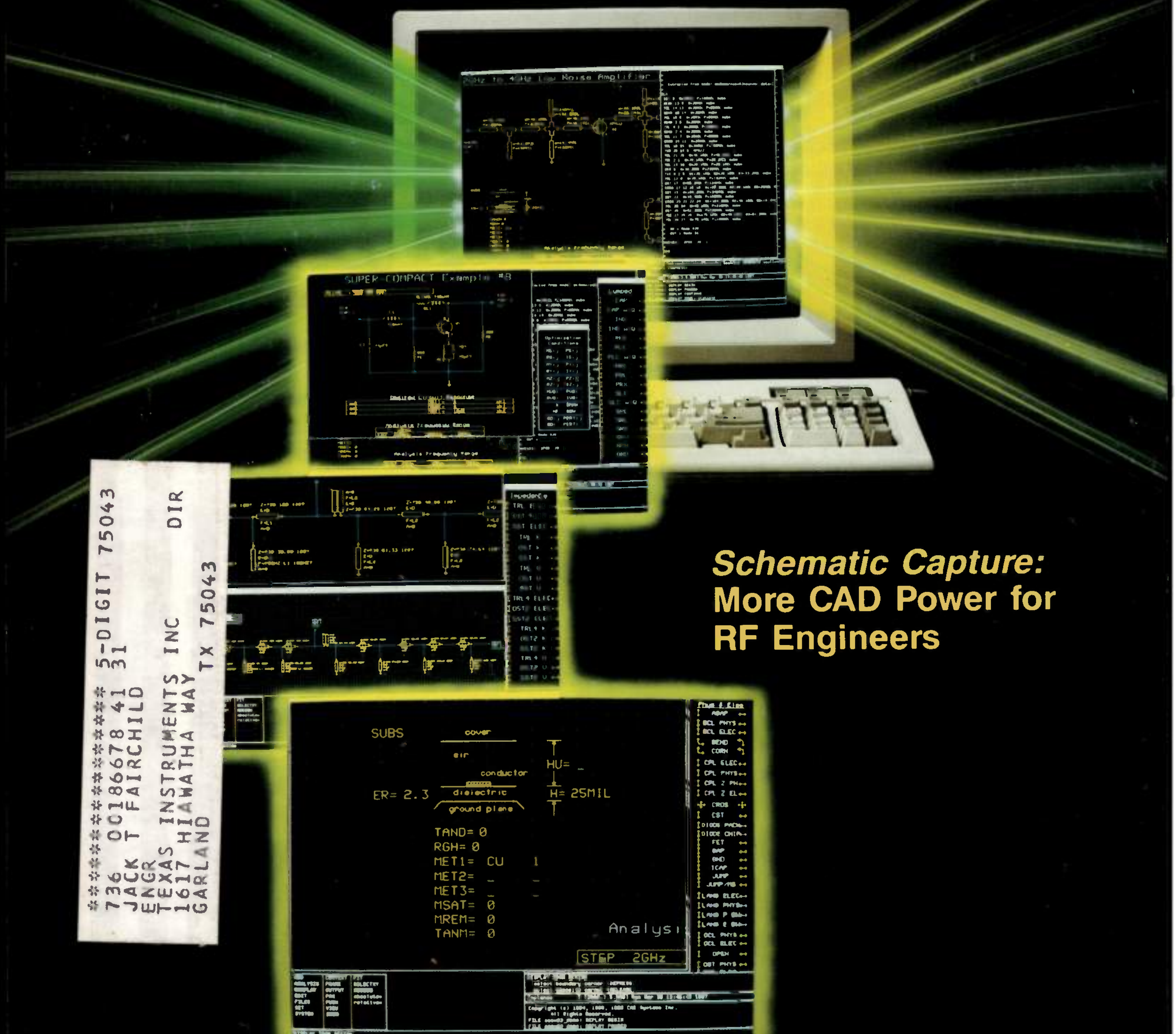
rf design

ideas for engineers

June 1987



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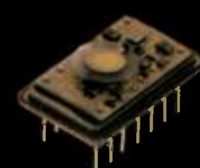

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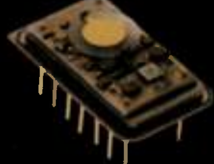

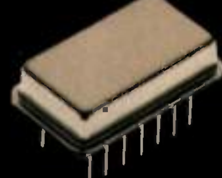

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June 1987

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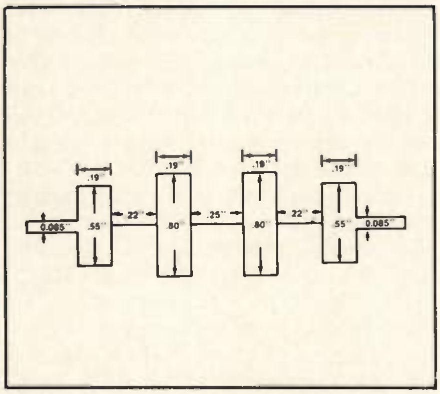

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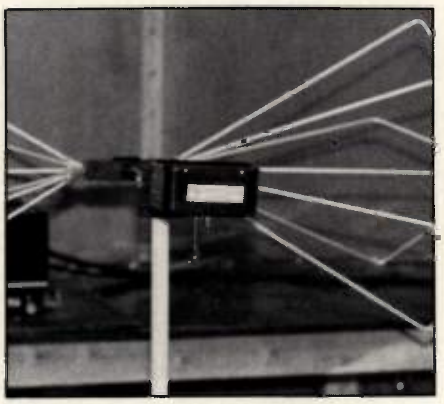

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rf editorial

Playing Hardball in April

By Gary A. Breed
Editor

The month of April had two major headlines — baseball and international trade. The Brewers had quite a winning streak, Bo Jackson was getting Royals fans excited; there were no-hitters and home runs enough to make any sports fan happy.

The other news headline wasn't quite as much fun. On April 17, President Reagan imposed import tariffs on Japanese laptop computers, color TVs and small power tools. This retaliation for computer-chip dumping and lack of Japanese cooperation has the potential for starting a major trade conflict. Baseball may the favorite American sport, but making profits from American consumers and businesses seems to be a favorite sport of many foreign countries, not just Japan.

Unfortunately, it is very difficult to deal with our trade imbalance. We have grown extremely dependent on imports, from oil to precious metals to VCRs. Quite simply, the advanced technology and prosperity of the U.S. cannot exist without strong economic ties to the rest of the world. There is not a country on Earth that is truly independent, economically. It is time for everyone to realize that we have a world-wide economic system, a collection of inter-connected national economies.

The problem with the global economy is that every player doesn't subscribe to the same set of rules. The game of baseball would cease to exist if a team could choose any set of rules it wished, and could change them at any time. The more serious game of international economics needs players who can agree on the rules. Just like baseball, if we don't like the way things are going, we can take our ball and go home. Unlike baseball, the result of a called-off game is chaos. Protectionism is a poor alternative to *free and fair trade.*

Electronics, particularly consumer and general business products, has been the most visible area of off-shore success. Our niche of RF has not been as strongly affected, since low-cost manufacturing has less effect on the relatively small numbers of high-quality units common to RF products. However, be assured that the rest of the world would be delighted to have a substantial piece of the U.S. RF market, and American companies would like to broaden their markets overseas.

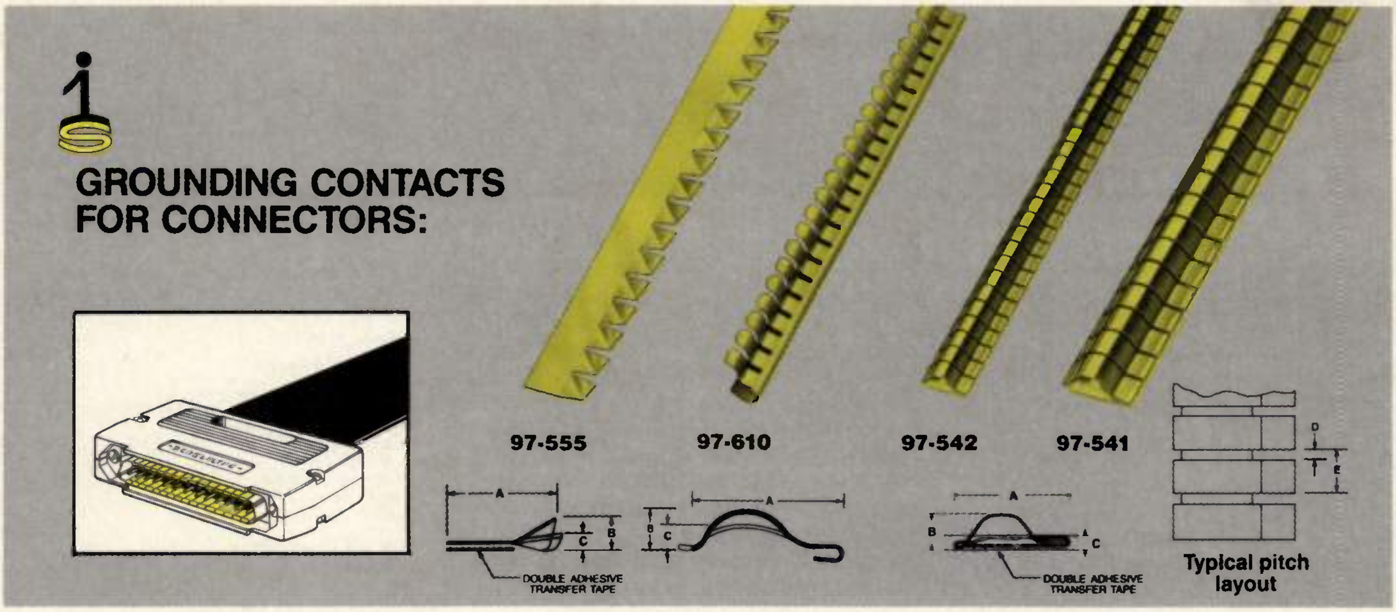
I don't mean to downplay the serious effect that foreign competition has had on U.S. manufacturers of consumer products, land mobile and amateur radio equipment, transistors and linear ICs. Like every other type of business, the RF industry has had to deal with unequal competition. The bright side is that RF is also an area where the U.S. is still a world leader: in avionics, satellite communications, military systems, test equipment and high-performance components.

The RF industry needs to be an example. We already have strong ties to Europe and Israel through military RF gear and international ownership of RF companies by Thomson, Philips, Rohde and Schwarz, Varian and others. Our products use components made in Singapore, Mexico, Japan and the Philippines along side American-made parts.

We have an edge over other industries in the art of international cooperation. If we use our heads, we can avoid the mistakes and shortsightedness that have caused the present crisis in consumer electronics and computers.

Play Ball!!!

Gary A Breed



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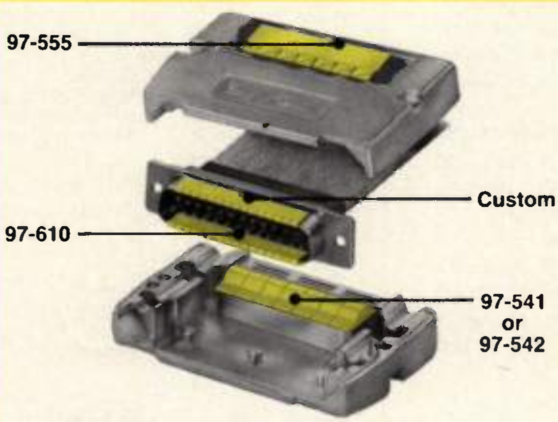

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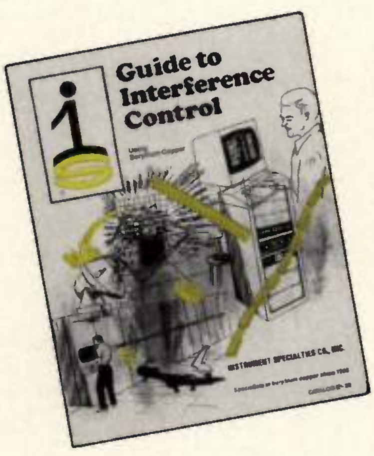

More complete descriptions of these strips and other shielding products can be found on pages 10 and 11 of our Guide to Interference Control. Write for your free copy. Address: Dept. RFD-35.

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Is *RF Design* Hard to Get?

By Keith Aldrich
Publisher

Yes, it was, 'til a few months ago. No, it isn't any more — assuming, of course, that you are "qualified" (meaning that you are involved in the design or development of RF systems or equipment).

Until recently, many engineers who *are* qualified had the experience of filling out a subscription card (like the one in the back of this issue), sending it in, then waiting for months without receiving their own copy of this magazine. You may be one of those. Chances are, however, you are now reading these words in a copy addressed directly to you. Chances are, if your RF engineering friend across town were to send in the "sub" card from this issue, he or she would be getting *RF Design* by August.

Does this mean that we've relaxed our standards or suddenly inflated our circulation? No. It means we've changed our priorities on who will get the magazine, when it comes to the oldest vs. the newest. To oversimplify it, we now *make room* for a new subscriber the minute a request comes in, by dropping the oldest name on our list.

Before you start rushing to the defense of that oldest subscriber, remember that he or she has been receiving the magazine for a year or more since being last renewed as a subscriber, and has received at least two mailers asking for a fresh renewal. Chances are pretty good that this reader has moved on, or up, or out of the spot that made the magazine a useful adjunct to his or her job.

The up side of our new policy is that we now have and will continue to have the newest people involved in RF, and a total audience of 34,000 involved 100 percent in the work on today's drawing boards. The down side is that only a certain core of our readership will be a long term, loyal family with whom we can share anniversaries and reminiscences on how it was in the old days.

Suppose it should come to pass that all 34,000 readers renew within a year, and 3,000 new RF engineers are also clamoring to be added to our audience?

Well, then we'll know the time has come to raise the ceiling, and enlarge our circulation. It will mean the RF population is growing, which will mean the market is too, and nobody will be happier than we.

Keith Aldrich

rf design

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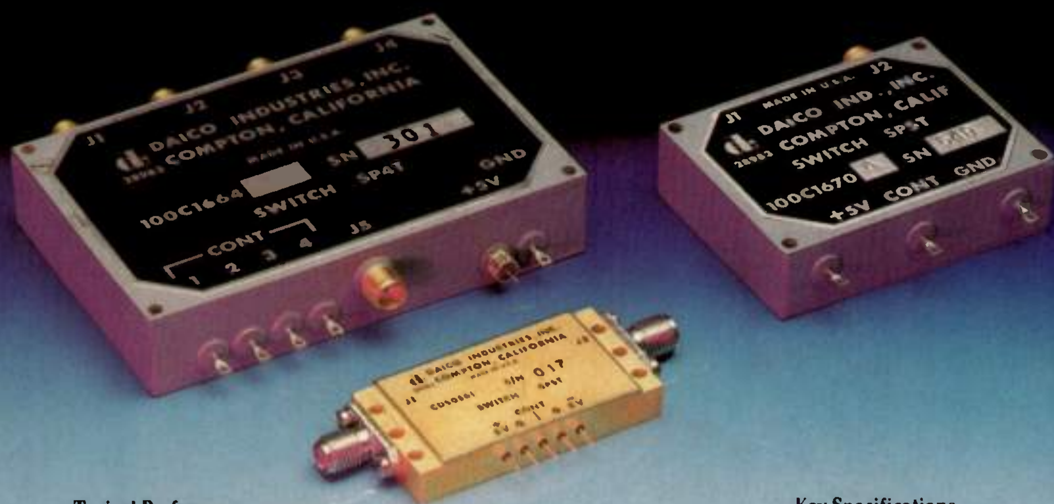

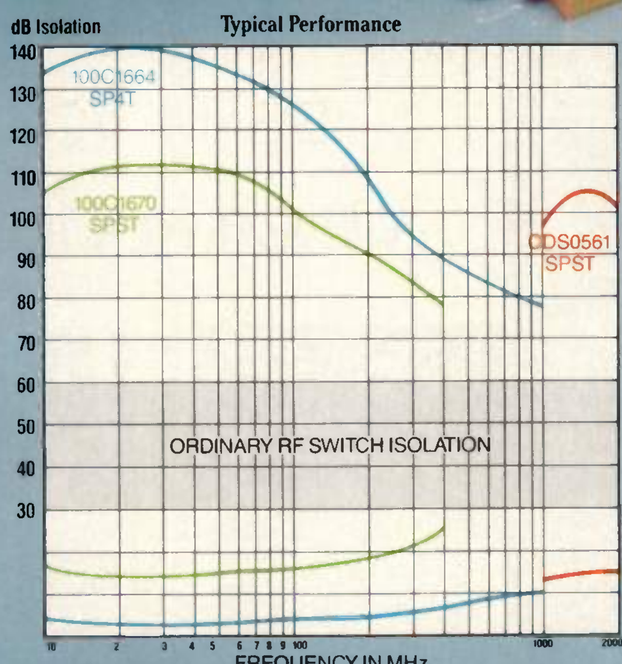

Key Specifications

PARAMETER	CDS0561 TYPICAL	100C1670 TYPICAL	100C1664 TYPICAL	UNITS	CONDITION
Control Configuration	1 LINE TTL	1 LINE TTL	4 LINE TTL	—	Logic
Switching Transients	155	10	600	mV	Peak Value
Transition Time	4	2	—	ns	90%/10% or 10%/90% RF
Switching Speed	17	33	400	ns	50% TTL to 10%/90% RF
Insertion Loss	1.5	1.5	—	dB	—
	—	—	0.7	dB	20 - 350MHz
	—	—	1.0	dB	350 - 600MHz
Isolation	106	100	—	dB	—
	—	—	105	dB	20 - 200MHz
	—	—	85	dB	200 - 600MHz
VSWR	1.15 / 1	1.2 / 1	1.1 / 1	—	—
Termination VSWR	1.5 / 1	1.2 / 1	1.1 / 1	—	—
RF Power,	+13.5	+12	+24	dBm	0.1 dB Compression
Operate Max.	—	—	+30	dBm	No Damage
Operating Frequency	1700 - 1900	10 - 100	20 - 600	MHz	—
Operating Temperature	−55 - +125	−55 - +85	−55 - +85	°C	TA

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INFO/CARD 5


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TRANSMITTERS

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Innovative solid-state building block designs and rigid quality assurance procedures are factors that assist in making MMD's medium to high power transmitters an ideal choice where highest reliability and performance are vital considerations. Typical examples are the transmitters designed and built by MMD specifically for wind profiling systems operating unattended on a 24 hour basis and self monitored. Some of the special features of these transmitters are listed below. MMD can provide any combination of these or other features on custom, built-to-requirements solid state transmitters.

- 16KW peak power, UHF.
- No single point failure mechanisms.
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- The main solid state pulsed amplifier is arranged in a quad configuration, a design which includes capability for operation at power levels below 16KW.
- Electronically switched redundant driver modules.
- The power supply has four (4) lightweight independent sections, one for each 4KW amplifier quad and redundant power supplies for each driver section.
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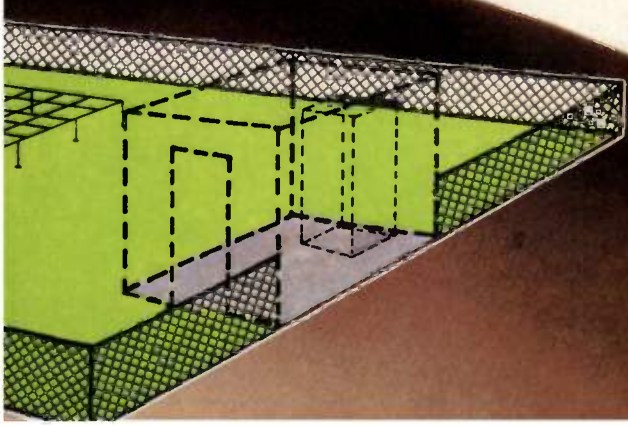
- Microprocessor-controlled self-diagnosis and fault detection/localization down to the modular level with remote monitoring and control through analog and digital interface with a host system.

The sophisticated solid-state amplifier shown here has been selected by Unisys (formerly Sperry Corp.) as the 16KW peak power transmitter used to excite the UHF arrays used in the wind profiling program. The concept has been developed by Unisys in support of the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. Data obtained from beam transmissions are processed to provide accurate monitoring of wind velocity and direction vector for weather predictions and air traffic safety and fuel economy. Results are transmitted at intervals by satellite and landline.



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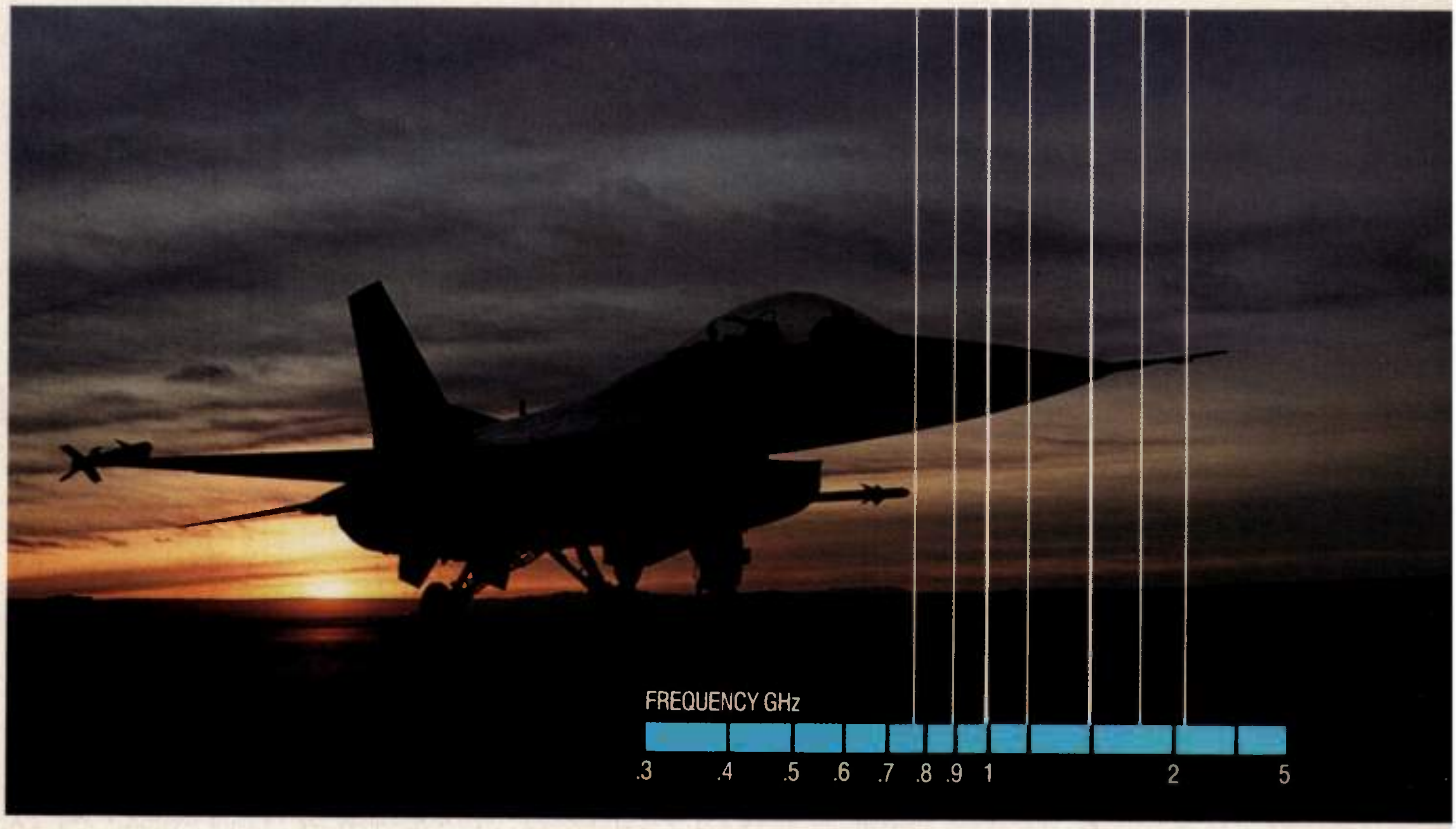

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INFO/CARD 14

rf letters

An Eye on the Future

Editor:

I read your "RF Editorial" of April '87 (and pp. 28-29) with great interest and am pleased to see an RF type person with such a broad acceptance of the encroachment of fiber optics onto our sacrosanct microwave spectrum. As you have stated, the hoopla and glory of technological achievements will probably soon be transferred to the "terrabit region on terra firma." I disagree with you on the impact of photonics causing a reduction of the demand for RF spectrum, however, since at the last two or three international RF spectrum allocation conferences, much of the argumentative subjects were the grabs for unused (and used) RF (LF, HF, VHF, UHF and microwave) frequencies. It might be well into the year 2000 before we see a receding of RF usage since it usually takes many years for a new type of transmission to take over and obsolete the well established "old method."

Consider, too, that the current investment (no pun intended) in wired systems and satellite links must be paid for before a proliferation of buried fiber-optic cables can economically replace existing systems. That will be a whole new ball game — I don't think I will live long enough to see the total disappearance of all those ugly telephone poles and beautiful satellite dishes that now clutter our landscapes. Also keep in mind the giga-dollar cost to design, build, launch and maintain our present group of satellite data, communication, TV and global weather, navigation and military satellite systems. All of these will have to be milked dry of profit and use before they can be replaced. (Look how long it took to get microwave repeaters, touch-tone phones and digital TV systems.)

I think you've started many of us thinking. To prove my point, I must confess that this is my first ever letter to an editor after 50 years plus in the electronics (and old Radio) business and I'm going to cut out and save your editorial for future reference.

Nick Marshall
Lockheed Missiles & Space Company
Palo Alto, CA

More German-English Information

Editor:

Check out the *IEC Multilingual Dictionary of Electricity*, 1983, ISBN 471-80 784-2, 461 pages hard cover, available from the IEEE for about $24.00, member price. However, Michael Waters would be better advised to sign up for a technical reading course in German at a local school.

Don Steinmeyer,
Emerson Electric Co.
St. Louis, MO

Understanding the "Black Art" of RF

Editor:

I was glad to see in the "RF Viewpoint" in the April *RF Design* that you recognize the existence of two "classes" of RF engineers, the traditional, and the new breed (no pun intended). As one of the older variety who has tried over the years to remove some of the "black art," I am well aware of the differences.

Unfortunately, the aspects of black art that concern me are as much black art with recent graduates as they have been with our class, who had to come up the hard way. My goal over the years has been to attempt to resolve the black art. The math used today looks fine, but if the parameter information used and/or regularly available does not characterize the elements used over their normal spectrum of use, but is useful at only one point, you are no better off than you were before.

Apparently the younger people who haven't had to make these circuits with tubes and both types of transistors or ICs just don't have the understanding of network fundamentals to a depth that they can apply sound technology to design. In a corollary way, you need reviewers thoroughly versed in both phases of the technology if they are to recognize the booby traps that still exist.

For example, a design article published in February depended on the use of "S" parameters. Unfortunately, S_{11} is related to h_{ie} (base input resistance), an approximate value defined by (kT/qI_b), a number that strongly depends on base current. Yet a single numerical value is typically provided for it. Not only that, but ALL of the "S" parameters depend on respective currents, S_{21} and S_{22} on output current, and S_{11} and S_{12} on input current. Clearly, while you can adjust one of these currents to a specified value, you can't adjust both at the same time because of the variations encountered in the value of beta.

In all the years I have been reading *RF Design*, I haven't seen this noted in one of your articles or in any other recent magazine carrying material of a corresponding technical level. Isn't this something you could do for your readers' benefit?

Keats A. Pullen
Kingsville, MD

RF Leads the Way in Automatic ID Tags

Radio frequency identification systems using bi-directional radio signals to read coded information are finding increasing use in automatic ID applications. The technology is being used by the transportation industry for vehicle and cargo container identification and for animal identification in the farm market. It is finding increasing applications in industrial automation and materials handling, especially where there is no line of sight between the scanner and ID tag.

RF coded identification systems have been acknowledged by the Automatic Identification Manufacturers, Inc. (AIM) to be one of the fastest growing ID technologies. In a recent general meeting of AIM, the organization drafted a position paper supporting universal standards for operation and coding of RFID tags. Such standards will enable products of different vendors to work together. In the past, AIM has made similar efforts for standardization of bar code ID systems, and will use that experience in the area of RFID. More information can be gotten from AIM, 1326 Freeport Road, Pittsburgh, PA 15328.

GaAs Wafer Test System Developed

Detecting flaws in gallium arsenide (GaAs) semiconductor materials should be easier with two polarized infrared light systems developed by National Bureau of Standards Semiconductor Electronics Division researchers in Gaithersburg, MD. Both are nondestructive methods wafer manufacturers can use to screen materials before marketing. One system can examine an entire wafer, while the other employs a 75- to 600-X microscope to view isolated wafer portions. Both systems allow digital storage of images and the use of false-color graphics to represent wafer characteristics such as variations in the transmitted infrared intensity, which could indicate potential problems.

The rapid growth of GaAs manufacturing has placed a great demand on wafer makers to provide the near-perfect GaAs crystals required, a process which has not yet reached the level of capability achieved in silicon technology. NBS is using the infrared techniques in-house, but will also assist industries in setting up there own systems.

U.S. Wire and Cable Industry Still Troubled

The U.S. insulated wire and cable industry experienced only sluggish growth in 1986, with more of the same predicted for 1987. In a report published by Business Trend Analysts, Inc., increased imports, growth of fiber optics, and overall depressed prices were the main factors influencing the wire and cable market.

Imports, which represented only 4 per cent of the market in 1978, have reached a level of 16 per cent. This increase has been partially mitigated by joint ventures between U.S. and foreign companies. The price of copper has been depressed for several years, and has combined with a weaker demand to push prices to a minimum.

Most important, according to the study, is the growth of fiber optic communications systems, using glass fiber cables instead of copper-based products. Telephone and telegraph cable products which totalled 30 per cent of the total insulated wire and cable market in 1977 are currently just 18 per cent of sales.

The report analyzes these aspects, and provides historical and projected market figures for these and other sub-sections of the whole insulated wire and cable market. Information is available from Business Trend Analysts, 2171 Jericho Turnpike, Commack, NY 11725.

