or the removal of a disabling control signal. Oscillation "start-up" usually occurs due to the random noise present at frequency f_0. In some situations, start-up can be influenced by a leakage signal at f_0 from another operating frequency source or from a high frequency component of the power supply or disabling control waveforms. As the amplitude of oscillation builds up, the gain at f_0 is eventually reduced to exactly 1 by either:

a) the lower large signal amplifier gain
b) amplitude clipping by junctions or diodes or
c) deliberate gain reduction by automatic gain control.

This means that $\hat{G}$ (f) is a function of the oscillation amplitude. The final amplitude of the sustained oscillation is that amplitude where the closed loop gain at f_0 equals 1. Since Θ (f) may also be a function of the oscillation amplitude, the oscillation frequency may drift during build-up.

Computer modeling can be done with SPICE or COMPACT using the open loop configurations shown in Figure 1. The actual component values along with the stray reactances are used in the model. COMPACT can model the small signal behavior of the transistor or amplifier. SPICE can model both the small and large signal transistor or amplifier behavior. The small signal behavior is useful in analyzing oscillation start-up. The large signal behavior is useful in understanding the final steady state amplitude of oscillation.

The Quartz Crystal

Quartz crystals are widely used as frequency stabilizing components in oscillators. A major reason is the large reactance change over a narrow frequency range near the crystal's series resonance. As an example, Figure 2 shows the equivalent series reactance versus frequency for the fundamental response of a 25 MHz crystal. This curve was determined using the equivalent circuit for a crystal response shown in Figure 3. R1, C1 and L1 represent the response of the quartz blank itself while C0 is the capacitance associated with the quartz plating and blank holder. In the circled region of Figure 2, the crystal unit's response is determined almost totally by the quartz blank and not by C0. Crystal oscillators are designed to operate in this region of a crystal's response. Figure 4 shows an enlargement of the circled portion of the Figure 2 response. The reactance versus frequency slope ($\Delta X/\Delta f$) near series resonance is equal to $4\pi L1$. For the 25 Mhz fundamental response shown in Figures 2 and 4, $\Delta X/\Delta f$ is

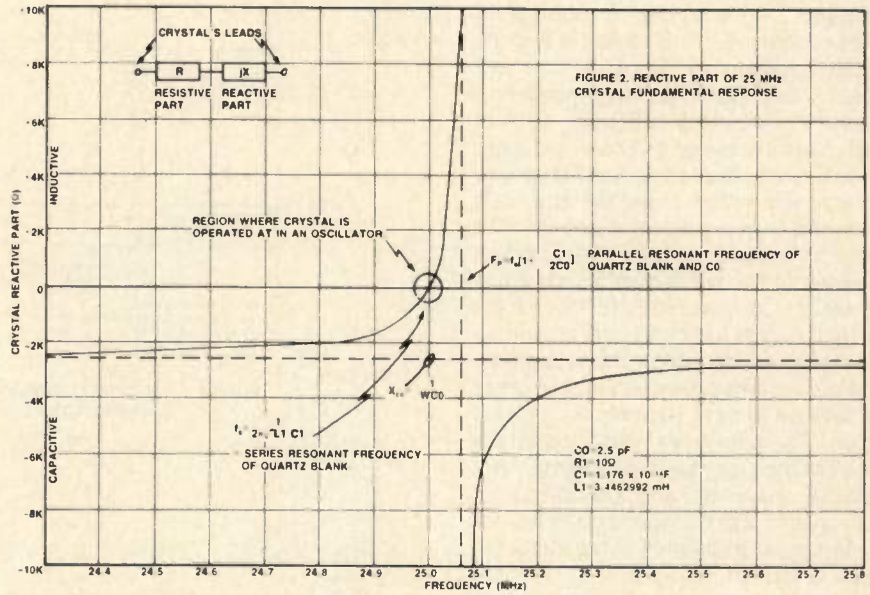
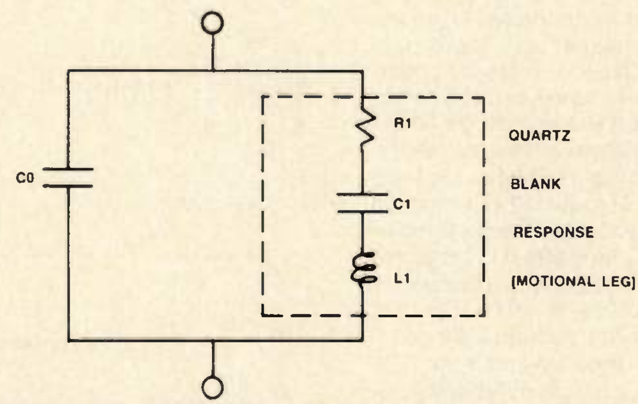


FIGURE 2. REACTIVE PART OF 25 MHz CRYSTAL FUNDAMENTAL RESPONSE



C0 = CRYSTAL HOLDER AND CRYSTAL PLATING CAPACITANCE.
C1 = MOTIONAL CAPACITANCE OF RESPONSE. THIS IS ASSOCIATED WITH THE QUARTZ STIFFNESS.
L1 = MOTIONAL INDUCTANCE OF RESPONSE. FUNCTION OF THE QUARTZ MASS.
R1 = MOTIONAL RESISTANCE OF RESPONSE. REPRESENTS LOSS OF QUARTZ AND HOLDER.

FIGURE 3. MODEL OF A CRYSTAL RESPONSE.

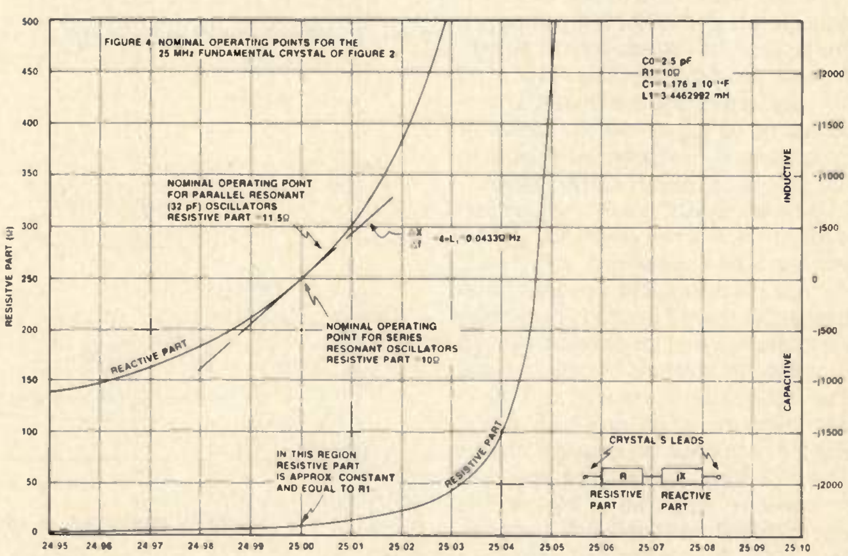


FIGURE 4. NOMINAL OPERATING POINTS FOR THE 25 MHz FUNDAMENTAL CRYSTAL OF FIGURE 2

0.0433 Ω/Hz at the crystal's series resonance. The crystal's equivalent series resistance in this region is approximately constant and equal to R1.

Each quartz blank has many responses across the frequency spectrum, each of which can be modeled as shown in Figure 3. Besides a fundamental mode response a crystal will have a response at all odd overtones (n = overtone number). The overtone responses are *not* perfect multiples of the fundamental frequency but are typically within 5-15 kHz of the multiple. Figure 5 shows a more generalized crystal model which shows the possible quartz responses. An indication of the relative model parameters is also shown. The spurious crystal responses are unrelated to the fundamental and overtone responses and are unique for each crystal. Each response will have a reactance vs. frequency curve similar in shape to that in Figure 2.

A crystal oscillator is designed to operate at either the fundamental or one of the overtone responses. The crystal designer optimizes the crystal for operation at the desired fundamental or overtone and attempts to minimize the $R1_n$ of the desired overtone relative to all the other overtones. Figure 6 shows the maximum value of $R1_n$ for AT-cut crystals that are optimized to operate at each particular overtone. Note that $R1_1$ increases very rapidly for crystals with a fundamental response below 1 MHz. For this reason, other crystal cuts should be considered for use below about 1 MHz. The higher the frequency of the fundamental the thinner the quartz blank. The fragile condition and handling requirements limit the bulk AT-cut fundamental frequency to about 35 MHz. Above about 25 MHz, the use of an AT-cut crystal overtone should be considered. A developing alternative to the At-cut is the "stress-compensated" (SC) cut. Using selective chemical etching and ion milling the quartz dimensions can be varied across the radius of the crystal blank. Fundamental responses of 100-300 MHz may become feasible.

For a given crystal, the $R1_n$ values (except for the optimized overtone) will be larger than the values shown in Figure 6. Table 1 shows the crystal response parameters for the first 13 overtone responses of a crystal designed for operation at 175 MHz on the 7th overtone. As an example of the optimization, note that $R1_7$ is almost the same value as $R1_5$. Figure 7 shows the reactance vs. frequency curve for this 175 MHz crystal. The shape of each overtone response in Figure 7 is similar to that shown in Figure 2. A comparison of the 7th overtone response of a

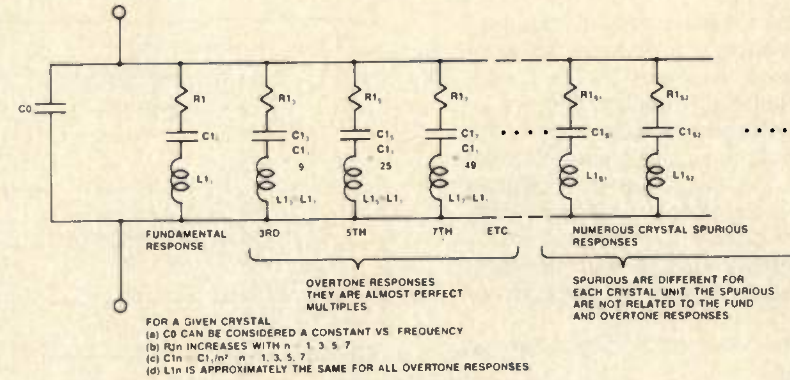


FIGURE 5. GENERALIZED MODEL OF A CRYSTAL UNIT SHOWING POSSIBLE RESPONSES.

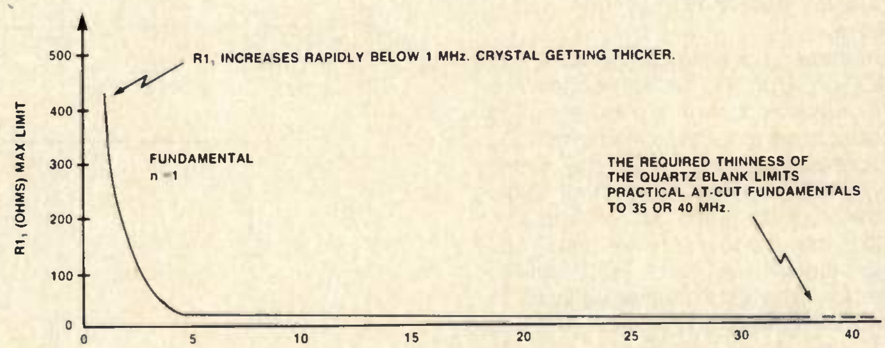


FIGURE 6a. MAXIMUM R1, FOR AT-CUT CRYSTALS DESIGNED FOR OPERATION AT THE FUNDAMENTAL.

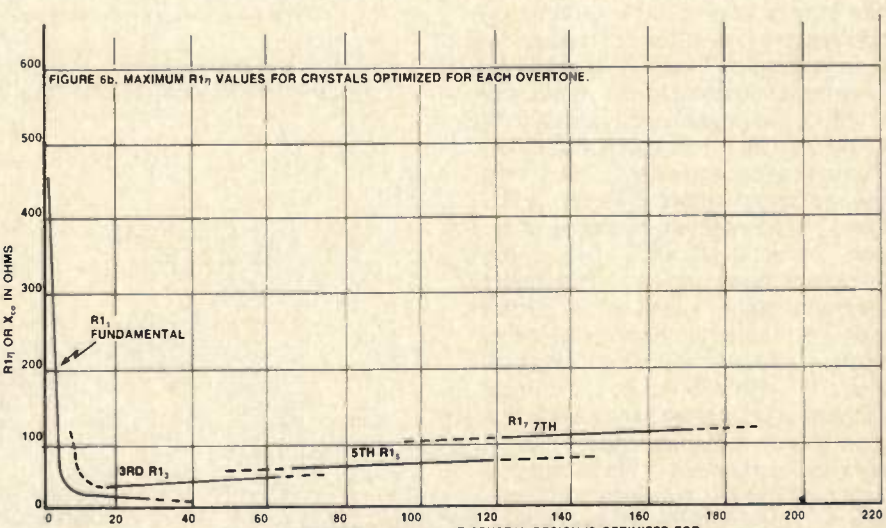


FIGURE 6b. FREQUENCY IN MHz THAT CRYSTAL DESIGN IS OPTIMIZED FOR.

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+20 dBm output level;
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and pulse modulation:
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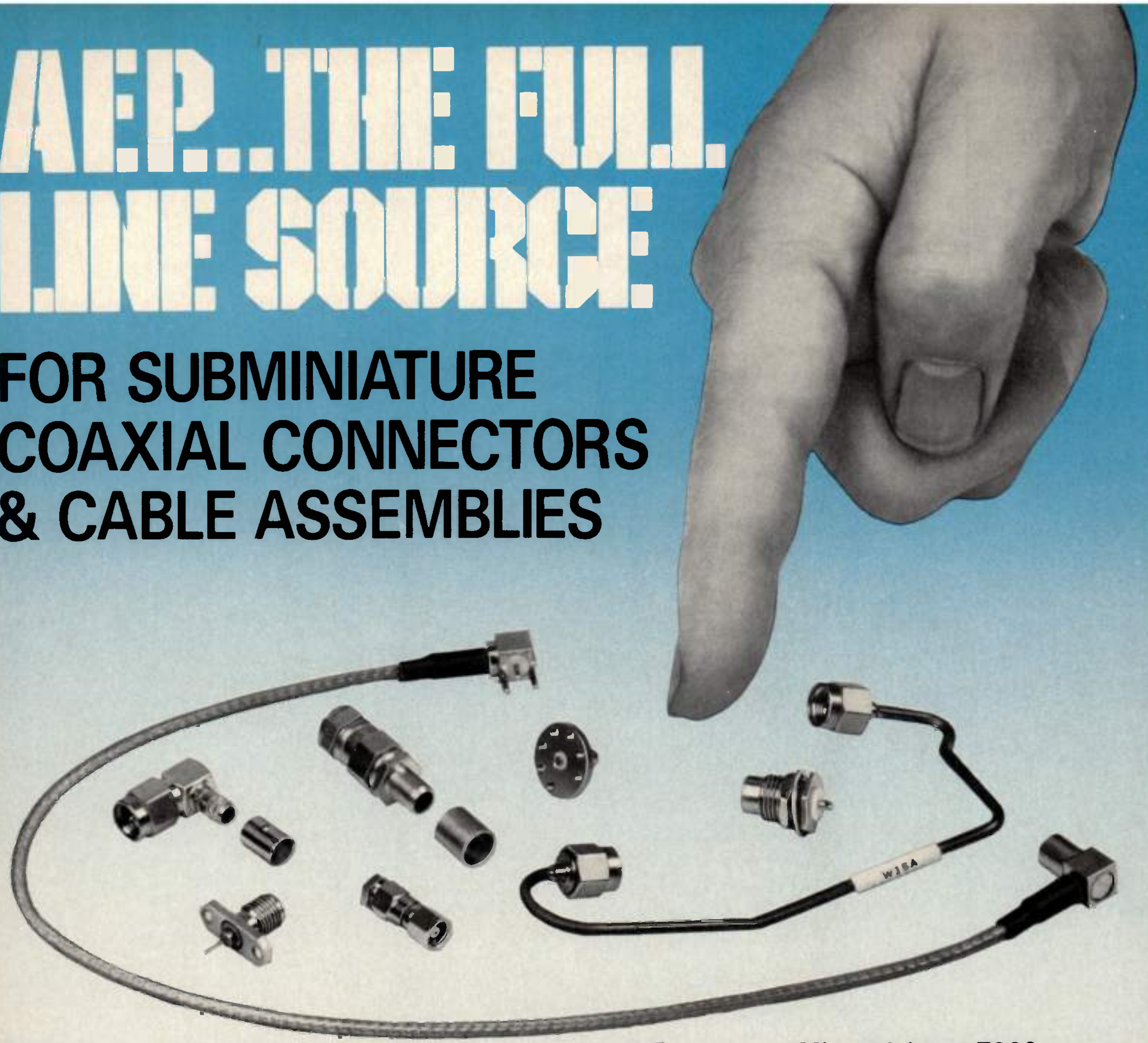

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175 MHz crystal and the fundamental response of a 25 MHz crystal is shown in Figure 8. For the 7th overtone crystal, the C0 parallel resonance occurs much closer to the series resonance.

The second advantage of a quartz crystal is the temperature stability of the fundamental and overtone responses. The quartz temperature characteristics are very predictable and vary with angles of cut and mode of vibration. Depending on the temperature range, the crystal series resonance frequency can be maintained within a range of a few parts per million to a range as large as 100 PPM.

Crystal Oscillator Configurations

A crystal oscillator is designed to use the quartz response which has been "optimized" by the crystal manufacturer. In general, the crystal is located in the feedback network H (f) so that the desired responses $\Delta X/\Delta f$ near series resonance (see Figures 2 and 4) maximize the $\Delta\phi/\Delta f$ of H (f). In this way, any variations of the loop phase shift due to other oscillator components can be corrected by a crystal reactance change ΔX. Because of the crystal's large $\Delta X/\Delta f$, only a small shift of the oscillator frequency will be necessary to compensate for the other oscillator components.

Many different oscillator configurations have been developed over the years. The selection of a particular configuration depends on such requirements as:

a) frequency of oscillation
b) frequency stability requirements
c) required output power
d) output waveform
e) requirements for crystal switching
f) circuit tolerance to stray reactances
g) susceptibility to unwanted oscillations.

The various crystal oscillator configurations can be classified as one of two types.

a) The crystal is operated where it exhibits inductive reactance which is parallel resonated with an external capacitive network to create a high impedance at the frequency of oscillation. Other frequencies should be "shunted" to ground by this network. The network is "tapped into" at an appropriate point to drive the input of the sustaining stage. Examples of this type are the Pierce, Clapp and Colpitts oscillator. These parallel resonant oscillators are generally used below 225 MHz. The crystal is typically parallel resonated by a network capacitance of either 30 or 32 pF. The nominal crystal operating point for a 32 pF parallel resonance is shown in Figure 4.

CRYSTAL MODEL PARAMETERS FOR 175 MHz 7TH OVERTONE CRYSTAL

n	C_0	R_1	L_1	C_1	f_s
1	2.5pF	15	3.4462992nH	1.176×10^{-14}F	25 MHz
3	↓	40	↓	1.306×10^{-15}F	75 MHz
5	↓	70	↓	4.704×10^{-16}F	125 MHz
7	↓	75	↓	2.4×10^{-16}F	175 MHz
9	↓	125	↓	$1.4518518 \times 10^{-16}$F	225 MHz
11	↓	185	↓	$9.7190082 \times 10^{-17}$F	275 MHz
13	↓	250	↓	6.958798×10^{-17}F	325 MHz

TABLE 1. CRYSTAL MODEL PARAMETERS FOR A 175 MHz CRYSTAL DESIGNED FOR OPERATION AT THE 7TH OVERTONE.

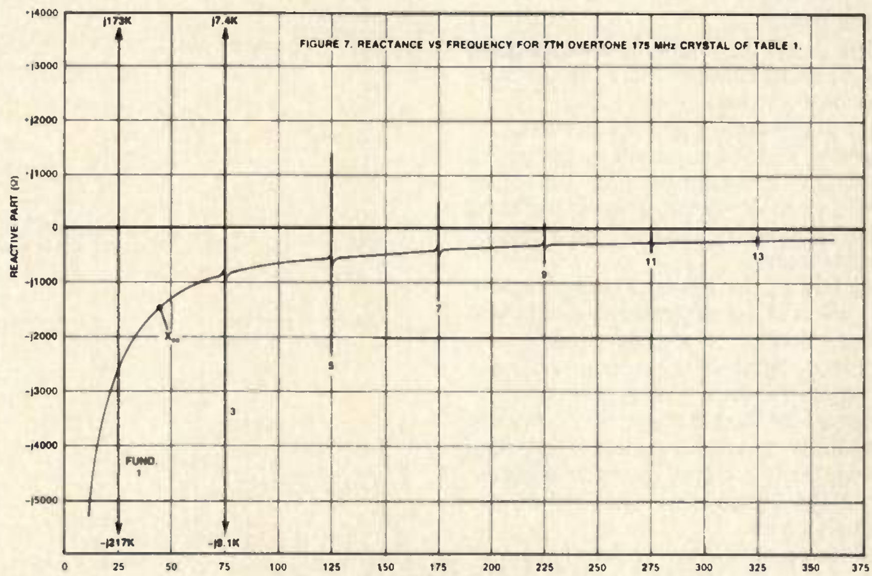

FIGURE 7. REACTANCE VS FREQUENCY FOR 7TH OVERTONE 175 MHz CRYSTAL OF TABLE 1.