Varian Acquires Pye TVT

Varian Associates' acquisition of Pye TVT Ltd., formerly the United Kingdom Transmission subsidiary of Philips was announced during the 1987 National Association of Broadcasters convention and trade show. Pye TVT designs and manufactures broadcast and transmission equipment for television frequencies. The plant employs 220 persons and is located in Cambridge, England.

Varian Awarded SDI Contract

A $3.2 Million Strategic Defense Initiative (SDI) contract has been awarded to the EIMAC division of Varian Associates, Inc., by the Los Alamos National Laboratory. Under terms of the research and development contract, Varian EIMAC will produce a 1/2 MW, 425 MHz version of its Klystrode™ power amplifier tube over the next 24 months. Plans call for the Klystrode to be used as the RF energy source for the linear accelerator portion of the neutral particle beam weapon system currently under development.

The Klystrode was developed as a high-efficiency amplifier for UHF television transmitters, using tetrode-type grids and a single-cavity with a short electron beam, relative to a klystron. The hybrid design combines the efficiency of a tetrode with the power handling capabilities of a klystron.

GaAs IC Price Reductions

Anadigics, Inc., has announced price reductions on three of its GaAs IC products. Credit for the reduction was given to the company's 0.5 micron, 24 GHz f_t process which produced higher than anticipated yields. For example, the price for the Anadigics AWA20601 2 to 6 GHz amplifier has been reduced from $109 to $37.50 for 1,000 pieces in package form. Prices of the ADA25001 DC-2.5 GHz amplifier and ADV3040 3 GHz 4-to-1 divider have also dropped.

Real Time Catalog for Military Test Specs

National Semiconductor has implemented a real-time electronics catalog of military test specifications for integrated circuits. RETS™ (Reliability Electrical Test Specifications) gives military IC customers essential current information on device testing.

The catalog resides in the company's mainframe computer and can currently be accessed by National's sales personnel. By the end of this year customers will be able to access the electronic catalog directly.

Shielding Systems Corp. Formed

The Shielding Systems Corporation (SSC), a subsidiary of Bairnco, was created on January 1, 1987 and is comprised as three former Keene Corporation divisions: Ray Proof, Keene Engineering and Construction (formerly Dow Industries), and Advanced Absorber Products. SSC's capabilities include concept and architectural design through manufacture, final test and service.

Philips and Fluke Join Forces

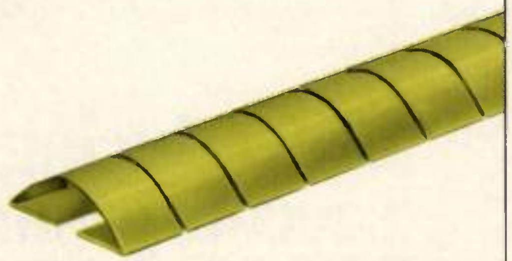
John Fluke Mfg. Co., Inc., of Everett, WA and Philips Test and Measurement (T&M), Netherlands, have announced their intention to establish an alliance regarding distribution of their electronic test and measurement equipment. The intended alliance entails a distribution agreement whereby Fluke would sell support and service Philips T&M products in North America and other markets including China, Hong Kong and Japan, while Philips would sell, support and service Fluke products in Europe and remaining markets.

Standard Oil Announces New Division

Standard Oil Engineered Materials Company announced the formation of an Electronics Ceramics Division. $8.5M will

New!

Symmetrical Shielding Strips (S^3) provide bi-directional engagement at severe shear angles!



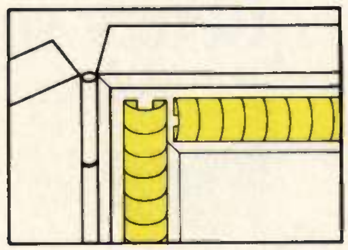
These new symmetrical slotted shielding strips of beryllium copper permit continuous spring contact throughout their length, providing the perfect answer for a variety of shielding requirements.

Three models are available: basic, rivet-mount and double-faced adhesive-mount designs. The basic design consists of low-compression, adhesive-mounted strips. A generous radius profile provides for the greatest incident engagement angle with the lowest force. As with all Sticky Fingers® shielding strips, the self-adhesive tape makes mounting easy and secure.

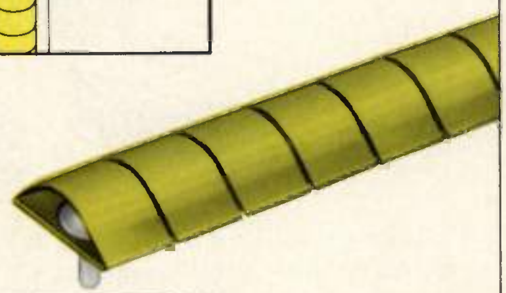
The rivet-mount design incorporates the addition of an integral track, pierced for mounting with nylon push rivets. This configuration allows bi-directional engagement, and is specially designed for slide applications, PC board connections, etc.

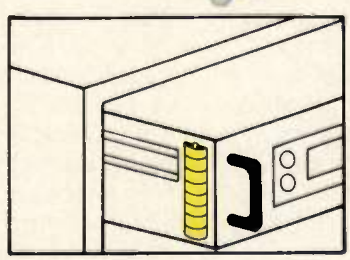
The third design also incorporates an integral track-mount design, but employs a double-faced adhesive tape instead of push rivets. This provides for fast, easy field replacement in military applications, especially where high frequencies do not permit the use of mounting holes.

For complete information, including exact specifications, dimensional drawings, etc., on these and other Instrument Specialties shielding strips, use this publication's Reader Service Card. Or write to us directly at Dept. RFD-36.

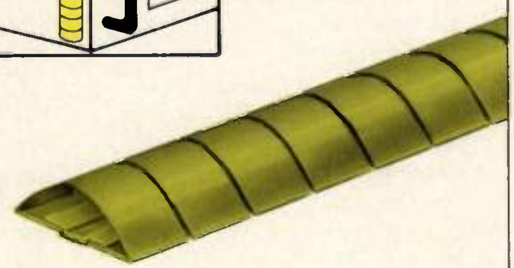


Adhesive-mounted strips for typical electronic enclosures.





Strips with integral mounting track* and nylon push rivets, for sliding drawer applications.



Strips with integral mounting track* and self-adhesive strip for fast field replacement.

INSTRUMENT SPECIALTIES COMPANY, INC.
P.O. Box A • Delaware Water Gap, PA. 18327
Phone: 717-424-8510 • TWX: 510-671-4526

Specialists in beryllium copper since 1938

***patent pending**

be invested in two facilities to produce materials substrates and planar diffusion sources. The division is composed of three business groups: electronics, integrated circuit thermal management and electro-mechanical.

Electrospace Receives $10.7M Contract

Electrospace Systems, Inc. has received two contracts from the Defense Communication Agency (DCA) for a total value of $10,697,416. The contract covers scientific and technical support to the center for command and control communication systems (C4S) over a three-year period.

FAA Awards Test Set Contract

Systron Donner's Instrumentation Division has received an initial contract from the FAA to produce 95 microwave repeater test sets (MRTS). The MRTS is integral to a complete test capability required for the new radio communication link used at approximately 750 sites used by the FAA throughout the U.S.

New Contracts for Herley Microwave

Herley Microwave Systems, Inc., announced the receipt of a series of contract additions and new awards totalling $7,700,000. With these contracts, the company's backlog is increased to $20 million. The primary Herley manufacturing plant in Lancaster received over $3 million in awards. Includes in the awards were transponders for the Titan II and Titan IV programs form Martin Marietta, signal processing devices from the Air Force for the ALQ-119 and 131 ECM programs, and an award for the IFM's from Northrop Corp. for the ALQ-135.

MwT Acquires MMI

Microwave Technology, Inc., has signed an agreement to acquire Monolithic Microsystems, Inc. of Santa Cruz, CA. MMI's proprietary silicon monolithic technology will complement MwT's emerging GaAs monolithic technology. MMI will operate as a wholly owned subsidiary of MwT and will continue its manufacturing operations in Santa Cruz.

Rockwell, IBM in GaAs Pact

Rockwell International Corp. and IBM have announced an agreement for co-operative development of advanced GaAs technology and production techniques. The joint effort is intended to accelerate the development of high speed digital and opto-electronic components for computers and telecommunications, utilizing the advantages of gallium arsenide.

Watkins-Johnson to Acquire Honeywell Microwave Operation

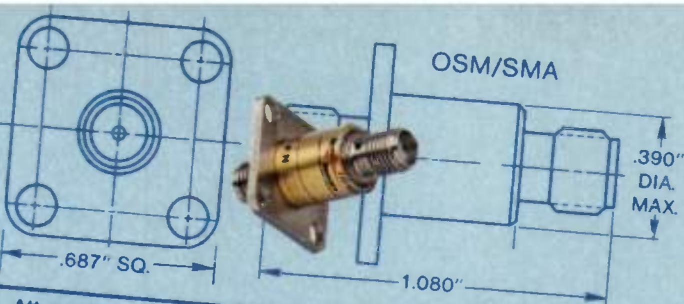
In an announcement made April 30, Watkins-Johnson Company will acquire Honeywell, Inc.'s Santa Barbara Microwave Center for approximately $2 million. The center currently employs 30 persons in the design and manufacture of mm-wave mixers and oscillators for defense electronics applications.

Litton to Buy Gould Microwave Division

Gould Inc. and Litton Industries, Inc. have signed a letter of intent for the sale of Gould's Microwave Products Division in San Jose, Calif., to Litton. The sale is expected to be completed within the next 60 days. The planned sale is part of Gould's previously announced action to divest its defense systems businesses.

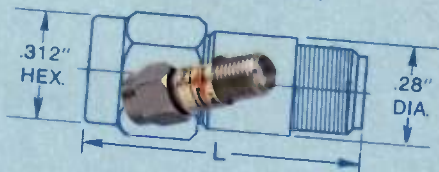
INFO/CARD 29

OSM/SMA



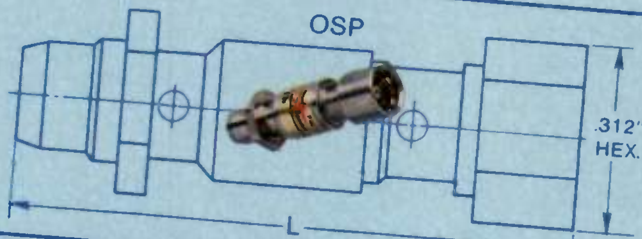
Attenuation (dB)	Flatness (dB)	VSWR	
0-6	±0.30	dc-4.0 GHz	1.15:1
7-10	±0.50	4.0-12.4 GHz	1.25:1
11-20	±0.75	12.4-18.0 GHz	1.35:1
21-30	±1.00		

OSM/SMA MINI



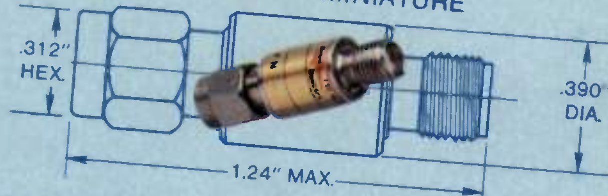
Attenuation (dB)	Flatness (dB)	Dim. L	VSWR	
0-6	±0.30	0.86″	dc-4.0 GHz	1.15:1
7-10	±0.50		4.0-12.0 GHz	1.25:1
11-20	±0.75	1.02″	12.4-18.0 GHz	1.35:1
21-30	±1.00			

OSP



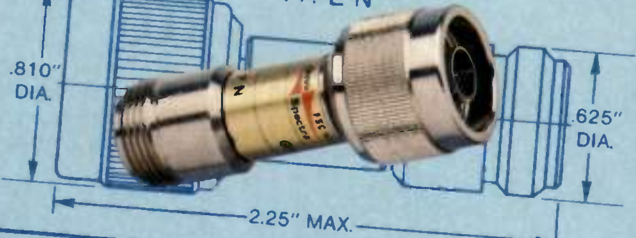
Attenuation (dB)	Flatness (dB)	Dim. L	VSWR	
0-6	±0.30	1.15″	dc-4.0 GHz	1.15:1
7-10	±0.50		4.0-12.4 GHz	1.25:1
11-20	±0.75	1.50″	12.4-18.0 GHz	1.35:1
21-30	±1.00			

OSM/SMA MINIATURE



Attenuation (dB)	Flatness (dB)	VSWR	
0-6	±0.30	dc-4.0 GHz	1.15:1
7-10	±0.50	4.0-12.4 GHz	1.25:1
11-20	±0.75	12.4-18.0 GHz	1.35:1
21-30	±1.00		

TYPE N

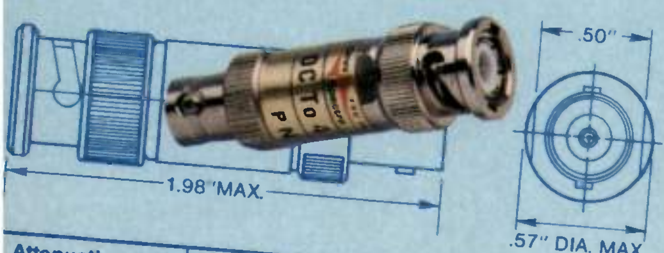


Attenuation (dB)	Flatness (dB)	VSWR	
0-6	±0.30	dc-4.0 GHz	1.15:1
7-10	±0.50	4.0-12.4 GHz	1.25:1
11-20	±0.75	12.4-18.0 GHz	1.35:1
21-30	±1.00		

TNC

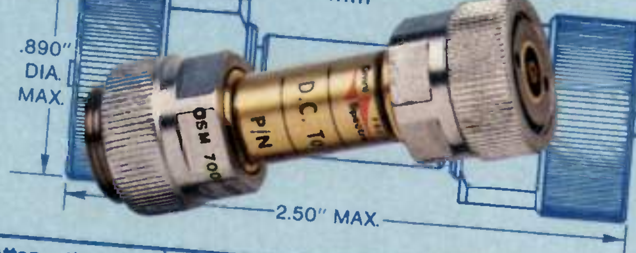
Attenuation (dB)	Flatness (dB)	VSWR	
0-6	±0.30	dc-4.0 GHz	1.15:1
7-10	±0.50	4.0-12.4 GHz	1.25:1
11-20	±0.75		
21-30	±1.00		

BNC



Attenuation (dB)	Flatness (dB)	VSWR	
0-10	±0.30	dc-4.0 GHz	1.25:1
11-20	±0.50		

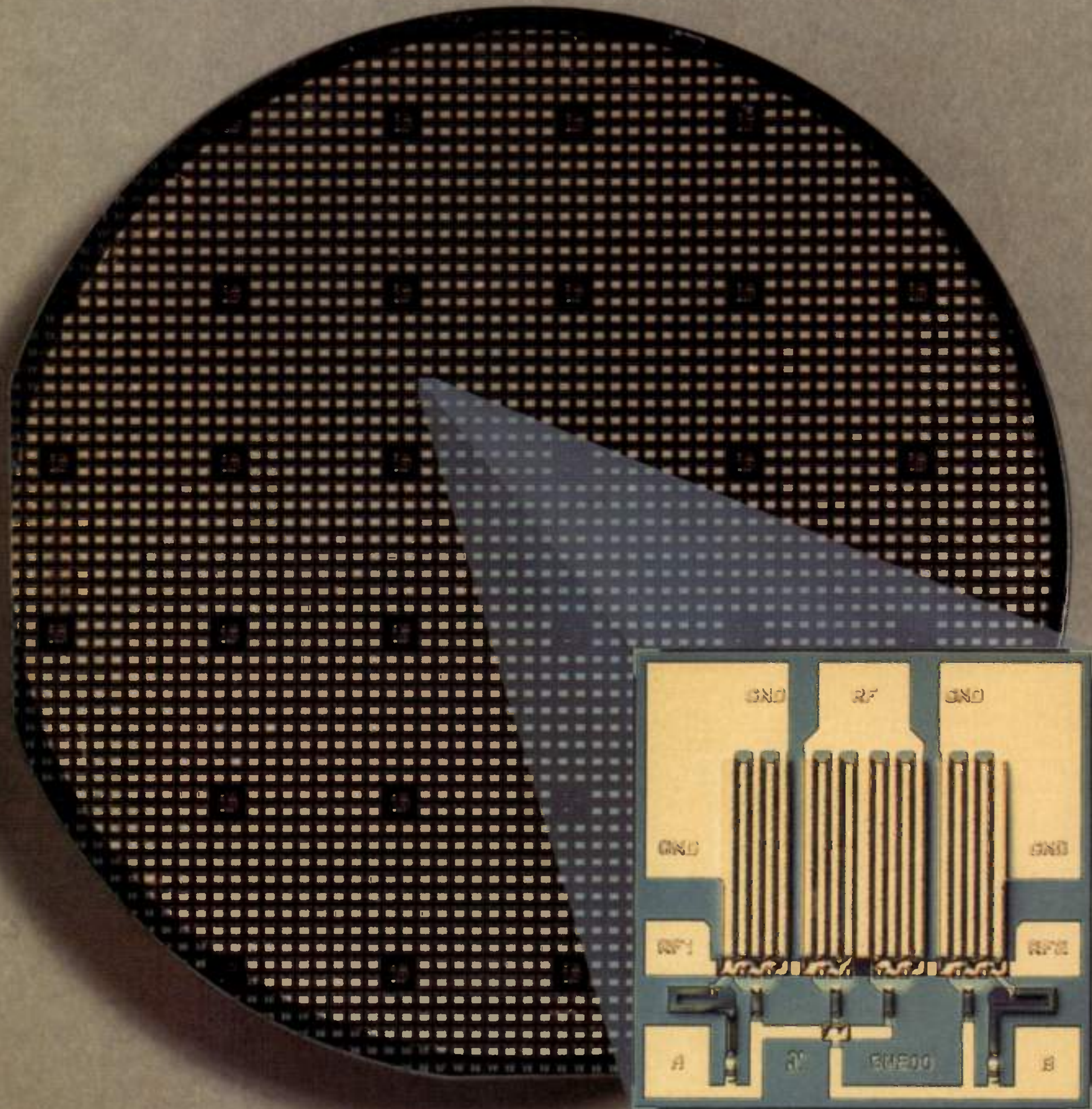
7mm



Attenuation (dB)	Flatness (dB)	VSWR	
0-6	±0.30	dc-4.0 GHz	1.10:1
7-10	±0.50	4.0-12.4 GHz	1.20:1
11-20	±0.75	12.4-18.0 GHz	1.30:1

Power: 2 W avg., 100 W peak. Temperature: −54 to +125°C. 50 ohm impedance.

HERE'S A SWITCH:



2 ns dc to 6 GHz GaAs MMIC!

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

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INFO/CARD 67

rf calendar

June 15-19, 1987
ISDN-87, ISDN/Broadband Networks for the Future
Atlanta Merchandise Mart and Westin Peachtree Plaza, Atlanta, GA
Information: Renee Farrington, Information Gatekeepers, Inc., 214 Harvard Ave., Boston, MA 02134; Tel: (617) 232-3111

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

June 23-25, 1987
1st SAMPE Electronics Materials and Processes Conference
Doubletree Inn, Santa Clara, CA
Information: Marge Smith, Business Director, P.O. Box 2459, Covina, CA 91722. Tel: (818) 331-0616

July 7-8, 1987
Telemetry UK
Bloomsbury Crest Hotel, London
Information: Sira Limited, South Hill, Chislehurst, Kent BR7 5EH, England. Tel: (212) 752-8400

July 17-20, 1987
1987 International Microwave Symposium/Brazil
Rio Palace Hotel, Rio de Janiero, Brazil
Information: Alvaro Augusto de Salles, CETUC-PUC/RJ, Rua Marques de Sao Vicente 225, Gavea, CEP22453, Rio de Janiero, Brazil

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

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

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

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

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

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And in you.

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2. Maah Sango, Ph.D.
Manager, Device Characterization
3. Chuck Holmes, Ph.D.
Vice President, Advanced Development
4. Dave Morton, Ph.D.
Manager, Touchstone Products
5. Paul Adams
Senior Staff Scientist
6. Stephanie Chou
Systems Programmer
7. Gary Hawisher
Manager, CAD Development
8. Jim Greene
Systems Programmer
9. Larry Lerner
Manager, CAT Development
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20. K.T. Lin
Senior Scientist
21. Vahid Asgharian
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22. Carol Yuan
Systems Programmer
... Max Medley (not pictured)
Senior Staff Scientist

It's astounding how EEsof's development staff can continue to dramatically enhance CAE/CAD/CAT tools that already set the standard for the microwave/RF industry. But then, our staff is far beyond any comparable group in any comparable company— both in number and credentials.

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microwave SPICE.™ The new version features revolutionary enhancements: signal-power analysis (with virtually unlimited harmonic number); FFT in the post processor that permits spectral displays; driving function synthesis.

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E-Syn.™ Our first release made network synthesis almost automatic. Now our people have automated synthesis from 1- and 2-port S-parameters and calculation of distributed network parameters. And they've added an adjoint optimizer.

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Our next *mwSPICE* release will feature a comprehensive FET model with an open database that lets *you* generate parameters; the newest *MiCAD* will let you create and edit circuit files from physical circuit layouts; new *E-Syn* will include exact distributed synthesis and elliptic function filter synthesis.

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rf courses

The George Washington University

Electromagnetic Pulse and its Effect on Systems
June 15-17, 1987, Washington, DC
Frequency Synthesis
August 3-5, 1987, Washington, DC
Frequency Hopping Signals and Systems
September 9-11, 1987, Washington, DC
Spread Spectrum Communication Systems
September 21-25, 1987, Washington, DC
Fiber Optics Technology for Communication
September 22-24, 1987, Washington, DC
Introduction to Receivers
October 19-20, 1987, Washington, DC
Modern Receiver Design
October 21-23, 1987, Washington, DC
Global Positioning System: Principles and Practice
November 4-6, 1987, Washington, DC
Information: Shirley Forlenzo, Continuing Education Program, George Washington University, Washington, DC 20052; Tel: (800) 424-9773, (202) 994-8530

UCLA Extension

Navstar Global Positioning System (GPS)
June 15-19, 1987, El Segundo, CA
Pave Pillar Avionic Systems and Related Technologies
June 23-25, 1987, El Segundo, CA
Kalman Filtering
August 31-September 4, 1987, Los Angeles, CA
Information: UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024; Tel: (213) 825-1901, (213) 825-1047, (213) 825-3344

Interference Control Technologies, Inc

Grounding and Shielding
June 9-12, 1987, San Jose, CA
July 21-24, 1987, Myrtle Beach, SC
July 28-31, 1987, San Diego, CA
August 11-14, 1987, Denver, CO
August 18-21, 1987, Ocean City, MD
September 15-18, 1987, Washington, DC
Tempest Design
June 16-19, 1987, Mountain View, CA
August 4-7, 1987, Washington, DC
Practical EMI Fixes
July 14-17, 1987, Denver, CO
August 25-28, 1987, Virginia Beach, VA
September 22-25, 1987, San Diego, CA
EMP Design and Testing
July 21-24, 1987, Washington, DC
Tempest Facilities
July 28-31, 1987, Mountain View, CA
MIL-STD-461/462
September 29-October 2, 1987, Washington, DC
Information: Penny Caran, Registrar, Interference Control Technologies, Inc., State Route 625, P.O. Box D, Gainsville, VA 22056; Tel: (703) 347-0030

Integrated Computer Systems

Digital Signal Processing
July 14-17, 1987, Washington, DC
July 21-24, 1987, Los Angeles, CA
July 23-26, 1987, San Diego, CA
August 18-21, 1987, Palo Alto, CA
September 22-25, 1987, San Diego, CA
October 27-30, 1987, Anaheim, CA
December 1-4, 1987, Washington, DC
December 8-11, 1987, Boston, MA
Machine Vision and Image Recognition
June 16-19, 1987, Washington, DC
July 28-31, 1987, San Diego, CA
September 15-18, 1987, Los Angeles, CA
September 29-October 2, Washington, DC
Fiber Optic Communication
June 23-26, 1987, Boston, MA
Information: Marilyn Martin, Integrated Computer Systems, 5800 Hannum Avenue, P.O. Box 3614, Culver City, CA 90321-3614; Tel: (800) 421-8166, (213) 417-8888

Norand Corporation

FCC, VDE, CISPR, and SAE Regulation and Design Criteria
September 1-2, 1987, Cedar Rapids, IA
Grounding, Bonding, Shielding and PCB Design for EMI/EMC
September 15-16, 1987, Cedar Rapids, IA
MIL-STD 461B/C and 462 Regulations and Design Criteria
October 13-14, 1987, Cedar Rapids, IA
RF Susceptibility and ESD Testing
November 3-4, 1987, Cedar Rapids, IA
Information: Bev Reynoldson, Norand Corp., 550 2nd St S.E., Cedar Rapids, IA 52401; Tel: (319) 846-2415

Besser Associates, Inc.

Microwave Circuit Design
July 1-5, 1987, Los Angeles, CA
Principles of RF Circuits
July 6-9, 1987, Santa Clara, CA
Information: Les Besser, Besser Associates, Inc., 3975 East Bayshore Road, Palo Alto, CA 94303; Tel: (415) 969-3400

R & B Enterprises

FCC Requirements & Test Methods per parts 2, 15 & 68
June 15-16, 1987, Boston, MA
Printed Circuit Board & Wiring Design for EMI & ESD Control
June 17-18, 1987, Boston, MA
Understanding & Applying MIL-STD-461C
June 23-24, 1987 Philadelphia, PA
Information: Registrar, R & B Enterprises, 20 Clipper Road, West Conshohocken, PA 19428; Tel: (215) 825-1966

California State University

Microwave Antenna Measurement Short Course
July 13-17, 1987, Northridge, CA
Information: Shirley A. Lang, Center for Research and Services, School of Engineering and Computer Science, California State University, Northridge, CA 91330; Tel: (818) 885-2146

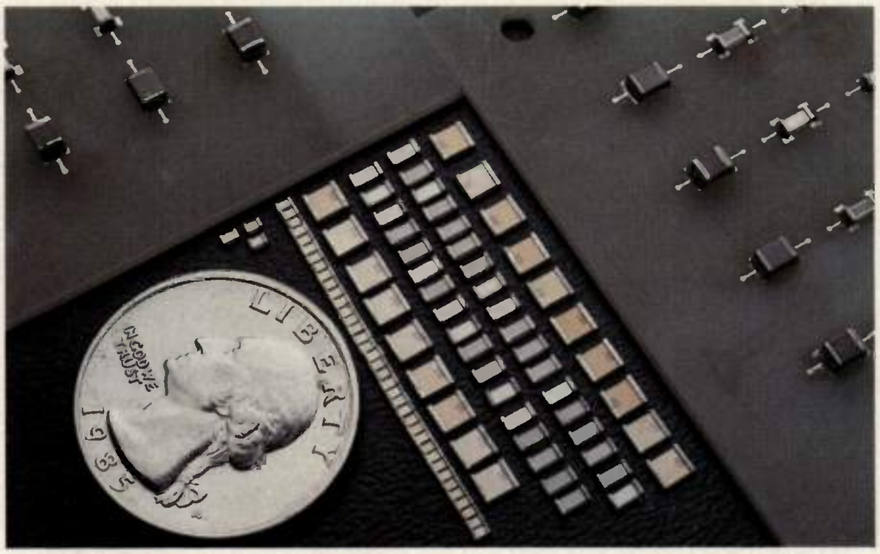
Georgia Institute of Technology

Millimeter and Microwave Ferrite Materials
July 27-29, 1987, Atlanta, GA
Modelling, Simulation and Gaming of Warfare
August 18-21, 1987, Atlanta, GA
Information: Deidre Mercer, Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385; Tel: (404) 894-2547

Microwave II

AVX TechFile Series

TECHNICAL INFORMATION FROM THE LEADER IN MLCs



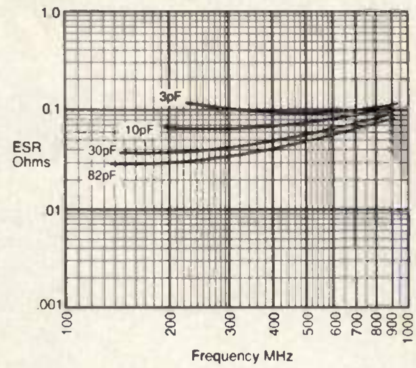


Figure 2 ACCU-F ESR vs Frequency

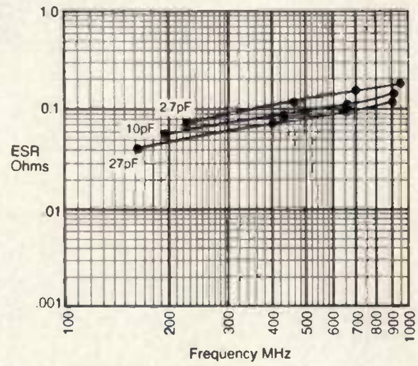


Figure 3 Microwave MLC, ESR vs Frequency

Thin-Film High-Q Chip Capacitors for UHF/VHF/Microwave Applications

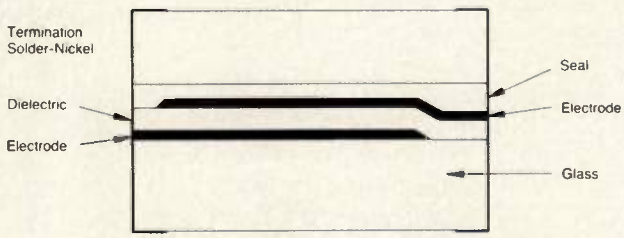


Figure 1 ACCU-F Cross-Section

In answer to the fast growing demand for surface mountable high-"Q" chip capacitors in the VHF/UHF/Microwave range, AVX has developed a thin-film capacitor in the standard EIA chip sizes. This capacitor is fully compatible with SMT and has Q/ESR performance superior to other capacitor types to above 1GHz.

The very high "Q" of these thin-film chip capacitors, called ACCU-F, is obtained through the use of low-loss dielectric of either silicon dioxide (SiO_2, $K = 4.4$) or silicon nitride (Si_2N_4, $K = 7.5$) sandwiched between electrodes of high conductivity aluminum and copper (Figure 1). The dielectric temperature coefficient meets EIA characteristics COH (0 ± 60 ppm/°C from -55°C to +125°C). Its nickel-solder terminations withstand the rigors of SMT, with leach resistance in excess of 30 seconds at 260°C and 90% coverage in 3 seconds.

Test Results

Figure 2 and Figure 3 demonstrate the superiority of ACCU-F's ESR as compared to the best microwave MLC's above 500MHz. The frequency limits of performance for ACCU-F are still under investigation, but the low-loss properties are maintained to above 2GHz.

Conclusions

ACCU-F has the edge over microwave MLC's, by virtue of its more gradual rise in ESR above 500MHz. In addition, tight dimensional control permits very small chip sizes (0603, 0504, 0403 etc.) to be more easily manufactured. Moreover, extremely tight capacitance tolerances ($\pm$0.1pf, $\pm$1%) can be obtained without major cost penalty.

☐ Please send me the AVX Technical Paper, "Thin-Film Chip Capacitors with Very High-Q."
☐ Please send me literature describing AVX MLC's.
☐ Please send me samples.

Name__________
Title__________
Company__________
Address__________
City__________
State__________ Zip__________
Phone__________

Send to AVX Corporation, Dept. 25, P.O. Box 867, Myrtle Beach, SC 29577.

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INFO/CARD 7

Microwave Subsystem Design Using Schematic Capture

Software Gives RF Designers More CAD Power

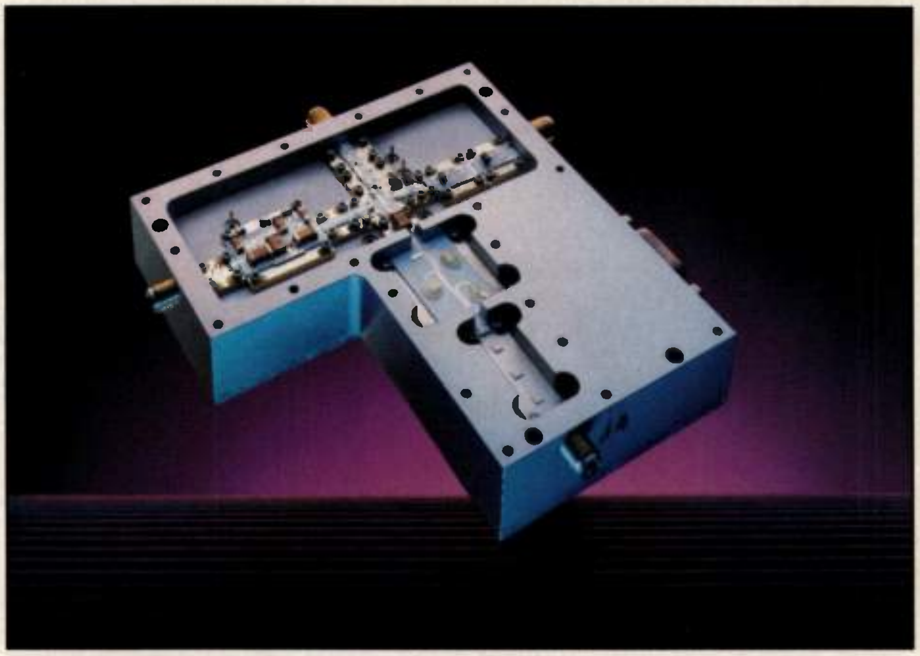
By John A. Mezak
Eaton Corporation, EID Division, and
Stephan A. Mezak
COMPACT Software

The availability of circuit analysis and optimization programs, such as SUPER-COMPACT™, has greatly enhanced the microwave circuit design process. By using MIC (Microwave Integrated Circuits) with alumina substrates on carriers, a relatively large number of circuits can be integrated into one assembly or subassembly. However, until now it has been too difficult to model the entire subsystem because the circuit file describing it has been too complex to enter by hand, and it has been difficult to collect the optimized circuit files from a number of design engineers. The use of schematic capture techniques, such as Tektronix' Designer's Database Schematic Capture (DDSC)™, provides the means to model a complex subsystem.

Schematic capture software has been used for several years to enter and debug large digital and low frequency analog circuit designs. The schematics are drawn from a library of components, placed and interconnected on the screen. Design verification can be performed by extracting a netlist file from the schematics and simulating circuit behavior with logic simulation software.

With Compact Software's DDSC/SUPER-COMPACT Interface™ microwave circuits can now be drawn, analyzed and optimized. A library of symbols representing SUPER-COMPACT circuit elements is used to draw the schematics. The symbols are selected off a menu and connected in a design "window" on the screen.

The underlying database used to store the schematics on the computer maintains information about each symbol as well as the connections to other symbols in the drawing. A command is provided in the DDSC system to extract this information and create a SUPER-COMPACT circuit file from the schematics.



This preamplifier assembly can now be modeled as a complete subsystem.

How DDSC Works

DDSC provides a friendly circuit design environment. The software runs in a workstation window concurrently with SUPER-COMPACT, and with other programs in their own windows. A designer can simultaneously view schematics and analysis results on the same screen.

The entry of a microwave circuit schematic is relatively error-free compared to the traditional typing of circuit files. The designer does not need to specify node numbers or remember the exact syntax of circuit elements parameters. When the schematics are complete, a single command is used to extract a SUPER-COMPACT circuit file and submit it for analysis and optimization. Analysis and optimization of the circuit occurs interactively with SUPER-COMPACT and the designer may modify or tune individual circuit element values or parameters in the circuit file.

At any time the designer can view modified parameters on the schematic through the back annotation process. Back annotation with DDSC automatically retrieves modified parameter values and places them on a revision of the original schematic drawings. The designer no longer needs to search through a circuit file for modified parameters, trying to visualize how the circuit has changed. In addition, notes and comments may be entered on the schematic to keep track of design decisions and results. Past schematic revisions are available and can be called from the database for comparison or reuse.

Microwave Subsystem Design

Typical microwave circuits are small, containing twenty to fifty components; sophisticated schematic capture tools have not been available for such small designs. However, individual circuits are often combined into a subsystem. These subsystems are rarely analyzed because circuit files to model them easily run into hundreds of lines and become difficult to use. But when the individual circuits are stored in a schematic database, combining them into a microwave subsystem is simple: they are tied together with a block diagram. Subsystem circuit files can be produced in a few minutes from block diagrams with any number of hierarchy levels.

Since the DDSC workstation computers are connected in a network, designers can work in a team. Depending on file protections, team members can view (but perhaps not modify) each others schematics. Team engineering allows the designer to develop his design in the context of the overall microwave subsystem. Meanwhile, the project leader can quickly combine the circuits to monitor total microwave subsystem performance.

Design Example: A Receiver Preamplifier Assembly

An actual subsystem design problem is shown in Figure 1, the block diagram of a receiver preamplifier assembly. In addition to the preamplifiers, the assembly contains a FET band switch, a band stop filter to attenuate signals at the first IF frequency, and a low pass filter to attenuate signals in the image band at microwave frequencies. In the complete system, the preamplifier assembly is followed by a mixer to upconvert signals to a fixed IF frequency of 4500 MHz. In addition, two of the input bands have YIG preselectors to reduce spurious receiver responses. The preselectors and preamplifiers in these two bands, 100 to 1500 MHz and 1.0 to 3.5 GHz, are required to have return losses typically greater than 10 dB to alleviate impedance mismatch interaction with the YIG filters and the resulting gain variation versus frequency.

The circuits for the preamplifier assembly were designed by several engineers before tools like the DDSC/

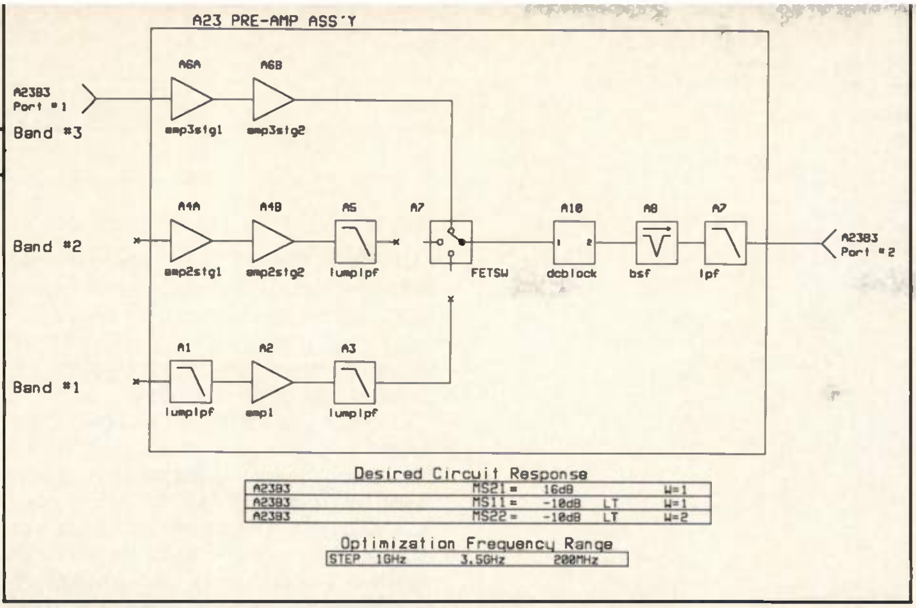


Figure 1. Block diagram of the preamplifier assembly.

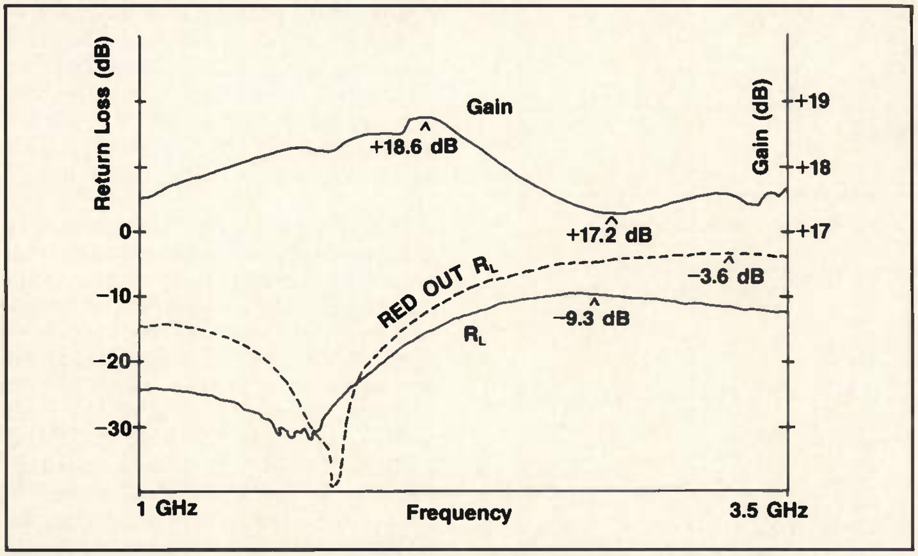


Figure 2. Initial return loss/gain of the preamplifier assembly.

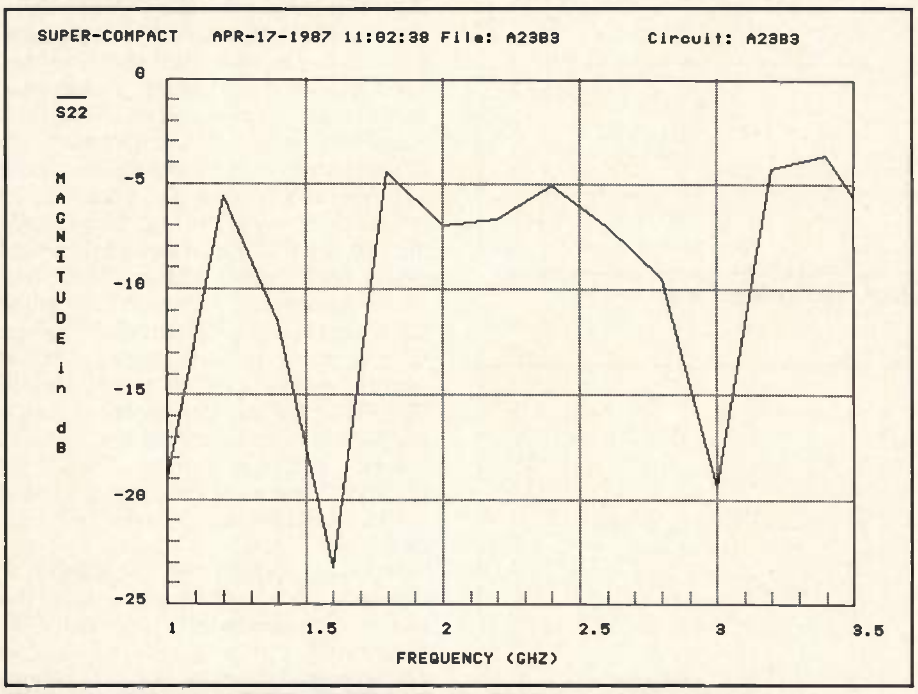


Figure 3. Initial SUPER-COMPACT prediction of return loss.

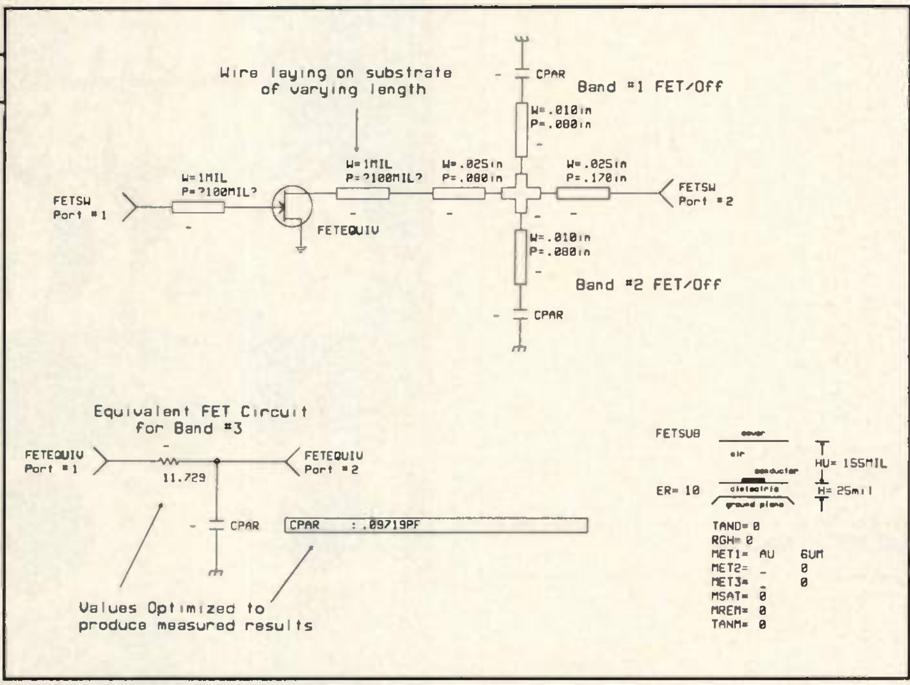


Figure 4. Schematic of FET band switch.

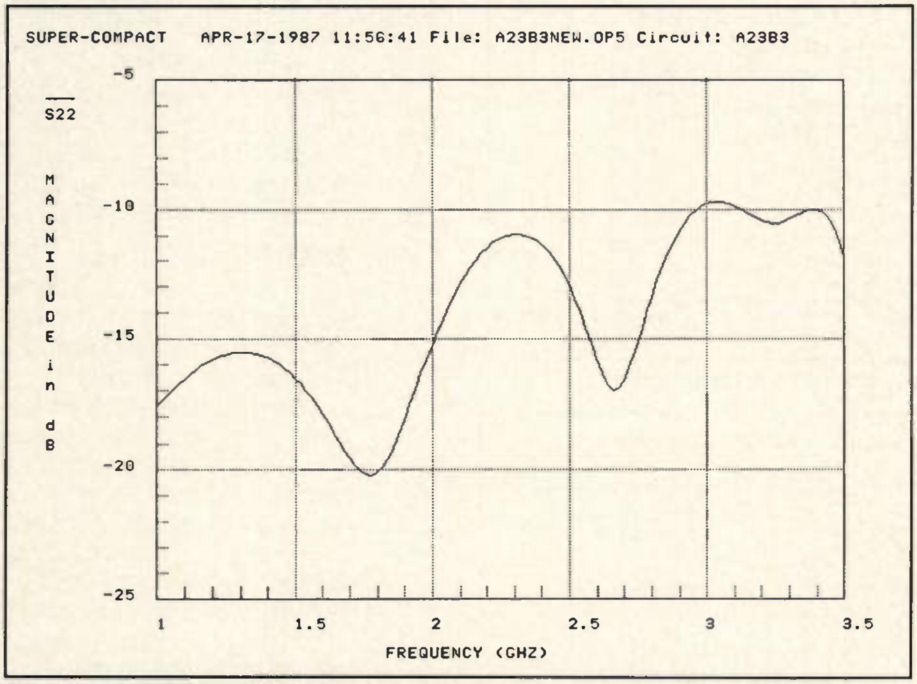


Figure 5. SUPER-COMPACT prediction of return loss with tuning.

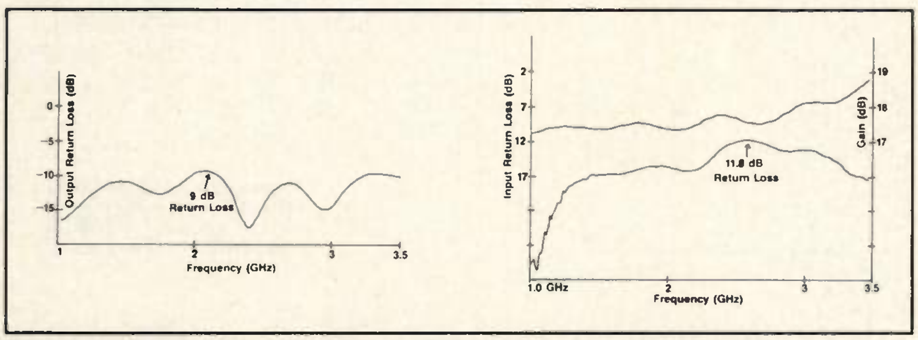


Figure 6. Final return loss/gain of the preamplifier assembly.

SUPER-COMPACT interface became available. Individual circuit files for some of the assembly circuits and were analyzed and optimized by computer, although no attempt was made to model the whole preamplifier assembly.

Originally, little attention was paid to the overall output return loss because the upconverting mixer would have an attenuator for trimming the overall receiver front end gain. This attenuator would also alleviate impedance mismatch and gain variation. Consequently, the individual circuits were designed for reasonably large but repeatable return losses. This appeared to be acceptable when the first four preamplifier assemblies built had output return losses of 8 to 9 dB, which did not degrade performance. However, the fifth assembly had 3.5 dB output port return loss along with unacceptable gain variation in the 1.0 to 3.5 GHz band (Fig. 2).

The fifth preamplifier assembly was disassembled and the individual circuits were remeasured and retuned. In addition, the complete subassembly design was drawn with the DDSC software on an Apollo R workstation computer. A circuit file was extracted from the block diagram and schematics of the 1.0 to 3.5 GHz band of the preamplifier (156 lines long). The SUPER-COMPACT analysis of output return loss for the 1.0 to 3.5 GHz band is shown in Figure 3, confirming the test results.

Model of the FET Band Switch

A powerful feature of DDSC is the easy entry of hierarchical designs. This was used to model the overall preamplifier with a block diagram and was also used in the FET band switch schematic. Published S-parameters for the device are not accurate in this case since the FET is biased at approximately I_{dss} (saturation). Instead, the FET was modeled as a subcircuit containing a series resistor and shunt capacitor (including an estimate of the shunt capacitance of the FET's physical mounting). The resistance and capacitance values were computed by the SUPER-COMPACT optimizer to match the measured insertion and return loss of the FET band switch in the band 3 on position. These were then back annotated automatically by DDSC to the FET subcircuit schematic.

A special FET symbol was created to represent the equivalent subcircuit in the overall FET band switch model. DDSC allows a subcircuit to be defined and used on the same schematic page. Therefore the equivalent FET subcircuit was conveniently placed on the same page as the overall FET switch model as shown in Figure 4.

Tuning the Preamplifier Assembly with the Optimizer

The type of tuning which improved the fifth preamplifier assembly in the lab was added to the preamplifier schematics. The tuning elements consisted of: 1. Additional shunt capacitance added to the interstage and the output of the 1.0 to 3.5 GHz preamplifier circuit; 2. Additional shunt capacitance in the low pass filter; 3. Open circuited tuning stubs at the input in the band stop filter; and 4. Series inductance at the FET switch junction (Figure 4).

A new SUPER-COMPACT file was extracted and initial analysis predicted a greater than 6 dB output return loss for the preamplifier assembly. Optimization of the assembly showed improvement in output return loss to greater than 9 dB while maintaining good input return loss and gain (Fig. 5). The optimized tuning parameters were back annotated to the schematics and applied to the preamplifier assembly, yielding an actual return loss of better than 9 dB (Fig. 6).

Conclusions

We have shown how a schematic capture program can be used to enter and help tune the design of an MIC subsystem. When DDSC is used in conjunction with SUPER-COMPACT, the designer has a powerful set of tools to analyze and optimize individual microwave circuits and then quickly combine them into a subsystem using a block diagram. With these design tools, the performance of the subsystem can be predicted and tuned.

Acknowledgements

Special thanks to Dr. Gunther Sorger, EID Division, Eaton Corporation for support of this work; Dr. George Vendelin, now at Avantek, who contributed to the amplifier designs while at Eaton; and to Chacko Easau at Eaton, for measurements and data plots. rf

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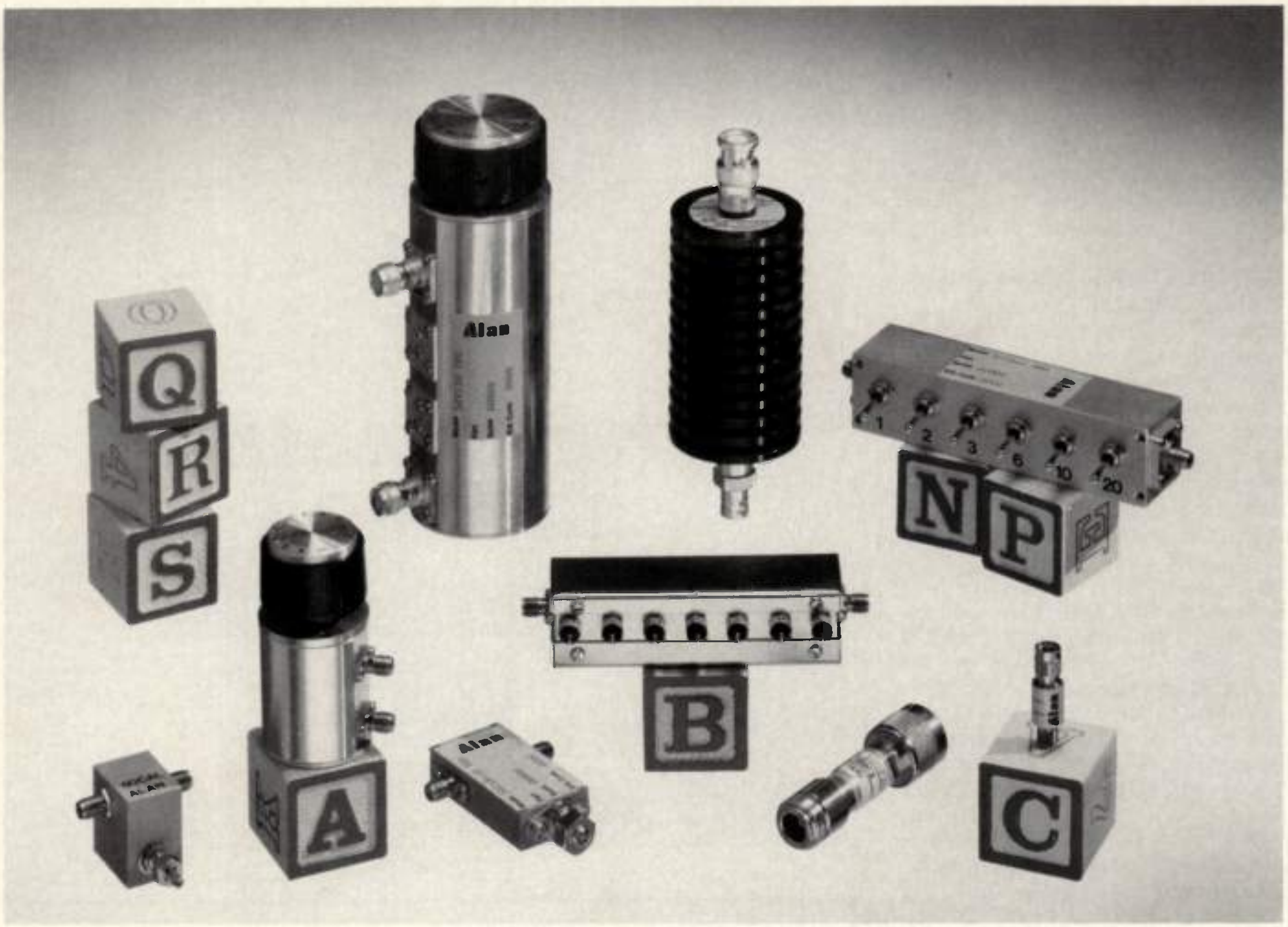

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The RF/Aerospace Alliance

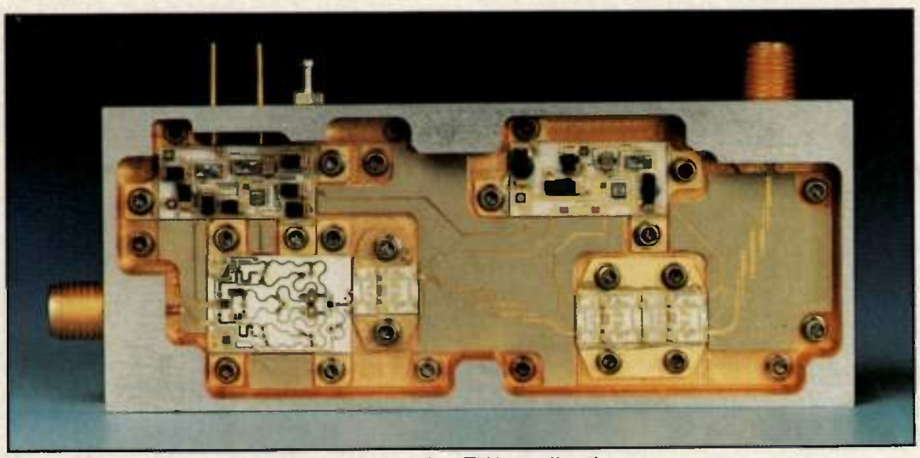
Part Three in a Series: The Integration of RF and Other Technologies.

By Mark Gomez
Assistant Editor

RF has found a constantly growing home in the aerospace industry. The RF role ranges from silicon MMICs for airborne EW systems, to subsystems (such as VCOs and synthesizers) for radar and military satellites, to major navigation and communication systems. The industry is so vast and diversified that this report can only skim the surface of the many ongoing projects and the companies that are a part of the RF/Aerospace alliance, the third and final part of our series on the integration of technologies.

RF "super component" devices such as silicon and GaAs MMICs play a major role in the aerospace industry. MMICs are used in expandable EW systems, missile radar IF amplifiers and GPS satellite receiver RF amplifiers. In the front end of GPS receivers, MMICs can be used as low noise amplifiers, down converters, VCOs and digital converters.

As an example of RF subsystem development, Eaton Corporation has recently introduced a low phase noise VCO specifically designed for electronic warfare. It covers from 8 to 16 GHz with a minimum output power of +20 dBm. Another example is the MSF series from Avantek, a family of silicon MMIC frequency converters. The devices simultaneously function as a self-oscillating LO and two port active mixer with up or down conversion gain or as an active mixer with low power LO injected at the input or output.


Eaton Corporation's VCO is designed for EW applications.

Military Systems Represent Biggest RF Role

The Global Positioning System (GPS) is a satellite based navigation system that may be incorporated into military aircraft. The problem of ground obstructions found in terrestrial based systems will be eliminated by GPS as the signals are obtained from satellites. Magnavox is developing a series of modular GPS sensors for applications in navigation and guidance systems. The basic assembly is a two channel satellite receiver and interface which can be expanded to provide additional channels when a higher degree of accuracy is needed.

Digital RF memory (DRFM) devices play an important part in jamming systems. An ideal DRFM would convert an incoming threat radar signal to an analog signal while preserving the characteristics of the radar, then would convert and store the data in digital format. This is required to reconstruct a replica of the original radar signal to be radiated by the jammer. The Avionics Group at ITT is currently developing a device to fit the above requirements. Also involved in the development of a DRFM is Thomson-CSF who is working on attaining a DRFM with an instantaneous bandwidth of 800 MHz and response time of 10 ns.

Jamming systems represent a major part of the electronic warfare industry. They came into play soon after radar was incorporated to track a possible threat. These systems are now used for jamming enemy radar and communication systems.

The airborne self-protection jammer is a system designed to provide automatic jamming protection from a large number of threats. Bistatic jamming is an effective means for disrupting automatic target tracking and missile guidance, involving a redirection of the victim's radar from the defended object to a false target. Velocity deception jamming diverts the range gate to a decoy, hence redirecting the radar to a false target. It is possible to imitate a large number of false targets causing the radar operator to see more than one target when there is actually one. Randomly switching jammers denies the radar the ability to track a target. These countermeasures are effective against surface based tracking radars and radar guided missiles. The ICMS 2000 made by Thomson-CSF is a self protecting suite that performs warning, jamming and decoying functions, and system management. It has a crystal video receiver and a superheterodyne receiver for detection of doppler and pulse doppler radars. The warning protection is provided by the superheterodyne receiver, processing units, direction finding antennas and an omnidirectional antenna.

The AN/ALQ-162, an airborne jamming system made by Northrop, has its own receiver and prcessor for managing the jammer against multiple threats. This continuous wave jammer will be used in Navy, Army and allied nation aircraft.