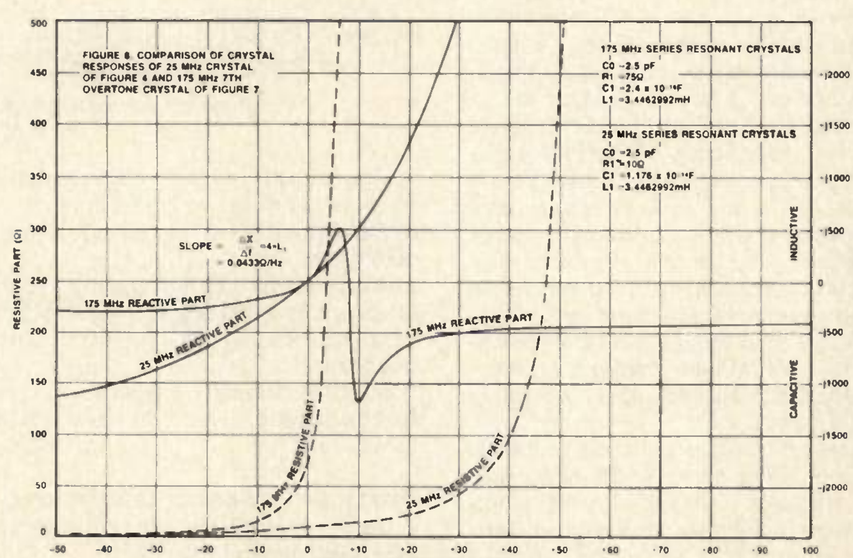

FIGURE 8. COMPARISON OF CRYSTAL RESPONSES OF 25 MHz CRYSTAL OF FIGURE 4 AND 175 MHz 7TH OVERTONE CRYSTAL OF FIGURE 7

b) The crystal is operated near series resonance, where the low impedance of the crystal allows the desired frequency signal to pass to the sustaining stage input. The crystal and a separate shunting network are employed to block all other frequencies from reaching the sustaining stage input. Examples of this type are the grounded base oscillator and the Impedance-Inverting Pierce. These types are generally used above 20 MHz. The nominal operating point for this type oscillator is also shown in Figure 4.

When specifying a crystal, the operating point on the desired overtone must be specified so the crystal is manufactured to provide the desired frequency at the oscillator operating point.

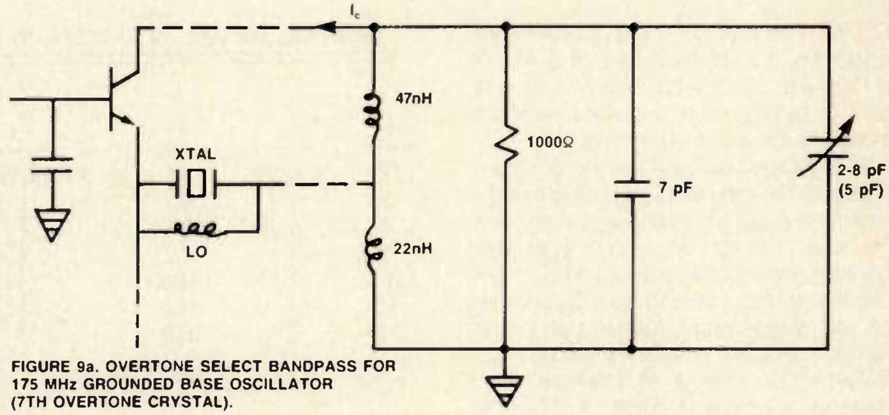

FIGURE 9a. OVERTONE SELECT BANDPASS FOR 175 MHz GROUNDED BASE OSCILLATOR (7TH OVERTONE CRYSTAL).

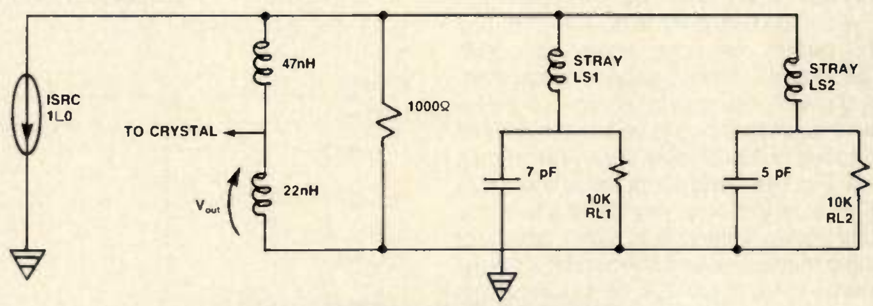

FIGURE 9b. SPICE MODEL OF OVERTONE SELECT BANDPASS WITH A FEW OF THE STRAY REACTANCES AND COMPONENT LOSSES.

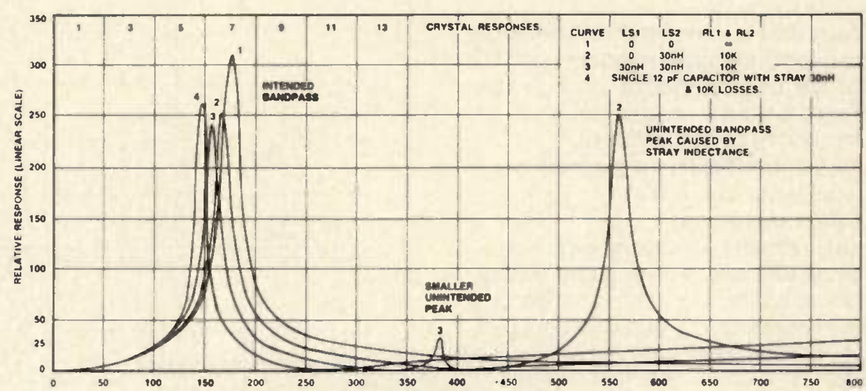

FIGURE 9c. FREQUENCY RESPONSE OF FIGURE 9b FOR VARIOUS STRAY REACTANCE VALUES.

The Unwanted Oscillation Problem

When the requirements for oscillation are satisfied at two or more frequencies, one of the following will occur:

a) The frequencies will compete at start-up, with one frequency becoming dominant and suppressing the other oscillations. Which frequency is dominant may vary with component variations or environment.

b) Two or more frequencies of oscillation will occur simultaneously at different levels. Viewed on a scope, the largest amplitude signal will have small to severe edge jitter. In some cases, one signal will amplitude modulate a second. A very low amplitude second oscillation is more readily observed on a spectrum analyzer since the scope edge jitter will be extremely small.

Once an oscillation reaches full amplitude it is more difficult for another oscillation to get started. This is because the sustaining stage gain G(f) decreases at all frequencies as the dominant oscillation reaches full amplitude. For example, if an oscillator is retuned to where the requirements of oscillation are met at two different frequencies, there will be a strong tendency to maintain the existing oscillation. If the oscillation was then stopped and restarted, however, the other oscillation may become dominant. The frequency of oscillation that dominates is determined by factors such as:

a) Closed loop voltage gain at each frequency. The greater the gain at a frequency, the faster oscillation will build up at that frequency.

b) Closed loop signal group delay at each frequency. The narrower the bandwidth at a frequency, the greater the group delay and the longer oscillation will take to build up at that frequency.

c) Power supply turn-on characteristics such as ramp rate and overshoot.

d) Oscillator disable control signal characteristics.

e) The existence of a leakage signal from another operating signal source which aids the start-up of one of the frequencies.

f) Reactive component losses.

g) The point at which the oscillator is tuned.

Types of Unwanted Oscillations

Unwanted oscillations can be classified into three general types:

1) Oscillation at a crystal overtone which is not the desired overtone.

2) A non-crystal controlled oscillation caused by either

a) a reactance which unintentionally shunts the quartz blank or a larger portion of the oscillator loop, or

b) a sustaining stage gain instability (amplifier oscillation).

3) Oscillation at a crystal spurious.

If an unwanted oscillation is dominant, a frequency counter can provide a clue to its type. Since types (1) and (3) are crystal controlled, the short term stability would typically be 7 to 10 digits. A non-crystal controlled oscillation would have a stability of 3 to 5 digits.

Unwanted Oscillation at Other Overtones

Oscillation is possible at all odd crystal overtones. Unwanted overtone oscillation is prevented by assuring that the closed-loop gain at all other overtones is less than one. Many fundamental mode oscillators rely on the fact that the overtone motional resistances ($R1_3$, $R1_5$ . . .) are significantly larger than $R1_1$. This allows the oscillator to be designed so oscillation will not occur with the smallest $R1_3$ expected. For some fundamental mode oscillators, specifying a minimum allowed value of $R1_3$ may be desirable.

Oscillators operating at other than the fundamental must incorporate an overtone select bandpass as part of H (f). This bandpass selects the desired overtone and rejects the fundamental and the undesired overtones. The design of the overtone select bandpass is critical. If the bandpass is not sharp enough, oscillation could occur at an adjacent overtone. If the bandpass is made too selective, some of the following may occur:

a) Component tolerances and stray reactances may move the bandpass peak far enough off frequency that an initial trim will be necessary to set the bandpass peak at the desired frequency.

b) Environmental variations may cause the bandpass peak to move away from the overtone frequency. The desired oscillation may stop or not occur.

c) A steep phase vs. frequency response of a sharp bandpass will increase the oscillator frequency variation with bandpass component changes.

Unintended Peaking in Overtone Select Filter

Figure 9 illustrates some of the problems that might occur with an overtone select filter. Figure 9a shows the overtone select bandpass of a 175 MHz grounded base oscillator. This bandpass is to be used to select the 7th overtone of the crystal shown in Table 1 and Figure 7. Figure 9b is a SPICE model of the overtone bandpass where a few of the stray reactances and component losses are included. This model is deliberately simplified in order to highlight several points. Figure 9c shows four amplitude responses for various stray reactance values and component losses.

Curve (1) shows the amplitude response of the ideal case where no stray inductance is in the circuit and the capacitors are lossless. The peak of the response occurs at the 7th overtone response (175 MHz). At the 5th (125 MHz) and 9th (225 MHz) overtones, the bandpass response is less than 1/6 of the peak value.

Curve (2) shows the effect of having 30 nH of stray inductance in series with the 5 pF trim capacitor value. 30 nH represents approximately 1.5 inch of total capacitor lead length (0.75" per lead). The effect of the stray inductance is twofold. First the peak of the desired response has been shifted lower in frequency by about 10 MHz. This shift in the peak would be compensated for by reducing the trim capacitor value. The second and more significant effect of the 30 nH is to cause an unintended amplitude peak at around 560 MHz. The unintended peak is almost as large as the desired peak.

Curve (3) shows how the unintended peak is significantly reduced when *both* the 7 and 5 pF capacitors have 30 nH stray inductance in series with them. The difference between curves (2) and (3) is representative of the effect of a different layout. This peak is smaller because the two series resonances occur near each other. If the capacitor values and the stray inductances are such that the two series resonances differ greatly, the unintended peak will be large.

Curve (4) shows the effect of using a single capacitor of 12 pF (5 pF + 7 pF) which has 30 nH of series inductance. The desired peak is shifted 30 MHz lower in frequency by the stray inductance but no unintended peaks occur.

Figure 9 illustrates the following:

- Shift of the desired response frequency location by stray reactance.
- Unintended peaking caused by a stray reactance.
- How the magnitude of an unintended peak can be affected by the layout.
- How the magnitude of an unintended peak is affected by the values of the lumped components.
- How an unintended peak is created or eliminated by a small circuit change (using two capacitors instead of one).

The lower the oscillator frequency, the larger the L and C component values and the smaller the effect of strays on the desired peak's location. However, the resonance of the larger L and C components with the strays will occur at lower frequencies. Consequently, any unintended peaking will also occur at lower frequencies. If an unintended peak happens to occur at another overtone, an unwanted oscillation may occur there. Unintended peaks can occur in any oscillator regardless of the intended oscillator frequency.

Minimizing Problems with Unintended Peaks

The following points should be considered in the oscillator design and layout:

a) Peaking of the amplitude response can be a problem at any frequency where the sustaining stage G (f) is of sufficient magnitude to allow for a closed loop gain of 1. The physical layout becomes more significant the higher the transistor f_T. A design and layout may work fine for one transistor type but may have problems if a transistor with a higher f_T is used even if the gain at the desired frequency of oscillation is the same for both transistors. An f_T of 10-20 times the desired frequency of oscillation gives good results. A lower f_T will result in a larger transistor phase shift, increasing the oscillator's sensitivity to transistor variations and causing larger phase noise. If the transistor f_T is greater than 20 times the frequency of oscillation, problems due to unintended peaks are more likely. The high frequency roll-off of amplifier or logic gate gain should be similarly considered.

b) Use practical L and C values — values which are large compared with "non-controlled" stray reactances. Minimize the value of all strays. The lower the stray reactance, the higher the stray resonance frequency and the more likely the peaking will occur where the sustaining stage G(f) is reduced.

c) Use an oscillator design and configure the layout so the stray reactances can be absorbed by the circuit elements. Stray inductance should be in series with an inductor. Stray capacitance should occur in parallel with a capacitor.

d) Design for the maximum repeatability of the mechanical configuration from unit to unit. Minimize variations in component and package lead lengths from unit to unit. Any compensation for the strays will be similar for all units.

e) In many oscillators, a trim capacitor with a maximum to minimum capacitance ratio of from 4 to 10 is used. The frequency location of an unintended peak involving the trim capacitor may vary significantly. When conducting design verification tests, trim capacitors should be varied over their full trim range.

f) Design verification tests should be repeated whenever a component value or type or the physical layout is changed.

About the Author

Jim Wieder is a design engineer at Westinghouse Defense and Electronics Center, P.O. Box 1521, M.S. 3642, Baltimore, MD 21203.

Smith Chart Calculations on Your Microcomputer

By Lynn A. Gerig
Magnavox Electronic Systems Company

During the three years since my article "Computer Interface for Smith Chart Calculations" was published in the Jan/Feb 1982 issue of *RF Design*, I have received several inquiries regarding conversion to a computer more modern than the HP-9830 (now obsolete). Several have successfully converted the program equations and calculations to run on the HP-85, for example, without being able to "get the graphics to play." I recently wrote a version to run on a Commodore 64 — the fastest selling microcomputer on the market today. This article will address only operation of the Commodore 64 program and differences between the two versions. For explanation of equations used, please refer back to the original article.

Program Description

This Commodore 64 program for Smith Chart calculations uses full-screen menus such as those shown in Figures 1 and 2, whereas the HP-9830 would only "display" one line at a time, forcing a series of prompts and inputs. The original version required that a pre-printed Smith Chart be placed on the plotter and data points then plotted on it. This program uses the excellent Commodore graphics and draws the Smith Chart on the screen in high-resolution graphics. It can be dumped to your printer at the press of a button.

This program uses Simons' Basic[1] for efficient utilization of graphics commands. However, if you have a different computer system you can still use the equations in lines 1000-7504 directly and add your own printing/plotting commands. A summary of the major program sections is listed in Table 1, and a detailed description of the program (see Figure 3 for LIST) follows.

Lines 1 through 44 are used for program initialization. In lines 10-11 you select a smooth or discrete plot. Either selection will plot a "+" on the Smith Chart at each frequency, but if you select a smooth plot, a line will connect the plots to form a continuous curve. In lines 12-13 you choose

```
      Choose Type of Matching Section
 1 SERIES C
 2 SERIES L
 3 SERIES TUNED (SERIES L-C)
 4 SERIES TUNED (PARALLEL L-C)
 5 SERIES TRANSMISSION LINE
 6 SHUNT C
 7 SHUNT L
 8 SHUNT TUNED (SERIES L-C)
 9 SHUNT TUNED (PARALLEL L-C)
10 SHUNT TRANSMISSION LINE
11 TRANSFORMER
12 SERIES R
13 SHUNT R

14 STOP ADDING SECTIONS

CHOICE (1-14)?.
```

Figure 1. Matching Section Menu.

a value of a VSWR circle to appear on the plot. In line 14 you select the characteristic impedance. All impedances are normalized to this before being plotted (lines 8120-8130). You are next asked how many frequencies you wish to work with (line 15), then you must input each frequency and the resistive and reactive series components of the starting (load) impedance at each frequency.

After you input all frequencies and load impedances, you are given a chance to start over if you made an error. Then you can choose to print the tabulated load impedances on your printer, plot them on a Smith Chart or begin matching. Lines 50-82 present a menu (see Fig. 1) for the type of matching element to select. The program next branches to the correct set of equations for that choice (lines 1000-7504), and you are then asked to input those component values.

Lines 8000-8195 contain the graphics plotting commands for plotting a Smith Chart on the screen. Most of these lines use graphics commands peculiar to Simons' BASIC; you may choose to write your own plotting subroutine if you have another system. A new chart is drawn in lines 8000-8023. If you choose to plot on an old screen, you enter at line 8100 which recalls the last graphics screen from memory. The impedance plotting is performed in lines 8115-8160. The equations in 8120-8130 convert the impedances to a point on the chart normalized to the previously selected Zo. The chart y-radius is 100 bits, and the x-radius depends on the value of "XM" (see section on printer interfaces below). Line 8150 will connect the "+" plots with a line if "smooth plot" was previously selected. The plotted chart will stay on the screen until either function key f7 or f8 is pressed. Pressing f8 will copy your plot to your printer, and f7 will return you to the tabular listing of frequencies and impedances with another menu.

No matter what type of matching section is chosen, after the appropriate impedance calculations are performed the program branches to line 9000 and the new impedances at each frequency are printed on the screen below the values of the network components you chose. A menu appears at the bottom of the screen

```
ADD SHUNT TUNED (PARALLEL L-C)
WHAT IS VALUE OF C (IN PF)? 30
WHAT IS VALUE OF L (IN UH)? .01
  FREQ.          RS        XS
  220.        34.74     29.62
  240.        39.82     16.21
  260.        44.16      8.03
  280.        46.41       .50
  300.        48.51     -8.48
  320.        48.31    -20.26
  340.        36.95    -31.46
  360.        25.69    -35.45
  380.        14.96    -34.89
  400.         8.27    -30.09

F1 = PLOT ON CLEAN SCREEN FOR
     VIEWING
F2 = PLOT ON CLEAN SCREEN FOR
     PRINTER
F3 = PLOT ON LAST SCREEN
F4 = SCREEN DUMP TO PRINTER
F5 = BAD VALUE: DISCARD THIS TRY
F7 = GOOD VALUE: KEEP & PROCEED
```

Figure 2. Print / Plot / Proceed Menu.

(see Fig. 2). You must then press a function key to continue. Pressing f1 or f2 will cause the impedances listed to be plotted on a new "clean" screen (see section on printer interfaces below). Pressing f3 will add the new plot to a previous chart. If you press f4, the tabulated data at the top of the screen is printed on your printer. Pressing f5 causes the computer to erase the bad value you just tried, and f7 causes the trial value to become the next load impedance to be matched (lines 9200-9230). You then branch back to the master menu at line 50.

LINE NOS.	PROGRAM CONTENT
1-10	FORMAT, SELECT DISCRETE OR SMOOTH PLOT
12-13	SELECT VSWR CIRCLE TO PLOT
14	SELECT CHARACTERISTIC IMPEDANCE
15-44	INPUT RESISTIVE & REACTIVE PARTS OF LOAD IMPEDANCE AT EACH FREQUENCY. PRINT OR PLOT RESULT IF DESIRED
50-82	SELECT TYPE OF MATCHING SECTION TO TRY
1000-7504	CALCULATION OF IMPEDANCES ACCORDING TO TYPE OF MATCHING SECTION CHOSEN
8000-8195	SUBROUTINE FOR GRAPHICS PLOTTING OF SMITH CHART
9000-9170	PRINT NEW IMPEDANCES IN TABULAR FORM THEN CHOOSE WHETHER TO PRINT, PLOT, DISCARD OR KEEP TRIAL VALUE
9200-9230	"GOOD" TRIAL VALUE BECOMES NEW IMPEDANCE TO MATCH WITH NEXT SECTION

Table 1. Major Program Sections.

Example

Several detailed examples of the program possibilities were given in my original article. A single example of the Commodore 64 screen to printer plot is shown in Figure 4. In this example, the initial load impedance and the final matched impedances are superimposed on the same chart.

Entering the Program

Type the program and take the normal precaution to SAVE it before you RUN it, so that if you have made a typing error that causes a lock-up you can go back to the saved version without having to retype the entire program. The following is an explanation of the mnemonics printed by my printer interface:

<CLR> = SHIFT-CLR
<DWN> = cursor down
<LFT> = cursor left
<BLU> = CTRL-7 (blue)
<RED> = CTRL-3 (red)
<C = 4> = Commodore-4 (gray 1)

In addition, my interface sometimes prints <ROF> directly following unique Simons' BASIC commands. Ignore it when you are typing the program (do not type "<ROF>").

Printer Interfaces

The program is designed to calculate impedances and display them in tabular or graphic form on the screen, so you can use the program even if you don't have a printer. Two printer commands are used: HRDCPY (lines 40, 9140) gives a normal screen dump (tabular data), and COPY (line 8195) will copy a high-resolution (320 by 200 bits) graphics screen to the printer. This program works successfully with Commodore 1525 and MPS-801 printers and will run successfully with any printer/interface combination which emulates the Commodore. It has been used with Epson, Gemini, Prowriter, Okidata and Panasonic printers with both Cardco and Tymac "Connection" interfaces. My Gemini-10X will plot the high-resolution screen dump in less than a minute with the "Connection," but it takes 45 minutes with the Cardco/? + G (some combinations require patience). However, I am not aware of any combination that won't work.

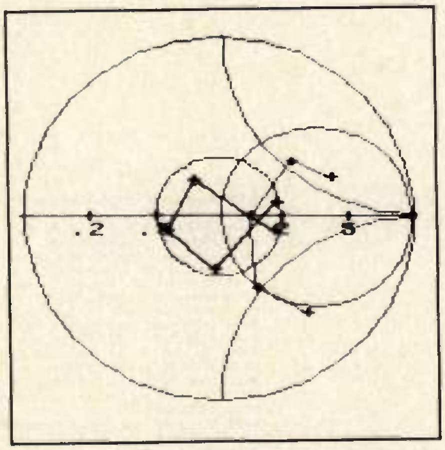

Figure 4. Typical Example of Program Output.

The aspect ratio (relative distance between dots on a line vs. distance between lines) is different for the screen than it is for a printer. To get a circle on the screen, an X/Y ratio of 1.4 (value of XM in lines 44, 9110) is required. However, this will COPY as an oval on the printer. If a chart for "printing" is selected (lines 9055, 9120) then the ratio is set to 0.833: this gives an oval on the screen, but you get a circle on your printer. If you get ovals on another brand printer, experiment with the value of XM in line 9120.

Footnotes

1. Simons' BASIC is a plug-in ROM cartridge which adds over 110 new BASIC commands to the Commodore 64 making programming much easier and more flex-

```
THESE WERE YOUR LOAD IMPEDANCE INPUTS

   FREQ        RS        XS

   110.        45.       -90.
   120.        50.       -50.
   130.        70.        0.
   146.        80.        60.
   160.       140.        90.


ADD SHUNT INDUCTOR
WHAT IS VALUE OF L (IN UH)? .06

   FREQ        RS        XS

   110.      17.66      60.52
   120.      40.56      49.10
   130.      23.02      32.88
   146.      12.34      37.29
   160.      12.07      47.35


ADD SERIES CAPACITOR
WHAT IS VALUE (IN PF)? 60

   FREQ        RS        XS

   110.      17.66      36.40
   120.      40.56      26.99
   130.      23.02      12.48
   146.      12.34      19.12
   160.      12.07      30.77


ADD SHUNT CAPACITOR
WHAT IS VALUE OF C (IN PF)? 30

   FREQ        RS        XS

   110.      90.94      12.62
   120.      40.83     -26.88
   130.      28.77      -5.40
   146.      36.32      14.31
   160.      87.67     -15.88
```

Figure 3. Program Listing

ible. For example, the entire bit-by-bit high-resolution screen dump to printer is done with a single command: COPY. It is made by Commodore and should be available from all Commodore dealers. One mail order source is Protecto Enterprises, Box 550, 22N049 Pepper Road, Barrington, IL 60010.

Lynn Gerig is Project Engineer for Magnavox Electronic Systems Company, Ft. Wayne, Indiana. A copy of the program is available from him. Send $5.00, a blank tape or disk and a stamped, self-addressed mailer to him at R.R. #1, Monroeville, IN 46773.

```
1 SP$="                ":FORJ=1TO23:CL$=CL$+SP$:NEXT
2 PRINT"<CLR><DWN><DWN><BLU>":CENTRE<ROF>"PROGRAM FOR IMPEDANCE MATCHING":PRINT"
<C=5><DWN><DWN>"
4 CENTRE<ROF>"USING":PRINT
6 PRINT"<DWN><DWN><RED>":CENTRE<ROF>"SMITH CHART"
8 PRINT AT(<ROF>22,20)"<C=4>BY LYNN GERIG<DWN><LFT><LFT><LFT><LFT><LFT><LFT><LFT
><LFT><LFT><LFT>WA9GFR<DWN><LFT><LFT><LFT><LFT><LFT><LFT>MARCH, 1984":PAUSE<ROF>
4
10 PRINT"<CLR>DISCRETE FREQUENCIES (D) OR SMOOTH":INPUT"PLOT (S)";D$
11 IF D$<>"D"ANDD$<>"S"THEN10
12 INPUT"<DWN>PLOT WHAT VALUE VSWR CIRCLE";VS:IF VS<1 THEN 12:VR=100*(VS-1)/(VS+
1)
13 VR=100*(VS-1)/(VS+1)
14 INPUT"WHAT CHARACTERISTIC IMPEDANCE";ZO
15 INPUT"<DWN>HOW MANY FREQUENCIES (1-10)";N
16 FOR J=1 TO N
18 PRINT"<DWN>INPUT FREQUENCY"J;:INPUT"IN MHZ";F(J)
20 PRINT"INPUT RS, XS  OF LOAD AT "F(J)"MHZ":INPUT R(J),I(J)
22 X(J)=R(J):Y(J)=I(J):NEXT
24 PRINT"<CLR> THESE WERE YOUR LOAD IMPEDANCE INPUTS<DWN>"
26 PRINT"<DWN>      FREQ           RS            XS":PRINT
27 FOR J=1 TO N: F$=STR$(F(J))
28 RS$=STR$(R(J)):XS$=STR$(I(J))
29 USE<ROF>"    #####.###",F$:USE<ROF>"    #####.##",RS$:USE<ROF>"    #####.##",XS$
:PRINT:NEXT
30 PRINT AT(<ROF>0,18)""
32 INPUT"ARE YOU SATISFIED (Y=YES)";A$
34 IF A$<>"Y" THEN GOTO 14
38 INPUT"PRINT LOAD VALUES (Y=YES)";A$
40 IF A$="Y" THEN PRINT AT(<ROF>0,18)CL$:HRDCPY<ROF>
42 INPUT"PLOT LOAD IMPEDANCE (Y=YES)";P$
44 XM=1.4:IF P$="Y" THEN GOSUB 8000
50 PRINT"<CLR>    CHOOSE TYPE OF MATCHING SECTION<DWN>"
52 PRINT" 1 SERIES C
54 PRINT" 2 SERIES L
56 PRINT" 3 SERIES TUNED (SERIES L-C)
58 PRINT" 4 SERIES TUNED (PARALLEL L-C)
60 PRINT" 5 SERIES TRANSMISSION LINE
62 PRINT" 6 SHUNT  C
64 PRINT" 7 SHUNT  L
66 PRINT" 8 SHUNT  TUNED (SERIES L-C)
68 PRINT" 9 SHUNT  TUNED (PARALLEL L-C)
70 PRINT"10 SHUNT  TRANSMISSION LINE
72 PRINT"11 TRANSFORMER
74 PRINT"12 SERIES R
76 PRINT"13 SHUNT  R<DWN>
78 PRINT"14 STOP ADDING SECTIONS
80 INPUT"<RED><DWN><DWN><DWN><DWN>CHOICE (1-14)";M:PRINT"<C=4>"
81 IF M<1 OR M>14 THEN 80
82 CGOTO<ROF> 500*(M+1)

1000 PRINT CHR$(147)"ADD SERIES CAPACITOR
1002 INPUT"WHAT IS VALUE (IN PF)";C
1010 FOR J=1TO N
1015 X(J)=R(J)
1020 Y(J)=I(J)-1/(2*π*F(J)*C*1E-06)
1025 NEXT: GOTO 9000
1500 PRINT CHR$(147)"ADD SERIES INDUCTOR
1502 INPUT"WHAT IS VALUE (IN UH)";L
1510 FOR J=1 TO N:X(J)=R(J)
1520 Y(J)=I(J)+2*π*F(J)*L:NEXT:GOTO9000
2000 PRINT CHR$(147)"ADD SERIES TUNED (SERIES L-C)
2002 INPUT"WHAT IS VALUE OF C (IN PF)";C
2004 INPUT"WHAT IS VALUE OF L (IN UH)";L
2010 FOR J=1 TO N: X(J)=R(J)
2020 Y(J)=I(J)+2*π*F(J)*L-1/(2*π*F(J)*C*1E-06):NEXT:GOTO9000
2500 PRINT CHR$(147)"ADD SERIES TUNED (PARALLEL L-C)
2502 INPUT"WHAT IS VALUE OF C (IN PF)";C
2504 INPUT"WHAT IS VALUE OF L (IN UH)";L
2510 FOR J=1 TO N: X(J)=R(J)
2520 Y(J)=I(J)+(2*π*F(J)*L)/(1-((2*π*F(J))^2)*L*C*1E-06):NEXT:GOTO9000
3000 PRINT CHR$(147)"ADD SERIES TRANSMISSION LINE
3002 INPUT"WHAT IS LINE IMPEDANCE (OHMS)";Z1
3004 INPUT"WHAT IS VELOCITY FACTOR";V
3006 INPUT"WHAT IS LENGTH (IN INCHES)";LL
3010 FOR J=1 TO N
3015 T=1.2*LL*F(J)/39.37/V
3020 D=(R(J)+Z1)^2+I(J)^2
3025 R=(R(J)^2-Z1^2+I(J)^2)/D
3030 I=2*Z1*I(J)/D
3035 Z=SQR(R*R+I*I)
3040 T=180/π*ATN(I/(R+1E-30))-2*T+180*(R<0)
3045 R=Z*COS(T*π/180)
3050 I=Z*SIN(T*π/180)
3055 D=(1-R)^2+I^2
3060 X(J)=Z1*(1-R^2-I^2)/D
3065 Y(J)=2*Z1*I/D
3070 NEXT:GOTO9000
3500 PRINT CHR$(147)"ADD SHUNT CAPACITOR
3502 INPUT"WHAT IS VALUE OF C (IN PF)";C
3506 FOR J=1 TO N: W=2*π*C*1E-06
3508 D=(1-W*F(J)*I(J))^2+(R(J)*W*F(J))^2
3510 X(J)=R(J)/D
3512 Y(J)=(I(J)*(1-W*F(J)*I(J))-R(J)^2*W*F(J))/D:NEXT:GOTO9000
4000 PRINT CHR$(147)"ADD SHUNT INDUCTOR
4002 INPUT"WHAT IS VALUE OF L (IN UH)";L
4015 FOR J=1 TO N: W=2*π*F(J)*L
4025 D=R(J)^2+(I(J)+W)^2
4030 X(J)=R(J)*W^2/D
4035 Y(J)=W*(R(J)^2+I(J)^2+W*I(J))/D
4040 NEXT:GOTO9000
4500 PRINT CHR$(147)"ADD SHUNT TUNED (SERIES L-C)
4502 INPUT"WHAT IS VALUE OF C (IN PF)";C
4504 INPUT"WHAT IS VALUE OF L (IN UH)";L
4510 FOR J=1 TO N
4515 W=2*π*F(J)*L-(1E+06)/(2*π*F(J)*C)
4517 D=R(J)^2+(I(J)+W)^2
4520 X(J)=R(J)*W^2/D
4525 Y(J)=W*(R(J)^2+I(J)^2+W*I(J))/D
4530 NEXT J:GOTO 9000
5000 PRINT CHR$(147)"ADD SHUNT TUNED (PARALLEL L-C)
5002 INPUT"WHAT IS VALUE OF C (IN PF)";C
5004 INPUT"WHAT IS VALUE OF L (IN UH)";L
5010 FOR J=1TO N
5015 W=(2*π*F(J)*L)/(1-((2*π*F(J))^2)*L*C*1E-06)
5020 D=R(J)^2+(I(J)+W)^2
5025 X(J)=R(J)*W^2/D
5030 Y(J)=W*(R(J)^2+I(J)^2+W*I(J))/D
5035 NEXT:GOTO9000
5500 PRINT CHR$(147)"ADD SHUNT TRANSMISSION LINE
5502 INPUT"WHAT IS LINE IMPEDANCE (OHMS)";Z1
5504 INPUT"WHAT IS LINE VELOCITY FACTOR";V
5506 INPUT"WHAT IS LENGTH (IN INCHES)";LL
5508 PRINT"OPEN (O) OR SHORTED (S) STUB";
5510 INPUT S$
5512 IF S$<>"O" AND S$<>"S" THEN 5510
5520 FOR J=1 TO N
5525 T=LL*F(J)*1.2/39.37/V
5530 IF S$="S" THEN W=Z1*TAN(T*π/180)
5535 IF S$="O" THEN W=Z1*TAN((T+90)*π/180)
5540 D=R(J)^2+(I(J)+W)^2
5545 X(J)=R(J)*W^2/D
5550 Y(J)=W*(R(J)^2+I(J)^2+W*I(J))/D
5555 NEXT:GOTO9000
6000 PRINT CHR$(147)"ADD TRANSFORMER
6002 INPUT"STEP UP OR DOWN (U OR D)";T$
6004 IF T$<>"U"AND T$<>"D" THEN 6000
6006 INPUT"WHAT TRANSFORMATION RATIO";W
6010 IF T$="D" THEN W=1/W
6020 FOR J=1 TO N: X(J)=W*R(J)
6025 Y(J)=W*I(J): NEXT: GOTO 9000
6500 PRINT CHR$(147)"ADD SERIES RESISTOR
6502 INPUT"WHAT VALUE OF R";RS
6506 FOR J=1 TO N: X(J)=R(J)+RS
6508 Y(J)=I(J):NEXT: GOTO 9000
7000 PRINT CHR$(147)"ADD SHUNT RESISTOR
7002 INPUT"WHAT VALUE OF R";RS
7004 FOR J=1 TO N
7006 D=(R(J)+RS)^2+I(J)^2
7008 X(J)=RS*(R(J)^2+RS*R(J)+I(J)^2)/D
7010 Y(J)=I(J)*RS^2/D: NEXT: GOTO 9000
7500 PRINT CHR$(147);
7501 INPUT "WANT TO RUN ANOTHER ONE";A$
7502 IF LEFT$(A$,1)="Y" THEN 10
7504 PRINT AT(14,10)"GOOD-BY.":END

8000 HIRES<ROF> 0,3:XR=100*XM
8002 CIRCLE<ROF> 160,100,XR,100,1
8004 LINE<ROF> 160-XR,100,160+XR,100,1
8008 ARC<ROF> 160+XR,0,180,270,10,XR,100,1
8010 ARC<ROF> 160+XR,200,270,360,10,XR,100,1
8012 CIRCLE<ROF> 160+XR/2,100,XR/2,50,1
8014 CIRCLE<ROF> 160,100,VR*XM,VR,1
8016 CHAR<ROF> 158-.67*XR,97,43,1,1
8017 TEXT<ROF> 153-.67*XR,104,".2",1,1,8
8018 CHAR<ROF> 158-.33*XR,97,43,1,1
8019 TEXT<ROF> 153-.33*XR,104,".5",1,1,8
8020 CHAR<ROF> 156+.33*XR,97,43,1,1
8021 TEXT<ROF> 156+.33*XR,104,"2",1,1,8
8022 CHAR<ROF> 156+.67*XR,97,43,1,1
8023 TEXT<ROF> 156+.67*XR,104,"5",1,1,8
8100 CSET<ROF> 2
8105 TEXT<ROF> 10,190,"F7=RETURN",1,1,8
8110 TEXT<ROF> 246,190,"F8=PRINT",1,1,8
8115 FOR J=1 TO N
8120 D=(X(J)+ZO)^2+Y(J)^2
8125 PX(J)=((X(J)-ZO)*(X(J)+ZO)+Y(J)^2)/D*100*XM
8130 PY(J)=-2*Y(J)*ZO/D*100
8140 CHAR<ROF> 157+PX(J),97+PY(J),43,1,1
8150 IF D$="S" AND J>1 THEN LINE<ROF> 160+PX(J-1),100+PY(J-1),160+PX(J),100+PY(J
),1
8160 NEXT
8170 GET A$:IF A$="" THEN 8170
8175 IF A$=CHR$(136) THEN NRM<ROF>:RETURN
8180 IF A$<>CHR$(140) THEN 8170
8185 TEXT<ROF> 10,190,"F7=RETURN",0,1,8
8190 TEXT<ROF> 246,190,"F8=PRINT",0,1,8
8195 COPY<ROF>:NRM<ROF>:RETURN
9000 PRINT"<DWN>      FREQ           RS            XS":PRINT
9005 FOR J=1 TO N
9010 RS$=STR$(X(J))
9015 XS$=STR$(Y(J))
9020 F$=STR$(F(J))
9025 USE<ROF>"    #####.###",F$:USE<ROF>"    #####.##",RS$:USE<ROF>"    #####.##",X
S$:PRINT
9030 NEXT
9050 PRINT AT(<ROF>0,18)"F1=PLOT ON CLEAN SCREEN FOR VIEWING
9055 PRINT"F2=PLOT ON CLEAN SCREEN FOR PRINTER
9060 PRINT"F3=PLOT ON LAST SCREEN
9065 PRINT"F4=SCREEN DUMP TO PRINTER
9070 PRINT"F5=BAD VALUE:  DISCARD THIS TRY
9075 PRINT"F7=GOOD VALUE: KEEP & PROCEED
9100 GET A$:IF A$=""THEN9100
9110 IFA$=CHR$(133)THEN XM=1.4:GOSUB 8000:GOTO9050
9120 IFA$=CHR$(137)THEN XM=.833:GOSUB 8000:GOTO9050
9130 IFA$=CHR$(134)THEN GOSUB 8100:GOTO9050
9140 IFA$=CHR$(138)THEN PRINT AT(<ROF>0,18)CL$;:HRDCPY<ROF>:GOTO 9050
9150 IFA$=CHR$(135)THEN 50
9160 IFA$=CHR$(136)THEN 9200
9170 GOTO 9100
9200 FOR J=1 TO N:R(J)=X(J)
9210 I(J)=Y(J):NEXT
9215 PRINT AT(<ROF>0,18)CL$;
9220 PRINT AT(<ROF>0,18)"<BLU>YOU NOW MUST MATCH THE IMPEDANCES LISTEDABOVE. (=4
>"
9230 PAUSE<ROF> 4:GOTO50
```

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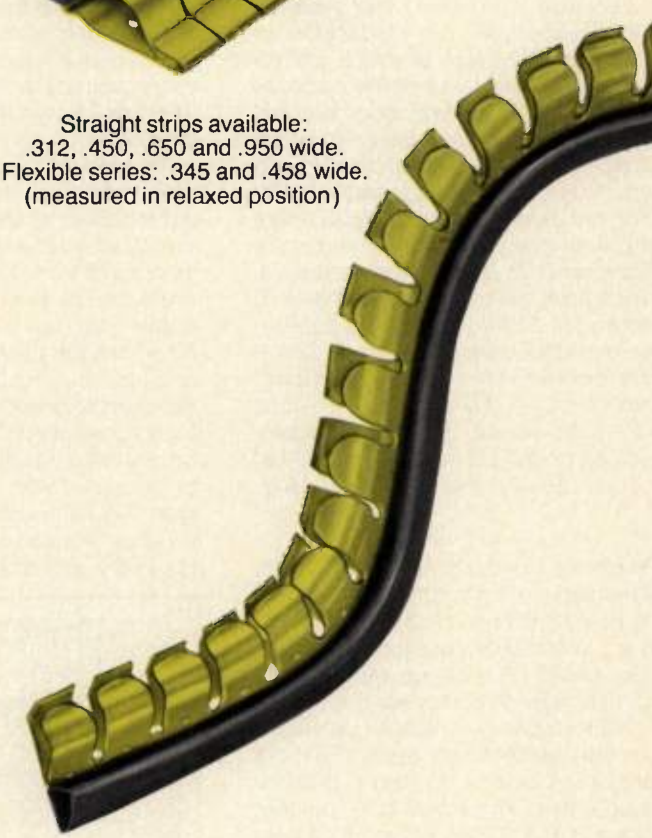

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INFO/CARD 16

Applying Power MOSFETs in Class D/E RF Power Amplifier Design

By H.O. Granberg
Motorola Semiconductor Products, Inc.

Class D and E are variations of switching mode amplifiers which are designated in the literature at least up to Class S. Switching means that the amplifying devices are either conducting or "open" during each half cycle and the switching from one state to the other is done as fast as possible. In some systems the switching is done at other than the carrier frequencies for modulation or other purposes. Class D and E usually refer to carrier switched amplifiers and are best suited for high frequency applications where the rise and fall times of the switching waveform are of main importance. They are directly adaptable to CW or FM, but other types of modulation are also possible by pulse width or amplitude modulation (1, 2, 3, 4, 5). The theoretical aspects have been well covered by F.H. Raab and N. Sokal in numerous publications over the years, and practical low power designs have also been shown. The author feels that since the evolution of the RF power FET, high power switching amplifiers can be designed at least up to 30 MHz and possibly 50 MHz.

Currently, Class D or E transmitters are marketed at up to 10kW power levels for the broadcast band (.55 MHz-1.6 MHz) and at 1 kW for shortwave (up to 15 MHz). All use power FETs as the switches and advertise high efficiency and reliability. When the efficiency is higher, the reliability is better since the transistor (FET) die operates at a lower temperature. Efficiencies of at least 70 percent to 80 percent in Class D and 80 percent to 90 percent in Class E are possible with the present RF power FETs at moderate power levels. Efficiency in Class D is limited mainly by the saturation resistance of the devices and the output capacitance. The objective in Class E is to use the device output capacitance as part of a tuned circuit, thus eliminating its effect as a load capacitance. In an ideal form it also ensures that the switching voltage and current waveforms are not overlapping (6, 7).

An obvious advantage of high efficiency is the smaller amount of heat generated compared to power output. This results in a smaller heat sink and more compact design, leading to smaller output devices and reduced cost. An important application of high efficiency amplifiers is in battery powered transmitters, where battery lifetimes 25 percent to 30 percent longer than Class C should be possible. Another advantage is simplified circuit design, since interstage matching networks are not required, as they are with Class A, B and C, where the amplifying devices act as current sources rather than switches. From the low level limiter to the P.A. the power gain can be as high as 40 dB to 50 dB and the system bandwidth is limited only by the response of the output transformer or matching network. Assuming a constant pulse width from the limiter on, extremely wide-band amplifiers can be designed with no variation in power gain. Figure 1 shows an estimated power level vs. frequency curve of Class D/E feasibility with today's technology.

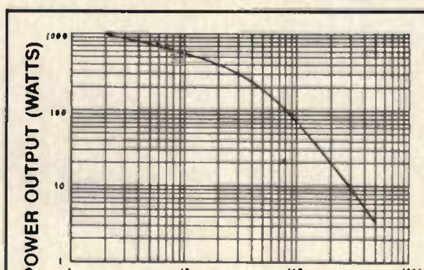


FIGURE 1. Estimated maximum power levels with a push-pull or single ended Class D/E amplifier based on present technology.

Preparing the Carrier Input Signal

Since the emphasis here is on relatively high power levels (up to 300W-400W per push-pull pair), the signal processing circuitry is only designed to operate up to 50 MHz. At higher frequencies it may be desirable to employ single ended designs in order to avoid any possible phase errors, which become exponentially more difficult to control with increasing frequency. The phase errors can be minimized in a push-pull circuit by providing the P.A. input drive through a transformer with bandwidth characteristics that will not affect the input rise and fall times considerably. Due to the difficulty in designing such transformers, which would require a bandwidth of one to several hundred MHz for a 2 MHz to 50 MHz carrier, it was decided to create the required 180 degree out-of-phase signals with ECL integrated circuits (Fig. 2).

The RF drive is first limited in a pair of cross coupled hot carrier diodes and then in three sections of ECL line receivers (MC 10H116). The limiter has approximately 50 dB dynamic range for amplitude modulated signals such as SSB. A peak detector circuit, shown at the upper left, was included, although the scope of this article is not to describe a modulated system.

The detector was designed to operate at audio frequencies, 300 Hz to 3 kHz, with an RF carrier down to 2 MHz. The detector output with two-tone RF input is shown in Figure 3.