Marconi Defense Systems has a family of electronic warfare systems that includes jamming of enemy radar and communication systems. The communications jammer is designed for monitoring enemy VHF communications and jamming those radio circuits from behind their positions. The device for radar band jamming detects threat radars and selects the best jamming mode for the given conditions.

The Rotman lens is a type of antenna array developed to simultaneously monitor and detect the direction of a number of signals, or to simultaneously jam several bearings. Raytheon's Electromagnetic Systems Division is working on an interferometer that will replace the Rotman lens on the ALQ-142. The 142 is a

The AMRAAM is shown mounted under the wing of an F-16.

shipboard electronic support measures system used to locate enemy threats. It is comprised of a series of spiral antennas and phase processing circuitry. This modification will provide resolution that is good enough to be used as targeting information for weapons launch when only target bearing is known. The greater sensitivity allows more targets to be detected.

Decoys are EW devices that provide tactical aircraft with protection against radar directed anti-aircraft missiles. They protect aircraft from enemy semi-active missiles that home in on the reflected radar energy from an aircraft. They transmit radar of the same frequency but of higher intensity than that is bounced off the aircraft causing the enemy missile to home in on the decoy rather than the aircraft. A typical decoy consists of a controller, phase lock loop, modulator, local oscillator, receiver, power amplifier and input frequency limiter.

Jammers need to know the exact operating frequency of the radar it is assigned to counter while radar warning systems scan the spectrum of radar threats to distinguish the type and approximate bearing of the threat.

Simple RWRs (radar warning receivers) detect radar pulse envelopes with the aid of crystal video receivers. The pulse repetition rate and frequency is determined by the radar and tracking status. A superheterodyne receiver can be added to the crystal receiver to separate pulses by frequency and to lead jammers to the proper frequency.

The Bragg cell is another type of receiver designed for intercepting and analyzing hostile emissions. It may be able to analyze up to 100 threat emitters simultaneously when it is fully developed. This method uses a transparent crystal that is attached to a transducer. RF signals are sent to the transducer which in turn generate acoustic pressure waves that change the optical refractive index of the crystal.

The Zeus system, developed by Marconi, is an electronic counter measures system designed for high performance combat aircrafts. It consists of a RWR and a jamming unit. When both are used concurrently, the RWR controls the jammer. The system can also control decoys, chaff and flares. It has eight receiving and two transmitting antennas. The receiving antennas detect missiles, anti-aircraft artillery and airborne intercept radars.

Watkins-Johnson Company has produced a triple channel interferometer radio direction finder. It has a frequency coverage of 20 to 500 MHz which is expandable to 2 to 1100 MHz. It is relatively immune to the type of signal modulation, permitting effective operation on noise-like signals such as spread spectrum as well as AM, FM, SSB, CW, and pulse type signals. Utilization of a discrete fourier transform algorithm provides signal amplitude and phase data which is used with signal frequency and antenna geometry to compute a line of bearing.

The AMRAAM — An RF Guidance System Example

Hughes Aircraft Company is currently testing their advanced medium range air to air missile (AMRAAM Aim-120). In a test of the missile's ability to distinguish between clustered targets, it passed within lethal distance of its target. The AMRAAM's active radar recognized two QF-100 drone aircrafts as individual targets and attacked one of them. During the test, the QF-100s were flying abreast, closely spaced. An F-15 flying at Mach 0.90 at an altitude of 10,000 feet launched the AMRAAM at medium range. The two QF-100s were flying directly towards the F-15 at Mach 0.80 at 1000 feet.

Before launching, the AMRAAM received target information from the F-15. Only one target was perceived at the time of launch. After launch, the missile guided itself in its command inertial midcourse mode during which it received target location update information over its data link from the F-15. The AMRAAM switched to its on board active radar and acquired the two target cluster before designating a single target for attack. Current medium range air-to-air missiles in the Air Force and Navy lack the AMRAAM's ability to zero in on one aircraft in a cluster which could cause them to miss all the targets.

The AMRAAM's seeker's RF signal processor is mounted behind its flat antenna resulting in a good signal to noise ratio and phase matching in the receiver. Watkins-Johnson Company has been contracted to produce the RF processors for use in the AMRAAM. The deliveries are expected to extend through late 1988.

This report has touched only a few of the many aspects of RF technology in the aerospace industry. The RF role ranges from simple components to massively complex electronic warfare systems. Design and development of these systems provides an unparalleled technical challenge for RF engineers. rf

The GaAs MMIC Explosion: Three Case Histories

By Gary A. Breed
Editor

Recent growth in gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) has been, to understate the case, rapid. Amplifiers, mixers, switches, attenuators, oscillators and every possible combination of these can now be created in a MMIC functional block. This feature highlights three companies and their most recent products. It is intended not only to show the current products available, but also to provide some insight into the technological and market factors which have given GaAs MMICs such a big push.

Before presenting the three feature stories, it is appropriate to recognize some of the other companies who are making substantial contributions to GaAs MMIC technology. These companies include M/A COM Advanced Semiconductor, who introduced new GaAs switches and attenuators at last November's RF Expo East. M/A COM components have already been designed into new products. Harris Microwave Semiconductor's amplifier products were early entries into the GaAs MMIC marketplace. They were also leaders in emphasizing the necessity for RF and microwave techniques in the implementation of digital GaAs ICs.

Nippon Electric (NEC) has drawn on the experience of 15 years of GaAs FET transistor production and six years of GaAs MMIC research to offer capabilities in 0.05-3.0 GHz IF amplifiers, 2-20 GHz wideband amplifiers, phase shifters, prescalers and LNA/Mixer/IF amplifier front-end circuits. Microwave Semiconductor Corp. (MSC) is a relative newcomer to MMIC technology, although experienced in discrete transistor technology. GaAs opto-electronic circuits are in production, with new MMIC products on the threshold of announcement.

Plessey's Three-Five Group has developed amplifier and switch products, including switch arrays for phase shifters, attenuators or filters. Plessey's GaAs foundry service offers custom MMIC production. Also in the foundry business is TriQuint, a Tektronix subsidiary.

Celeritek, Rockwell, Texas Instruments and ITT have also joined the ranks of companies with GaAs MMIC capabilities. The growing list of companies and products is evidence of the manufacturer's confidence in the technology. The following case histories are examples of product developments and perspectives on GaAs technology by three companies.

GaAs Receiver ICs for GPS
Pacific Monolithics, Inc.

The Global Positioning System (GPS) will be the first satellite system to provide continuous, precision navigation throughout the world. Eighteen operational satellites, plus three spares, orbiting in 55 degree inclined orbits 20,200 km above the earth will provide a three-dimensional navigation solution (latitude, longitude and altitude), time reference and velocity information anywhere in the world.

The system's signals are transmitted in L-Band at 1227.6 and 1575.4 MHz. A GPS receiver has a "generic" block diagram like that illustrated in Figure 1. Microwave electronics make up much of the receiver, including a low noise amplifier, frequency converter and frequency standard. Using discrete microwave circuits, the RF portion of the receiver represents about half its cost. With GaAs MMIC technology, a factor of five reduction in cost and size can be realized.

In 1984, Pacific Monolithics developed a complete C-Band satellite receiver front-end using GaAs MMIC technology. During 1985, over 25,000 devices were delivered for these applications. The technology both improved the quality and reduced the cost of TVRO satellite systems. Applying the same principles to a GPS receiver, a set of chips meeting the RF functional requirements of Figure 2 were developed. The circuit performance specifications are summarized in Table 1.

The *L-Band low-noise amplifier* (PM-AM0101) is a two-stage cascode design with a chip size 0.5 × 0.75 mm. Amplifier gain of 20 dB with a noise figure of 1.9 dB is achieved over the 1.2-1.6 GHz band of interest. Designed for minimum power consumption, the chip has a current drain of 21 mA with an 8 V supply.

The *frequency converter* brings a high level of integration into a 1.2 × 1.2 mm die. The PM-CV0202 chip combines RF amplification, IF amplification, LO buffer and a double-balanced mixer. Each component makes a specific contribution to the MMIC's performance. For example, the RF amplifiers add gain, but reduce the subsystem noise figure and provide reverse isolation for LO and IF leakage to the RF port. The LO buffers supply a constant power level to the mixer and reduce the LO power requirement. The LO buffer also improves mixer performance by its very short electrical distance from the mixer diodes.

There are two downconverter chips available. The CV-0201 has balanced (push-pull) inputs for RF and LO signals, while the CV-0202 has single-ended inputs. Both convert 1.2-2.5 GHz inputs to IF signals of 15-1000 MHz, with 20-25 dB RF-IF conversion gain using a ±5 V supply. LO input level requirement is −5

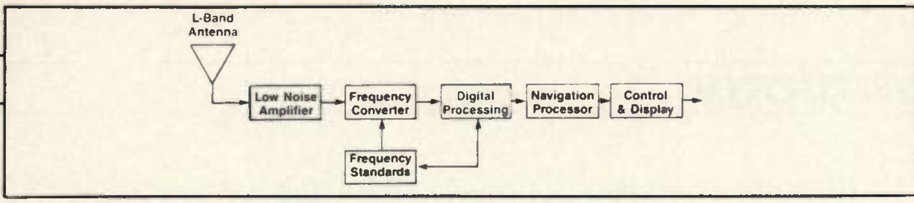


Figure 1. Block diagram of generic GPS receiver.

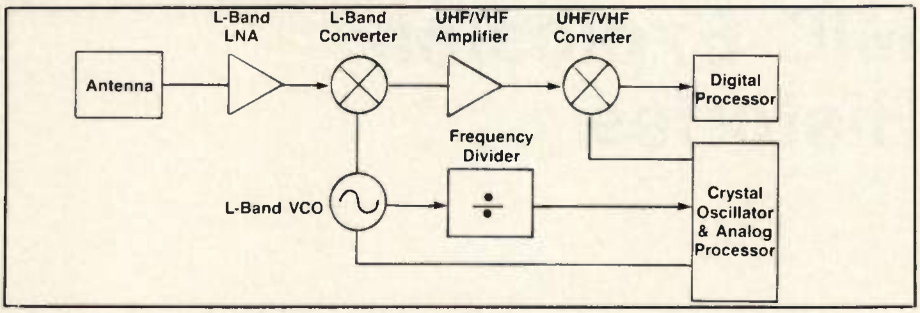


Figure 2. RF electronics of GPS receiver.

dBm or greater (up to +10 dBm), and the output 1 dB compression point is +15 dBm.

A GaAs MMIC *voltage controlled oscillator (VCO)* was designed using a two-stage FET oscillator with an output buffer for load isolation. The frequency determining feedback element is external to the PM-OV0101 chip, which has been tested with SAW resonators at 696, 928 and 1250 MHz. The 696 MHz oscillator demonstrated 125 dBC/Hz phase noise 10 kHz from the carrier.

The PM-DD0201 is a microwave *frequency divider* designed for divide-by-two operation from DC-2 GHz. The device is a static frequency divider, and the input can be either capacitively or DC coupled to the signal source. The output is capable of ECL-level voltage swings into a 50 ohm load.

A monolithic *VHF/UHF converter* based on the Gilbert multiplier cell was designed using active phase splitters and an active balun to achieve proper drive signals. Conversion gain is from 5 to 15 dB, depending on frequency, and worst-case LO-IF leakage of −27 dB (1-2000 MHz) was measured with +5 dBm LO drive.

The final member of the GPS chip family is the PM-AG0101 *VHF/UHF AGC amplifier,* providing IF gain with gain control from 20-1000 MHz. The chip has 25 dB gain and more than 25 dB of gain control range, together with 50 dB output to input isolation.

Drawing on past experience in C-Band satellite receiver MMICs, Pacific Monolithics sees GPS system components as the area they are best able to serve with new GaAs MMICs. Despite the delays in deployment of the entire constellation of GPS satellites, the worldwide navigation accuracy and convenience that GPS will provide is seen as a significant market.

The SW-200 GaAs SPDT MMIC Switch
Adams-Russell Electronics Inc., Anzac Division

Among the first MMIC components available from Adams-Russell's new GaAs production facility is the SW-200 series of SPDT RF switch products. Adams-Russell saw that GaAs technology could achieve switching performance comparable to PIN diode designs, but with nanosecond switching speed, low power consumption and standard CMOS or TTL logic drive. These advantages can be put to use in phased array radar, ECM and EW systems and switching matrices, as well as general purpose RF switching.

The SW-200 is based on the use of Metal-Semiconductor Field Effect Transistors (MESFETs) as the active devices. The technology used is N-channel depletion mode GaAs MESFETs with 1 μm Schottky gates. Implanted resistors and Schottky diodes are configured into a switch circuit utilizing air bridge interconnects. MMIC wafer fabrication follows an eight-mask process using direct ion implantation into semi-insulating GaAs substrates. The SW-200 chip size is 30 × 30 × 10 mils.

As shown in the schematic of Figure 3, four MESFETs are arranged in two mirror-image series-shunt configurations originating at the common RF node. Four 2k ohm resistors connect the control inputs to the MESFET gates while providing isolation between the RF path and the control circuitry. The series device gate is connected to the gate of the shunt device on the opposite arm of the switch. Long-term static buildup is prevented by connection of a Schottky diode/20k ohm resistor network between each control input and its respective ground. Although there is gate leakage present, the DC power consumption is dominated by the currents in the 20k resistors. When the control input is low (0 to −0.2 V), the current is 20 μA and with the control high (−5 to −8 V), current is 40 to 200 μA.

Arrangement of the control network is such that complementary gate control

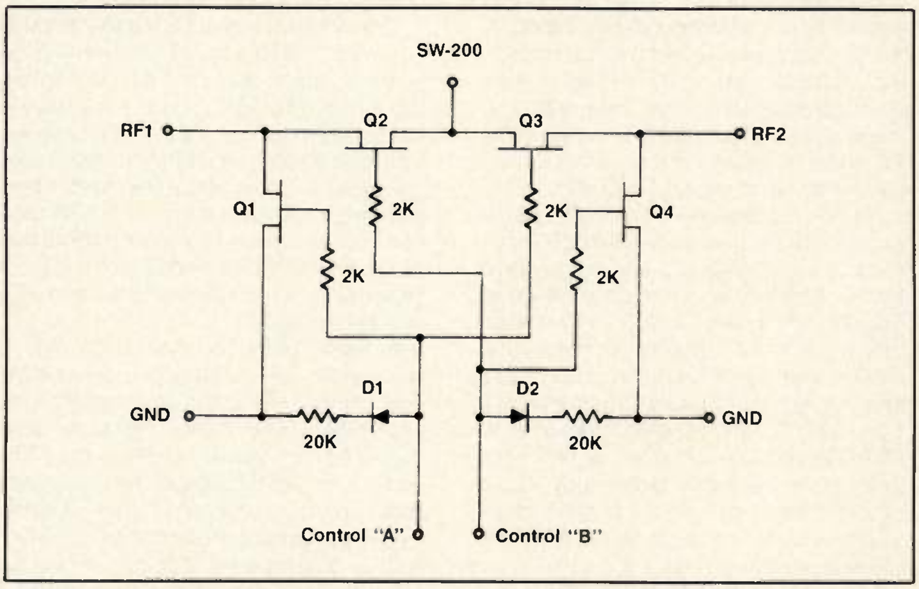


Figure 3. Schematic diagram of SW-200 GaAs MMIC SPDT switch.

voltages applied at the control inputs switch the appropriate series-shunt MESFETs "on" and "off." The "on" state occurs with a 0 to −0.2 V control input, resulting in an "on" resistance of only four ohms and a capacitance of 0.2 pF across the MESFET. The −5 to −8 V "off" control state causes the MESFET to cease conduction, with a resistance of 100k ohms and the same 0.2 pF capacitance. The MESFET pinch-off voltage determines the minimum "off" control voltage, and is determined by the ion-implantation dose of the MESFET channel. This is designed to be −4 V maximum, to provide the lowest "on" channel resistance that can be reliably turned off by a −5 V control input.

MMIC Switch Performance

Figure 4 shows the measured performance of the SW-200. At 4 GHz, the insertion loss is less than 1 dB, with over 30 dB "off" port isolation. The absence of DC blocking capacitors and bias chokes enables operation literally down to DC, as well as reducing the size of the circuit. The upper frequency performance is limited to 6 GHz by parasitic source-drain capacitance. With the SW-200's direct coupling, rise and fall times of 2 ns are typical (determined by the RC time constant of the 2k resistor and the 1 pF gate input capacitance.

Input power for 1 dB compression is +25 dBm with a control of −5 V, increasing to +31 dBm with −8 V control. (The −8 V maximum control voltage lies midway between the pinch-off and the gate breakdown voltage.) Typical second and third order intercept points are +66 and +41 dBm.

Drive circuitry for the SW-200 must provide complementary control voltages to the gate drive inputs. Compatibility with common logic families such as CMOS or TTL is highly desirable for convenience and low DC current consumption.

One method, shown in Figure 5, raises the channel of the MESFETs above ground. The DC voltage is applied through 1k ohm (or larger) resistors and bypass capacitors to the chip "grounds." 10k ohm or greater resistors are required for proper isolation at the drains (switched ports), with DC blocking capacitors for the external RF inputs and outputs. This biasing method changes the control requirements to 0 V for "off" and +5 V for "on." The diagram shows the SW-200 driven by a CD54HCT04 hex inverter. The HCT family of CMOS is LSTTL compatible, but with lower power consumption and a full 0 to +5 V output voltage swing.

Alternate drivers include the 54LS04 hex inverter and the standard CMOS CD4041 quad true/complement buffer. Additional pull-up circuitry is needed between the LSTTL outputs and the +5 V supply to achieve the required voltage swing. The maximum operating voltage of the CMOS device cannot be utilized, since the limit of the SW-200 control voltage is 8 V. However, both LSTTL and HCT CMOS have +5 V maximum supply voltage ratings. Standard CMOS can be used to take advantage of the maximum signal handling capability of the switch MMIC when used with an 8 V supply.

Anzac offers the GaAs MMIC switch family in seven configurations. The TTL-compatible versions use the CD54HCT-series drivers:

1. SW-200: chip only.
2. SW-201: basic chip in 8-pin TO-5 package.
3. SW-202: basic chip in 3/8-inch flatpack.
4. SW-205: switch plus TTL-compatible driver in 14-pin DIP, plus two additional switches to terminate the "off" port and increase isolation.
5. SW-206: switch plus 8-volt CMOS driver in 14-pin DIP, with termination feature.
6. SW-207: same as SW-205 without termination (has lower insertion loss).
7. SW-208: same as SW-206 without termination.

Although packaged versions are available to give designer's greatest flexibility in component choice, the real value of the SW-200 GaAs MMIC switch is the potential for integrating switches and amplifiers in a monolithic format. Alone, the SW-200 devices offer an immediate alternative to PIN diode switches when low power and driver interface convenience is important. The devices have the additional benefit of monolithic reliability and low volume cost.

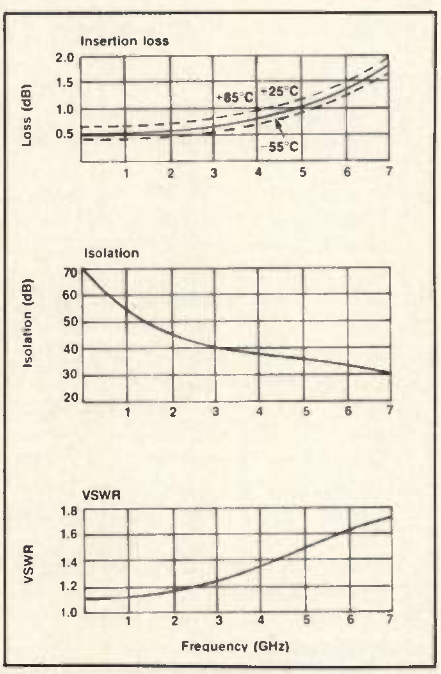


Figure 4. Performance curves for the SW-200.

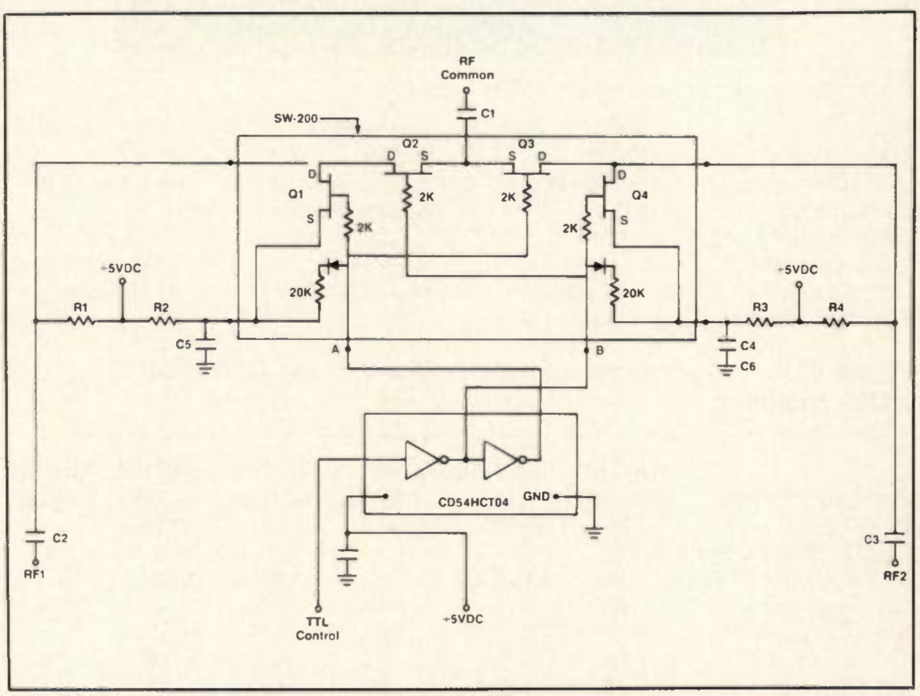


Figure 5. Drive circuitry for GaAs MMIC switch.

Designing and Fabricating a 2-6 GHz Amplifier: Anadigics, Inc.

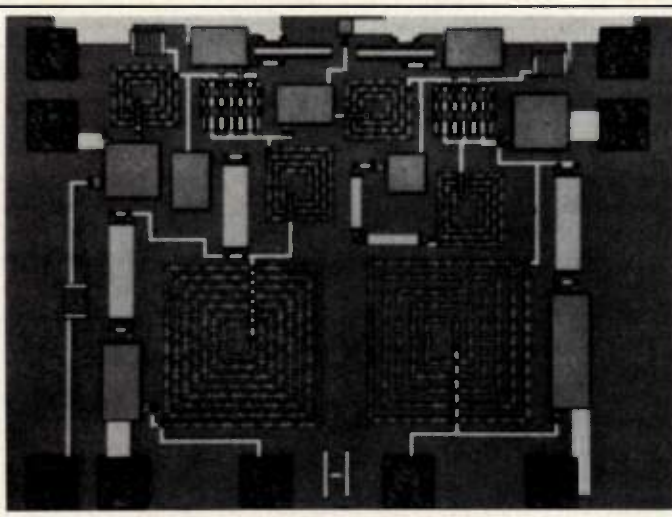
Anadigics, like most other companies involved in GaAs MMIC technology, places a strong emphasis on *capabilities,* not just product offerings. With relatively few standard components to choose from, the GaAs MMIC customer can't just pick an off-the-shelf device. He needs a specific design or a specific combination of proven circuit modules. This case history describes the design and fabrication process for GaAs MMICs such as the AWA20601 2-6 GHz amplifier (photo and Figure 6).

Any monolithic integrated circuit begins as a software-generated model. Typically, the design is established and optimized using available software (SUPER-COMPACT™, Touchstone™ or MSPICE). The foundry, in this case Anadigics, has a library of circuit models, including all of the active and passive elements available in the fabrication process. Anadigics also offers proprietary enhancement of SPICE called AISPICE, which allows both time-domain non-linear analysis and frequency-domain linear analysis to be performed with SPICE.

Analysis, optimization and reiteration of circuit layout is required to "fine tune" the design. The design task is far more complex than choosing circuit elements from a menu and assembling them into a circuit. Impedance matching, transistor parameters, sizes and values of passive components, and layout considerations for both crosstalk and wafer yield require extreme care. With all the software assistance available, it still takes the intuition gained from experience to estimate parasitics and make layout decisions.

In the case of the AWA20601, the circuit models were evaluated on an ongoing basis, comparing the models to measured data. As the first standard product to come from Anadigics recently completed foundry, the AWA20601 development was monitored closely from start to finish. The result of this care was a product with a correct design the first time, a rarity in the world of ICs.

The Anadigics foundry service is based on their 0.5 micron, 24 GHz f_T depletion-mode MESFET technology. The foundry service was made available to customers in December 1986.



Chip photo shows layout of AWA 20601 amplifier.

Gain:	9.5 dB	Input VSWR:	1.5:1
Gain flatness (0 dBm):	±0.75 dB	Output VSWR:	1.5:1
Noise Figure:	6.0 dB	Supply Voltage:	+2.5 to +7 V
Gain Control Range:	5.0 dB	Supply Current (VDD = +5):	100 mA
Output Power (1 dB comp.):	+14.5 dBm	Input Power:	+20 dBm max.
Reverse Isolation:	30 dB	Power Dissipation:	1 W Max.

Figure 6. Typical performance specifications for the AWA 20601 GaAs MMIC amplifier.

	AM0101	CV0202	OV0101	DD0201	CV0101	AG0101
Frequency (MHz)	1200-1600	1200-2600	400-1700	DC-1500	5-2000	50-600
Gain (dB)	20	20	N/A	6	15 to 5	25
Output Power (dBm)	0	15	−4	8	0	0
IF Frequency (MHz)	N/A	15-1000	N/A	N/A	3-1000	N/A
LO Drive (dBm)	N/A	5	N/A	N/A	0	N/A
Noise Figure (dB)	1.9	6	N/A	N/A	7	7
DC Voltage (V)	+8	+5	+5	+4	+5	+5
DC Power (mW)	170	800	80	580	100	120

Table 1. Performance summary of GaAs MMIC chip set for GPS receivers.

To receive more information on the GaAs MMIC products and capabilities of these companies, circle the Info/Card numbers given below:

Pacific Monolithics, Inc., Sunnyvale, CA. Info/Card #137
Adams-Russell, Inc., Anzac Division, Burlington, MA. Info/Card #136
Anadigics, Inc., Warren, NJ. Info/Card #155
M/A COM Advanced Semiconductor, Burlington, MA. Info/Card #134
Harris Microwave Semiconductor, Milpitas, CA. Info/Card #133
California Eastern Laboratories (NEC), Santa Clara, CA. Info/Card #132
Microwave Semiconductor Corp., Somerset, NJ. Info/Card #131
Plessey Three-Five Group Ltd., San Diego, CA. Info/Card #130
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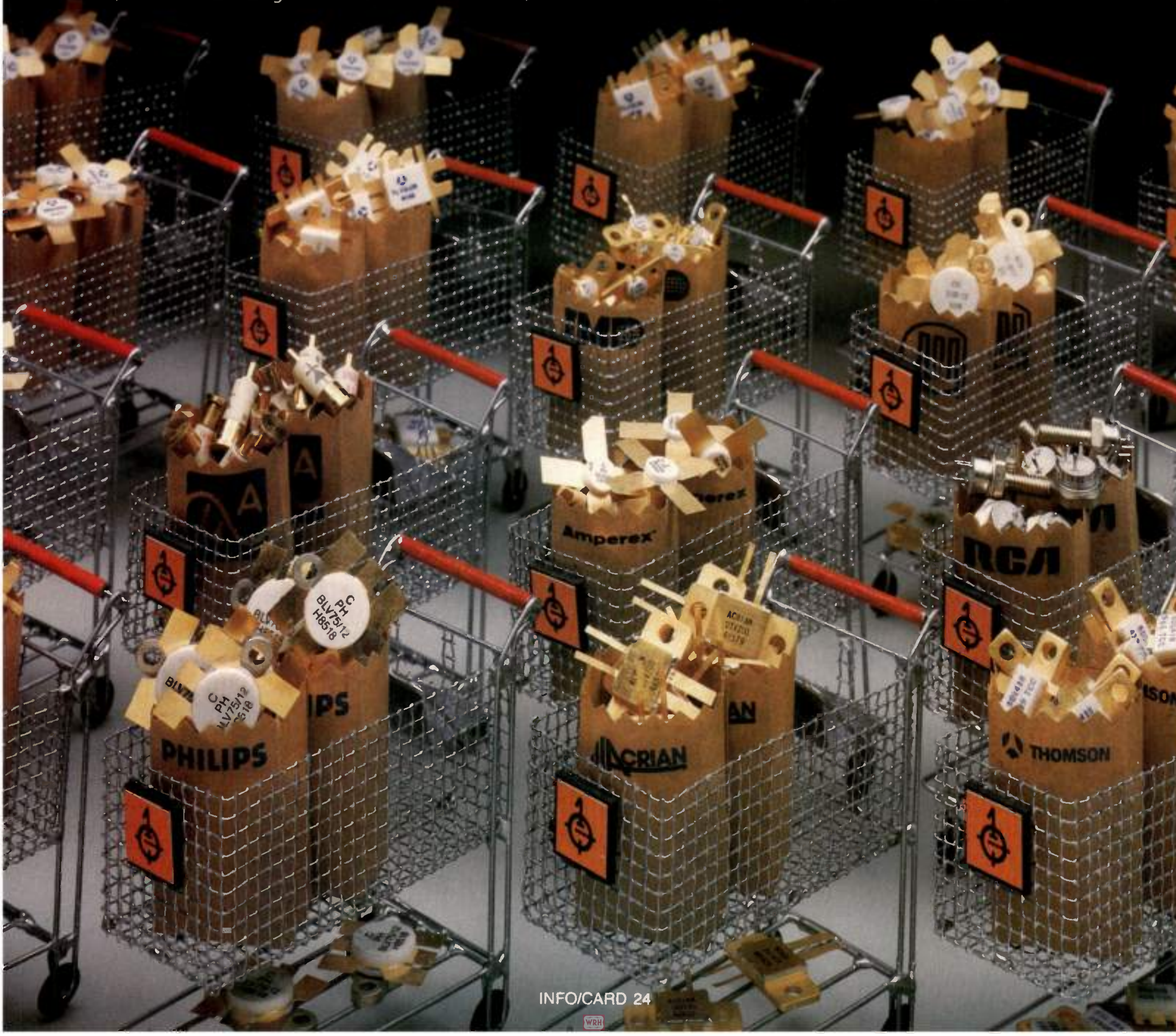

INFO/CARD 24


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Power Transistor Output Port Model

For analyzing A Switching-Mode RF Power Amplifier or Resonant Power Converter.

By Nathan O. Sokal and Richard Redl
Design Automation, Inc.

To derive accurate equations for switching-mode RF power amplifiers, the engineer needs a model for the output port of the switching power transistor. This article gives a model for field effect and bipolar junction transistors (FETs and BJTs) which yields accurate performance predictions. Also included are new figures of merit for power transistors and for power amplifiers and power converters, measured model parameters for a power MOSFET, and appraisals of the resulting transistor performance in an example switching-mode HF power amplifier.

Why *another* transistor model? Engineers can derive equations which predict accurately all of the following for high-frequency switching-mode RF power amplifiers (the power transistor acts as a switch at the carrier frequency) and resonant DC/DC power converters:

- RF or DC output power,
- DC input power,
- collector or drain efficiency, and
- power dissipation.

At present, the Class-E member of these families is the most thoroughly documented. The upper frequency limits, at the time of this writing, are about 3 GHz for RF power amplifiers and 50 MHz for DC-DC converters. The limits result from the electrical parameters of available economical power semiconductors.

However, to derive the equations, the engineer needs a model for the output port of the switching power transistor. The model must include the important electrical parameters, and be simple enough to include the model in deriving tractable equations.

Published models [1]-[3] are not appropriate for this purpose. Oxner [1] gives an accurate small-signal model of a silicon MOSFET. That model is excellent for computer simulation of the small-signal linear characteristics of a circuit with a specific set of component values, but it is not appropriate for our present purpose: deriving analytic expressions for the performance of a switching-mode power circuit. Other published models [2], [3] accommodate large-signal switching-mode operation, but all of the models in [1]-[3] are too complex for use in deriving tractable analytic expressions. They were all intended for use with computer programs which simulate circuit performance with specified sets of component values. Although such simulation is very useful, it does not take the place of equations which predict circuit performance in symbolic terms. The model given in this article applies to the output port of a BJT, usually silicon, a MOSFET, also usually silicon, and a metal-semiconductor FET (MESFET), now usually gallium arsenide.

This model is simple enough to produce tractable analytic expressions, and it yields accurate predictions of the performance of high-frequency switching-mode power circuits.

A similar model can be derived for the transistor input port, for analyzing operation of the input circuit and predicting input/ouput power gain. However, although BJTs, MOSFETs and MESFETs have the same output-port model, three different models of input port are necessary.

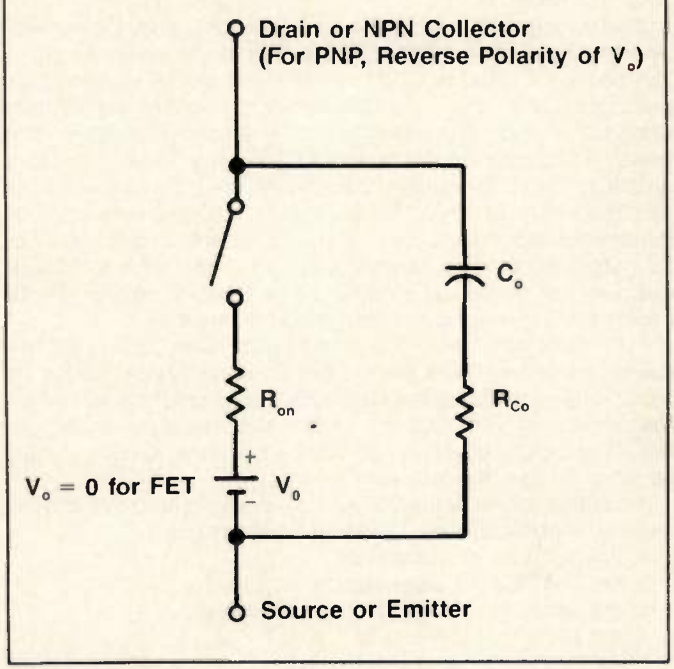

Figure 1.
Model for output port of switching transistor.

What is "High Frequency?"

In a low-frequency switching-mode power circuit, the effects of the transistor switching times and output capacitance are negligible. Then the "on" transistor can be modeled as a resistor, the "off" transistor can be modeled as an open circuit, and the transitions between those two states can be taken as instantaneous. But in a high-frequency switching-mode power circuit, the switching times and the output capacitance are important:

1. The switching times are usually appreciable fractions of the waveform period (e.g., up to 10 percent of the period). That can reduce the power efficiency substantially unless the circuit is designed to accommodate those switching times.

2. The output capacitance has important effects on the circuit operation:

a. The output capacitance comprises an appreciable part of the total capacitance to ground from the collector or drain. Therefore it affects the tuning and timing in resonant circuits.

b. Appreciable power is dissipated if the output capacitance

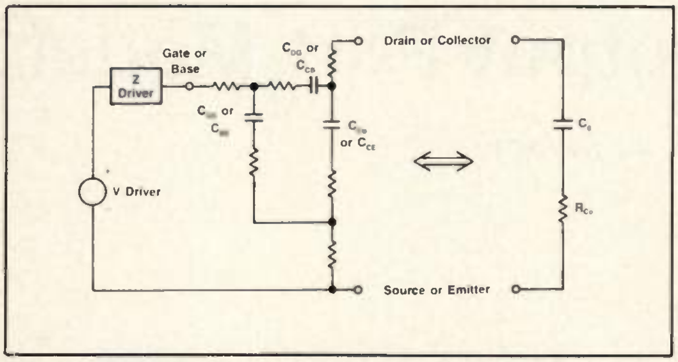

Figure 2. Complete equivalent circuit of "off"transistor.

is discharged to zero from a substantial voltage by the turned-on transistor, once or twice per cycle for single-ended or push-pull circuits: $C_oV^2f/2$ or C_oV^2f, respectively, where C_o is the output capacitance, V is the voltage change when the capacitor is discharged, and f is the switching frequency. For example, that power dissipation would be about 80 W for a 10-MHz voltage-switching Class D amplifier using a pair of IRF540 transistors operating from an 80-volt DC supply. An amplifier with a pair of those transistors would be designed to supply about 200 W of RF output. 80 W of power dissipation is too much, for a 200-watt switching-mode power amplifier. The Class-E circuit [4]-[10] avoids the capacitor-discharge power dissipation.

c. In many high-frequency circuits (e.g., Class E [4]-[10] and current-switching Class D), the output capacitance carries an appreciable fraction of the high-frequency output current when the transistor is "off." That can result in substantial power dissipation if the capacitance has appreciable series resistance. (It has, as we shall see subsequently.)

A suitable model of the output port of a switching power transistor in high-frequency operation must include:

a. the "on" switch resistance,
b. the "off" output capacitance,
c. the series resistance of that capacitance,
d. the switching times, and
e. the maximum current for which the model is valid (at higher currents, the transistor no longer acts like a switch: it leaves the voltage-saturated region of operation (low V_{ds} or V_{ce}), and enters the saturated-current region of operation (high V_{ds} or V_{ce}).

Model of Switching Transistor:

A. Approach to Modeling Switching Transistor

Figure 1 shows a model of the output port of a switching transistor. It is less detailed than the models of [1]-[3], but is simple enough to be included in analytical expressions, and it gives accurate predictions of the performance of high-frequency switching-mode power circuits. The switch models the two states of the transistor: "on" and "off." The other components model the transistor behavior in those two states; they will be discussed further insubsequent sections.

Because the model given here is less detailed than those of [1]-[3], the values of the parameters in Figure 1 are somewhat frequency-dependent; the reason is discussed further in Section D below.

B. "On" State — "On" Resistance

For both FETs and BJTs, the branch $C_o - R_{Co}$ usually can be ignored when the transistor is "on." That branch is discussed further in the sections dealing with the switch "off" state. Ignoring the $C_o - R_{Co}$ branch, a FET in the voltage-saturated "on" state can be characterized as a resistance R_{on}. R_{on} is almost always specified [as $R_{DS(on)}$] for power FETs intended for use in DC power supplies. As of February 1987, it is not specified for any RF power FETs. The engineer can measure R_{on} easily; but if it is not specified, there is no guarantee on its maximum value in production.

C. "On" State — BJT Saturation Offset Voltage

A BJT in the "on" state can be characterized as a resistance R_{on} in series with a saturation offset voltage V_o. V_o is shown in Figure 1 as a battery opposing the collector supply voltage (V_{cc}). R_{on} and V_o of a BJT are increasing functions of frequency, especially if the transistor is made "rugged" (resistant to second breakdown) by placing a high-resistivity layer on the collector side of the metallurgical collector-base junction. V_o is of the order of 0.1 V at low frequencies ($<f_T/100$) and can be as large as several volts at high frequencies ($>f_T/10$). Although R_{on} and V_o are important parameters of a BJT, they have not yet been well characterized as functions of frequency, base drive, and transistor manufacturing process. They are never specified in data sheets for bipolar RF power transistors. (Data sheets for RF power transistors sometimes specify the DC saturation voltage, but that has no relevance to operation at frequencies higher than a few hundred kHz.)

V_o "bucks" the supply voltage. The effect of V_o on efficiency and output power is accounted for exactly by subtracting V_o from the collector supply voltage: the efficiency and output power which would be obtained in the absence of V_o are multiplied by the factors $(1 - V_o/V_{cc})$ and $(1 - V_o/V_{cc})^2$, respectively.

D. "Off" State — Output Capacitance

1. *Elements of the model.* In the "off" state, the transistor is characterized primarily by its output capacitance (C_o), and secondarily by the parasitic resistance (R_{Co}) in series with that capacitance. Usually the gate or the base is held at a cutoff voltage by a low-impedance drive source. Then C_o and R_{Co} are a one-branch representation of the combination of three capacitors and their associated loss resistances shown in Figure

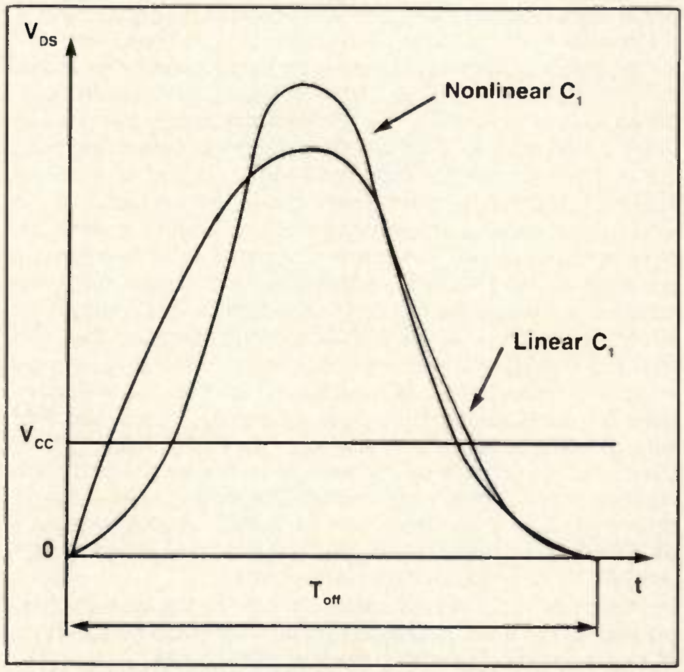

Figure 3. Switch-voltage waveforms in Class-E circuit with linear and nonlinear capacitors in parallel with switch.

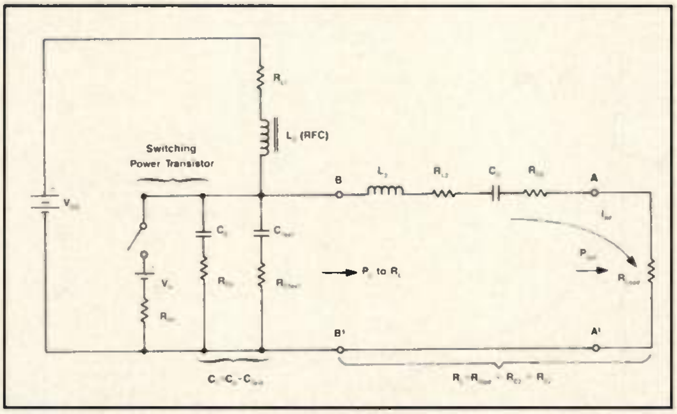

Figure 4. Class-E RF power amplifier.

2. Usually the output impedance of the drive source is low. Accordingly, the transistor output capacitance is usually specified as the value measured with the enhancement-mode FET gate (or the BJT base) shorted to the source (or the BJT emitter). For a depletion-mode FET, the gate is biased beyond pinch-off, by a low-impedance voltage source. Hence, the output capacitance of a grounded-source FET is approximately $C_{ds} + C_{dg}$. Usually that capacitance (or its two components) is specified on the transistor data sheet. For an enhancement-mode FET, the output capacitance is called C_{oss}. The output capacitance of a grounded-emitter BJT is approximately $C_{cb} + C_{ce}$. Usually C_{ce} is much smaller than C_{cb}. C_{cb} is specified on the transistor data sheet as C_{ob} or C_{obo}.

2. *Nonlinearity of output capacitance.* The transistor output capacitance is voltage-dependent,decreasing with increasing voltage. Figure 6 shows an example: C_{oss} vs. drain-source voltage for a 100-volt MOSFET, International Rectifier IRFD1Z0. To be able to derive tractable analytic expressions for predicting circuit performance, the engineer must replace that voltage-dependent capacitance by an "equivalent" fixed-value (linear) capacitance. The definition of "equivalent" depends on the application. For analyzing switching-mode RF power amplifiers such as the Class-E amplifier [4]-[6], "equivalent linear capacitance" can be taken to mean the linear capacitance which would result in the switch voltage returning to zero during the switch "off" interval at the same time as occurs with the actual nonlinear capacitor. (During that "off" interval, the capacitor is being charged and discharged by a current which is determined partially by the transistor output capacitance.) The peak voltage on the nonlinear capacitor will be larger than the peak voltage which would occur in the same circuit using a linear capacitance of the same "effective" value.

Because most analytical methods assume linear capacitors, the designer should expect the actual peak voltage to be somewhat larger than the calculated value. The difference will be up to about 20 percent, depending on what fraction of the total circuit capacitance is supplied by external linear capacitance.

3. *Capacitance multiplier effective during transistor-current fall time.* The transistor-current fall time usually occupies only the first 20 percent or less of the "off" portion of the cycle. In circuits which provide high efficiency at high switching frequencies, the voltage on the capacitance during the current fall time is much lower than it is during the remainder of the "off" portion of the cycle. With that much-lower voltage goes a much-larger capacitance, because of the voltage dependence of the output capacitance. Therefore the effective value of the nonlinear output capacitance during the current fall time is significantly larger than C_o, the value which is averaged over the entire "off" portion of the cycle. The result of having that larger capacitance is a substantial reduction of the transistor turn-off power dissipation. (The capacitance holds the transistor voltage low while the transistor current is falling; [5] gives a detailed explanation.) The larger effective capacitance during the turn-off transient is taken as cC_o, where c is a capacitance-multiplying factor.

4. *Estimated values of C_o and c.* Transistor manufacturers usually spedify the voltage-dependent C_{oss} or C_{ob} at 25 or 28 VDC. C_o is a weighted-average value of that voltage-dependent output capacitance, averaged over the range of voltage traversed during the "off" portion of the cycle. (That range of voltage is $\geqslant 0$ to $<BV_{DSS}$ or BV_{CEx}.) Analytical relations and test methods have not yet been published for determining C_o and c as functions of the voltage-dependent output capacitance, for use in analyzing tuned switching-mode power amplifiers, such as the Class-E amplifier. At present, the authors come close by estimating c as approximately 2, and the effective C_o for a 100-volt silicon MOSFET, over the voltage range of 0 to 80 V, as about equal to the value of C_{oss} at 25 V.

5. *R_{Co}: lossiness of output capacitance.* R_{Co} represents the lossiness of the combination of the three capacitors described above. At high frequencies, an appreciable part of the circuit capacitance from collector or drain to ground (e.g., C1 in the Class-E circuit [4]-[9]) is supplied by the transistor's C_o. In that case, an appreciable part of the high-frequency output current flows through C_o during the half-cycle when the transistor is "off." Then R_{Co} is important because the substantial high-frequency current flowing through C_o also flows through R_{Co}, where it can cause substantial i^2R_{Co} power dissipation.

The MOSFET models of [1] and [3] suggest that R_{Co} will be equal to or less than R_{on} at high frequencies. All silicon MOSFETs measured at 0.5 to 13 MHz by the authors have R_{Co} greater than R_{on}, by as much as an order of magnitude.

As of February 1987, R_{Co} is never specified by the transistor manufacturers, but it can be measured by the users. Further work is needed to develop meaningful measurement methods.

6. *Frequency dependence of parameters.* The R and C values of the one-lump approximation to the output capacitance and its loss resistances are frequency-dependent, because only one capacitor and one resistor are being used to model in one lump the combined effects of three capacitances and their associated six loss resistances. C_o and R_{Co} should be evaluated in the fre-

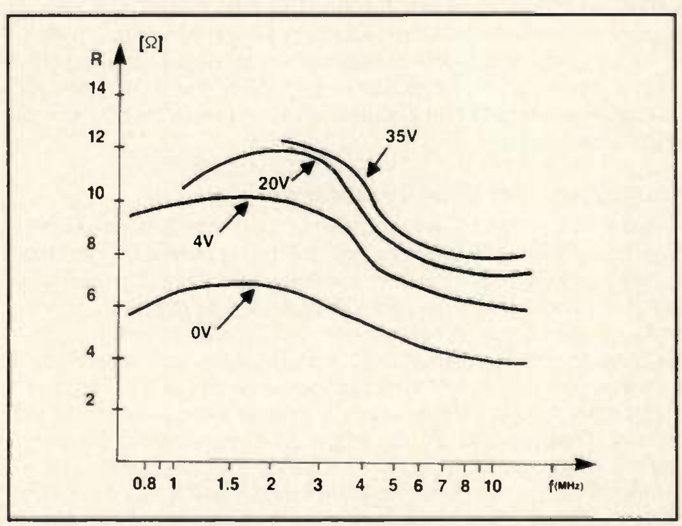

Figure 5. R_{Co} vs. frequency and V_{DS} for IRFD1Z0.

quency range of interest. For a tuned power amplifier or power converter (such as the Class-E circuit), that frequency range is from one to about three times the switching frequency. With that choice, the parameters will be characterized in the frequency range which contains the major components of the current flowing in C_o. Because the output capacitance is voltage-dependent, R_{Co} depends also on the capacitor voltage. The "equivalent" fixed-value (linear) resistance is one which results in the same power dissipation as with the actual voltage-dependent resistance, in a circuit which applies a voltage waveform to the capacitance similar to the waveform in the power circuit. In Section VI, we give experimental data on the variation of R_{Co} with frequency and drain-source voltage, for a 100-volt MOSFET.

E. Switching Times

The transistor power dissipation increases with increasing transistor switching times.

1. *Fall time,* t_f. When the transistor turns "off," the collector or drain current falls from 100 percent to 0 percent in a fall time t_f. For a BJT, that time is inversely proportional to $I_{B2}f_T$, where I_{B2} is the turnoff base current and f_T is the product of grounded-emitter current gain and frequency, in the region where current gain is inversely proportional to frequency (i.e., the extrapolated unity-gain frequency). f_T is a function of V_{ce} and I_c. The appropriate voltage and current for specifying or measuring f_T are those existing during the turnoff transient. f_T is much lower (e.g., by a factor of 20) at the few volts of "on" voltage in a switching circuit than it is at the 10-20 V at which f_T is usually specified. For a FET, t_f can be predicted from a knowledge of the driver output and the input capacitance of the FET. Knowing the value of tf, the engineer can derive an expression for the associated power dissipation, in terms of the circuit parameters.

2. *Rise time.* In most power converters, the collector or drain current is injected into the turning-on transistor by the external circuit. At high switching frequencies, the transistor turn-on time can be an appreciable fraction of a period of the switching frequency. If too high a current is injected into the transistor during the turn-on transient, the transistor voltage becomes high during that transient. In that case, the power dissipation during the turn-on transient can be substantial. In the Class-E circuit, the current injected into the transistor by the external circuit starts from zero and increases at a well-defined and limited rate. As a result, the transistor voltage remains low during the turn-on transient, and the power dissipation during the turn-on transient is usually negligible.

F. Maximum current, I_{max}

I_{max} is the maximum current for which the model is valid, with the particular input drive being provided (V_{gs} for a FET, or I_b for a BJT). At higher currents, the transistor no longer acts like a switch: it leaves the voltage-saturated region of operation (low V_{ds} or V_{ce}), and enters the saturated-current region of operation (high V_{ds} or V_{ce}). In that region of operation, the transistor can no longer be modeled as a switch, and the present model is not applicable.

Normalized Electrical Parameters

Power transistors usually come in families comprising various numbers of the same basic cell connected in parallel. The rated output power is proportional to the number of cells. The normalized electrical parameters are the same for all members of the family. C_o (the equivalent linearized output capacitance) is proportional to the number of cells, and R_{on} (the "on" resistance) is inversely proportional to the number of cells; but their product is a normalized parameter which is independent of the number of cells. That product, $R_{on}C_o$, is the time constant at the transistor output port. It is a fundamental parameter which characterizes the entire family of transistors which use the same basic cell. For Class-E circuits, and probably for most other high-frequency switching-mode power circuits, $R_{on}C_o$ is the

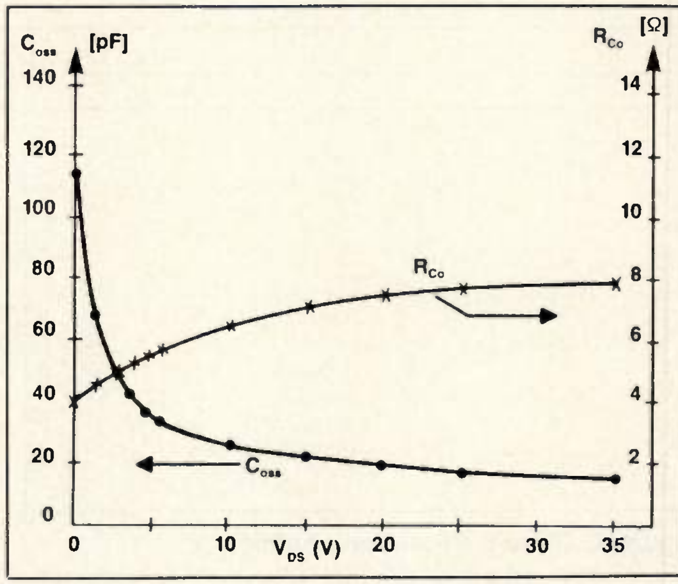

Figure 6. R_{Co} and C_{oss} vs. V_{DS} t 13 MHz, IRFD1Z0.

most important factor determining the achievable drain or collector efficiency at high frequency, and the associated transistor power dissipation. The second important factor is the time constant of the output capacitance: $R_{Co}C_o$. It characterizes the high-frequency loss characteristic of the output capacitance. In the section evaluating circuit performance, we give quantitative information on the relationship between those time constants and the corresponding components of transistor power dissipation.

The output-port time constants $R_{on}C_o$ and $R_{Co}C_o$ are such basic figures of merit for switching-mode power transistors used at high frequencies that they deserve special symbols: τ_o and τ_{Co}. (Similarly, the input port is characterized by the parameter $\tau_i = R_{on}C_i$, where C_i is the weighted-average value of the FET input capacitance C_{iss} or the BJT input capacitance C_{ies}. τ_i determines the required input-drive power and the input-output power gain. Those relationships are the subject of an intended future publication.)

The authors encourage manufacturers of high-frequency power transistors to publish and specify τ_o and τ_{Co} for their transistors. As of February, only the vendors of transistors for swithing-mode DC power supplies publish the parameters from which the user can derive τ_o, and no vendors publish information on R_{Co}.

Criteria for Evaluating Circuit Performance

A. Efficiency and Power Dissipation

For high-efficiency power amplifiers or power converters, it s meaningful to evaluate both the efficiency and the power dissipation.

Efficiency (η) is relevant when considering the input power needed to obtain a specified output power:

$$P_{in} = \frac{P_{out}}{\eta} \tag{1}$$

Efficiency is important when the available input power is limited. Examples are battery-powered portable equipment, or ground-mobile or airborne equipment supplied by a generator which has little reserve capacity. Efficiency is important also for high-power equipment: over the equipment's operating life, the cost of the electric power for the equipment and its associated motors for refrigerant compressors and/or air blowers can be substantial, compared with the purchase and maintenance costs of the equipment.

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Power dissipation is important when considering thermal factors, which relate directly to the equipment size and weight (heat sink), and reliability (transistor junction temperature). A power amplifier or power converter usually is designed for a specified output power. Hence a meaningful criterion for comparing different design approaches (all yielding the same output power) is the fractional power dissipation: the power dissipation as a fraction of the output power: P_{diss}/P_{out}. The relationship between fractional power dissipation and efficiency is:

$$\eta = \frac{1}{1 + P_{diss}/P_{out}} \tag{2}$$

B. Importance of a Seemingly "Small" Increase of Efficiency

In a high-efficiency power equipment (η near 1.0), increasing the efficiency by only a few percentage points reduces the fractional power dissipation by a large factor. That can result in large reductions in equipment size and weight, and/or a large decrease of failure rate (increase of MTBF). The large effect of efficiency on fractional power dissipation can be seen from the mathematical relationship between them:

$$\frac{P_{diss}}{P_{out}} = \frac{P_{in} - P_{out}}{P_{out}} = \frac{1}{\eta} - 1 \tag{3}$$

For example, if the efficiency is 80 percent, increasing the efficiency by only nine percentage points (from 0.80 to 0.89) reduces the fractional power dissipation by a factor of 2.0 (from 0.250 to 0.124). If the designer chooses to maintain the same temperature rise, the heat-sink's surface area is reduced by a factor of 2.0,and the volume and weight are reduced by a factor of 2.8. Alternatively, if the designer retains the original heat sink, the temperature rise is reduced by a factor of 2.0. If the original temperature rise has been 130C above a 50C ambient (T_J = 180C), T_J will be reduced to 115 C (a 65C rise above the 50C ambient). Reducing T_J from 180C to 115C will reduce the failure rate (increase the MTBF) of a silicon bipolar junction RF power transistor by a factor of approximately 14 [4]. Comparable increases of MTBF apply to other types of transistors.

C. Need for Transistor Figures of Merit

The transistor power dissipation is usually the major contributor to P_{diss} in a well-designed switching-mode power amplifier. Usually, most of that is in R_{on} and R_{Co}. Those two components of power dissipation can be assessed quantitatively, a priori, as functions of the switching frequency and the transistor parameters R_o, R_{Co}, and C_o (hence τ_o and τ_{Co}). Then circuit designers can design their circuits with full knowledge of all of the components of power dissipation, and transistor designers can use explicit quantitative trade-off criteria for choosing the transistor design parameters which affect R_{on}, R_{Co}, and C_o.

D. Example Application of Transistor Figures of Merit

For an example application of the transistor figures of merit, we use the Class-E RF power amplifier shown in Figure 4, for which extensive analytical results are already available.

1. *Frequency ranges.* Recall that low frequencies are frequencies at which the transistor switching times and output capacitance do not have important effects on circuit performance, and that high frequencies are frequencies at which those effects are important. For explaining the application of the transistor figures of merit to the Class-E circuit at high frequencies, we subdivide the high-frequency range into two sub-ranges: "lower-high" frequencies and "upper-high" frequencies.

The "lower-high" frequency range is the range in which C_1 is larger than C_o and the designer adds external capacitance in parallel with C_o. In this frequency range, the designer is free to choose the output power (P_{out}) and the corresponding value of C_1 for delivering that value of output power at the chosen switching frequency (f). (This frequency range includes also the low-frequency range, and the equations to be given below are applicable at low frequencies, too. But there would be no reason to use a Class-E circuit at low frequencies; at low frequencies, Class-D circuits are superior.)

In the "upper-high" frequency range, C_o is larger than the value of C_1 required in the published circuit, and the nominal Class-E waveform cannot be generated with the published circuit. Then the published analyses are not applicable. Other (unpublished) circuits and design procedures must be used. (The authors use an in-house computer program which simulates and optimizes high-frequency Class-E circuits. Simulation of the voltage and current waveforms of a complete cycle of the steady-state circuit operation takes only 2 seconds on an IBM PC, and about ½ second on an AT.) "Borderline frequencies" are frequencies on the borderline between "lower-high" and "upper-high" frequencies, i.e., they are the upper limit of the frequency region in which the published circuit analyses are applicable. At borderline frequencies, C_o supplies all of the needed C_1, no external capacitance is added in parallel with C_o, the circuit operates with the nominal Class-E waveform, and the published analyses apply. At borderline frequencies, C_1 is pre-determined as the value of C_o supplied by the transistor; and P_{out} is pre-determined by the existing C_1, the chosen switching frequency (f), and the chosen DC supply voltage (V_{cc}), as given in (8).