The output audio envelope can be fed to an audio amplifier which can drive an emitter-follower or switchmode regulator that supplies the V_{DD} to the Class D P.A. The principle is to provide the amplitude information through this audio chain and the phase information through the RF chain. They are then combined in the output stage to provide a restored AM or SSB signal. This technique is called Envelope

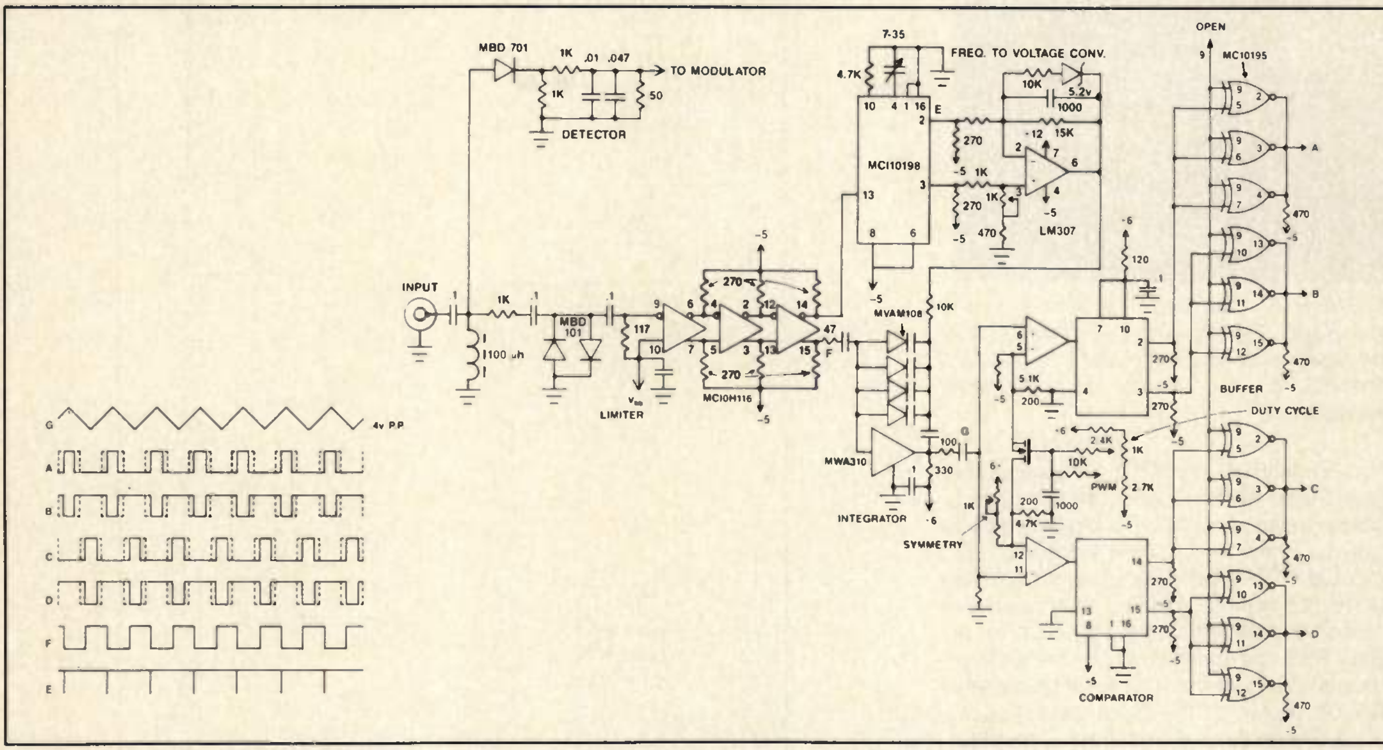


FIGURE 2. Schematic of the signal processor used in all the Class D experiments described. If the input is in sine wave, the amplitude can vary from .5 to 100 peak to peak. The output duty cycle is independent of the frequency.

Elimination and Restoration (EER) (2, 3, 4, 5). Pulsewidth modulation techniques can also be used to amplify AM and SSB signals with a Class D amplifier (1); however, the technique involves generating an inverse sine reference signal at the carrier frequency, and the distortion would be directly reflected to the output. The finite switching speeds also limit the dynamic range in this system. Both problems make the pulse width modulation technique practical only up to a few MHz. In contrast, distortion in an EER system is generated only by phase errors between the audio and RF chains (4, 5).

Although the circuit in Figure 2 is not intended for pulse width modulation, a provision was made to adjust the pulse width manually to allow the power output to be varied and to ensure that the P.A. drive signals would not be overlapping. The objective was to provide a constant duty cycle with frequencies anywhere between 2 MHz and 50 MHz. This was difficult to achieve, and the final result was that the frequency was split into two segments: 2-25 MHz and 25-50 MHz. Adjustments in the MC10198 (one shot) timing as well as the LM307 and the comparator biases were necessary to cover each band. The problem was mainly with the limited capacitance range of the MVAM108 tuning diodes in the integrator. Their capacitance should track the frequency in order to provide a constant amplitude triangular wave output from the integrator. It must be pointed out that the physical circuit layout of the integrator is critical for low distortion output. All lead lengths should be minimized and elsewhere proper ECL wiring techniques should be followed.

The circuit of Figure 2 was intended to be used with a number of Class D P.A.s studied. It is remotely located from the driver and the P.A. assembly, and the signals between the two are connected by twisted wire lines. The pull down resistors in the MC10195 outputs are provided only for testing purposes, while the terminations are located at the driver and P.A. assembly.

The Driver

Because of direct coupling between the stages, each side of the push-pull circuit requires its own driver and pre-driver. This has the advantage that the high peak current requirement from the driver is divided between two circuits, which will be discussed later in detail. For this reason also the push-pull configuration was chosen. A single ended design would require an output FET twice as large, having proportionally higher gate input capacitance.

The ECL level limited signal must be converted first to a voltage swing of at least 2 to 3 volts above ground to feed the driver, which may have a FET or bipolar input. The circuit shown in Figure 4E can be used for this, or 4F, if the ECL is operated between ground and +5 volts. Alternatively, integrated circuits, such as the MC10G125 ECL to TTL converter or MC10177 MOS clock driver, can be used for this function, as shown in Figure 5. These ICs can be operated with single phase inputs as well as two phase. The voltage swing must be increased to 8 to 10 volts above ground to ensure that the P.A. FETs will be fully "turned on."

Figure 4 gives examples of drivers that are fairly simple and can drive heavy capacitance loads. Figure 4A is the most complex, but it performs well providing the devices are correctly selected and the gate threshold voltages of Q3 and Q5 are equal. Without a load no current should flow through Q2 and Q3. The last statement applies to 4B also, if Q2 and Q3 are switched correctly. This basic circuit is used in the output stages of many TTL gates and buffers, and in integrated form the transistor base-emitter forward and saturation voltages can be controlled closely. In a discrete form the value of Q1 emitter resistor must be adjusted according to the parameters above. In addition, Q3, which is in common emitter configuration, must be of a fine geometry, high frequency design to minimize the base-emitter junction stored charge effect. Such devices in the NPN polarity are currently available in many package configurations.

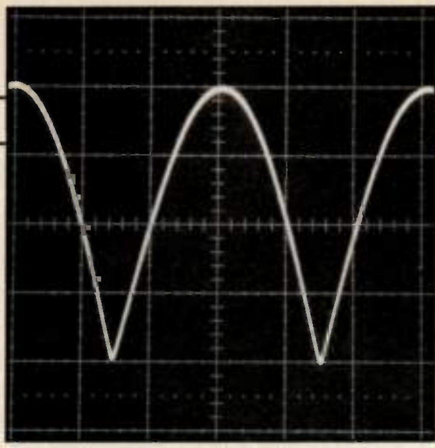


FIGURE 3. The peak detector output waveform (Fig. 2) with a two tone SSB drive signal. This can be used to control the P.A. supply voltage for amplitude modulation.

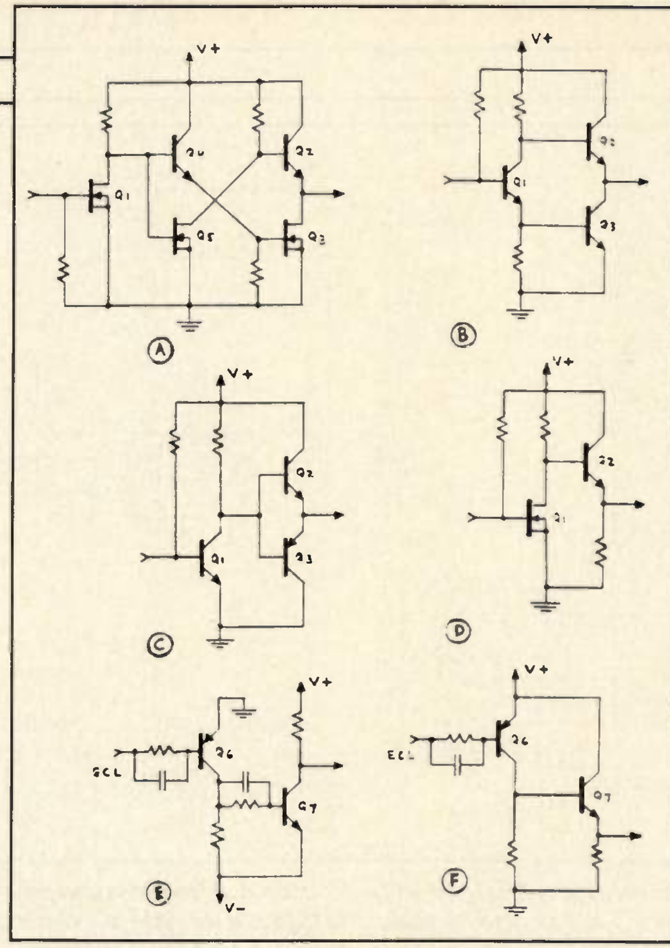


FIGURE 4. Various Class D driver configurations. E and F are intended for ECL to positive level conversion, while A, B, C and D are designed to operate from higher voltage inputs to drive capacitive loads, such as the FET fates.

Circuits in 4C and 4D are the simplest and least critical, although both have some drawbacks. 4D uses a passive pull down, where the resistor value can be calculated for the desired turn off time when the voltage and FET input capacitances are known. A typical value for a 50W FET operating at 50 MHz would be around 3 to 4 ohms. The resistor current will be added to the input capacitance (C_{iss}) charge current, requiring a doubled current capability from the emitter follower (Q_2), although the average power dissipated is equal to that of circuits with active pull down. The complementary emitter follower in 4C is probably the most efficient driver, considering its simplicity. It is tolerant against variations in device parameters and has the lowest output impedance if the transistors are properly selected. The only disadvantage is the scarcity of high frequency PNP transistors with sufficient current capabilities. In all Figure 4 circuits the pre-driver (Q_1) can be a bipolar transistor or a FET depending on the exact requirements and the input signal amplitude.

Power MOSFET HF Switching Characteristics

At low frequencies the MOSFET gate should present a purely capacitive load to the driver. In switching applications, however, the rise and fall times represent a much higher frequency component than the fundamental. For example, if at 30 MHz carrier 4 nanosecond switching times can be tolerated, at 80 percent amplitude the 4 ns represents roughly a 100 MHz sine wave. Examining the MRF150 Smith Chart (data sheet) and converting the information into parallel form we find that the input capacitance remains a constant 800 pF up to 150 MHz. This is an average value under biased and linear operating conditions, but it indicates that the wire bond and package inductances have a minimal effect at that frequency. For switching applications, where the FET goes into saturation, the input capacitance is more difficult to define.

As shown in Figure 5, the C_{iss} varies with gate and drain voltages. At left (zero gate voltage) we can see the value under the conditions where the parameter is normally specified. At increased gate voltage the capacitance goes down to its lowest value, just before reaching the threshold voltage. When the FET begins to draw drain current, there is a point where the device gain is at its highest value. At that time the drain voltage is also lowered, resulting in reduction of the depletion area and causing an overlap between the gate and the bulk material. This in turn increases the value of drain to gate capacitance (C_{rss}), which will be multiplied further by the gain and reflected back to the gate. As a result, a sharp peak in the C_{iss} will occur. When the FET is fully saturated, the C_{iss} settles to its value under zero drain voltage and positive gate conditions. A similar effect is present with all power MOSFETs to some extent depending on their exact parameters. The data was taken at 1 MHz but is not expected to change considerably at higher frequencies.

Figure 6 shows two input drive waveforms superimposed at 25 MHz repetition rate: the driver waveform without a load (A) and when loaded by the FET gate (B).

The notches in B are the result of the C_{iss} peak in both turn on and turn off. In low frequency switching applications this may not be directly noticeable due to the much slower transition times involved. For HF, the peak value of the C_{iss} must definitely be taken into consideration when designing the driver. Assuming the driver pulse amplitude is 8 volts, the driver has a relatively easy task in turning the FET on. The C_{iss} is low up to the threshold point, approximately 3.5 volts, increasing to 4.5 volts. After this, the voltage only has to increase another 3.5 volts, loaded by the high capacitance. Since this period falls within the "on" cycle of the FET, a slower rise time is of lesser importance. In turning the FET off the driver must supply the highest current at the beginning of the cycle. Its dissipation is also at the peak at this point and high until the first 3.5 volts of discharge is completed, the load capacitance lowered and the voltage across the driver gradually reduced. This is the most critical part of the cycle since it can result in a

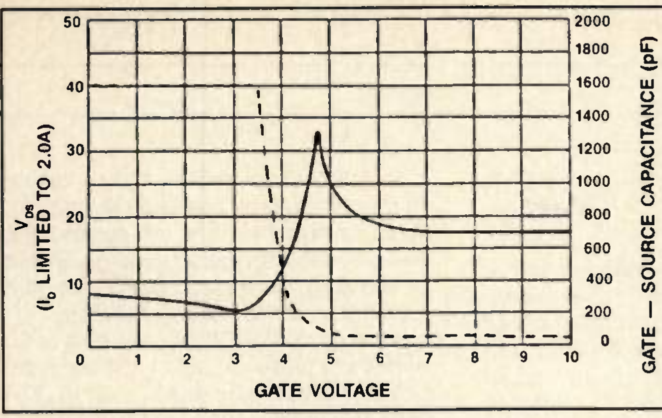


FIGURE 5. Typical TMOS (MRF-150) gate-source capacitance versus gate and drain voltages. All power MOSFETs behave more or less similarly, depending on their die structures, geometries and electrical parameters.

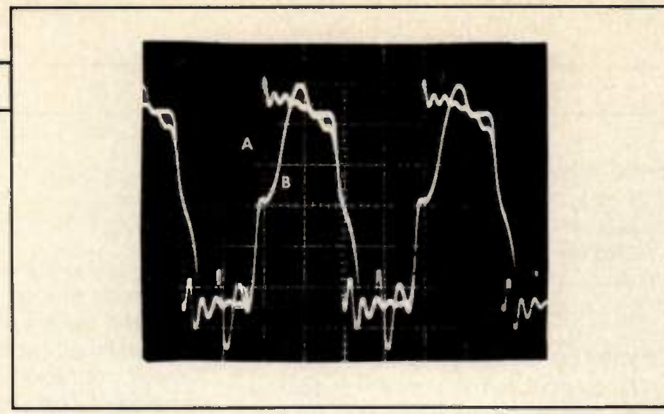


FIGURE 6. Driver output waveform at 25 MHz. A without a load. B loaded by the P.A. FET gate. Results of the uneven gate capacitance distribution versus gate and drain voltage can be noticed in B. 10 nS and 2v/div.

delay in the turn off of the FET, causing both sides of a push-pull circuit to draw current simultaneously for a part of the cycle. The delay can be prevented or minimized by adjusting the driver voltage amplitude only to a level necessary to switch the output FETs to a full saturation and completely off. Any excess voltage swing increases the delay and also the dissipation in the driver.

Considering the complex nature of the FET C_{iss}, a most realistic figure for the required driver output impedance can be obtained if it is calculated for the peak capacitance value and the gate voltage swing between saturation and threshold:

$$\frac{-t}{C \times L_n(1 - \frac{V_2}{V_1})}$$

where:

-t = required switching time (4ns).
C = FET input capacitance at the peak (1300 pF).
V_1 = gate voltage at saturation (8V).
V_2 = gate voltage between saturation and threshold (4.5V).

then:

$$\frac{-4\text{x}10^{-9}}{1.3 \times 10^{-9}(-.82)} = \frac{-4}{1.3 \times (-.82)}$$

= 3.74 ohms

This translates to 1.2 amperes up to where the driver transistors (NPN and PNP) must have a linear h_{FE}. As stated earlier, the 4 ns transition times represent about a 100 MHz sine wave, which means that an HF beta of 10 would require an f_t of 1000 MHz for the driver transistors according to the 6 dB/octave slope (8). The DC beta (h_{FE}) is not critical but must be greater than 10.

For the complementary emitter follower, the PNP half may be difficult to find with the above specifications. In fact, some special units were built for experimental purposes using a multiple die similar to the 2N5583. The NPN counterpart was an MRF630. This combination worked well except that heat sinking of the TO-39 packages was difficult because of the close proximity of the pair, which is necessary to minimize all inductances.

Output Impedance Matching

In low voltage Class A, B and C designs the output impedance matching becomes difficult due to the low impedance levels involved at 100 W and higher output levels, if broadband operation is required at HF. The matching is usually done with broadband transformers, of which the transmission line types offer the best broadband performance. For many applications, however, they are considered impractical and bulky in higher than 9:1 or 16:1 impedance ratios (9). There are other transformer types that are more convenient in physical aspects but lack the bandwidth characteristics. This poses a real problem, especially for Class D where bandwidths from 1 MHz to 100 MHz or higher may be required. A transformer type which is fairly good for impedance ratios to 25:1 and higher is one where the low impedance winding is formed by metal tubes inside ferrite sleeves and the high impedance widing is threaded through the tubes (7, 9). Such a transformer was used in the design of Figure 7, where the power output specification was 100 W, requiring the closest integer of 16:1 impedance ratio.

Two points in its behavior must be noted.

1. The high leakage inductance of this type transformer requires an unusually large capacitance for compensation limiting the bandwidths. These capacitances, of which the device output capacitance will be a part, are normally located across the primary or secondary windings, or both (Figure 7, C_1 and C_2). The required compensation can be calculated from the measured leakage inductance, and the maximum frequency will be limited by the device output and stray capacitances. At the resonant frequency the transformer VSWR will be 1.2:1, increasing to approximately 6:1 an octave higher (10). The leakage inductance can be measured across the secondary with the primary shorted. The connection inductances must be added to this and the maximum tolerable value is:

$$L_1 = \frac{R_L}{2\pi f}$$

where:

L_1 = Leakage inductance (μH)
R_L =Load impedance (50 ohms)
f = Maximum frequency (Mhz)

In Class D, the limited bandwidth will slow down the output rise and fall times. Since the transformer acts as a low Q resonant circuit, this can be used to place the amplifier in Class E mode of operation by moving the resonance down to the carrier frequency, although the Q cannot be properly controlled and the system may not be optimized.

2. The coupling between the two halves of the low impedance primary winding is only provided through the secondary and is very poor at higher frequencies due to the leakage inductances. If the amplifier is designed for voltage switching configuration, the transformer center tap is bypassed to ground. Due to the decreasing coupling the effect of the center tap is lost and at higher frequencies the amplifier will turn into current switching mode. With these two configurations the drain voltage and current waveforms are reversed (7), resulting in unpredictable waveshapes at the between frequencies. This will not affect the amplifier's efficiency, which theoretically should be equal for voltage and current switching modes, but makes its operation more difficult to analyze. If the transformer is properly designed, e.g., the tube diameter to

length ratio is high for increased couplings and the inductances between the transformer and FET drains are low, satisfactory operation up to 50 MHz is possible, depending on the impedance ratio in question.

Efficiency Considerations

The efficiency of an amplifier is defined as the ratio of DC input power to RF output power and is usually expressed in percentage. There are three main device parameters that affect the efficiency of a Class D amplifier:

1. Saturation voltage, in some data sheets given as saturation resistance, is directly proportional to the current and more linear with FETs than with bipolar transistors due to the latter's nonlinear diode characteristics. In contrast to the bipolar the FET has a highly positive temperature coefficient slope (saturation voltage increases with temperature), approximately 1 percent/°C. The DC value starts higher with FETs than with comparable devices. At RF the saturation voltage is further increased by the package and wire bond inductances and is more noticeable with low voltage devices due to the low impedances and high current levels involved. The RF saturation voltage can be more accurately measured than calculated. Typical values for MRF140 and MRF150, for example, are 1.7 volts and 3.0 volts, respectively, at 10 amperes and 30 MHz. From these numbers the efficiency can be calculated simply as:

$$\frac{V_{DD}-V_{sat}}{V_{DD}}$$

2. The switching speed of a transistor or a FET is mainly related to its high frequency characteristics, as discussed earlier in the driver paragraph. The internal capacitances have a large effect, but they in turn are a function of f_t, except for small differences between various FET structures such as interdigitated and overlay or TMOS and VMOS. For comparable geometries the FET has about three times higher f_t than the BPT. This means that some of the low frequency switching FETs can be used as RF switches up to 20 MHz to 30 MHz if a low output impedance driver is provided. In case of a sine-wave driving signal (7) the switching speed relies totally on the device high frequency gain and the input signal amplitude, whereas with a square-wave drive, it is affected by the input rise and fall times as well. Assuming a linear ramp with no distortion, the effect of transition times on efficiency can be calculated as:

$$\frac{360 \times \sin\Theta s}{2\pi \times \Theta s}$$

where: Θs is the phase angle portion of a full cycle that the transition time covers.

3. The device output capacitance, or any external capacitance shunting the output, reduces the efficiency of an amplifier. This capacitance must be charged to nearly twice the supply voltage during each cycle, and the power used is dissipated in the amplifying device. In narrowband designs and Class E switching it can be tuned out but not completely since its value varies with the output voltage swing. With power transistors and power FETs, the C_{ob} or C_{oss} is usually dominant and stray capacitances can be disregarded for practical purposes. Their values in data sheets are specified at DC and at the recommended supply voltage for RF, or mostly at 25 volts for LF switching. For example, the C_{oss} for the MRF150 is given as 250 pF at 50 volts but is higher at lower voltage and increases sharply at voltages below 5; thus, for accurate calculations a higher C_{oss} value should be used for an average, but it can only be obtained from a C_{oss} vs voltage curve. According to the formula in Reference 7, (p.446) the power loss for a push-pull amplifier is:

$P_s = C_s(2\ V_{eff})^2(2f) = 8\ C_s\ V_{eff}^2 f$ where:
P_s = Power loss
C_s = Device output capacitance
$V_{eff} = V_{DD} - V_{sat}$
f = Frequency

From this we can see that power loss depends mostly on supply voltage and on capacitance and frequency to a lesser degree. The output rise and fall times for these calculations are irrelevant since they only affect the peak power dissipated in charging the load capacitance, the average power remaining constant.