2. *Components of power dissipation.* The transistor power dissipation in R_{on} and in R_{Co} can be quantified as shown in (4) and (5) below for operation at lower-high frequencies, and in (6) and (7) for operation at borderline frequencies.

$$\left[\frac{P_{Ron}}{P_{out}}\right]_{1-h} = \frac{2.367\ R_{on}\ P_{out}/\eta}{(V_{CC} - V_o)^2} \qquad (4)$$

$$\left[\frac{PR_{Co}}{P_{out}}\right]_{1-h} = \frac{(2\pi f\ \tau C_o)\ (2\pi\ fC_o)\ (V_{CC} - V_o)^2}{\eta_{L2,C2} P_{out}/\eta}\ 3.6207 \qquad (5)$$

In (5), $2\pi f\ \tau_{Co}$ is the loss tangent of the capacitor C_o at the frequency f.

$$\left[\frac{PR_{on}}{P_{out}}\right]_{b-f} = \frac{46.72\ \tau_o f}{\eta_{L2,C2}} \qquad (6)$$

$$\left[\frac{PR_{Co}}{P_{out}}\right]_{b-f} = \frac{7.241\ \tau_{Co} f}{\eta_{L2,C2}} \qquad (7)$$

$$P_{out(b-f)} = 2\pi^2 f\ C_o\ (V_{CC} - V_o)^2 \eta \qquad (8)$$

In (4)-(8), the subscripts l-h and b-f indicate lower-high frequency and borderline-frequency, respectively; η is the circuit efficiency due to all causes of power dissipation other than the V_o of a BJT (recall that V_o is zero for a FET); and $\eta_{L2,C2}$ is the circuit efficiency in transferring power through L_2 and C_2 (including their parasitic series resistances R_{L2} and R_{C2}) from Port B-B' to Port A-A' of Figure 4:

$$\eta_{L2,\ C2} = 1 - \left[\frac{Q_L}{Q_{uL2}} + \frac{Q_L}{Q_{uC2}} \times \frac{Q_L - 1.7879}{Q_L - 0.678}\right] \qquad (9)$$

In (9), Q_L is the loaded Q of the load network at the switching frequency f: approximately $2\pi f L_2/R_L$; and Q_{uL2} and Q_{uC2} are the quality factors (X/R) at frequency f of L_2 and C_2.

Interpretation of (4) Through (8)

1. In lower-high frequency operation, the fractional power dissipation in R_{on} is proportional to R_{on} and the output power.

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2. In lower-high frequency operation, the fractional power dissipation in R_{Co} is:

- proportional to the loss tangent of C_o at the switching frequency,
- proportional to the switching frequency, because with increasing frequency, C_o comprises an increasing portion of the total C_1; hence an increasing fraction of the total output current I_{RF} flows in C_o and R_{Co}; and
- inversely proportional to output power, because with increasing output power, an increasing portion of C_1 is made up of external capacitance, decreasing the fraction of I_{RF} which flows in C_o and R_{Co}.

3. In borderline-frequency operation, the fractional power dissipation:

- in R_{on} is proportional to the product of frequency and the transistor parameter τ_o, and
- in C_o is proportional to the product of frequency and the transistor parameter τ_{Co}.

For example, using a 100-volt International Rectifier HEXFET(R) at 25 MHz, with all of C_1 supplied by the transistor C_o, the power dissipation in R_{Co} would be about 62 percent as large as the power dissipation in $R_{DS(on)}$. Conclusion: The power dissipation in R_{Co}, ignored until now, is important when operating at frequencies high enough that half or more of the capacitance C_1 is being supplied by the transistor output capacitance. Transistor designers should take account of this fact when they choose the design parameters to optimize the transistor design.

Equations comparable to (4)-(9) for the Class-E circuit could be derived for other high-frequency power circuits.

Transistor Experimental Data

Initially, we tested two members of the International Rectifier 100-volt family of MOSFETs: the IRFD1Z0 and the IRF510. The two transistors are different numbers of the same basic cell connected in parallel; the ratio of their numbers of cells is 4:1. The IRFD1Z0 is the smallest member of the family, with "typical" $R_{DS(on)}$ given in the I_R data sheet as 2.2 ohms (we measured 1.75 ohms, 80 percent of the published "typical" value). We chose the smallest member of the family for further testing because its relatively high impedances are easier to measure accurately than are the lower impedances of the larger members of the family, such as the IRF510 (typically 0.5 ohms) through IRF540 (typically 0.07 ohms).

We measured the small-signal values of R_{Co} and C_{oss} as functions of frequency and V_{DSS}, using a Hewlett-Packard 4192A Low-Frequency Impedance Analyzer, at a test voltage of 60 mV rms. The measured values depended noticeably on the test-signal level; 60 mV was the lowest level at which we could obtain reliable measurements.

Figure 5 shows the measured R_{Co} vs. frequency and voltage. The measured value of R_{Co} varies by about ±50 percent for measurement frequencies in the range of 0.7 to 13 MHz and drain-source voltages in the range of zero to 35 V. The variation would be smaller over a smaller frequency range. Fig. 6 shows R_{Co} and C_{oss} vs. V_{ds} at 13 MHz. C_{oss} vs. V_{ds} is about the same as shown in IR's published data. R_{Co} at 13 MHz varies by ±34 percent over the voltage range of 0 to 35 Vdc. The variation of R_{Co} with frequency and V_{ds} is small enough for making satisfactory predictions of circuit performance.

Eventually, we shall measure directly the large-signal value of R_{Co}.

Conclusions

1. The power dissipation in R_{Co} is important in high-frequency switching-mode power circuits, when the transistor output capacitance comprises half or more of the capacitance across the switch.

2. The efficiency achievable with a given transistor family, at frequencies near the upper limit of practical operation, can be characterized by two new figures of merit: τ_o and τ_{RCo}.

3. The proposed model is simple enough to be used in quantitative analyses of the operation of high-frequency switching-mode power circuits. (Some of the analytical results for the Class-E circuit, obtained using that transistor model, were given here as examples of the use of the new transistor figures of merit).

4. The transistor-model parameters can be measured easily.

5. The variations of the model parameter values with frequency and voltage are low enough that engineers can make satisfactory practical predictions of circuit operation. Certainly those predictions are much more accurate than the results which would be obtained by not using the model: an explicit value of zero for the power dissipation in R_{Co}.

Acknowledgements

The authors thank their colleague, Antal Banfalvi, for deriving the expression for power dissipation in R_{Co} in a Class-E circuit, while Banfalvi was at Design Automation, Inc., on leave from the Technical University of Budapest, Hungary. They thank Brian Pelly of International Rectifier for information about the relative sizes of IR's IRFD1Z0 transistor.

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Microstrip Low Pass Filter Design

By Alan Tam
Space and Communications Group
Hughes Aircraft Company

There are some important reasons why microstrip design becomes more attractive than its conventional lumped element counterpart. The major advantages are lower loss, lower cost, higher reliability and superior consistency in electrical performance. The main drawback of using discrete components is the limited self resonating frequency and the quality factor Q. The Q can degrade the electrical performance of a filter drastically.

The objective of this article is to design a reasonably low cost high performance low pass filter to the following criteria:

Cutoff frequency: 2.0 GHz
Insertion loss: 2 dB max
Passband ripples: 0.5 dB max
Stopband attenuation at 1.5 times the cutoff frequency: 40 dB min
Input and output return loss: ⩽ −12 dB
Input and output impedance: 50 ohms

A 31 mil thick teflon fiberglass circuit board has relatively low dielectric constant (ε_r =2.55) and reasonably good thermal characteristics. The highest recommended frequency is 4 GHz. Since the material is soft, it can be easily cut to the required size. The physical handling of this material is fairly straightforward when compared to the alumina substrate. With good manufacturing processes the dielectric constant of the teflon fiberglass board can be controlled to within 0.5 percent.

Filter Selection

The Chebyshev filter has a high Q making it ideal for applications where a steep rolloff characteristic is required at the stopband and a flat response is not desired at the passband. In order to achieve an attenuation of better than 40 dB, a seven-element filter is needed. This can be seen in Figure 1. f/f_c is 3 GHz/2 GHz for the horizontal scale.

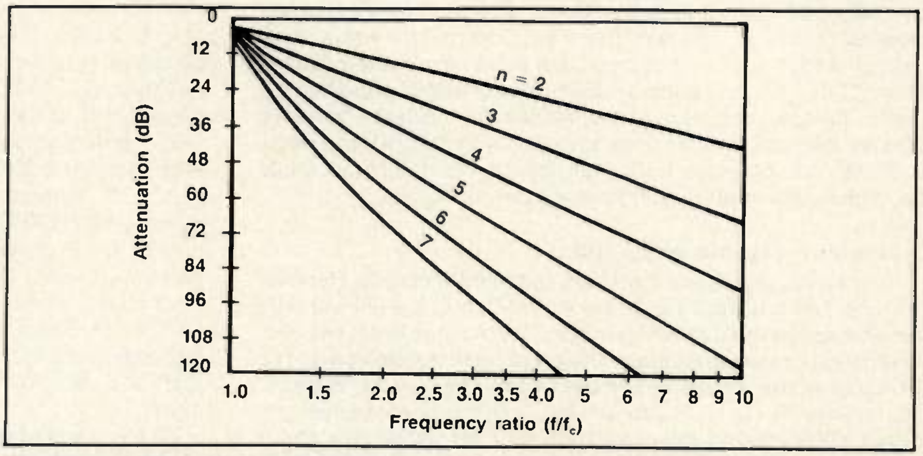

Figure 1. Attenuation characteristics for a Chebyshev filter with 0.5 dB ripple.

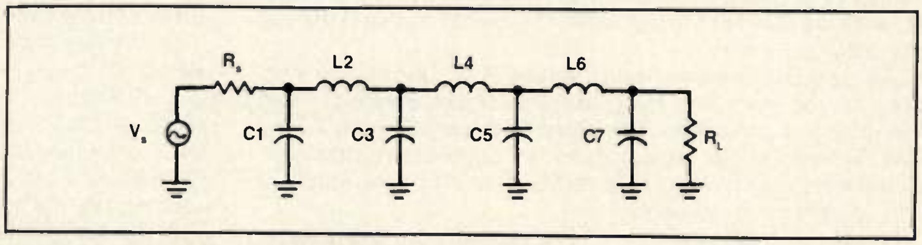

Figure 2. Chebyshev low pass filter model.

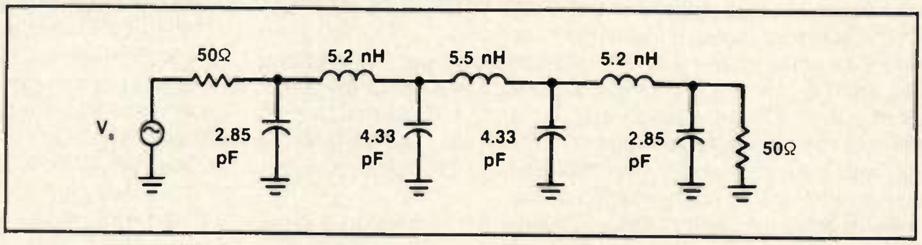

Figure 3. Discrete component values for the model.

Frequency and Impedance Scaling

The models of a 7 element Chebyshev low pass filter is shown in Figure 2. The cutoff frequency (f_c) is 2 GHz. The source and load impedance are both 50 ohms. Normalized values for R_s and R_1 are 1 ohm. The normalized impedances for the inductors and capacitors are transformed by the following formulas:

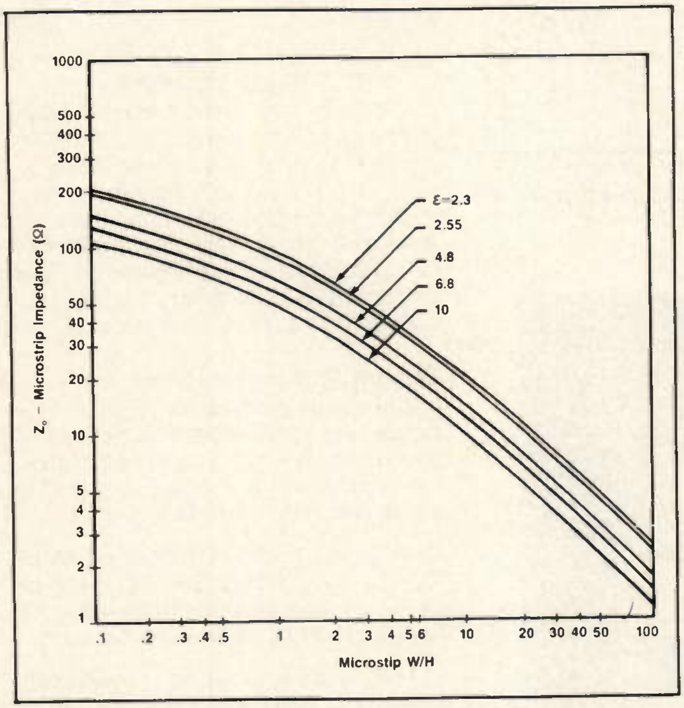

Figure 4. Microstrip impedance vs. W/H

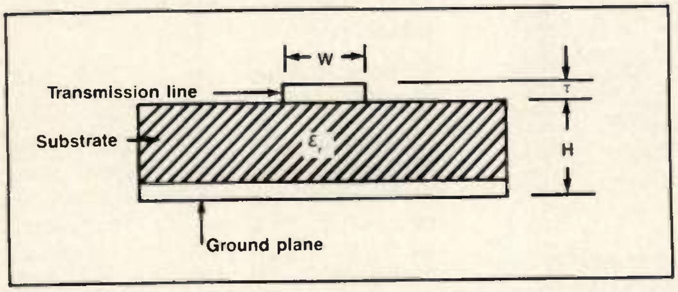

Figure 5. Physical structure of microstrip on circuit board

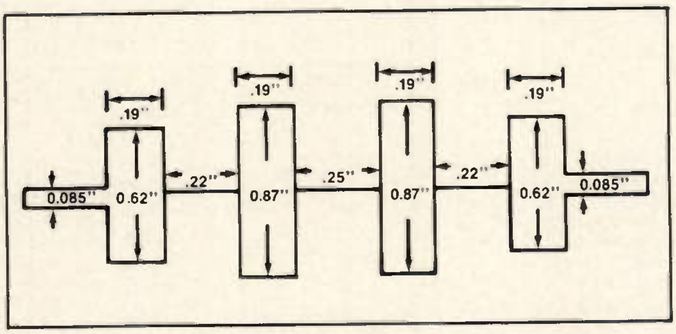

Figure 6. The final theoretical microstrip filter.

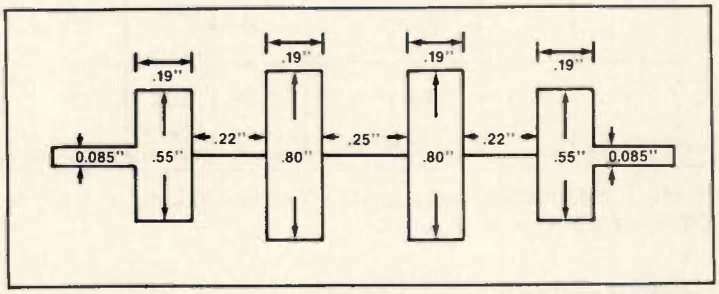

Figure 7. final dimensions for filter after optimization.

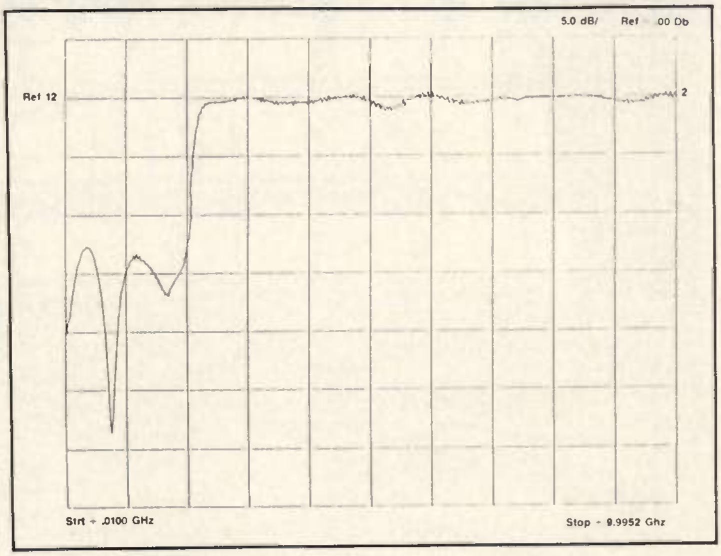

Figure 8. A plot of S_{11}/S_{22}.

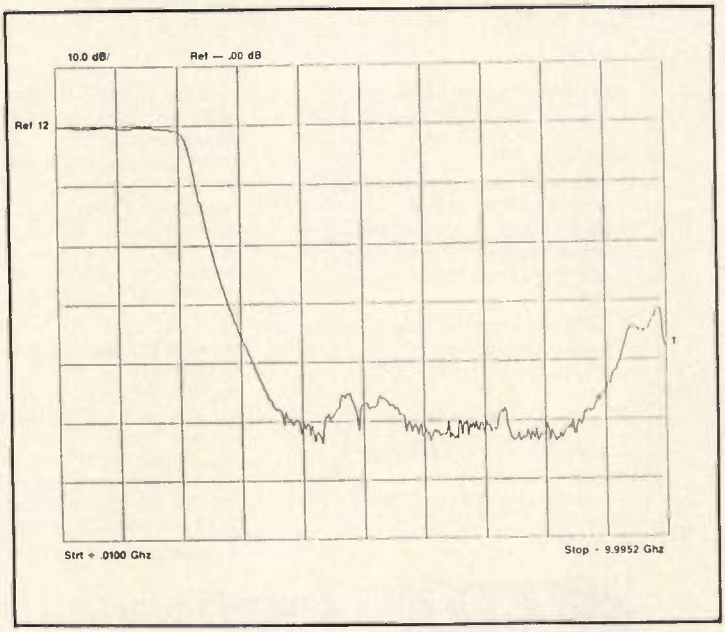

Figure 9. A plot of S_{21}

N	C1'	L2'	C3'	L4'	C5'	L6'	C7'	R_s/R_l
7	1.79	1.30	2.72	1.39	2.72	1.39	1.30	1.0

Table 1. Normalized values for a 7 element Chebyshev low pass filter with 0.5 dB ripple.

$C = C_n/(2\pi f_c R)$ (1)

$L = L_n R/(2\pi f_c)$ (2)

where C = final capacitor value
L = final inductor value
C_n = normalized capacitor value
L_n = normalized inductor value
R = final load resistor value
f_c = final cutoff frequency

The normalized values for a seven-element Chebyshev low pass filter with a 0.5 dB passband ripple is shown in Table 1. Note that the values for C_1' and C_7', C_3' and C_5', and L_2' and L_6' are equal.

Design Implementation

The design process is simplified if the lumped element components for the filter are calculated first. This is done by substituting values in equation 1 and 2. The solution is shown below.

$C_1 = C_7 = 1.79/(2\pi(2\text{ GHz})50) = 2.85\text{ pF}$
$C_3 = C_5 = 2.718/(2\pi(2\text{ GHz})50) = 4.33\text{ pF}$
$L_2 = L_6 = 50(1.30)/(2\pi(2\text{ GHz}) = 5.2\text{ nH}$
$L_4 = 50\,(1.39)/(2\pi(2\text{ GHz})) = 5.5\text{ nH}$

The finalized discrete component values and complete circuit diagram is shown in Figure 3. Before the lumped components are converted to distributed elements, the electrical wavelength of the teflon fiberglass circuit board must be calculated.

$\lambda_g = 3 \times 10^{10}\text{cm}/(\sqrt{\varepsilon_r}\, f)$ (3)
$= 4.0"$

Since C_1, C_3, C_5 and C_7 will be transformed into double sided open stubs on the circuit board, a characteristic impedance (Z_o) of 30 ohms is recommended for this application. The capacitive reactance X_c is calculated by using equation 4.

l (length)	L (inductance)
.100"	1.9nH
.125"	2.5nH
.150"	3.2nH
.175"	3.9nH
.200"	4.6nH
.225"	5.3nH
.250"	6.0nH
.275"	6.7nH
.300"	7.4nH

Table 2. Inductance values for different wire lengths.

$$X_c = \frac{1}{2\,\pi C f} \quad (4)$$

The following steps aid in the calculation of the microstrip lengths.

$$2X_c = -jZ_o \operatorname{Cot} \Theta \quad (5)$$
$$\Theta = \operatorname{arc\,Cot} (2X_c/Z_o) \quad (6)$$
$$\Theta = 2\pi l/\lambda_g \quad (7)$$
$$L = 2l \quad (8)$$

Inserting C_1=2.85 pF in equation yields X_c = 28 ohms. Θ is calculated to be 28.2 degrees in equation 6. Using equation 7 and 8; l = .31" and L = .62" is obtained. Note that in equation 7, 360 degrees is substituted for 2π. Solving for C_3 = 4.33 pF, L = .87". The microstrip length, L, is preferably set to be less than one quarter of the wavelength for practical purposes.

For inductors:

$$L = 0.005081(2.303 \log(4l/d)-1)\ \text{uH} \quad (9)$$

where, l = the desired length of a straight round conductor
d = the diameter of a straight round connector

Note that a AWG #40 is used in this case because of the small inductance needed and the size constraint of the circuit board. The diameter of the AWG #40 enamel wire is 0.0034". Table 2 is derived for wire lengths ranging from 0.1" to 0.3" with 25 mil increments by substituting values in equation 9. From here the lengths of L_2 and L_6 (5.2 nH) are 0.22" and L_4 (5.5 nH) is 0.25".

The effective width of the open stub is determined from Figure 4. Since Z_o is 30 ohms and ε_r is 2.55, the W/H ratio is 6. Figure 5 is an illustration of the physical relationship between W (width) and H (height) of a microstrip on a circuit board/substrate with different dielectric constant. Since the height of the teflon fiberglass board is 31 mils, the width of the double sided open stub should be 6 times 31 mils which is 190 mils. Likewise, the 50 ohm transmission line width should be 85 mils. Figure 6 is an illustration of the microstrip Chebyshev low pass filter.

Conclusion

The filter was tested and optimized. The final dimensions for the distributed elements are shown in Figure 7. Figures 8 and 9 are the actual measurements done on the HP 8756A Scalar Network Analyzer. Note that the filter performs closely to the specifications. The same design technique can be used for higher frequency LPFs if the circuit board or substrate material is changed to either duroid or alumina.

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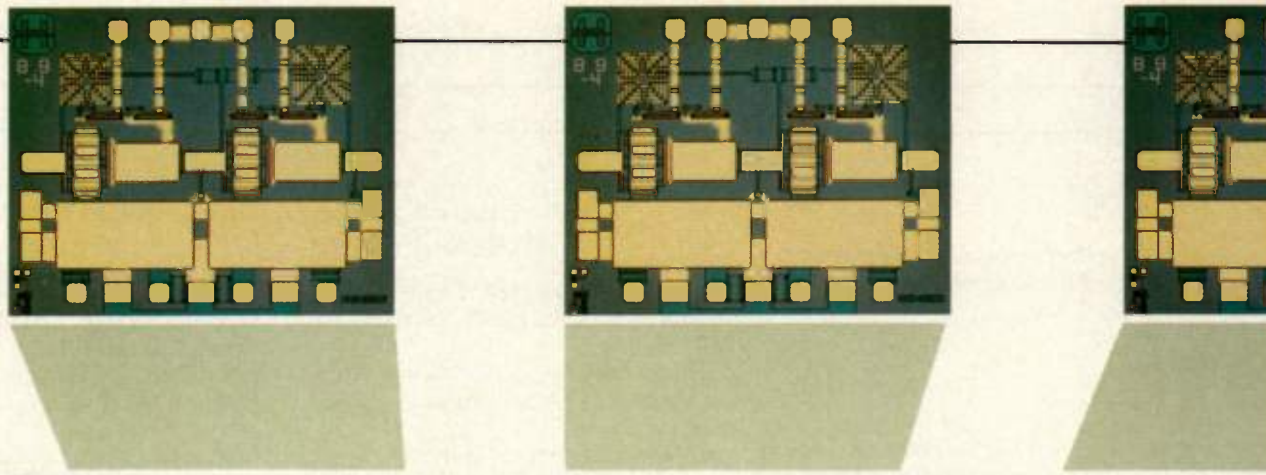

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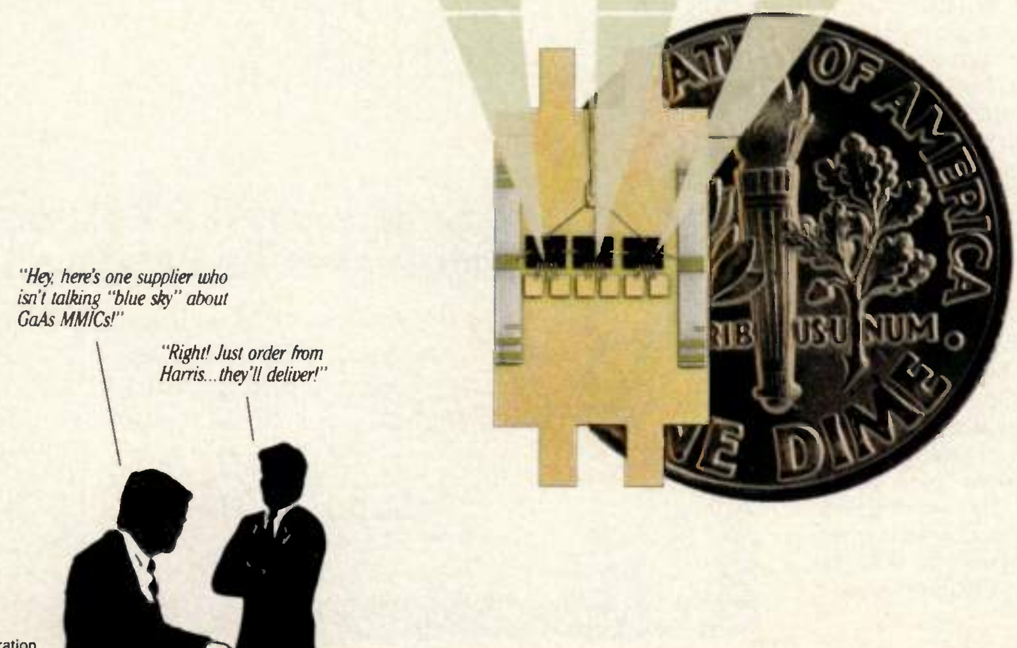

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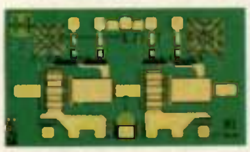

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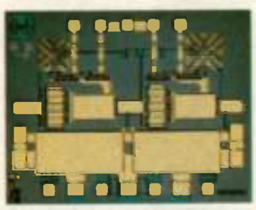

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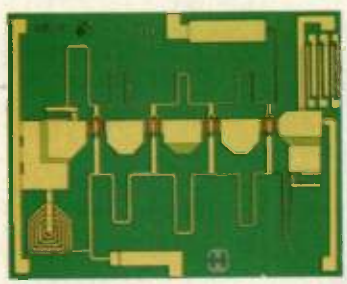

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MIL-STD 461B/C Test Requirements and Comparison

Part II: MIL-STD 461C Requirements and MIL-STD 462 Test Methods

By Mike Howard
Norand Corporation, EMC Test Lab

MIL-STD 461C became effective along with notice 5 of MIL-STD 462 on August 4,1986. Several changes have taken place in MIL-STD 461C over MIL-STD 461B particularly the addition of EMP (electromagnetic pulse) test requirements as listed in Part 1 of MIL-STD 461C. These modifications have superseded or been added to MIL-STD 461B in 461C for both emission and susceptibility testing. Details of all methods & procedures required to fulfill specifications of 461C are called out in MIL-STD 462. Notice 5 (Navy) of MIL-STD 462 includes test methods required for EMP testing for 461C.

The purpose of this article is not to detail every change in 461C over 461B, but to highlight specific changes and to detail the new test requirements for EMP. In part 1 of 461C three new test methods for EMP have been added. They are:

CS10 — Conducted susceptibility, damped sinusoidal transients injected on connector & cable pins.

CS11 — conducted susceptibility, damped sinusoidal transients injected directly into cable assemblies.

RS05 — radiated susceptibility, electromagnetic field transients.

Part 1 also provides an improved definition of items listed within the specification such as in paragraph 3.3 which defines the difference between control and signal leads. Technical requirements for filtering (Navy only) have been established in Part 1 in that the maximum line-to-ground capacitance values are to be 0.1 uF for 60 Hz and 0.02 uF for 400 Hz equipment. This applies for all filtering used for EMI control in the equipment under evaluation.

Part 2 will serve as an overall indicator of the type of changes reflected in Parts 3 through 10 of 461C as compared to 461B. In Part 2, CE01 test limits have been left unchanged. The applicability of this requirement has been expanded to include Navy equipment and subsystems intended for use on aircraft which have very low frequency (VLF) subsystems and equipment. For CE03 tests, the narrowband limit has been relaxed by 10 dB for class A1e equipment procured for Navy or Air Force use. The broadband limit has also been revised for Navy and Air Force equipment. For CE06 the requirements are the same as 461B, with the exception of the suppression limit for the 2nd and 3rd harmonics at the antenna port being suppressed by 50 + log P. In 461B the requirement was 40 + 10 log P.

The requirements for CE07 are the same, but if transients are found to exceed 50 usec then the equipment must also meet the requirements of MIL-STD 704. Limits for CS01 have been revised over 461B. The limit at 50 kHz has been set at 1 V (rms) and the limit between 30 Hz to 1.5 Hz now has a minimum of 1 V (rms). This actually represents a relaxation in the limit as compared to 461B. CS06 pulse width tolerances of 20 percent have been added in 461C. RE01 has been expanded to include Navy equipment intended for use on aircraft having very low frequency (VLF) equipment. The limit for RE01 has been revised and the limit relaxed from 500 Hz to 50 kHz. RE02 remains the same with improved chart definitions to select limits for Army, Navy and Air Force.

For RE03, the same changes that took place for CE06 for harmonic suppression are in effect. For RS02 no changes have taken place other than the addition of pulse width tolerances of ±20%. For RS03 the field strength levels have been increased from 10 & 5 V/m to 20 V/m from 2 MHz to 10 GHz.

Miscellaneous changes worth describing are as follows:

- A new category A2d has been established for Part 3 of 461C
- RS03 in Part 5 has a new category added for susceptibility tests of equipments with non-metallic hulls.

Parts 3 through 10 of 461C have similar changes as listed herein for Part 2. Parts 2 through 10 of 461C, as in 461B, outline the requirements for various classes of equipment for Army, Navy and Air Force procurement activities. The basic cifferences between sections 2 through 7 relate to specification limits, with each service branch defining limits as they apply to their individual requirements.

Parts 8 through 10 outline requirements for tactical and special purpose vehicles, engine driven equipment, uninterruptable power sets, mobile electric power equipment and commercial equipment. Requirements for these sections are covered by Unique Methods (i.e., UM03, UM04, and UM05). In 462C, UM03 has been expanded to include radiated narrowband limits as well as broadband limits. UM04 remains unchanged. UM05 has been expanded to include narrowband radiated emissions limits and a radiated susceptibility requirement between 0.15 to 400 MHz of 10 V/m.

MIL-STD 462:

This standard establishes techniques to be used for the measurement and determination of the electromagnetic interference characteristics (emission and susceptibility) of electrical, electronic, and electro-mechanical equipment, as required by MIL-STD 461C. Specific changes to MIL-STD 462 relating to these test methods or specific test requirements of the procuring agency (i.e. Army, Navy, etc.) are in the form of notes or notices that supersede current 462 requirements and are revised accordingly.

To get a better understanding of these test requirements, we will now look at the following test methods as they pertain to Part 2 of MIL-STD 461C which deals with

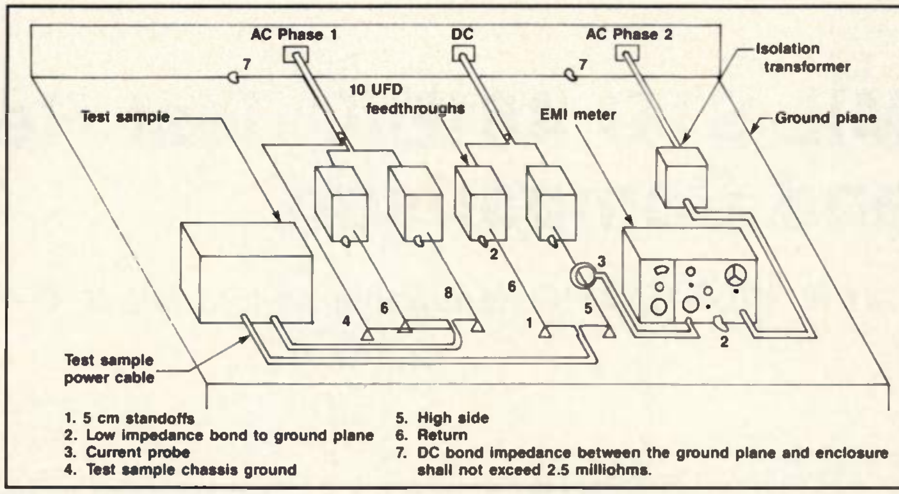

Figure 1. Typical current probe test setup for conducted emission measurements on power leads.

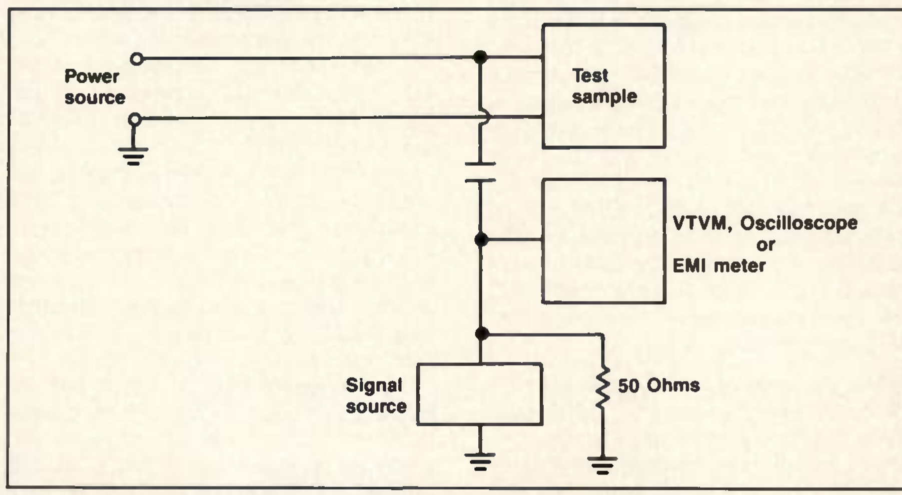

Figure 2. Conducted susceptibility 50 kHz to 400 MHz.

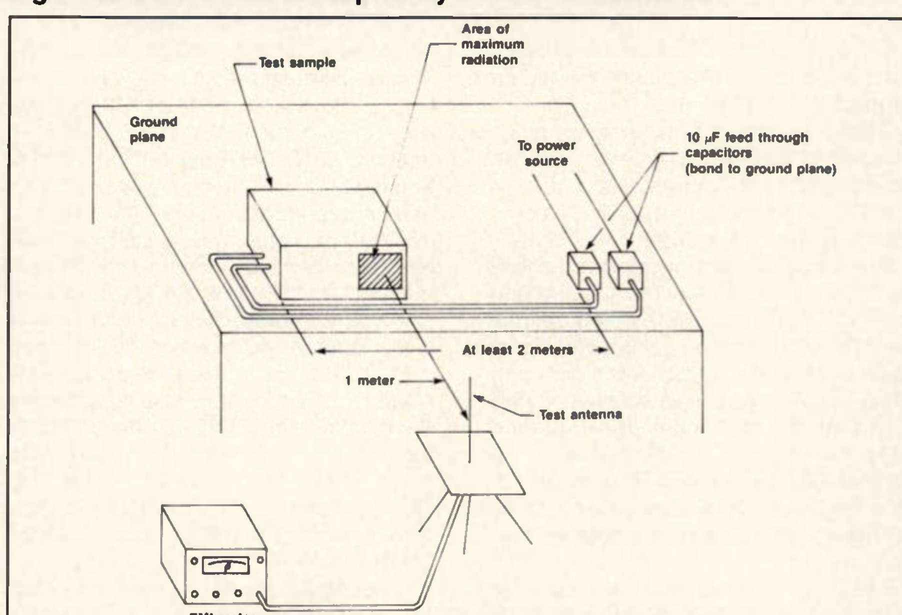

Figure 3. Typical test setup for radiated measurements.

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Class A1 equipment (i.e. aircraft equipment and subsystems). The following test methods have been selected for review here since they reflect some of the more commonly required test methods for procurement activities. They are:

CE03 — Conducted emissions from 15 kHz to 50 MHz for both narrowband and broadband emissions.

CS02 — Conducted susceptibility from 50 kHz to 400 MHz on all AC and DC power leads.

RE02 — Radiated emission tests of E field emanations from 14 kHz to 10 GHz.

RS03 — Radiated susceptibility tests from 14 kHz to 10 GHz.

CS10, CS11, and RS05 — Conducted and radiated EMP test requirements.

A vast majority of the tests required for MIL-STD 461C will typically be completed in a shielded or an absorber lined chamber (ALC). MIL-STD 462 lists the requirements for the test medium, as well as the type of test equipment required for a particular test method. Proper use and knowledge of the test medium and equipment used for a test is essential to ensure a high degree of repeatability of test results as well as providing meaningful and realistic data. In the case of the shielded enclosure, reflections can occur during emission and susceptibility tests adding to measurement uncertainty. In these cases a certain degree of absorbing material placed in locations of high reflectivity within the shield room is highly desirable to minimize reflections. Other concerns during radiated and conducted emissions is to ensure that the integrity of the shield room shielding provides an ambient that is at least 10 dB below the required test limit.

During 461C tests the equipment under test (EUT) will be placed on a copper clad bench top and bonded securely to this copper ground plane. This is to simulate the mounting of the EUT as it would be mounted on vehicular surfaces, decks, racks, consoles or similar metallic structures. The ground plane as mentioned is typically constructed of copper or brass to facilitate soldering ground straps or leads when required for actual mechanical bonding of the EUT to the ground plane. This ground plane is in turn bonded to the wall of the shielded enclosure at no greater than 30 cm spacing. The table is typically 76 cm in depth and 3 meters in length with a table height of 80 to 90 cm. The bond resistance from this

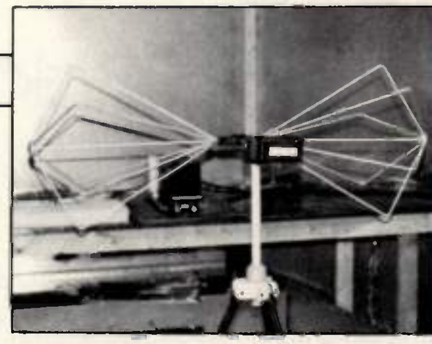

Figure 4. REO2 emissions test using a biconical antenna in the horizontal plane one meter from the EUT.

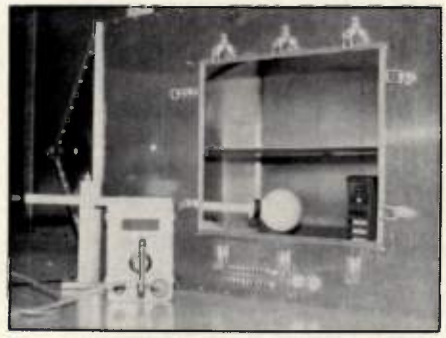

Figure 5. A TEM cell can be used for small EUTs for susceptibility testing to RS02 from 14 kHz to 100 MHz.

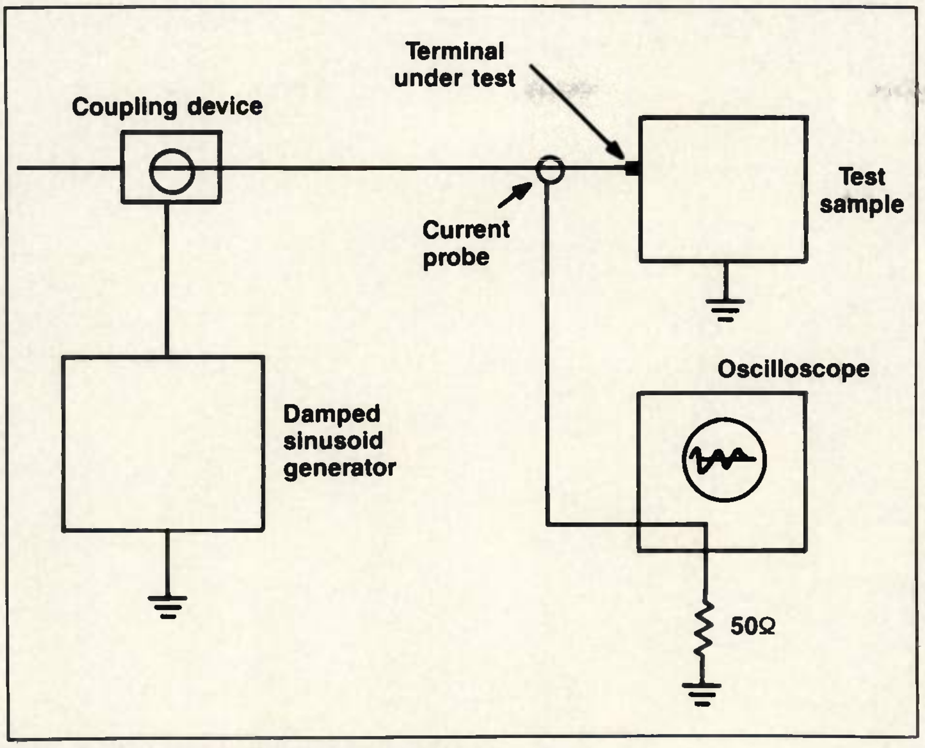

Figure 6. Typical test setup for terminals.

test ground plane to the shielded chamber wall should be less than 2.5 milli-ohms DC resistance. The EUT should be attached and bonded to the ground plane that most closely resembles its actual installation. Here again, it is important to maintain bond impedances that reflect the actual EUT installation. In some cases the vibration and shock test jig or fixture exactly duplicates an installation and may be used for mounting and bonding the EUT to the copper ground plane. A pictorial diagram can be seen in Figure 1.

Depending on the test method used, either 10 uF isolation capacitors or line impedance stabilization networks (LISN) are used to provide additional filtering and isolation of the power supplied to the EUT for MIL-STD 461C tests. Also, any I/O cabling is supported off the ground plane by dielectric spacers (5 cm spacing) to minimize I/O cable emission field reduction by too close proximity to the ground plane. As seen in Figure 1 an isolation transformer is shown along with the EMI meter also mounted on the ground plane. The test sample and the EMI instrumentation should both derive their power from two separate phases of AC power source as well as breaking up any ground loops through the use of the isolation transformer. Audio frequency ground currents can flow through this potential loop, if not broken through the use of separate phases and an isolation transformer. The EMI instrumentation can also be mounted outside the shield room or in an ANTE room attached to the shield room to meet this criteria.

CE03 is a conducted emission test used to measure RF emissions that are conducted on AC, DC and interconnecting control and signal leads. Both narrowband and broadband emissions must be identified for this test over the frequency range of 15 kHz to 50 MHz. For this test, an RF current probe is used in association with an EMI meter. As with all emission tests, it is essential that proper EUT loading and operation is evaluated to ensure that the worst case emissions are produced and measured from the EUT. Conducted switching spike emissions (including ON/Off switching) on AC and DC power leads, for Navy and Air Force procurements, shall also meet the requirements of CE07.

CS02 is used to determine whether communication electronic equipment is susceptible to RF energy injected on its power leads from 50 kHz to 400 MHz. The test sample shall not exhibit any malfunction, degradation of performance, or deviation from its operational specification tolerances when subjected to a 1 V signal from a 50 ohm source over the specified frequency range. A typical test setup can be seen in Figure 2.

RE02 is applicable for radiated emissions from equipment and subsystems, cables (including control, pulse, IF, power, and antenna transmission lines), and in-

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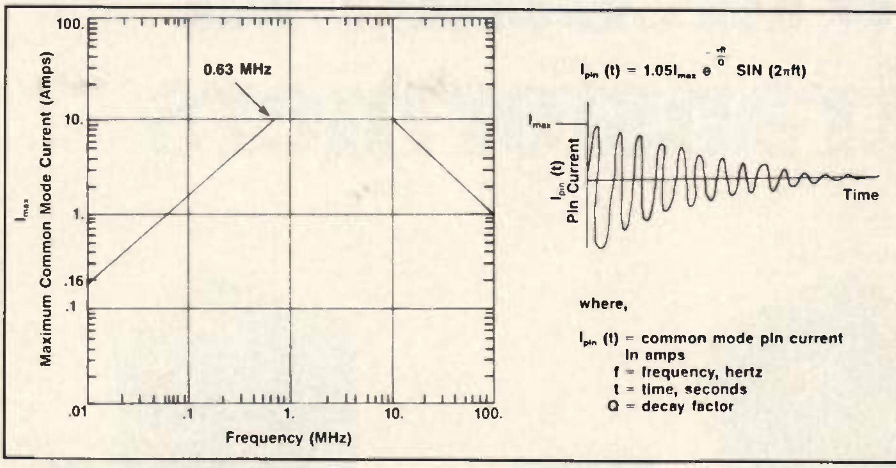
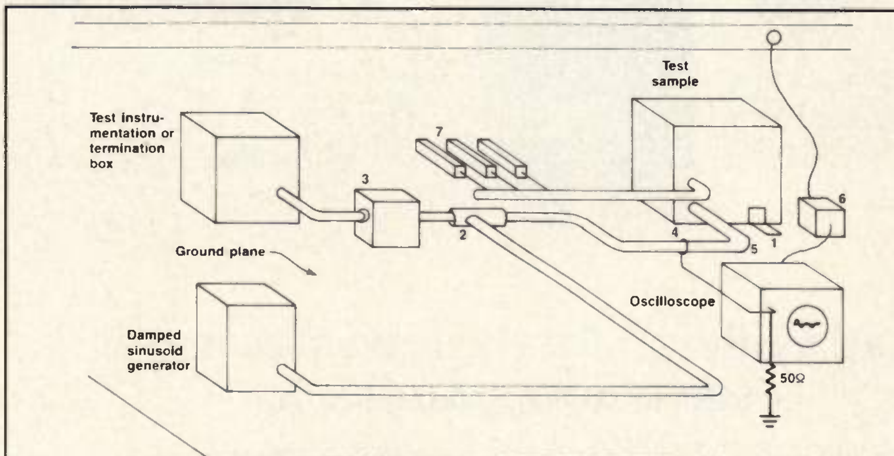
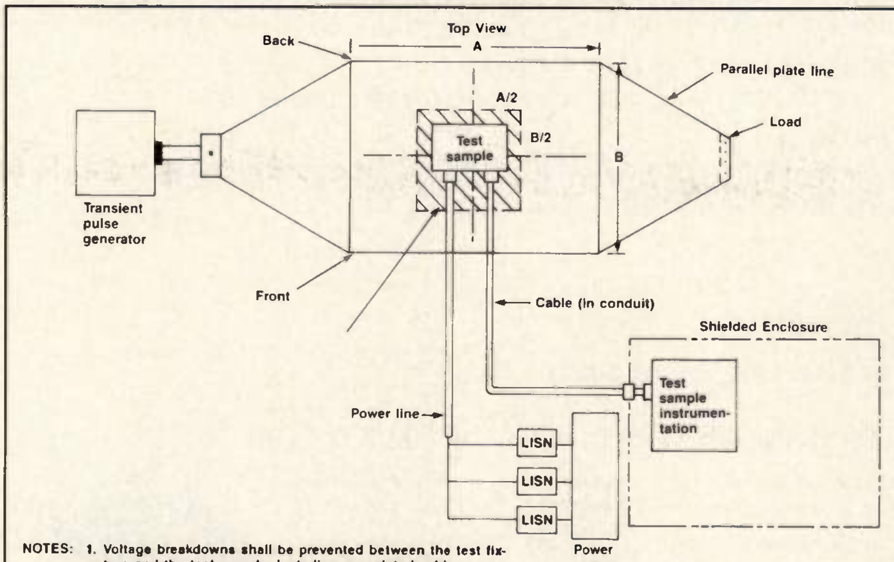


Figure 7. Limit for CS10.



Notes: 1. The DC bond resistance between the ground plane and the test sample shall not exceed 2.5 milliohms.
2. Capacitance or inductance coupling device.
3. A filter or isolator may be used to prevent damage or interference to the test instrumentation.
4. Current probe ≤15 cm from test sample connector.
5. Cable under test.
6. Isolation transformer.
7. LISN terminated in 50 ohms.

Figure 8. Typical test setup for indirect bulk cable injection.



NOTES: 1. Voltage breakdowns shall be prevented between the test fixture and the test sample, including associated cables.
2. All cables to the test sample shall be in metallic conduit.
3. Warning: See safety notice in test procedure.

Figure 9. Typical radiated susceptibility test setup for RS05 EMP tests.

terconnecting wiring of the EUT. This test covers the frequency range of 14 kHz to 10 GHz for narrowband emissions and 14 kHz to 1 GHz for broadband emissions. For narrowband emissions, measurement of the fundamental frequencies and all spurious emissions, including harmonics, is required. Radiation from actual antennas is exempt. Above 25 MHz both vertical and horizontal emissions must be identified and measured. Test arrangement can be seen in Figure 3 and an actual test setup can be seen in Figure 4.

RS03 is performed to ensure that a test sample does not exhibit any degradation of performance, malfunction, or undesirable effects in the frequency range of 14 kHz to 10 GHz when immersed in an electric field of 20 V/m. Test arrangement would be similar to that used for radiated emissions, as seen in Figure 3, above 30 MHz using discrete antennas to generate the susceptibility field. For small EUT dimensions a parallel plate or TEM cell (see Figure 5) is more ideally suited for generating susceptibility fields below 100 MHz than discrete antennas (i.e. rods, biconicals, dipoles, etc.). For Army procurements from 14 kHz to 2 MHz, the field strength is 1 V/m instead of 20 V/m.

CS10 is used to determine EUT susceptibility to damped sinusoidal transients caused by electromagnetic pulses. This test is applicable for all interface pins and terminals of control leads, signal leads, power leads, and grounds and neutrals which are not grounded internally to the EUT as specified in MIL-STD 461C or the individual EUT specification. A typical test setup for terminals is shown in Figure 6 and the actual CS10 transient and limit can be seen in Figure 7.

CS11 is basically the same as CS10 but the damped sinusoidal waveform is coupled into complete cables instead of actual pin injection. This test can be thought of as a bulk current injection (BCI) method. A typical test setup can be seen in Figure 8.

RS05 is a test method to determine EUT susceptibility when immersed in a transient electromagnetic pulse field (EMP). This requirement is intended for Navy equipment and is applicable when both of the following conditions exist:

(a) operation of the EUT is essential for safety or the success of a mission and

(b) the EUT is installed on a non-metallic aircraft.

It is interesting to note here that cables that are shown to meet the CS11 transient requirements are exempt from this requirement. The EUT is required to function properly and not malfunction when exposed to field strengths from a simulated EMP pulse of 52,500 V/m with a rise time of 5×10^{-19} sec, pulse width of 30×10^{-19} sec and a falltime of 550×10^{-9} sec. Parallel plates are typically used to generate these types of EMP fields. These can be seen in Figure 9.

Conclusion

This is just a brief look at a few selected test methods from Part 2 of MIL-STD 461C. As mentioned earlier there are 10 parts with as many as 24 possible test limits and methods. A thorough understanding of MIL-STD 461C and 462 is necessary as well as final design considerations before any tests are undertaken for the product. This is due to the broad range of test requirements for the three procuring agencies (i.e., Army, Navy, and Air Force). rf

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About the Author

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

Variable Bandwidth Intermediate Frequency Amplifier

By Steve Kuh
Motorola, Inc.

The Intermediate Frequency (IF) Amplifier is typically located in the front end section of a receiver in order to amplify the signal level. As the desired signal is amplified, the undesired noise is also amplified. Often, this is an attractive location to place a Bandpass Filter (BPF) centered around the carrier frequency in order to help bring the signal to noise ratio (SNR) up as much as possible. With the amount of the noise reduced and with the signal amplified to the desired level, the receiver has a better conditioned signal to process.

In a TDMA environment, it is often desired to receive the data at a rate spanning as much as two decades, from 0.4 to 40 megasymbols per second. In this case, a fixed bandwidth bandpass filter may help the SNR at one particular symbol rate but may hinder the signal at different symbol rates. An ideal and logical choice for an IF amplifier is one that has a variable bandwidth bandpass filter characteristic. In addition, the variable bandwidth IF amplifier can be considered as an approximated match filter to the various data modulated signals. The fact that the IF bandwidth is variable is advantageous in a TDMA receiver design.

Theory

The basic building block of the variable bandwidth IF amplifier is a monolithic integrated circuit designed and developed by Motorola. It is an analog switch used to control the bandwidth of the bandpass filters in the IF amplifier.

As shown in Figure 1, the analog switch has two small amplifiers. The amplifiers have a gain function that is controlled by the magnitude of the bandwidth control voltage, V_{bwc}. This is a control voltage which could be generated by other control circuitry or by a user's control knob. One of the amplifiers in Figure 1 has a gain function that is directly proportional to V_{bwc} while the other amplifier has a gain function that is proportional to V_{bwc} by $(1 - V_{bwc})$. Therefore, as the magnitude of V_{bwc} increases, the gain of one amplifier increases while the gain of the other decreases. Consequently, as the signal splits into two paths, it is proportionately divided between the two amplifiers by V_{bwc}. Since the two paths contain bandpass filters of different bandwidths, the effect of a variable bandwidth IF amplifier is achieved. Furthermore, the switch also provides an amplification factor, A, and signal amplification is obtained by an amplification control voltage, V_{ac}.

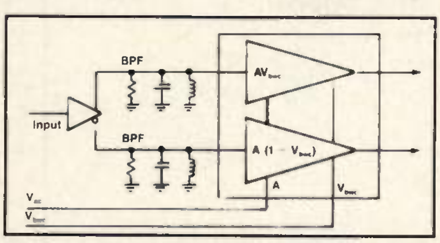

Figure 1. Functional diagram of the analog switch.

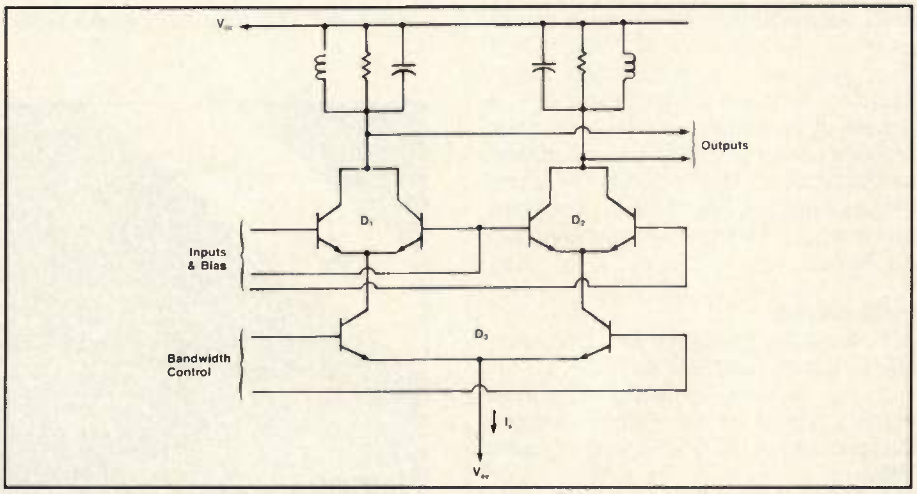

Figure 2. Simplified circuit diagram of variable bandwidth IF amplifier.

Figure 2 shows a simplified circuit diagram that can be used to perform the analog switching function. The differential amplifier pairs D1 and D2 can be used as amplifiers for the input signals. The amplification control is obtained by the constant current sink, I_s. The variable bandwidth control is given by the pair, D3. A control voltage across the inputs of D3 will select either D1 or D2. Then, as the outputs of D1 and D2 are shared, the effect of analog switching results. (The results shown later used a special IC to operate at an IF frequency of 160 MHz).

A block diagram of the IF amplifier is shown in Figure 3. The input buffer takes the signal and provides two paths in which the signal can flow. Notice that six bandpass filters are used. This provides additional resolution to the variable bandwidth. The control voltage, V_{bwc}, controls the bandwidth of the overall filter, and V_{ac} controls the amplification of the signal.

The bandpass filters are also chosen to be single pole filters in order to minimize the distortion that the filters may cause. This is especially important when several filters are cascaded together to form an overall approximated matched filter. For example, equation 1 describes the transfer function of N_p-pole Butterworth filter,

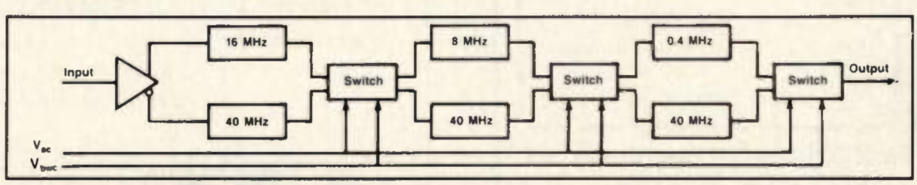

Figure 3. Block diagram of IF amplifier.

$$H(f) = \frac{1}{\sqrt{1 + \left(\frac{f}{f_3}\right)^{2N_p}}} \qquad (1)$$

where f_3 is the 3 dB cutoff frequency of the filter. As the transfer function is inversely proportional to the number of the poles, the group delay of H(f) would be inversely proportional to the number of the poles at a higher order. Furthermore, cascading other filters will introduce more poles. Therefore, in order to minimize the number of poles in the filter, single pole filters are chosen for use in the IF amplifier.

Results

Figure 4 shows the resulting family of bandpass filter frequency response curves corresponding to various bandwidth control voltages. It shows that the bandwidths can be varied from 2 MHz to 100 MHz. The IF center frequency was arbitrarily chosen to be 160 MHz.

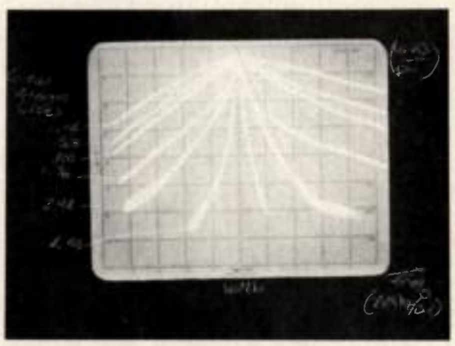

Figure 4. Frequency response of IF amplifier.

Figure 5 is a plot of output vs. input power. It is evident that the transfer curve is that of a differential amplifier. This indicates that the IF amplifier can also be used as a soft limiter.

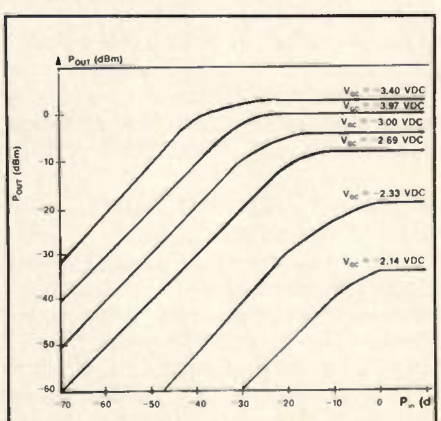

Figure 5. Power out vs. power in.

The IF amplifier described can be very useful in a receiver design. It is not only an amplifier, but also a variable bandwidth bandpass filter that can be used as an approximated matched filter. The control of gain and bandwidth is very easy. It can also be used as a soft limiter to aid in the data decision. Thus, the variable bandwidth IF amplifier is a cost effective building block to aid in a receiver design, particularly in a TDMA application. rf

About the Author

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New Products at MTT-S

Las Vegas Exhibition Spotlights New RF and Microwave Offerings.

IFF Oscillator
Andersen Laboratories

The Andersen 1030 and 1090 MHz oscillator utilizes SAW technology. A SAW delay line is used in the oscillator to provide sufficient bandwidth and pulling range. Temperature stable quartz is used as the SAW substrate to ensure medium term frequency stability. **Andersen Laboratories, Inc., Bloomfield, CT. INFO/CARD #220.**

Horn Antenna
Amplifier Research

The AT4001 antenna operates within the frequency range of 400 to 1000 MHz with power handling capability to 1000 W. Its minimum 10 dB gain, at 400 MHz, increases almost linearly to beyond 15 dB at 1000 MHz.

Amplifier Research will also be introducing a high power RF pulse amplifier and a broadband amplifier. **Amplifier Research, Souderton, PA. Please circle INFO/CARD #219.**

Low Loss Microwave Material
Keene Laminates

Cu-Clad, the newest member of the Keene low loss microwave materials line is tailored for applications in telecommunications, radar and satellite transmissions. **Keene Laminates, East Providence, RI. INFO/CARD #218.**

Comtran 84
Jensen Transformers, Inc.