For a pair of MRF150s operating at 50 volts and a power output of 300 watts the power loss would be 8 (250 x 10^{-12}) $(47)^2$ (30 x 10^6), considering the worst case at 30 MHz. (2 x 10^{-3}) (2200) (30) = 132 watts and the efficiency is:

$$\frac{300}{132 + 300}$$

= 69 percent.

If the same die (MRF140), with its 450 pF output capacitance, were used in a similar 28 volt system, the efficiency would be (3.6 x 10^{-3}) (692) (30) = 75 percent. This is in contrast to the belief that a higher supply voltage automatically results in higher efficiency except when the circuit losses become high at very low output impedances. Considering this, it would seem that Class D efficiency is not much better than Class B or Class C, at least at higher supply voltages. If we calculate the total efficiency, taking all the above factors into account, it is only about 60 percent, However, efficiencies up to 80 percent have been demonstrated in practice in similar systems, using the MRF150s or comparable devices.

It is obvious that load capacitance is the one factor that limits amplifier efficiency most seriously, unless it can be compensated for. Assuming a perfect output transformer in a Class D push-pull amplifier,

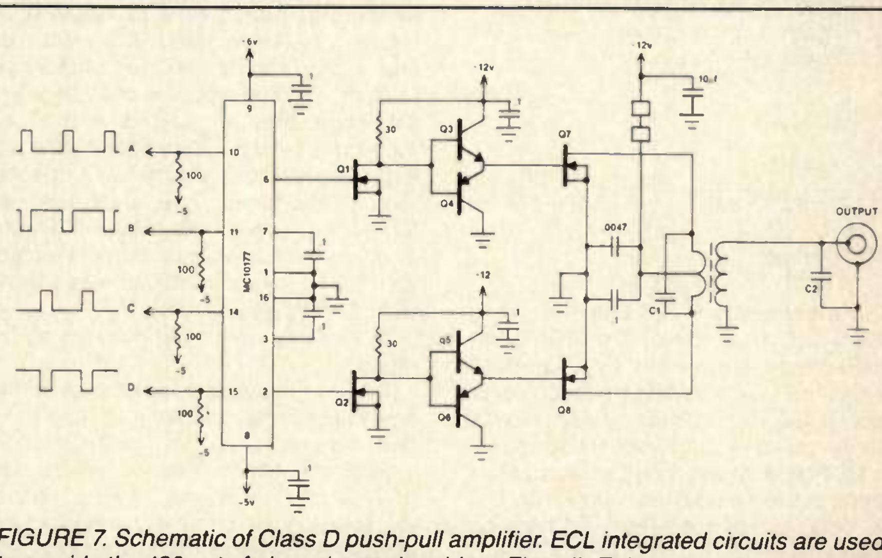
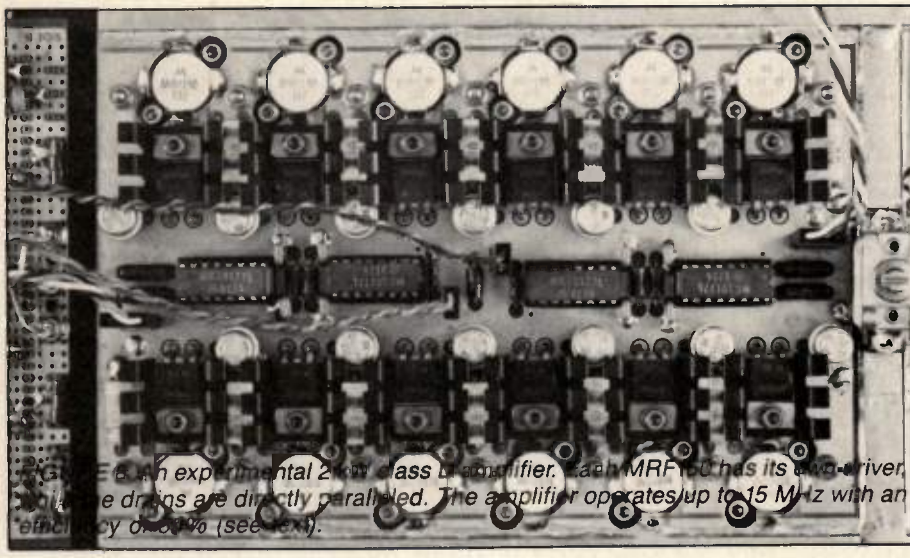


FIGURE 7. Schematic of Class D push-pull amplifier. ECL integrated circuits are used to provide the 180 out of phase input signal (see Fig. 12). This makes the pulse width easy to control compared to transformer coupling.



[illegible] An experimental 2 [illegible] Class [illegible] amplifier. [illegible] MRF[illegible] has its [illegible]-driver, [illegible] the drains are directly paralleled. The amplifier operates up to 15 MHz with an efficiency [illegible]% (see text).

the compensation could be done by inserting a required amount of series inductance between the drains and the transformer primary. This would form a resonant circuit with the device C_{oss}, limiting the bandwidth to some extent, and the advantage of the perfect transformer would be lost. This inductance can be used and sometimes is used unintentionally to tune out the device output capacitance, but since the effective C_{oss} varies within the RF cycle, total compensation can hardly be achieved. Thus, in practical amplifier circuits of this type, there is a tradeoff between efficiency and bandwidth, which also applies to Classes B and C.

Conclusion

Commercial Class D and E transmitters up to 1 kW and 10 to 15 MHz are on the market. The author demonstrated a 1 kW, 10 MHz amplifier in 1981 (11), which was later evaluated by the National Bureau of Standards. Other designs since then include an 800 W amplifier at 13.54 MHz with four MRF150 FETs, a 100W unit for 25 to 50 MHz operating at 12 volts and a 2 kW, 50 volt system (Fig. 8) which did not function as expected at frequencies above 15 MHz. The main problem was increasing inductance in the power FET drain connections to the output transformer. The component physical size undoubtedly places a limit for high power designs of this type, unless multidimensional constructions can be made feasible.

The importance of the physical layout must be emphasized, since it is the key to a properly operating system no matter how good the electrical design is. We must remember that we are dealing with frequency components of 100 MHz and higher in a 30 to 50 MHz carrier system, where even a nanosecond difference in delays between each side of a push-pull circuit drive signal will noticeably affect efficiency.

Since high power Class D and E designs up to 15 MHz with efficiencies far exceeding those at Class B have been shown, the author feels that the frequency range can be extended to at least 30 MHz with proper physical design, leading to high efficiency linear and other applications.

About the Author

Helge Granberg is Principal Staff Engineer at Motorola Semiconductor Products, Inc., P.O. Box 20912, Phoenix, AZ 85036.

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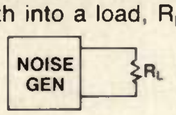
A Noise Nomograph

By Seymour Schneider
Micronetics, Inc.

The output from a noise source can be expressed in many different ways, depending on the frequency range and the system with which the noise source is used. For example, at microwave frequencies the output of a noise source is expressed as ENR (Excess Noise Ratio), which is defined as the noise ratio minus unity, where noise ratio is the ratio of the equivalent noise temperature of the noise source to room temperature. At audio frequencies the output of a noise source is expressed as $\mu V/\sqrt{Hz}$, where voltage is the RMS voltage measured in a given bandwidth, divided by the square root of the measurement bandwidth.

Other expressions are dBm (per bandwidth), V_{rms} (per bandwidth) and equivalent noise temperature. The noise nomograph relates these commonly used terms associated with noise power calculations. In addition, it can be used easily to determine the effect a change in a given parameter has on noise power.

The relationships used in the nomograph refer to a noise generator that provides power output over a specified noise bandwidth into a load, R_L



$$ENR = 10 \log \left(\frac{T_E}{T_o} - 1\right)$$

$$P_n = K\, T_E\, B$$

$$V_{rms} = (P_n R_L)^{1/2}$$

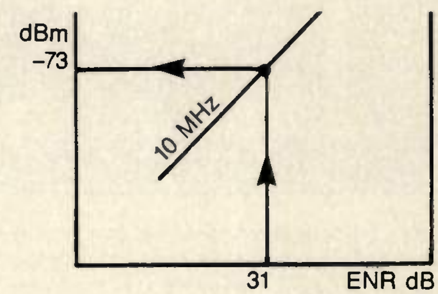
$$dBm = 10 \log \left(\frac{P_n}{10^{-3}}\right)$$

$$V/\sqrt{Hz} = V_{rms}/\sqrt{BW}$$

Where
T_o = Room temperature, 290°K
T_E = Equivalent temperature of noise source in °K
K = 1.38 x 10^{-23} joules/°K
B = Bandwidth in Hz
Pn = Available power from noise source in watts

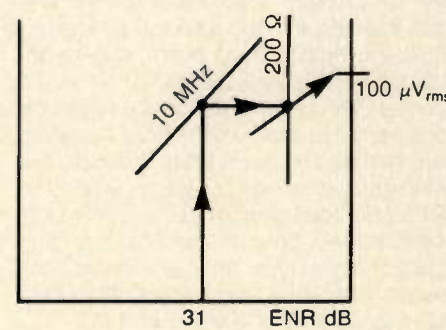
Example 1

Given: ENR = 31 dB
: Noise Bandwidth = 10 MHz
Find: dBm = −73



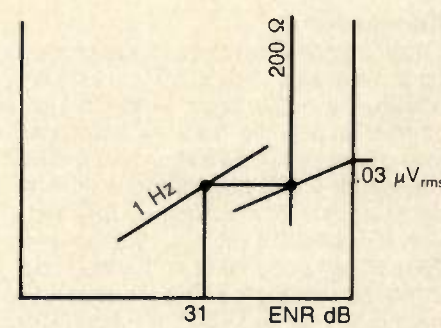
Example 2

Given: ENR = 31 dB
: R_L = 200 Ω
: Noise Bandwidth = 10 MHz
Find: V_{rms} across load = 100 μV



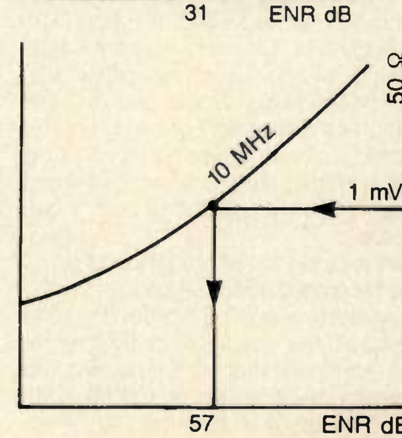
Example 3

Given: ENR = 31 dB
: R_L = 200 Ω
Find: Noise spectral density in $V_{rms}/\sqrt{Hz}$ across 200 Ω = .03 μV_{rms}



The given and to find can be interchanged as shown in the following example.

Given: 1 mV_{rms} across
: 50 Ω load
: Noise Bandwidth = 10 MHz
Find: ENR = 57 dB



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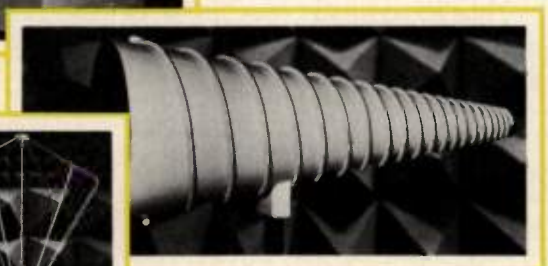

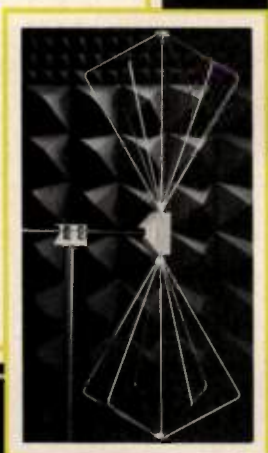

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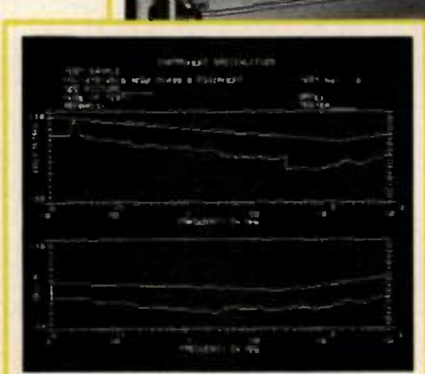

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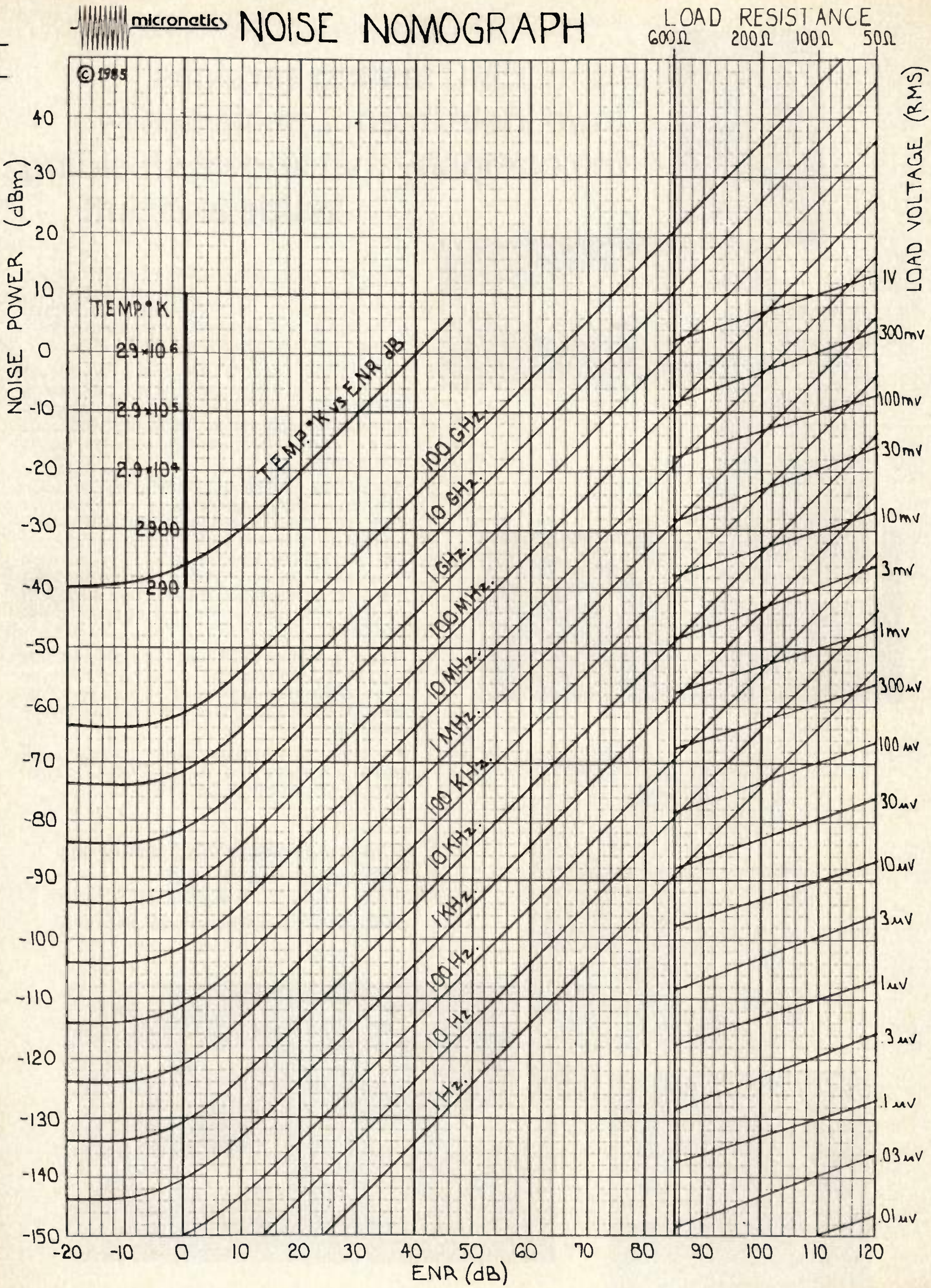


Anechoic Chamber Considerations

By Gabriel Sanchez
Advanced Electromagnetics, Inc.

In general, it is the test engineer's goal to simulate a far field condition while conducting an electromagnetic test, i.e., antenna patterns, power testing, susceptibility testing, etc. The engineer wishes to illuminate a test device with an electromagnetic wave that is uniform in amplitude and phase. The ideal condition would be to place the device in free space at a large distance, providing the perfect test situation. In practice this is rarely a true option. Instead the engineer must set up tests near the earth and/or in a supporting structure. This leads to certain compromises in both amplitude and phase uniformity.

The familiar range equation:

$$R = \frac{2D^2}{\lambda}$$

is a result of deciding that for most testing the acceptable phase variation is 22.5 degrees. This equation is applicable to all test facilities except those operating in the near field.

The amplitude compromise most often used is approximately 0.5 dB, with precision ranges having a 0.2 dB or less requirement. This is achieved by carefully selecting the type of source antenna and, in the case of ranges based on the use of energy reflection, the geometry of the facility.

Extraneous energy is unwanted energy reflecting from the ground, support structure or the walls of anechoic chambers which reaches the test region and causes errors in the measurement process. The effect of extraneous energy on the accuracy of the measurement is a great concern to the engineer. This concern is generally limited to distortion in amplitude uniformity, but it can have an effect on phase when precise polarization measurements are required.

A final consideration is isolation of the test environment from interference from outside sources such as TV stations, radio stations, communications dishes, etc. Isolation can also be for security reasons, keeping the energy radiated within a facility from getting out and being detected with special equipment.

Far Field Facilities Using Suppression Techniques

The outdoor elevated antenna range and the indoor rectangular anechoic chamber are examples of far field facilities designed to suppress unwanted reflections. The designer builds an outdoor range so extraneous energy from the source antenna does not reach the test antenna.

The rectangular anechoic design is similar in that the antennas are carefully chosen to minimize the energy reaching the sidewalls of the chamber. The walls are then covered with microwave absorbers to attenuate energy that may reach the wall.

Both facilities are guided by the range equation with regard to phase accuracy. This means that the outdoor range is suitable for large aperture devices and the indoor range is suitable for smaller apertures. Both ranges are suitable for testing at microwave frequencies rather than at UHF or VHF frequencies. In general, antennas operating at these frequencies are very low gain and radiate energy in all directions, thereby limiting the amount of extraneous energy suppression achievable. The rectangular anechoic room is generally limited to operation above 1.0 GHz.

Far Field Facilities Using Reflection Techniques

The ground reflection site and tapered anechoic chamber are facilities which use reflections from the surroundings to help produce an acceptable test environment. The ranges are far field in that the $2D^2/\lambda$ requirement is still applicable, but instead of suppressing the reflection encountered on the ranges, the physical parameters of the facility are selected so that direct path and reflected path energy arrive in phase at the test region. With the energy arriving in phase rather than out of phase a constructive field distribution is set up in the test region.

On the outdoor range this in-phase condition is established at a given operating frequency and polarization by adjusting the transmitter height until a maximum signal level is received at the test antenna. A uniform signal level illuminates the test antenna when it is properly adjusted. The smoothness of the range surface determines the uniformity of the field at the test antenna.

The tapered chamber can be visualized as a four-sided ground reflection range; thus, the source antenna must be carefully placed in the cone end to achieve the desired uniform field in the test region. Here the symmetry of the structure and the type of absorbers used determine the performance achieved. These types of ranges are especially suited for low frequency testing. When broad beam antennas are properly placed in the cone they provide proper illumination so reflections can be controlled to be in phase at the test zone.

Near Field Testing

In recent years two methods of near field testing have been developed and are being used by several testing facilities. One method is to place the antenna under test in the field of a larger antenna, simulating the far field requirements. This has been found to be successful for moderately directive antennas up to four feet in diameter operating in the frequency range of 3 GHz to 18 Ghz.

The second type of near field measurement uses a small probe antenna very close to the antenna under test sampling over the whole aperture. This data is then fed into a computer and translated into the far field pattern by numerical analysis.

Rectangular Anechoic Chambers

This type of chamber is in the form of a rectangular shell covered on the entire inner surface with one or more types of absorber materials. Chamber width and height are usually in the range of one-half to one-third the required transmission length. A chamber of this design has difficulty in providing good performance at UHF and lower frequencies, as discussed above. The basic problem is that reflected signals that arrive in the test region are the result of specular reflection from the bounce points on the sidewalls, floor and ceiling. At lower frequencies it becomes increasingly difficult to limit reflected signals traveling those paths for two reasons:

1) finite size of the source antennas, i.e., the lower the frequency the broader the pattern.

2) absorbers become less effective at the longer wavelengths, especially at wide angles of incidence.

For these reasons a rectangular chamber of reasonable size is limited to operation down to approximately 1.0 GHz.

Tapered Anechoic Chamber

In facilities using specular reflection to establish the test environment (ground reflection range and tapered anechoic chamber) the design is somewhat complex because facility geometry, ground or surface effects and operating frequency determine the purity of the test environment achieved.

On the outdoor ground reflection range source antennas are selected to illuminate the surface. The surface is graded to a tolerance in keeping with the Rayleigh criterion so it represents a microwave mirror to the incoming wave. The range length and tower height are then adjusted so the direct path and the wave reflected from the range surface are in phase at the test aperture, thereby producing a smoothly varying cosinusoidal interference pattern peaked on the antenna under test. The mere fact that the reflected wave can approximately equal the direct path wave in amplitude in no way detracts from the range's usefulness as a test facility, since the purity of the incident field and how this purity was obtained are the important considerations.

The tapered chamber is characterized by five attractive features.

1) Using the tapered surfaces properly, the chamber can provide a quiet zone free from periodic amplitude variations which characterize a rectangular chamber at lower frequencies.

2) This additional design parameter permits the designer to control the level of reflections to a significantly lower level than is attainable with absorber alone.

3) The source antennas used are low gain versions which permit operation down to very low frequencies.

4) The area to be covered by high quality absorber is significantly reduced from that of a rectangular chamber providing the same transmission length.

5) A smaller percentage of thick, high-performance absorber is required. Measurements have shown that tapered chambers provide quiet zones of relatively uniform phase amplified at frequencies as low as 30 MHz and as high as 30 GHz.

Tapered chambers are, therefore, well suited for almost all the typical measurements made in microwave anechoic chambers: measurements of antenna patterns, antenna gain, power, systems compatibility and systems boresight. On the other hand, certain types of tapered chambers are not as well suited for other uses. It is worthwhile to consider these uses specifically.

Gabe Sanchez is President of Advanced Electromagnetics, Inc., 369 North Raleigh, El Cajon, CA 92020.

Some Questions You Should Ask Your EMI/RFI Test Equipment Supplier

How long has your company been in the EMI/RFI Testing Equipment business?

The Electro-Mechanics Company has been designing and manufacturing EMI/RFI Test Accessories for over 25 years.

We began with Magnetic Field Instruments and Radio Frequency Antennas for the military. Since the mid-sixties we have been working closely with the military and industry standard setting groups, and EMCO now has one of the broadest lines of Test Antennas and EMI/RFI Test Accessories in the World.

What exactly is your major product line?

EMCO's primary business is Test Antennas for use in Emissions and Immunity (Susceptibility) Testing as required for MIL Standard, FCC, VDE, and CISPR Test Procedures.

Typical Military Antennas for Radiated Immunity (RS) and Emissions (RE) Testing cover the frequency ranges from **30 Hz to 18 GHz**, and are noted in MIL STD 462, Notice 3, Table 1. EMCO currently manufactures **Magnetic Field Loops**, the 41" **Rod Antenna**, **Parallel Strip Line**, both

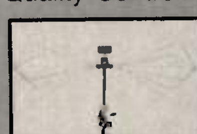
Biconical Antennas, the **Conical Log Spirals** and the **Double Ridged Guide Antennas** shown on this table.

Antennas which are currently acceptable for use in FCC Volume II, Part 15 Emissions Testing include, **Adjustable Element Dipole Sets**, Broadband **Biconical Antennas** and Broadband **Log Periodic Antennas**. EMCO manufactures all of these separately or can include them as part of an FCC "Class A" and "Class B" **Antenna Test System**.

What differentiates your antennas from your competitors?

One major difference is Calibration. Each Antenna is calibrated using NBS Traceable Testing Equipment, on our own FCC open field test site. Calibration data includes Antenna Factor, Numeric Power Gain, and dBi Gain for each individual Antenna. For Immunity Testing Antennas we include Field Strength measurements in Volts Per Meter, and Radiation Patterns where applicable.

Another difference is Design and Construction. Each Antenna is designed to be durable and long-lasting, yet functional in varied applications, such as in Anechoic Chambers or Outside Test Sites. Antennas and accessories are machined and constructed "in-house" for Optimum Quality Control.



One last difference and maybe the most important, is EMCO's continual Product improvement thru Research and Development. For example, our **Dipole** and **Biconical Balun** design is much improved from the old DM-105 and military designs . . . and we are continually researching and redesigning to make EMI/RFI Testing simpler and more accurate.

What other Test Equipment and Accessories do you offer?

EMCO adds efficiency to EMI Testing with an **Antenna Positioning Tower** (1-6 meters) and an **Equipment Testing Turntable**. Both are suitable for outside or indoor use, come with a standard Digital Readout Controller and are available with **IEEE-488 Bus** Option.

For Conducted Emissions Testing, EMCO manufactures **Line Impedance Stabilization Networks** to satisfy FCC and VDE requirements. Our unique design allows production of as many as 4 separate lines (three phase) in one unit.

Other Related Equipment include: **Signal Rejection Networks**, **Acceptance Networks**, **Magnetic Field Intensity Meters**, **Magnetometers** and **Helmholtz Coil Systems.**

Why should my company buy your EMI/RFI Test Equipment?

The Electro-Mechanics Company is more than just another manufacturer. We realize that in order to grow and help improve EMI/RFI Testing we must constantly forge ahead . . . not live in the past.

As the FCC moves toward better and more Standardized Test Procedures, EMCO is staying close to ANSI (American National Standards Institute), NBS (National Bureau of Standards) and other standards groups so we can keep improving our equipment. Involvement with current and future industry needs also helps us plan for design of new equipment . . . an ongoing process at EMCO.

EMCO is committed to offering Technical Assistance, as well as Test Accessories, to help solve EMI Testing Problems. Part of that Technical Assistance is advice on purchasing only the equipment needed, not kits or systems with unnecessary items. We can also advise on various manufacturers of other complimentary test equipment.

If you have more questions and are looking for Helpful Answers, Call us at (512) 835-4684.

The Electro-Mechanics Company

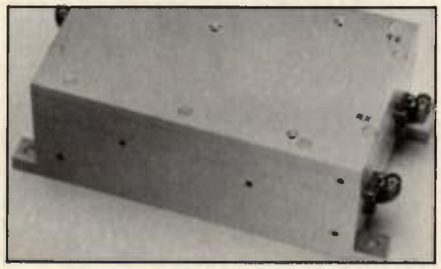
P.O. Box 1546/Austin, Texas 78767/Telex 767187

INFO/CARD 33

rf products

Cavity Diplexers and Multiplexers

Eaton Corporation Microwave Products Division, introduces a new product line of high quality diplexers and multiplexers with contiguous or noncontiguous capability. This S-Band diplexer, with bandwidths ≤2%, utilizes computer-aided "TEM Iris Coupled Cavity" design techniques. The device provides very high selectivity of 90 dB minimum, high unloaded "Q" and strict VSWR requirements of 1.25:1 maximum. Operating



temperature range is -40°C to +85°C, with 100% R.H. Diplexers and multiplexers from Eaton Corporation meet or exceed MIL-E-5400, MIL-E-16400. **Eaton Corporation, Sunnyvale, Calif., please circle INFO/CARD #176.**

8-Junction Ring Quad Schottky

Metelics Corporation announces a new 8-Junction Ring Quad Schottky diode. This monolithic beam lead schottky diode has two junctions in each leg. This results in a higher drive ring quad than can be obtained with four junctions. The monolithic construction results in close matching between legs. Many combinations of forward voltage at 1 mA, junction capacitance and junction resistance will be available. **Metelics Corporation, Sunnyvale, Calif., INFO/CARD #175.**

Antiparallel Schottky Pair

Metelics Corporation announces a new Antiparallel Schottky Pair. This monolithic beam lead schottky diode has two opposing junctions. The beam lead configuration results in very close matching of the diode junctions. The antiparallel pair is intended for subharmonic L.O. mixing and clamping applications. It is available in low, medium, high, and extra high barriers. **Metelics Corporation, Sunnyvale, Calif., INFO/CARD #174.**

Beam Lead Pin Diode

Metelics Corporation introduces a new Beam Lead Pin Diode. The diode, whose mechanical outline will be very similar to the existing "B10" outline, has a depleted junction capacitance of less than 30 femtofarads. The diode resistance measured at 20 mA will be less than 6 ohms. **Metelics Corporation, Sunnyvale, Calif., please circle INFO/CARD #173.**

IF To Tape Frequency Converter

The 1000 ITC-3A, IF to TAPE Frequency Converter manufactured by Apcom, Inc. accepts an input frequency of 21.4 MHz and provides three output center frequencies of 31.5 kHz, 250 kHz and 1075 kHz, each with full data bandwidth. Imageless mixers permit exceptional output signal-to-noise ratios and multi section group delay equalizers provide minimal distortion. Both front panel and IEEE-488 remote control are implemented. The 1000 ITC-3A is a dual unit and each channel has a pair of buffered outputs. **Apcom, Inc., Rockville, Md., please circle INFO/CARD #171.**

Precision Coaxial Inter Series Adapters

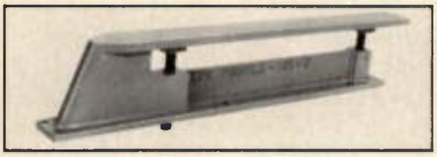
In addition to the "standard" MIDISCO inter- and intra-series adapters, MIDISCO now has a complete line of precision types with performance to 26 GHz and beyond. Construction is stainless steel passivated and connector interface is in accordance with MIL-C-39012, where applicable. The "X" series of adapters are available in 7 mm, 3.5 mm, SMA, SSMA, N, TNC, BNC, SC, C and GR 874. **MIDISCO, Commack, N.Y., INFO/CARD #170.**

Dual Junction Isolators and Circulators

MIDISCO has just announced a complete line of dual junction isolators and circulators in selected frequency ranges from 0.50 to 26.5 GHz. Models are specified in either high performance narrow band or octave and broadband. SMA female connectors are standard, but other types are available. The isolators, M41 series, and circulators, M4C series, are dual junction devices designed to be lightweight, small size and operate over full temperature ranges with standard storage temperatures from 55°C to 100°C. **MIDISCO, Commack, N.Y., please circle INFO/CARD #169.**

VHF Low-Profile Vehicular Antenna

A new, all metal communications antenna designed for special applications such as locomotives, mass transit vehicles and construction equipment, has been added to The Antenna Specialists Co.'s line of land mobile antennas. Constructed of cast aluminum, the Model ASP-579 covers the VHF frequency range from 150-166 MHz. It provides a vertically-polarized, omnidirectional pattern when mounted on a horizontal flat metal surface. **The Antenna Specialists Co., Cleveland, Ohio, please circle INFO/CARD #168.**



Termination Insensitive Mixer

The Anzac Division of Adams-Russell Company introduces a low cost 1-1500 MHz termination insensitive mixer. The MD-160 provides 7.5 dB typical mid-band conversion loss and VSWR on all ports is typically less than 2.5:1. The unit's third order intermodulation ratio is insensitive to port mismatches. It is screenable to MIL-STD-883B and operates over the full MIL SPEC temperature range of -55°C to +85°C. **Anzac Division of Adams-Russell, Burlington, Mass., please circle INFO/CARD #167.**

Miniature Tone Ohmmeter

Now all the functions of desk-sized tone ohmmeters can be performed by a new instrument, the Model SQ-1 Shorts-queek™, no bigger than a marker pen — everthing but the visual read-out. In testing boards for hairline shorts or shorted components the hand-held probe

is placed on the clad surface of a bare or loaded PC board; in the presence of a short a tone is emitted from the probe itself. As the tip of the probe moves about the tone pitch rises or falls as the short-circuit is closer or farther away. When the pitch can rise no higher the short is located and the clad repaired or the board discarded. The miniature tone ohmmeter can locate a short circuit in discrete wiring as well as on clad boards. **Global Specialties, New Haven, Conn., please circle INFO/CARD #166.**

Wideband Analog Operational Amplifier

Harris Semiconductor has introduced the HA-2542, a wideband op amp that offers ±100 mA output current at a high slew rate of 350V per microsecond. The monolithic design uses Harris dielectric isolation (DI) technology, and the HA-2542 amplifier offers 60 MHz gain bandwidth. The HA-2542 has a 5.5 MHz full power bandwidth. This amplifier is most suitable for high frequency signal conditioning circuits and pulse/video amplifiers, high speed coaxial cable driver circuits, wideband amplifiers, fast sample-hold circuits, and flash A/D converter drivers. **Harris Corp., Melbourne, Fla., please circle INFO/CARD #165.**

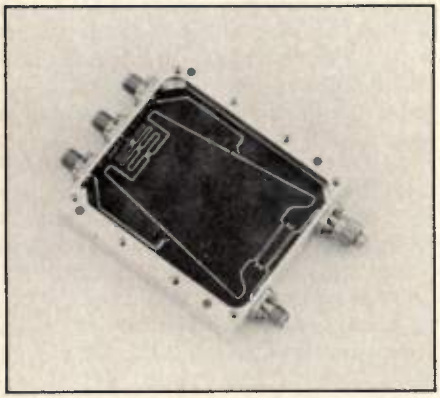
Video Analyzer

Rohde & Schwarz, introduces its Video Analyzer Model UVF, suitable for all standard insertion test signal measurements. Quasi-analog display of measure values and automatic limit indication is appropriate for TV studios and OB units, test vans and cable-distribution systems, maintenance and repair, as well as development and production. Remote control,

possible with the IEEE bus, and limit-value monitoring permit the Video Analyzer to be used in the most diversified test systems. **Rohde & Schwarz, Lake Success, N.Y., INFO/CARD #164.**

Quadrature IF Mixer 1.5 to 6 GHz

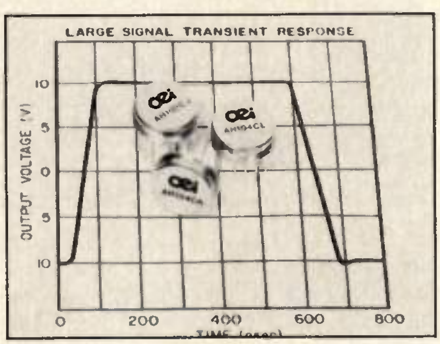
Model 1226A QIFM operates in the 1.5 to 6 GHz frequency range. Conversion loss is 12 dB max. LO to RF isolation is 20 dB min. LO to IF isolation is 25 dB min. Amplitude unbalance between two IF outputs is 1 dB max. The phase deviation from quadrature is ±10° over the frequency range. The device exhibits low VSWR: 1.6:1 max. LO input and 2.4:1 max. RF input. IF bandwidth is DC to 500 MHz. LO power level is +10 dBm. The units



operate without degradation over -54°C to +125°C temperature range. Units were designed to meet and were tested to Military Airborne requirements. **Norsal Industries, Inc., Central Islip, N.Y., please circle INFO/CARD #163.**

AH103/AH104 Fast Settling FET Op Amp

OEI has developed the new AH103 and AH104 FET op amps, which offer the user extremely fast settling, excellent DC specifications and very good drive capability. When stabilized for pulses and a gain of -1, the AH104 will settle to within 0.1% in 160 ns maximum. For optimum flexibility the AH104 is uncompensated. For ease



of use the AH103 is internally compensated for unity gain inverting pulses. The slightly slower AH103 still has a minimum slew rate of 190V/μs and a minimum full power bandwidth of 3.0 MHz. Active trimming of these hybrid circuits allows even the less expensive AH103CJ and AH104CJ grades to have maximum initial offset of 2.0 mV and maximum drift of 20 μV/°C. **Optical Electronics Inc., Tucson, Ariz., INFO/CARD #162.**

CAD Programs for Apple Computers

RF filter programs from 8th Dimension Enterprises will calculate component values for the following filters: low pass DC to 1200 MHz, high pass 1 kHz to 1100 MHz, band pass from 10 kHz to 1000 MHz, band reject from 10 kHz to 1200 MHz, and microstrip low pass from 100 MHz to 26.5 GHz. Other CAD programs only let you see the frequency response after you have calculated all the component values. Not this one. You can specify the termination impedances (i.e. 35, 50 or 75 ohms), frequency range and so much more. No other commercial RF filter CAD program matches this ability with this ease of use. **8th Dimension Enterprises, Sunnyvale, Calif., INFO/CARD #130.**

AC300 Video Current Booster

The AC300 provides 1000V/μs min and ±100 mA min. drive at ±10V. It is specifically designed for driving coaxial cable and features a small signal bandwidth of 250 MHz. To complement the high slew rate and drive capability of the AC300, settling time to 0.1% is 50 ns. The AC300DJ provides ±100 mA minimum drive at ±10V from 8-pin mini-dip packages. The AC300CJ version is housed in a standard 12-pin TO-8 package, allowing easy heat sinking where temperature or load conditions require. **Optical Electronics Inc., Tucson, Ariz., INFO/CARD #161.**

1 KW Solid State FM Amplifier

The first 1-kilowatt, solid state RF amplifier for the 88-108 MHz FM broadcast band is now available from Acrian, Inc. The new amplifier, called the FM1KW-IPM, is a self-contained unit with output power exceeding 1100 watts, with 10 watts of input drive into a 50 ohm load. Other FM1KW-IPM specifications include 20 dB power gain, 1 dB maximum gain ripple, −10 dB minimum overall efficiency, 28 volt supply voltage, 75 amps typical supply current, and 10 watts input power. **Acrian, Inc., San Jose, Calif., please circle INFO/CARD #160.**

RF Amplifier Model 9126

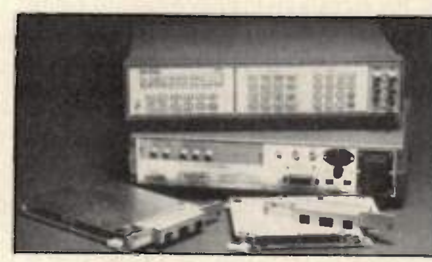
Amplifonix has announced a new RF Hybrid Amplifier, Model TM 9126, in a TO-8 hermetic package. This new design provides a gain of 20.5 dB typical over the frequency range of 10-1500 MHz. Other specifications include: noise figure, 5.0 dB; power out at 1 dB comp. +16 dBm; Max. VSWR (In/Out), 2.0:1; current at 15V, 64 mA; temperature range, -54°C to +85°C. All units meet MIL-STD-883B screening. **Amplifonix, Inc., Bristol, Penn., INFO/CARD #159.**

Digital Multimeter and Tone Generator

Simpson Electric Company has announced a new digital multimeter specifically designed for telecommunications servicing. The new Model 467-2T is a 3½-digit instrument with direct-reading dB ranges (switchable 600Ω and 900Ω references) for both "new and old" telecommunications systems. It also has a built-in 1004 Hz tone generator for line checking and signal tracing. The 467-2T has Simpson's Digalog™ (digital and analog) LCD readout with pulse, continuity and low-battery indicators. The DMM has true RMS AC capability. Basic DC voltage accuracy is 0.1%. AC voltage frequency response is typically 100 kHz. **Simpson Electric Co., Elgin, Ill., please circle INFO/CARD #158.**

6½-Digit Systems Multimeter

A 3½- to 6½-digit multimeter from Hewlett-Packard Company provides systems and bench users with seven measurement functions, extended resolution to 7½ digits and scanner capabilities. Reading rates of the new HP 3457A systems multimeter vary from less than one every second for extremely stable readings to 1,350 readings per second for high-speed measurement bursts. The multimeter offers basic DC volts accuracy as good as 5 ppm and the maximum amplitude through the input terminals is 300 volts RMS. Two optional plug-in scanner cards



permit multiplexing access of up to 10 signal channels. Users can store up to 1,050 readings or entire measurement sequences in the instrument. The built-in math routines include statistical functions, thermistor linearization, pass-fail limit test, dB, dBm, scale, offset and single-pole digital filters. **Hewlett-Packard Co., Palo Alto, Calif., INFO/CARD #157.**

Monolithic Dual JFETs

For specialized electronic designs that require parts with a combination of low leakage and low noise specifications, Siliconix now offers high performance monolithic dual n-channel JFETs. The performance specifications of these devices greatly increase design flexibility for medical and test equipment such as low noise FET input amplifiers, low frequency amplifiers, precision instrument amplifiers and comparators. The high performance features of these devices include a

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RIGHT WHERE MOST OF YOUR SIGNAL GENERATOR APPLICATIONS ARE

And we're there, not with one, but with *three* programmable generators — each one optimized for a particular frequency range — each one with the best modulation performance of any generator, regardless of price — and each one a performance/price leader.

Need a high performance signal generator from 150 kHz to 1.08 GHz with pushbutton and spin knob control? The Boonton 1021 gives you that *and* it functions as an analog and digital sweeper, a low distortion audio oscillator, and a generator with NVR memory that can recall up to 250 complete panel setups — as well as a fast responding IEEE488 bus-operated instrument with free format data entry and full talk and listen capability.

Need to go only to 540 MHz? Then the 1020 is the choice — same features, less money.

If your highest frequency is less than 180 MHz, the 1030 can save you even more money, with all the same features *and* 7 dB of additional output power to + 23 dBm.

All three generators offer dc-coupled f.m. deviation to 600 kHz, 6 radians of phase modulation, a.m. to 100%, f.m. broadcast distortion less than 0.05% at 75 kHz deviation, a.m. distortion less than 1% at 30% a.m. (0.3% for 1030), controlled a.m. phase shift for low VOR bearing error, ATE speed of 20 frequency steps per second, choice of 50 – ohm or 75 – ohm voltage calibration, and built-in r.f. reverse power protection.

If you're caught in the middle between the choice of a low price, low performance generator and a very high price, "does it all" generator, we've got your solution. Call your local representative or Boonton Electronics for a convincing hands-on demonstration.

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Signal Generators
Modulation Meters
RF Power Meters
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Capacitance Meters and Bridges
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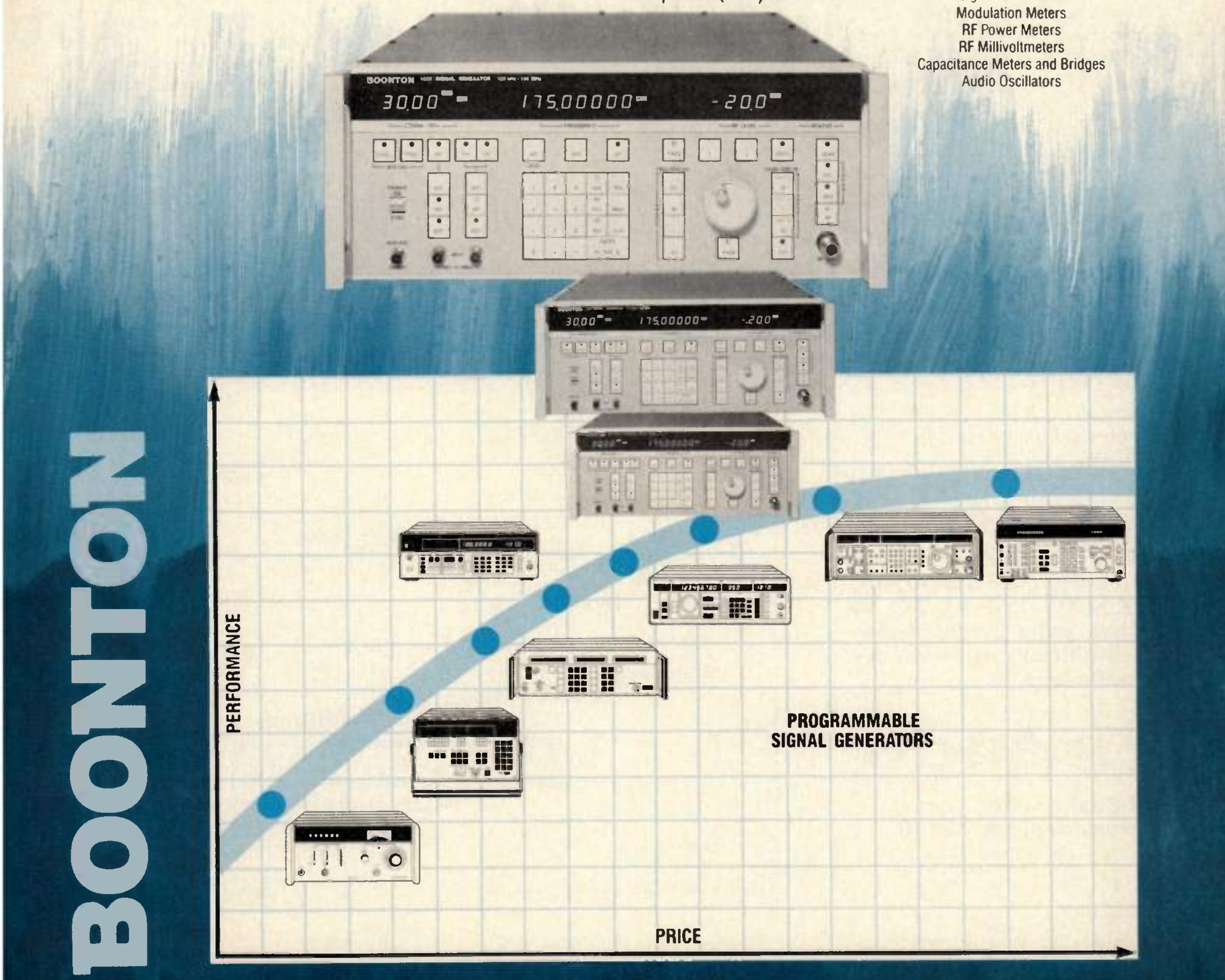

INFO/CARD 40

gate-source cutoff voltage of less than 2.5 volts, low noise of 15 nanovolts per root hertz and low gate current of -2 picoamps typical. Sample parts are currently available. **Siliconix, Inc., Santa Clara, Calif., INFO/CARD #156.**

Nine-In-One HF Antenna Kit

An easily portable multi-purpose antenna kit from Britain contains all the components needed for one person to erect any of nine different antennas covering the HF band in less than ten minutes. The

MTA (multipurpose tactical antenna) kit covers the frequency range 1.6 MHz to 30 MHz. Components can be selected to provide omnidirectional or directional characteristics for short-, medium- or long-range communications. By using trees or buildings, dipole, delta, base-fed vee, inverted "L" or sloping-vee configurations can be rigged. Transmitter powers up to 500 W can be used. **British Information Services, New York, N.Y., please circle INFO/CARD #152.**

High Performance Multicoupler

Watkins-Johnson Limited has developed a new series of improved-per-

formance, wide-dynamic-range multicouplers for operation in the 1 to 30 MHz frequency range. The new units offer the following features: 7 dB maximum noise figure at 30 MHz; 77 dB third-order intermodulation product suppression; 73 dB

CLOSE THE CIRCLE

The SYNERGY SOURCE-LINE

THE NEW SOURCE FOR THOSE SINGLE-SOURCED MIXERS.

MINI-CIRCUITS Alternative Source-Line CROSS REFERENCE			
Model	Price	Mini-Circuits	Description
S-1	\$ 3.80 (100 pcs) \$ 4.25 (10-49 pcs)	SBL-1	1-500 MHz, Metal Case
*S-2	\$ 3.70 (100 pcs) \$ 4.15 (10-49 pcs)	*	1-500 MHz, Metal Case
S-3	\$10.95 (1-49 pcs)	SRA-1	.5-500 MHz, MIL-STD
S-4	\$ 5.35 (10-49 pcs)	SBL-1X	10-1000 MHz, Metal Case
S-5	\$ 5.35 (10-49 pcs)	ASK-1	1-600 MHz, Plastic Flatpack
S-6	\$10.95 (1-49 pcs)	TFM-2	1-1000 MHz, 4-Pin, MIL-STD

* Reduced Performance Version of S-1
Cross reference based on published specifications.

Call today for literature, quotes, delivery!

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INFO/CARD 43

Take the guess out of rfi testing.

You've decided not to take chances with rfi susceptibility. Then why mix and match the tools you'll use to test for it?

Instead, you can equip your entire test loop with instruments from Amplifier Research that have been thoroughly tested and work well with our high-performance broadband rf amplifiers.

From 1W to 10kW, 10 kHz to 1,000 MHz, in 32 standard models, AR amplifiers give you optimum power, bandwidth, and versatility for your cw, sweep, and pulse requirements. Each model provides instantly available bandwidth without bandswitching or tuning, is completely immune to load mismatch, and won't shut itself down when you may need it most.

But a high-quality test presumes high-quality test equipment throughout. So we also supply specialized antennas, leveling preamplifiers, field sensor systems, fiber-optic telemetry links, TEM cells, matching transformers, and directional couplers.

With this full-system approach, equipment variables are less likely to show up in your test results. It'll pay you to talk with us about *all* your rfi test requirements.

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INFO/CARD 44

second-order suppression; 10 W CW and 2 kV impulse input protection; 1.3:1 VSWR; bandpass filter and DC supply options available. **Watkins-Johnson Limited, Windsor, England, please circle INFO/CARD #151.**

Phase Measurement

Leader Instruments Corporation announces a new Stereoscope. The LBO-552BH1 displays left and right channel traces side by side, simplifying channel to channel amplitude comparisons. This new Stereoscope is rack mountable and is provided with rear panel XLR input connectors. The graticule has indications for left and right channels and a zero phase angle reference line making the LBO-552BH1 an optimum unit for making stereo channel measurements of level, balance, azimuth, separation and phase angle. **Leader Instruments Corporation, Hauppauge, N.Y., INFO/CARD #149.**

TO/5 Style Attenuator

KDI Electronics has announced the availability of a Thick Film T Pad attenuator in a hermetically sealed TO/5 package. Frequency response is from DC to 2 GHz with a maximum VSWR of 1.35:1. The standard attenuation range is from 3 dB to 20 dB. The characteristic impedance is 50 ohms. These devices are based on a distributed element attenuator, and will meet or exceed the requirements of MIL-A-3933/23B. The TO/5 package is top marked with identifying part number and attenuation value. **KDI Electronics, Inc., Whippany, N.J., please circle INFo/CARD #147.**

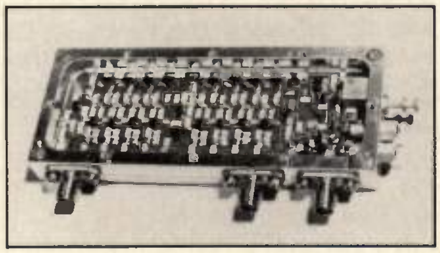
Die Attachment Evaluator

Sage Enterprises, Inc. announces the latest version of the Bipolar Transistor Die Attachment Evaluators, the D.A.E. 205B,

designed for bipolar device manufacturers as a production process Q.C. tool and for device users as an incoming inspection tool for prescreening burn-in or life cycle testing. **Sage Enterprises, Inc., Mountain View, Calif., please circle INFO/CARD #146.**

30-50 MHz Log Amplifiers

The SD Series of logarithmic amplifiers from Pascall Electronic Systems uses surface mounted technology to cover the frequency range 30-50 MHz, with bandwidths from 10 MHz to an octave. The SD



Series were especially developed for radar and EW applications and these amplifiers give a dynamic range of 75 dB, video output of 0.1 to 2.2 V DC coupled into 100 ohms and limited IF output of 0 ±2 dBm into 50 ohms. **Pascall Electronics Ltd., Middlesex, England, please circle INFO/CARD #129.**

Programmable Oscilloscope Calibrator

The new 6127B programmable oscilloscope calibrator delivers the test signals required, either manually from its "smart"

front panel or as the principle stimulus component in a computer-controlled test system using the IEEE 488 BUS. An "auto step" feature lets the operator step through internal calibrator settings. There is a 1 MHz rep rate on the 200 picosecond fast rise pulse. A 50-ohm termination, when required, is automatically connected across the scope input, and a software activated filter removes broadband noise from the test signals. **Ballantine Laboratories, Inc., INFO/CARD #128.**

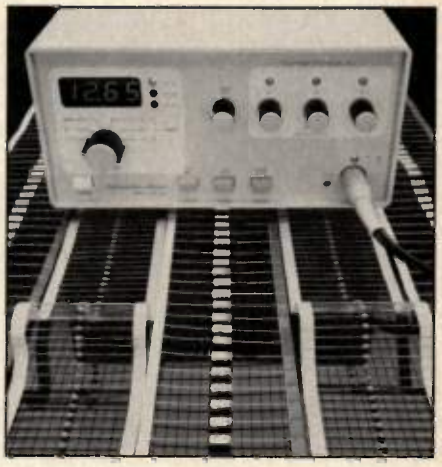
Universal Counters

Racal-Dana's new 1990 series of universal counters offer "system" counter performance in a compact, half-rack package. Two models are available: the 160 MHz Model 1991 and the 1.3 GHz Model 1992. **Racal-Dana Instruments, Inc., Irvine, Calif., INFO/CARD #127.**

High Rejection Filters

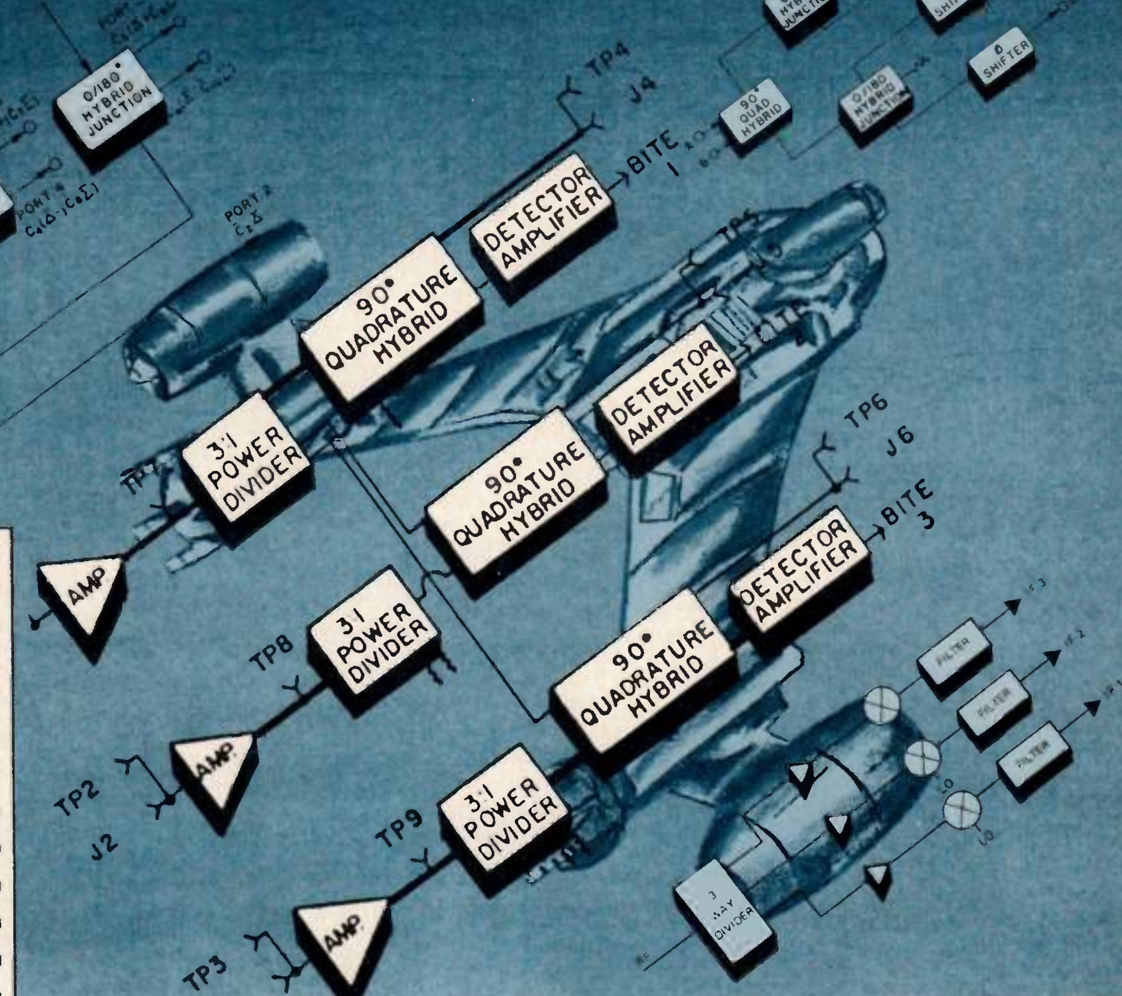
A full line of very high power low pass transmitting filters designed in standard EIA 6⅛" rigid co-axial configuration in the range of 10-650 MHz, with CW power ranging from 25-100 kW are now available from Cir-Q-Tel, Inc. Harmonic rejections of 20 to 100 dBc are standard. Losses as low as 0.02 dB on certain models and VSWR as low as 1.15:1, depending on complexity and cutoff frequency. **Cir-Q-Tel, Inc., Kensington, Md., INFO/CARD #144.**

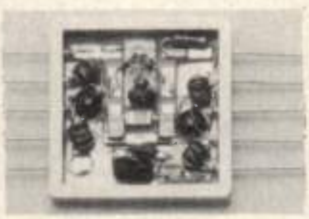
L/C Meter With Handler Interface

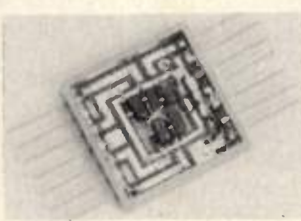


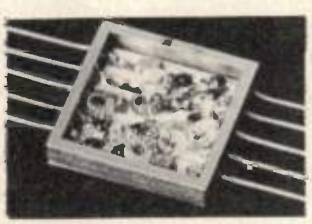
An option to the company's Model 520 digital inductance and capacitance meter series that permits interfacing the built-in tri-mode comparator to component handlers has been introduced by Cambridge Technology, Inc. Five lines are provided: three are open collector TTL outputs, one of which goes low if the high, low, or dissipation limit is exceeded. The fourth is a trigger input that allows the handler to tell the instrument when to begin the measurement. The fifth is a data ready output that tells the handler when the data is valid. The basic Model 520 is accurate to 0.25% of reading, performs true 4-terminal measurements and is supplied with shielded 4-terminal Kelvin clips. It has an internally adjustable, 0 to 10 VDC capacitor bias voltage, and measurement frequencies of 120 Hz or 1 kHz are automatically selected. The instrument autoranges from 0.1 pF/μH to 1999 μF/H. Full scale and a range-hold feature permits fast repetitive measurements. **Cambridge Technology, Inc. Cambridge, Mass., please circle INFO/CARD #142.**

Network Leader




IQF-2-70 — I&Q Networks


PDF-5E-1000 — Power Divider


DMF-2A-2000 — Mixer

BMF-2-60 — Beam Former

AM-20-1.3 — L-Band Amplifier

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IMAGE REJECT MIXERS
- Frequency up to 4 GHz
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- Bandwidth to 1 GHz
- MIL-STD-S-45743/MIL-WS-6536D

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rf products Continued

Ferrite Bead-On-Lead Kit

Fair-Rite Products has made available a sample kit of 12 different lead-mounted ferrite beads in a range of impedance values for EMI/RFI suppression. When inserted in a circuit which contains both DC or low frequency signals and high frequency noise or interference, a properly selected bead will pass the desired low frequency energy unimpeded and attenuate the unwanted high frequency components. The Fair-Rite Bead-on-Lead Kit contains an assortment of single hole beads with either axial or radial tinned copper wire leads. Production quantities are available taped and reeled for use with automatic insertion equipment, per EIA standards RS 296D and RS 468 respectively. The included Engineering Bulletin guides the designer in using the beads to solve his EMI/RFI problems. **Fair-Rite Products Corp., Wallkill, N.Y., please circle INFO/CARD #139.**

Quartz Crystal Frequency Control Devices

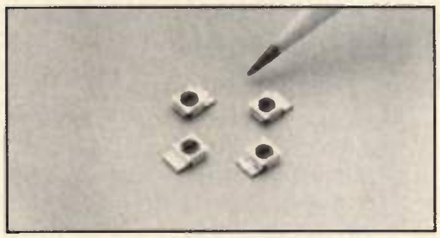
SFE Technologies' Electro Dynamics Division has introduced a new line of quartz crystal frequency control devices in the RW-45 package configuration. The downsized "AT cut" crystal is hermetically sealed in a resistance-weld holder having maximum dimensions of 0.345 inches high x 0.274 inches wide x 0.135 inches thick. Frequency range is 10 MHz to 16.999 MHz. These devices are intended for high density circuit assembly. Optional configurations include special pin cut, lead forming and third "lead" for horizontal mount. **SFE Technologies, San Fernando, Calif., INFO/CARD #138.**

Battery Operated Log Amplifiers

The CBLA series of Log Amplifiers has been designed specifically for battery applications. The log amplifier has both standby and active current modes. When in the standby mode (low power consumption) it responds as a high gain linear amplifier and allows for full signal detection. In the active mode it becomes a wide dynamic range log amplifier with extremely fast rise and fall times. The amplifier can be provided with dynamic range up to 80 dB and input RF frequency range from 10 MHz to 1.2 GHz. Power is supplied from a single 12 volt supply. Video output voltages are available to 0.3 volts. The amplifiers have a wide temperature range and will meet the environmental requirements of MIL-E-5400 **Log Tech, Inc., Newbury Park, Calif., please circle INFO/CARD #137.**

Surface Mount Trimmer Capacitor

Voltronics Corp. now produces screw-tuneable surface mount precision trimmer capacitors. These miniature parts are available in two ranges: 0.1 to 2.5 pF (CPA2) and 0.5 to 8.5 pF (CPA10). Qs are over 1000 and 500 respectively at 250



MHz and are over 100 at 2 GHz. Self-resonance frequency is over 4.5 GHz. The self inductance is only 0.3 to 0.5 nH. Dimensions are 0.20" wide (5.08 mm) x 0.26" long (6.60 mm) x 0.09" high (2.29 mm). D.C.W.V. is 150 and temperature coefficient is -100 ppm/°C. They are suitable for extreme conditions of shock and vibration of over 500 G because the moving electrode is held in place by forces over 1000 times greater than its weight. **Voltronics Corp., East Hanover, N.J., please circle INFO/CARD #135.**

Higher Current Assemblies

A series of higher current assemblies, designed and produced to meet JAN, JAN TX and corollary military specifications, has been introduced by Edal Industries, Inc. Intended for application in RF generators, broadcast AM/FM and TV transmitters, medical devices, RF welders, precipitators, Klystron magnetron supplies and radar transmitters, the new series is offered in current ratings from 12 amp to 300 amp. All units are subjected to 100% power rectifier testing before assembly in order to meet the high reliability requirements demanded by both military and commercial applications. **Edal Industries, East Haven, Conn., please circle INFO/CARD #134.**

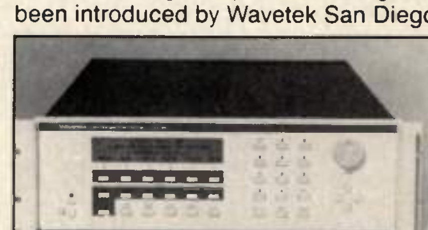
Mobile Radio Test Set

Marconi Instruments announces a new Mobile Radio Test Set, Model 2955, with advanced features designed to make mobile radio testing simpler and faster. A major portion of the front panel area is devoted to a large 5½" wide x 4½" high CRT, which acts as the prime source of information. Control is via color-coded keys: Mode, Function, Numeric Data + Units, together with just a few other selector keys and oscilloscope controls. This simplicity of layout belies the fact that this instrument embodies the functions of eleven separate instruments required for complete transceiver testing: Signal Generator, Modulation Meter, RF Frequency Counter, Audio Counter, RF Power Meter, Audio Generators, Audio Voltmeter, Audio Distortion Meter, SINAD Meter, Encoder/Decoder and Oscilloscope. The comprehensive display screen of Model 2955 shows all the control and measurement data. Vertical bar-graphs for both transmitter and receiver tests provide maximum

resolution for circuit adjustments of power, SINAD, etc. The 2955 can perform and display simultaneous tests on transmitters and receivers in full duplex applications. Comprehensive tone facilities are built-in to this test set including all major National and International Standards. In addition, user-defined tones may be entered and retained. **Marconi Instruments, Allendale, N.J., INFO/CARD #133.**

Precision Variable Phase Synthesizer

The Model 650 Precision Variable Phase Synthesizer, capable of extreme phase accuracy and suitable for multichannel testing with phase tracking, has been introduced by Wavetek San Diego.



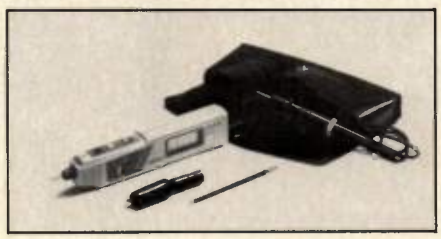
Multichannel phase tracking is attainable to within 0.005° below 1 kHz and has 0.01° setability. The 5¼ inch wide unit is controlled by two 6803 microprocessors and one 68000 microprocessor. The latter is used as a co-processor and as the computational portion of the phase accumulator. Phase relationship of each channel to every other channel can be preset by the user. Model 650 can be used as a phase standard or for calibration of other phase standards in such applications as phase meters, synchro/resolver-to-digital converters, phase locked loops, DPSK/QPSK (communications) and phased arrays sonar. The output capability of Model 650 is 40 volts peak-to-peak. Frequency range is 100 μHz to 2 MHz, with a resolution of 100 μHz (10 digits). Waveforms available are sine, square, triangle, and variable duty cycle, square and triangle. **Wavetek San Diego, San Diego, Calif., please circle INFO/CARD #136.**

18 Position RF Switch Control Unit

K&L Microwave Inc. announces the release of a new 18 position RF switch control unit. With automated testing in mind, this unit interfaces with a computer to remotely switch up to 18 devices cabled to the unit. Standard units are rack mounted with RF switches internally arranged in a single pole, 18 throw configuration. Switching specifications are: VSWR 1.5:1 maximum from DC to 18 GHz; insertion loss 0.5 dB maximum from DC to 18 GHZ; and isolation >60 dB thru 18 GHZ. Rear mounted SMA connectors provide easy access to RF switches. Visual confirmation of activated switch is provided by front panel mounted LEDs. **K&L Microwave Inc., Salisbury, Md., INFO/CARD #132.**

LCD Pen Type Tester

The Akigawa AD20 auto-ranging and auto-polarity 3½ digit LCD Pen tester with extended ranges features five DC volt ranges (200 mV/2000 mV/20V/200V/500V,) four AC volt ranges (2000 mV/20V/200V/500V), six resistance ranges (200 ohm/2K/20K/200K/2000K/20 MEG) and continuity test. Data hold function allows lock reading advantage. Unit is complete with case, test lead, clip, short test probe, long test probe and batteries. **World Distributors, Inc., Huntsville, Ala., please circle INFO/CARD #131.**



SMA Attenuator Sets

Elcom Systems, Inc. announces the availability of two new sets of 50 ohm coaxial SMA attenuators suitable for lab testing or breadboard use. Each set contains a 3, 6, 10 and 20 dB attenuator. They are available in calibrated or uncalibrated models. Attenuation accuracy is 0.5 dB from DC to 1000 MHz, and 1 dB from 1000 MHz to 1500 MHz. VSWR is less than 1.35:1 at 1500 MHz, averaging 1.2:1 over the band. They can dissipate 0.5 W CW or 1 KW peak power. The design utilizes MIL type connectors and high reliability MIL resistors in a MIL plated housing. **Elcom Systems, Inc., Boca Raton, Fla., please circle INFO/CARD #179.**

Fast Switching Power Transistors

Solitron Devices, Inc., Semiconductor Division, has announced the immediate

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availability of a new series of low cost, high current power transistors with IC (max) ratings up to 70 amps and VCE (sat) voltages as low as 1.25 volt at 50A. Identified as the SDT 96307-8-9 Series, these fast switching devices are packaged in a TO-3 case with 60 mill pins. The energy saving capabilities of the SDT 96307-8-9 Series result in high efficiency for pulse width modulated conversion systems, including motor controllers, power supplies and servo drivers. These single chip planar devices make excellent replacements for SCRs as well as equivalents for MOSFETs in may applications. **Solitron Devices, Inc., Riviera Beach, Fla., please circle INFO/CARD #178.**

Component Analyzer

The 6425 Precision Component Analyzer is the newest addition to Wayne Kerr's component analyzer line. Utilizing a powerful microprocessor, the 6425 contains all the measurement facilities required for the detailed analysis of capacitors, inductors and resistors.

With six figure resolution and a basic accuracy of 0.05%, the Wayne Kerr 6425 measures capacitance with the associated minor terms D and Q; AC resistance and impedance (series or parallel), inductance with associated minor terms of D and Q; conductivity, admittance and phase angle. Internal DC bias voltage is adjustable. The external power extends the voltage range to a maximum of 50 Vdc. At full accuracy (0.05%) the 6425 will measure capacitance as high as 5mF at 100 Hz with a resolution of 0.2 nH at 10 kHz, and resistance with a resolution of 0.01 milliohms.

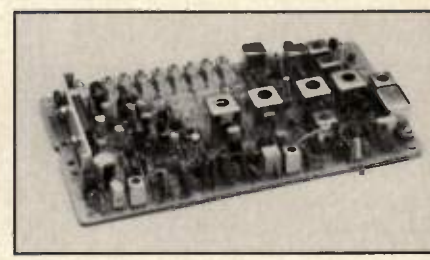
The 6425 also features an amber display screen, soft key control (manual, semi-automatic or GPIB remote control); and battery-backed historical file management. **Wayne Kerr, Inc., Woburn, Mass., INFO/CARD #130.**

Power Amplifiers for 500-1000 MHz

The 510 Series is a new family of power modules for 500-1000 MHz applications. The modules, designated the MA510-.5, MB510-15 and 85 are combined using quadrature hybrids, producing excellent input and output isolation. The MA510-.5 is a .05-watt multistage linear transistor amplifier for 500-1000 MHz low-level, preamplified applications. The MB510-15 is a compact, 15-watt linear amplifier for applications within the 500-1000 MHz frequency range. The MB510-85 is a 75-watt linear bipolar transistor amplifier that operates across 500-1000 MHz. This power module employs push-pull, quadrature-combined circuitry for enhanced isolation and broadband performance. **Acrian, Inc., San Jose, Calif., please circle INFO/CARD #126.**

PC Board Option for RF Links

Neulink announces a "board only" option for its telemetry links. The UHF, VHF, and mid-band radios are designed as separate transmitting and receiving boards. These radios replace costly telephone lines and expensive microwave ap-



plications where voice, tone, or low speed digital information is being transmitted. The 6¼" x 3" boards allow field personnel easy installation and integration into current telemetry systems. The single board's radio also provides service personnel with easy access during service periods. **Neulink, San Diego, Calif., please circle INFO/CARD #125.**

IBM PC Instrumentation Control Software

The new GPIB package known as GURU consists of GPIB interface board with self-test/diagnostics, a high-quality shielded GPIB cable, tutorial manual and extensive support software including a test procedure generator and subroutines library. GURU is competitive in price with GPIB similar packages which do not include tutorial and application support software. **Tektronix, Inc., Beaverton, Ore., please circle INFO/CARD #124.**

Telecommunications Signaling Components

Tektronix, Inc. Hybrid Components Operation (HCO), announces the availability of two new microelectronics components: the Tek Multifrequency Generator 3501 and Tek Multifrequency Receiver 3101. These microelectronics components are small, reliable and provide a multiple source alternative to Aptek Microsystems' AMS 3501 and AMS 3101 components. HCO plans to offer additional telecommunications products in the near future. The MF Generator 3501 contains a CMOS digital frequency synthesizer, digital-to-analog converter, and filtering circuitry. A 2.976 MHz crystal is used to generate the 18 frequencies required for multifrequency inter-office signaling. The MF Receiver 3101 was designed for use with either the U.S. RI or European CCIT No. 5 signaling formats. A multifrequency receiver detects pulses and transfers the digital information to control equipment and establishes connections through the switches. **Tektronix, Inc., Beaverton, Ore., INFO/CARD #123.**

Component Signal Generator

Rohde & Schwarz has announced the Model SPF2C Component Signal Generator which produces signals to test: a) new CCIR 601 specs for digital and analog components; b) analog component-based VTRs and ENG cameras; and c) MAC formats for satellite distribution. New signal waveforms utilizing a low and medium frequency triangular and saw-tooth signal have been used with special consideration given to noise measurement. All signals are available (on three 75-ohm outputs) as Y, R-Y (V), and B-Y (U). A button display allows selection of 26 different signals . Signal variants such as APL, risetime or polarity use modification switches. **Rohde & Schwarz Sales Co., Lake Success, N.Y., INFO/CARD #122.**

Synthesized Signal Generator

Comstron has announced the availability of a Synthesized Signal Generator, Model 740A with AM, FM phase and pulse modulation; excellent in-close phase noise; spinwheel and keyboard entry of

all functions; non-volatile memory for 40 complete configurations; 20 mSec. settling time; superb level accuracy; 10 Hz resolution across entire frequency range; and IEEE-488 BUS programming. The RF frequency coverage over the range 100 kHz-1120 MHz (doubler option from 560 MHz) is derived from a crystal reference driving a 10 Hz steps synthesizer, thus producing the desired features of accuracy, stability and spectral purity. **Comstron Corp., Freeport, N.Y., please circle INFO/CARD #121.**

INFO/CARD 60

rf literature

New Literature

"Library" of Micro-Min Components For Surface-Mount Assemblies

Allen-Bradley Electronics Group and AWI have issued a Micro-Min Component Library to educate the user on the benefits of surface mount manufacturing technology developed by AWI. It is called Micro-Min for micro-miniaturization of circuit assemblies. The spiral-bound softcover book is to be used as a guide to help the user visualize the benefits of micro-min for the design and manufacture of circuits. Available passive and active components, including part numbers, certain specifications, descriptions, packaging and vendors, are listed. **AWI, Sunnyvale, Calif., please circle INFO/CARD #155.**

Press-Fit Connector Catalog

SAE, Stanford Applied Engineering, has a catalog covering the company's new generation of press-fit connectors. The product line features SAE's TRI-LOK™ compliant pin system which provides a gas-tight pressure fit between a pin and plated thru hole in a PC board. The 20-page, 2-color catalog presents in-depth descriptions of a complete family of backplane connectors, such as fully shrouded, MODCON,™ reverse DIN and edge card versions. Also included are I/O connectors in three and four wall shrouded configurations, unshrouded and telephone models. **Stanford Applied Engineering, Santa Clara, Calif., INFO/CARD #154.**

Graphics Printed Circuit Drafting Technical Manual

Bishop Graphics, the world's largest manufacturer of pressure-sensitive, printed circuit design and drafting products, announces the publication of their newly revised technical manual and catalog. The publication, containing more than 220 pages and called Bishop Graphics Printed Circuit Drafting Technical Manual & Catalog 107A, is available free, upon request, from any Bishop dealer or direct from Bishop Graphics. New products featured in the 107A include Bishop's comprehensive line of microelectronic artwork patterns for creating artwork masters for today's high density PCBs. Also included for the first time is information on ACCUPUNCH™, Bishop's unique dual system punch designed to give users the hole pattern of their choice for overlay drafting applications. **Bishop Graphics, Inc., Westlake Village, Calif., INFO/CARD #153.**

Applications Brochure for Linear Action DIP Switches

For application ideas and suggestions on how to use special linear DIP switches, Grayhill, Inc. has published a new product brochure, "Application Notes, Linear Action DIP Switches." Grayhill linear action DIP switches described in the brochure are available in 10 and 16 station lengths and three circuitries, binary coded output, single pole tap switch, and circuit selector. **Grayhill, Inc., La Grange, Ill.,INFO/CARD #150.**

D.A.T.A. "Linear ICs" Breaks Out Device Types for Faster Search

The 34th edition of "Linear ICs," the industry-standard technical reference book on linear IC devices, divides technical sections into specific device types for the first time, according to publisher D.A.T.A., Inc. Designers and purchasers can search faster by going directly from the table of contents to the correct page number without sorting through related devices. The expanded table of contents now lists 15 major component categories and 62 specific device functions within those categories, each with page numbers to lead directly to the device information. The "Amplifier" category, for example, is broken down into Buffer Amplifier/Voltage Followers; Differential Amplifiers; Power Amplifiers; RF/IF Amplifiers; and Video Amplifiers, each with a specific page number. **D.A.T.A., Inc, San Diego, Calif., please circle INFO/CARD #140.**

New Brochure Simplifies Selection of Electronic Counters

A new brochure from Hewlett-Packard Company describes the company's extensive line of electronic counters. Some 21 products are positioned to help the reader select the counter best suited to solving a particular measurement problem. Selection is further simplified by using the feature/price comparison at the back of the brochure. **Hewlett-Packard Co., Palo Alto, Calif., please circle INFO/CARD #148.**

DC-DC Converter Handbook

This new 48-page product handbook includes comprehensive data on Power General's complete line of DC-DC converters, including over 50 new products. Power supply characteristics are presented in quick selection tables followed by complete engineering data on all models. Also included is a glossary of DC-DC converter terminology and tutorial information on DC-DC converter operation. **Power General, Canton, Mass., please circle INFO/CARD #143.**

Condensed Product Catalog

A new, 16-page, full product line short form catalog has been published by Global Specialties, an Interplex Electronics Company, to briefly describe the company's entire line of instruments and components for electronic testing and design. This booklet is divided into instruments, frequency counters, logic monitors, logic probes, solderless breadboarding, Data Routers, Data Directors, and instrument enclosures for convenience. The use of a built-in reply card will bring the reader specific data on each of these product groups. **Global Specialties, New Haven, Conn., INFO/CARD #145.**

Environmental Chamber Product Guide

ESPEC Corporation, a manufacturer of environmental chambers, has announced the availability of their new Product Guide/Catalog. Featured in this catalog will be the complete line of ESPEC environmental chambers, which include temperature and temperature and humidity chambers, accelerated life testing chambers, thermal shock chambers, burn-in test systems, heat treating chambers, vacuum ovens, clean room ovens and a range of special chambers. Sizes range from laboratory scale through to large scale test chambers and walk-in chambers. **ESPEC Corporation, S. Plainfield, N.J., INFO/CARD #91.**

Electronic Hardware Catalog

Cable clamps, cable straps, cabinet feet, tilt stands, PCB mounting posts, grommets, hole plugs, shoulder bushings, shoulder washers, antenna connectors and antenna insulators are offered in this revised publication. Information provided on each product includes prices, engineering data, application information and installation instructions. **Budwig Manufacturing Company, Ramona, Calif., INFO/CARD #90.**

LCD Catalog

Hamlin, Incorporated, the leading U.S. manufacturer of standard and custom LCDs, has issued a new 24 page catalog featuring hundreds of standard displays exactly cataloged for application in most industries and environments. This catalog provides in-depth technical and dimensional information on specific LCD types including: guest-host dichroic, multiplex, and direct drive (TNFE) displays. Available display options include: number of digits, display size, fluid type, segment and background color, termination, operating voltage and more. Also included is a custom LCD design sheet for applications where a standard display does not meet the designers' exact requirement. **Hamlin Incorporated, Lake Mills, Wis., INFO/CARD #93.**

Switches Catalog

ITT Schadow announces its new 1985/1986 full line switch catalog. The 112 page catalog features high performance key switches, high volume key switches, keyboard switches, pushbutton switches, power switches, telecom switches and rotary switches. In addition to new products, ITT Schadow has improved their key switch selector guide and has included an Introduction to Power section, which contains option guide, approval options, definition of terms and symbols and worldwide approval agencies. The catalog details features, benefits, technical data, mechanical data and ordering codes for each of ITT Schadow's switch products. **ITT Schadow, Eden Prairie, Minn., INFO/CARD #92.**

Lock-In Amplifiers

EG&G Princeton Applied Research has published a "Lock-In Applications Anthology" that describes the use of lock-in amplifiers in a variety of low-level signal measurements. The 74 page booklet contains 20 application notes and is divided into six sections covering solid-state, spectroscopy, electrochemistry, mechanical, instrumentation and engineering applications. Among the covered topics are: "Measurement of Semiconductor Device Capacitance," "Automated Measurement of Interface States," "Ratiometric Spectroscopy," "Basics of AC Impedance Measurements," "Detection and Measurement of Light Signals," and "Femtosecond Signal Measurement." **EG&G Princeton Applied Research, Princeton, N.J., INFO/CARD #107.**

Miniature Circular Connectors

A new eight page catalog from Souriau describes the company's 8526 Series of miniature circular connectors and associated contacts. Thirteen outline drawings and dimension tables are given for the plug, plug with RFI fingers, jam-nut mount receptacle, square flange receptacle, solder mount hermetic receptacle, square flange hermetic receptacle and jam-nut hermetic receptacle. **Souriau Inc., Valencia, Calif., INFO/CARD #106.**

Modular Probes

A six-page folder from Ballantine Laboratories, Inc. catalogs and details an extended new family of rugged, modular probes for oscilloscopes and meters made available for the commercial marketplace. The new catalog also details specifications and applications for a unique high voltage RF detector probe. The Ballantine Model 10851A, one of the company's new line of probes for multimeters, high voltage AC and DC meters and high current meters, features an optional "Tee" connector for direct 50-ohm measurements and a 100:1 divider to handle very high RF input voltages. These are the first multimeter probes capable of this performance. Charts and photographs detail specifications for the full line of Ballantine probes. **Ballantine Laboratories, Inc., Boonton, N.J., INFO/CARD #109.**

Measuring Instruments Catalog

The Fred V. Fowler Company announces publication of the new Catalog No. 1684, Quality Measuring Instruments and Precision Tools. Included is a wide selection of digital electronic instruments with computer interface capability, plus the latest in measuring machines and electronic measuring systems. Additional items in the catalog include precision tools, optical measuring instruments, toolmakers' aids, shop tools, work holders and more. **Fred V. Fowler Co., Inc., Newton, Mass., INFO/CARD #104.**

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RF/MICROWAVE ENGINEERS

Representing companies (in New England and Nationally) with hundreds of opportunities for RF and Microwave Engineers means we are the one contact necessary for that right position, whether it be a new challenge or career advancement.

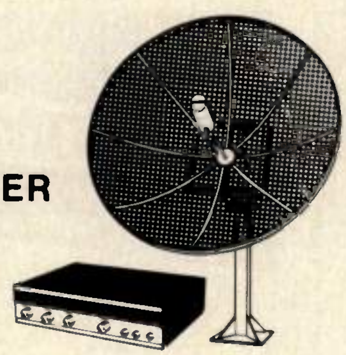
ENTRY TO 3 YRS. EXP	22-35K
MID LEVEL	30-45K
SENIOR AND MANAGEMENT	40-70K

Professional, confidential, free resume preparation service. Client companies assume all interviewing, employment and relocation costs.

Nationwide Business Service

PERSONNEL CONSULTANTS
ESTABLISHED 1937
145 STATE STREET,
SPRINGFIELD, MASSACHUSETTS 01103

RF ENGINEER
Colorado



Manufacturer of RF products for TV broadcast, CATV and satellite TVRO needs EE's to design new products. Experience in RF/microwave circuit design required.

Based in Burlington, Iowa and recognized as an industry leader for 30 years, Winegard Company develops new products at its engineering and research division located in a scenic Colorado mountain community within commuting distance of Denver.

Our medium-sized, stable, independent company offers multiple benefits for its professional employees.

Phone or send resume to Jim Kluge, Winegard R&D Lab, P.O. Box 940, Evergreen, CO 80439.

(303) 674-5576

WINEGARD

Growing electronic manufacturer offers excellent career opportunities and benefits including medical, dental and pension plans.

APPLICATIONS SALES ENGINEER

R.F. Induction Heating Equipment

Excellent opportunity for an EE or ME or equivalent with good selling skills to grow with the fastest growing manufacturer of induction heating systems in the U.S.

R.F. DESIGN ENGINEER

**.5 - 120 MHz
3kW - 500kW Output
Induction and Dielectric Heating Systems**

An outstanding opportunity awaits a creative, problem solving person with a BSEE, MSEE or equivalent with 2 - 3 years applicable experience

**For the above positions, please send resume including salary history to:
N.A. Greene**

Radio Frequency Co.

**150 Dover Road
Millis, MA 02054**
An equal opportunity employer

Diagnose the Present. Discover the Future.

"Each scientific discovery increases one's ability ... to control future events." **Dr. Laurence J. Peter, Academician and Author**

Put yourself in the forefront of today's advanced systems technologies and you can get a head start on making the breakthroughs that shape the future of avionics electronics.

Northrop DSD engineers have a unique advantage. They are immersed in the newest hardware, software and systems. They are challenged within demanding project environments. And, they have the opportunity to interact with highly motivated individuals in close-knit project teams. It's a career future worth investigating. Immediate opportunities at Northrop DSD include:

Electrical Design/ Development Engineers

Positions require BSEE or equivalent, and design and development experience in one of the following specialized areas:

Power Supplies • Microwave Receivers • Analog • Digital

Antenna Design Engineers

BSEE or Physics or equivalent, MS desirable. Requires knowledge of

phased arrays, monopulse, D.F. system and millimeter wave techniques.

ATE Engineers

BSEE or equivalent, and related software/hardware experience required. Advanced degree and avionics/military ATE background desirable.

Project Engineer

BSEE, or equivalent; experience in one of the following areas:

- High efficiency broad band solid state RF power amplifiers having precision linearity. Strong documentation skills required.
- Military receiver HW design for precision phase track receivers to DoD requirements using ultra-precision internal phase/amplitude alignment.

TWT Project Design Engineers

BSEE or Physics or equivalent; advanced degree a plus. Will develop TWT design, fabrication and testing procedures with product line design responsibility.

Qualified candidates are invited to send resume with salary requirements to: **Supervisor Staffing, Northrop Corporation, Defense Systems Division, 600 Hicks Road, Rolling Meadows, IL 60008.** An equal opportunity employer M/F/V/H. U.S. Citizenship Required.

NORTHROP

Defense Systems Division
Electronics Systems Group

Northrop DSD: Where the individual thrives...on foresight.

Advertiser Index

High tech leadership in high power amplifiers

Application requirements for solid state RF/Microwave amplifier systems become more demanding every day. Power outputs up to 20 KW and frequencies up to 20 GHz present formidable challenges in circuit design and fabrication techniques. Add to that a host of complex operational and environmental requirements which are now being met by M/A-COM MPD with a diverse array of technological disciplines: high power switching for antenna T/R; electro-mechanical and solid state filter switching for harmonic suppression; prime power conditioning; antenna integration; high power tunable filters for co-location conditions; microprocessor interfacing for control and BITE; air and liquid cooling for high density packaging.

The compact assembly shown here is a Class AB solid state amplifier sub-system for airborne communications. It delivers 1000 watts in the UHF band, and includes a unique digitally addressable high power filter to assure extremely clean RF output, allowing multiple amplifiers and receivers to be co-located without impinging on one another. Featuring high density easily maintainable packaging, with an ability to perform in a mission-critical environment, it is one more example of our expanding high tech leadership in high power amplifier systems and sub-systems...the kind of leadership that can meet the most difficult requirements of your EW, radar, communication and test applications.

M/A-COM

MPD M/A-COM MICROWAVE POWER DEVICES, INC.
330 OSER AVENUE, HAUPPAUGE, N.Y. 11788 (516) 231-1400 TWX 510-227-6239

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