Comtran is a set of programs that simulate and optimize the design of analog circuits. It includes digitizing waveform data from the HP 5183T 4 MHz digital oscilloscope with 12 bit resolution and time domain averaging for improved signal to noise ratio. **Jensen Transformers, Inc., North Hollywood, CA. INFO/CARD #217.**

Miniaturized Amplifiers for Phased Array Radar
Advanced Microwave, Inc

The .2 to 18.0 GHz A-Pak amplifiers offer MIC technology, dense packaging, multi-octave bandwidth and low price tag. The A-Pak is designed for applications like array antennas employing thousands of radiating elements. Also being introduced is the GPS integrated antenna preamplifier assembly Model AT1575-30. It has a VSWR of 1.5:1 with a minimum gain of 32 dB. **Advanced Microwave, Inc., Camarillo, CA. INFO/CARD #216.**

GaAs MMIC Amplifier
Harris Microwave Semiconductor

Harris introduces the HMM-11810-0 GaAs MMIC for use in gain stage applications. The device has an operating range of 6 to 18 GHz. Its features include large gold bonding pads, dielectric scratch and short circuit protection, and DC blocking on RF input and output. **Harris Microwave Semiconductor, Milpitas, CA. INFO/CARD #215.**

Microwave Spice 1.1
EEsof, Inc.

Microwave Spice 1.1 is the latest version of EEsof's non-linear microwave/RF circuit design and simulation tool. It features a signal power analysis component, a fast fourier transform and user definable functions. **EEsof, Inc., Westlake Village, CA. INFO/CARD #208.**

Microwave Substrates are High-Q
Polyflon Company

Polyflon introduces a pure TFE dielectric with a dielectric constant of 2.1 for applications up to 100 GHz. Copper cladding is electroplated directly to the TFE which eliminates added loss and instability of a secondary dielectric.

Also featured are TFE constructed capacitors that are shock and vibration resistant with Q > 5000. **Polyflon Company, New Rochelle, NY. INFO/CARD #211.**

20 W Amplifier
M/A-COM MPD, Inc.

M/A-COM introduces an amplifier that covers 2 to 4 GHz and delivers 20 W of power. The GaAs FET amplifier, LWA2040-20, is designed to replace TWT's in S-band systems among its various other uses. Also available is a laboratory version featuring a rack mount cabinet and built in power supply. **M/A-COM Microwave Power Devices, Inc., Hauppauge, NY. INFO/CARD #212.**

Fixed Frequency Phase Locked Sources
Watkins-Johnson Company

The units feature low phase noise, −100 dBc/Hz at 10 kHz offset in Ku band, fixed frequency output, 500 MHz to 21 GHz, internal/external crystal reference and high-output power, +23 dBm. The fixed frequency phase locked sources measure 3" × 4" × 1.6". **Watkins-Johnson Company, Palo Alto, CA. INFO/CARD #214.**

Variable Delay Line
Sage Laboratories

Sage unveils a variable delay line or phase shifter with in line SMA or type N connectors. The model 6801 features a variable delay line from 4.3 to 6.8 ns. The maximum insertion loss is 0.6 dB.

A low loss phase shifter with matched insertion phase is another product being introduced. Model FPS3828 is a matched pair of 1.0 to 1.1 GHz mechanical phase shifter with insertion loss of less than 0.2 dB over the band.

Other products to be introduced include a compact DC block, a six way power divider, coaxial phase shifters and a fail safe terminated switch. **Sage Laboratories, Inc., Natick, MA. INFO/CARD #210.**

Miniature High Pass Filters
Daden Associates, Inc.

The Model MH 800-4SS and Model HP 2000-4SS are members of a series of miniature highpass filters being introduced by Daden. The MH 800-4SS covers from 0.8 to 18 GHz with less than 1 dB insertion loss. The HP 2000-4SS is similar except for a cutoff frequency at 2 GHz. **Daden Associates, Inc., Laguna Hills, CA. INFO/CARD #209.**

100 Hz to 22 GHz Spectrum Analyzer
Hewlett-Packard Company

HP introduces two products in the HP 70000 modular system product line. The 71210A is a spectrum analyzer with a frequency range from 100 Hz to 22 GHz. The 70700A is a 20 mega sample/second, 10 bit digitizer with 256 K words of waveform memory.

The HP 8510B is a microwave network

analyzer. Its applications include characterization of microwave semiconductor wafers and ICs, frequency translation devices and far field antenna pattern measurements.

HP will show the HP 8562A and HP 8562B spectrum analyzers which cover the 1 kHz to 22 GHz range. Other products that will be featured include the Vector generator and analyzer, the HP 8970T microwave noise figure measurement system and video detectors. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #207.**

MMIC Packaging
Technical Components, Inc.

TCI introduces a line of multilayer ceramic MMIC packages suitable for the 2-10 GHz frequency range. The hermatic packages are available with five 50 ohm microstrip feedthroughs and two leads for DC and bias functions. They meet MIL-STD 883-B. **Technical Components, Inc., Warwick, RI. INFO/CARD #206.**

Medium Power Amplifier
Trontech, Inc.

The P4GA is a broadband medium power class A amplifier that has a minimum gain of 40 dBm ± 1.5 dB.

The AS100C and the AS101C are amplifiers designed for cellular radio base station applications. Both operate in the 820 to 860 MHz range. **Trontech, Inc., Neptune, NJ. INFO/CARD #203.**

FET Power Transistors
Microwave Semiconductor Corporation

MSC introduces an internally input matched balanced pair of silicon FET power transistors. The operating range is from 225 to 400 MHz and it operates at signal and bias levels comparable to bipolar transistors.

Another featured device is the D Amp 110. This broadband GaAs amplifier features a distributed design for stability and cascadability. It has a minimum signal gain of 5.0 dB and operates from 500 MHz to 10 GHz. **Microwave Semiconductor Corporation, Somerset, NJ. Please circle INFO/CARD #202.**

Video Colorizer Module
Optical Electronics, Inc.

The 6730 is a video colorizer module signal processing block. It takes 8-bit monochrome video information and converts it into RGB pseudo-colors via luminance levels.

Also being introduced is the 2545 video enhancement module. It is capable of implementing image compression, image expansion, contrast enhancement, contrast compression and edge detection. **Optical Electronics, Inc., Tucson, AZ. INFO/CARD #204.**

Wideband Crystal Filters
Microsonics, Inc.

Wideband filters that provide a 480 kHz 0.5 dB passband with an insertion loss of less than 3.5 dB and 0.25 dB maximum passband ripple are introduced by Microsonics. The packaged device measures 2.0" × 2.0" × 0.65" **Microsonics, Inc., Weymouth, MA. INFO/CARD #213.**

UHF High Power Amplifiers
TRW RF Devices Division

The PAM-0810 series of class A UHF power amplifier modules operate in a 800 MHz to 1000 MHz frequency range and power outputs of 3 W, 5 W, 12 W, 25 W or 50 W. The modules feature high 3rd order intercept point, reverse polarity protection, and a machined housing. **RF Devices Division, TRW Electronic Components Group, Lawndale, CA. Please circle INFO/CARD #201.**

Frequency Extension Receiver
COM DEV, Ltd.

The receiver downconverts a number of 12 GHz frequency bands in the 18 to 105 GHz range. It is tailored to fit in existing aircraft space. **COM DEV, Ltd., Cambridge, Ontario, Canada. Please circle INFO/CARD #200.**

Anti-Aliasing Filters
TTE, Inc.

Anti-aliasing filters are very sharp cutoff low pass filters used to attenuate the Nyquist frequency in digitized signals. The frequency range of the series is 10 kHz to 20 MHz. They measure .4" × .6" × 1.2" and 1.2" × 1.2" × .5". **TTE, Inc., Los Angeles, CA. INFO/CARD #199.**

DC to 26.5 GHz Coaxial Switch
Teledyne Microwave

Teledyne Microwave has developed a DC-26.5 GHz single pole double throw electromechanical coaxial switch. Typical specifications from 18 to 26.5 GHz include a VSWR of 1.8:1 with an insertion loss of 0.7 dB. **Teledyne Microwave, Mountain View, CA. INFO/CARD #205.**

GaAs Fets
Microwave Technology, Inc.

MwT introduces 6 GaAs FET products. Each features a Ti-W/Au 0.3 micron recessed gate. Gate widths range from 80 to 630 microns resulting in a noise figure of 2 dB and gain of 13 dB at 18 GHz. **Microwave Technology, Inc., Fremont, CA. INFO/CARD #198.**

Direct Synthesized Signal Generator
Eaton Corporation

Eaton introduces the 382A and 384A direct synthesized signal generator. They feature 20 microsecond switching and low phase noise.

Also being introduced is the 2276S noise figure test system. Its features include a direct digital plotter output and single and double sideband capabilities. **Eaton Corporation, Electronic Instrumentation Div., Los Angeles, CA. INFO/CARD #197.**

Thick Film Hybrid Amplifier
Aydin Vector

This cascadable modular thick film amplifier is packaged with blindmate or SMA connectors. The packaging, designated the AMX series, is available for applications from 5 to 1500 MHz. **Aydin Vector, Newton, PA. INFO/CARD #196.**

5 GHz Frequency Divider
California Eastern Labs

California Eastern Labs unveils a 5 GHz GaAs MMIC from NEC. The operating range for this device is from 1 GHz to 5 GHz. The UPG501B features a division ratio of 4. Contained in the chip is an input blocking capacitor.

Also being unveiled is the UPG102B GaAs MMIC wide band amplifier. It is a cascadable device that operates from 2 to 20 GHz.

The NE202 is a low noise GaAs FET. At 12 GHz the typical noise figure is 1.0 dB and the high associated gain is 12 dB.

California Eastern Labs, Inc., Santa Clara, CA. INFO/CARD #195.

Directional Couplers
Synergy Microwave Corp.

Synergy introduces three and four port directional couplers that cover from .5 to 1000 MHz with multi-octave bandwidths and coupling values of 10 dB, 15dB, and 20 dB.

Also being introduced are broadband multi-octave transformers in five port surface mount packaging. The frequency range is from 5 MHz to 1000 MHz with an impedance ratio from 1:1 to 1:16. **Synergy Microwave Corporation, Paterson, NJ. INFO/CARD #194.**

Sliding Loads
Maury Microwave Corp.

The Model 2608C is a 7 mm sliding load with a one piece inner and outer conductor transmission line with integral connector.

A family of thread on connector gauges is also being introduced. The Model A034E is for measuring 3.5 mm connectors while the Model A028D is for measuring 7 mm. **Maury Microwave Corp., Cucamonga, CA. INFO/CARD #193.**

Waveguide Noise Source
Noise Com, Inc.

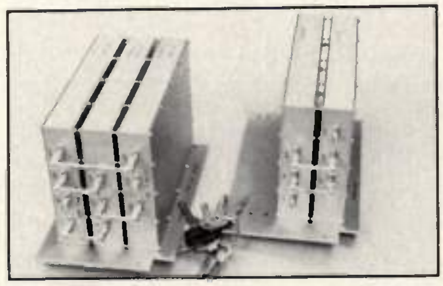
The NC 5000 millimeter-wave waveguide noise source combines the performance of a gas-tube-type source with the light weight, low power requirements and small size of solid state sources. Also being introduced is the X-301 pocket signal generator. It is used to align radar and communication receivers in the field. It provides a continuous signal from 100 kHz to 1000 MHz. It costs $995. **Noise Com, Inc., Hackensack, NJ. Please circle INFO/CARD #192.**

Phase-Locked Oscillator
Communication Techniques, Inc.

CTI introduces dielectrically stabilized phase-locked oscillators. The PDRO-1401 is mechanically tunable from 11.26 to 11.76 MHz and phase locks to an internal crystal oscillator. **Communication Techniques, Inc., Whippany, NJ. Please circle INFO/CARD #191.**

Frequency Synthesizer
Sciteq Electronics, Inc.

This unit covers up to an octave with the upper limit at 2 GHz and resolution of 1 Hz. The VDS-1600 typically switches between any two inband frequencies in



about 25 usecs. It is a hybrid that combines PLL with direct digital design. **Sciteq Electronics, Inc., San Diego, CA. INFO/CARD #189.**

GaAs Tuning Varactor
M/A-Com Semiconductor Products, Inc.

M/A-Com Semiconductor will introduce GaAs hyperabrupt tuning varactors, silicon hyperabrupt tuning varactors, hermatic surface mount PIN diodes, beam lead constant gamma GaAs hyperabrupt tuning varactors, GaAs PIN diodes and beam lead Schottky diodes. **M/A-Com Semiconductor Products, Inc., Burlington, MA. INFO/CARD #190.**

RF Amplifiers
Penstock Engineering Labs

A full line of cascadable RF amplifiers are available with typical specifications for noise figure at 1 dB and a frequency range from 50 to 250 MHz. Pricing for 1 to 9 pieces is $350. **Penstock Engineering Labs, Los Altos, CA. Please circle INFO/CARD #188.**

L-Band Bandpass Filters
Sawtek, Inc

Sawtek introduces L-Band SAW bandpass filters that operate from 1 GHz to 2 GHz. They exhibit insertion losses from 15 to 40 dB. The fractional bandwidth obtainable varies from 1 to 15 percent center frequency with shape factor capabilities as low as 1.5:1. **Sawtek, Inc., Orlando, FL. INFO/CARD #187.**

DC to 18 GHz Switch Matrices
Dow-Key Microwave Corp.

Dow-Key introduces a line of DC to 18 GHz switch matrices in standard 19" rack enclosures. The 2 × 20 or 4 × 40 switch matrix can be controlled with simple protocol statements via a GP-IB/HP-IB com-

patible computer or any IBM PC compatible computer. **Dow-Key Microwave Corporation, Carpinteria, CA. Please circle INFO/CARD #186.**

SMA Plug and Jack
Gilbert Engineering Co., Inc.

These SMA plug and jack thread in to .020 C/C seal are connectors that provide impedance matched launches into component installed hermatic seals. **Gilbert Engineering Co., Inc., Glendale, AZ. INFO/CARD #185.**

Signal Calibrator
Weinschel Engineering

Weinschel Engineering introduces the VM-7 attenuator and signal calibrator. **Weinschel Engineering, Gaithersburg, MD. INFO/CARD #184.**

Measurement and Computation Tools
EIP Microwave, Inc.

This modular workstation can be configured as a microwave network analyzer among its other applications. The Model 21200A offers 1 to 18.6 GHz bi-directional network analysis capability for testing passive and linear active devices. The Model 21100A offers 1 to 18.6 GHz unidirectional capability. It allows amplifiers and other active devices operating near or in their non-linear reigons to be characterized under the same conditions in which they will actually be used. **EIP Microwave, Inc., San Jose, CA. Please circle INFO/CARD #183.**

NOW, IT'S EASY TO FUNNEL YOUR THOUGHTS INTO PRODUCTS...


MODEL 686-VHF RECEIVER
ENT
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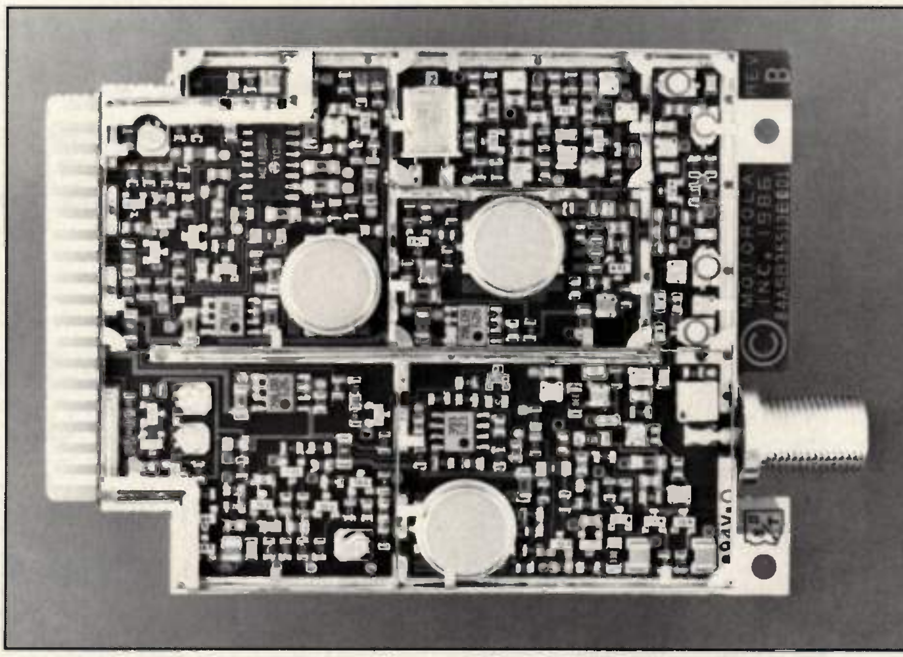
REACTION INSTRUMENTS

Motorola Introduces an RF Modem Module

The MHW10000 RF Module is designed to provide the RF functions needed for implementation of a complete modem compatible with the IBM Personal System/2, earlier members of the IBM PC family and IEEE 802.7 broadband specifications. It is a full duplex, continuous phase frequency shift keyed (CPFSK) transceiver. The design is such that the module operation is completely compatible with a broadband coaxial cable environment. The transmitter occupied bandwidth and the receiver selectivity and overload characteristics have been controlled so that the module operation is completely transparent to the cable system operation.



The module transmitter operates at a nominal carrier frequency of 50.75 MHz (CATV channel T-14) with a total frequency deviation of 2 MHz. Transmitter occupied bandwidth is controlled by a SAW filter. A companion receiver operates at a center frequency of 219 MHz (CATV channel J). The circuitry is capable of operating with center frequency offsets up to ±500 kHz. The receiver RF selectivity is provided by a two resonator bandpass filter at the RF amplifier input and a two resonator filter between the RF amplifier and the mixer. Receiver noise bandwidth control and adjacent channel selectivity is provided by two cascaded SAW filters in the IF circuitry.

Conversion of the analog RF data to the digital data stream is provided by a Motorola MC 13055 data IC. This IC provides the final IF amplification and limiting, the quadrature detector, data carrier detect (squelch) and data sharper functions. The basic card occupies about 8 square inches and the construction utilizes surface mount technology. **Motorola, Inc., Phoenix, AZ. INFO/CARD #156.**

2.6 GHz Frequency Counter from Racal-Dana

A high speed 2.6 GHz frequency counter has been introduced by Racal-Dana. Model 1999 features nine-digit resolution over the 10 Hz to 2.6 GHz frequency range. Sensitivity at 2.6 GHz is 10 mV. With higher level inputs, the counter is usable to 3 GHz.

It features an error free burst frequency capability which allows six-digit resolution for signals as short as 2 msecs. Use of the counter's external arming provides different portions of the burst to be synchronized for frequency profiling. This capability is beneficial for electronic warfare and radar applications.

Optional GPIB capability provides full programmability of front panel functions keys and signal conditioning controls. For maximum stability, a standby power mode ensures that continuous power is applied to the frequency standard. It is priced at $2,400. **Racal-Dana Instruments Inc., Irvine, CA. INFO/CARD #155.**

"I'd settle for a bare bones spectrum analyzer just to have one right on my bench."

we never stop asking

"What if..."

Newton refracts light through a glass prism, circa 1672.
"The Bettmann Archive."

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HP 8590A
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Use the HP 8590A's briefcase handle to carry it anywhere. It weighs just 30 lbs. and slips into all the tight spots. Including the space under your airplane seat. And it's sturdy enough to withstand the rigors of real portability.

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$9,500: U.S. list price.

HEWLETT PACKARD

INFO/CARD 46

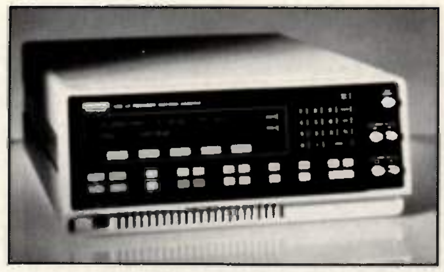
RF Amplifier

Amplifonix introduces an RF hybrid amplifier, Model TM 5138 in a TO-8 hermetic package. The design provides a gain of 15 dB typical gain over the frequency range of 5 MHz to 150 MHz. Other specifications include a noise figure of 2.5 and VSWR of 2.0:1. All units meet MIL-STD-883B screening. Price for 1 to 9 is $84. **Amplifonix, Inc., Langhorne, PA. INFO/CARD #116.**

Crimp-type Coaxial Connector

E.F. Johnson Company introduces a tool-less coaxial connector. The self-crimping connector can be reused without detectable signal degradation. **E.F. Johnson Company, Waseca, MN. Please circle INFO/CARD #115.**

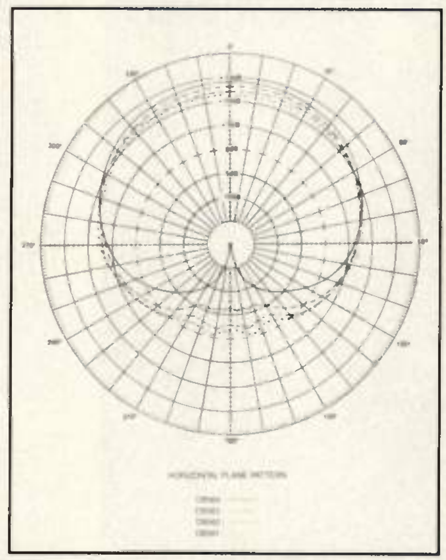
Frequency Response Analyzer



The instrument features two channels operating in parallel and offering basic gain and phase accuracy of 0.02 dB and 0.2 degrees, respectively. The analyzer uses a single sine correlation analysis technique to provide fast and precise measurement of amplitude and phase. It featured easy set-up from the front panel or remotely via the standard RS423 and IEEE-488 interfaces. The unit is priced at $18500. **Solartron Instruments, Elmsford, NY. INFO/CARD #154.**

Directional Antennas with Variable Gain

Decibel Products introduces variations of the 820-900 MHz, 14 dB gain, 120 degree directional Model DB564 antenna to obtain choices of gains and patterns. The directional antennas are for cellular radio-



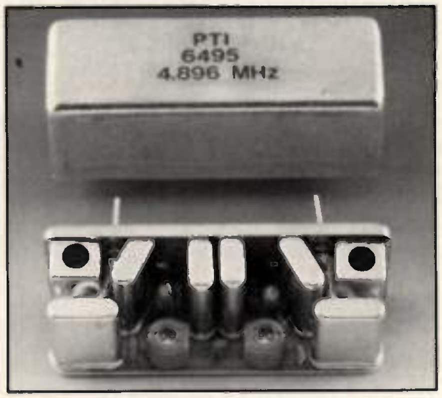
phone receive (820-855 MHz) and transmit (865-900 MHz) and 800 MHz conventional/trunked site installations. The design provides control of VSWR across the operating band. **Decibel Products, Inc., Dallas, TX. INFO/CARD #153.**

High Speed Silicon OP Amp

Plessey Semiconductors introduces a monolithic bipolar op amp that features a slew rate of 1400 V/us, a unity gain bandwidth of 800 MHz and a gain bandwidth product of 2.5 GHz. Open loop gain, output current, supply voltage range and output DC offset can be programmed on the SL2541. Settling time to within 0.5 percent of full bandwidth is 30 ns. **Plessey Semiconductors, Irvine, CA. Please circle INFO/CARD #152.**

Upper Sideband Crystal Filter

Piezo Technology introduces an upper sideband crystal filter, Model 6495. It operates with a carrier frequency of 4.896 MHz, providing a minimum of 10 dB attenuation of the carrier with a 3 dB passband



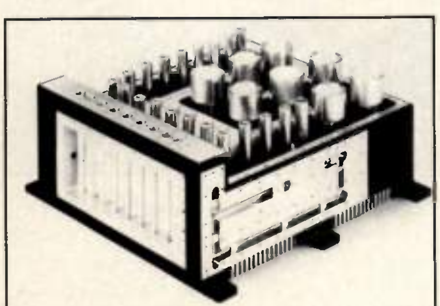
of fc +30 kHz to +3.825 kHz. Stopband attenuation of 30 dB minimum is at fc +7.65 kHz. **Piezo Technology, Inc., Orlando, FL. INFO/CARD #151.**

Quad CMOS/D-MOS Analog Switch

CDG211CJ is a quad single pole, single throw (SPST) analog switch with TTL compatible control inputs in 16 pin plastic dip, pin and function compatible with CMOS devices. The technology combines CMOS and D-MOS (double-diffused MOS) processes on a single chip. The use of D-MOS results in low insertion loss and high OFF isolation (66 dB at 10 MHz with 50 ohm load) at video frequencies. It is priced at $1.60 in 100-up quantities. **Topaz Semiconductor, San Jose, CA. Please circle INFO/CARD #150.**

High Power Triplexer

This combline filter high power triplexer is designed for ground-based applications. The specfications of this device include a passband VSWR of 1.2:1, rejection greater than 160 dB at 240 MHz and the operating frequency is designed to



customer specifications. **Transco Products, Inc., Camarillo, CA. Please circle INFO/CARD #148.**

Spectrum Analysis Peripheral

The R340 is a spectrum analyzer peripheral for the IBM PC, XT, AT and compatible computers. It uses an on board data acquisition front end connected to a high speed digital signal processing board to turn PCs into real time spectrum analyzer or digital oscilloscope. Features include menu driven real time spectrum analysis using 1024 point FFT and 20 MHz TI TM32010 based digital signal processing board. **Rapid Systems, Inc., Seattle, WA. INFO/CARD #147.**

Surface Mount Oscillators

Seiko Instruments introduces the SMO-100 surface mount crystal oscillator. It covers from 262 kHz to 24 MHz. A strip

resonator crystal is hermetically sealed within the SMT packaging. **Seiko Instruments U.S.A., Inc., Torrance, CA. Please circle INFO/CARD #146.**

RF Amplifier is Low Cost

Aydin Vector's MHT-220 series is a thick film high gain, low noise, cascadable wideband amplifier. The amplifier offers a typical gain of 28 dB with a noise figure of 2.8 dB. **Aydin Vector Division, Newton, PA. Please circle INFO/CARD #114.**

HF Antennas

Trans World Communications unveils a series of broadband HF antennas. The average power levels are 1 kW and it covers the 2 to 30 MHz HF frequency spectrum. Coverage up to 2500 km is obtainable. **Trans World Communications, Inc., Datron Systems, Inc., Escondido, CA. INFO/CARD #145.**

Amplifiers Offers 30 dB gain

A 0.5 to 4.0 GHz high gain amplifier with a ±0.5 dB gain flatness has been intro-

duced by Celeritek. The CMS-4-0503 provides +14 dBm output power and a 4 dB noise figure. Gain is 30 dB typical and 28 dB minimum. **Celeritek, San Jose, CA. INFO/CARD #144.**

8-Bit A/D Converters

Sony unveils two 8-bit flash monolithic A/D converters:the CXA1076K, rated at 200 million samples per second (MSPS) and the CXA1176K rated at 300 MSPS. These products have an input bandwidth of 100 and 120 MHz and power consumption of 860 mW and 1.5 W respectively. In addition to 8-bit output data, there is an over-range output and two digital inputs which are used to program output format for true or inverse binary or offset two's complement. Internal circuits include input amplifier, error supression and linearity compensation. **Sony Corporation of America, Cypress, CA. Please circle INFO/CARD #143.**

SMT Inductors

Piconics introduces a surface mount version of its M series air core inductor. The MC series chip inductor has values from 6.3 to 684 nH with operating frequencies from 100 MHz. The coil is constructed of 47 AWG wire. The base of the device is an alumina substrate with gold plated wrap-around terminations to which the coil is welded. **Piconics, Inc., Tyngsboro, MA. INFO/CARD #142.**

Coaxial Rotary Joint

Mast Microwave Model No. RC27001H1 is a dual channel coaxial rotary joint with a frequency range of 145-225 MHz.

VSWR for channel 1 is 1.2 and for channel 2 is 1.25 with insertion losses of .1 dB max and .2 dB max respectively. Peak power for channel 1 is 50 kW and for channel 2 is .5 kW with average power being 15 kW and .15 kW. Rotational speed is 20 rpm. **Mast Microwave, Billerica, MA. INFO/CARD #141.**

Arbitary Waveform Generator

The LeCroy Model 9100 arbitary function generator (AFG) is capable of generating standard or custom waveforms. It features custom waveforms in a dual out-

put generator and at up to 200 megapoints/sec. The AFG can generate square waves or pulses up to 100 MHz and sine waves up to 25 MHz. **LeCroy, Spring Valley, NY. INFO/CARD #139.**

Scanning Acoustic Microscope

The Olympus UH-3 applies sound waves to permit comprehensive observation and measurement of previously inaccessible subsurface and details of opaque materials. An array of lenses to focus sound waves ranging from 30 MHz to 1 GHz provides a broad spectrum of penetration depths and resolutions by scanning the specimen immersed in a coupling fluid (usually water). The sound waves are reflected back from the specimen through the lens and electronically converted to a digital signal, which is stored until a full scan is completed. The image can then be displayed on a TV screen. **Olympus Corporation, Lake Success, NY. INFO/CARD #140.**

Broad Band Coaxial Relays

A line of coaxial reed relays with bandwidths from DC up to 800 MHz and available in configurations from two to 24 throw is introduced by Matrix. Designated the 7000 series, these relay modules are designed to maintain coaxial switching continuity over a wide range of applications. All signal paths are silver plated with covers gasketed for maximum EMI protection. The basic reed switch elements are hermetically sealed in nitrogen filled gas envelopes and employ rhodium plated contacts to insure non stick operation. **Matrix Systems Corporation, Calabasas, CA. INFO/CARD #138.**

Frequency Synthesizer

A standard line of single loop frequency synthesizers covering the 10 MHz to 1.2 GHz range is available from Pacific R & D. Octave bands and parallel TTL digital controls are standard features. Other features include: step size of 1 kHz, switching speed of 10 ms, spurious output of −60 dBc and output power of +13 dBm. **Pacific Research and Development, Montrose, CA. INFO/CARD #123.**

GaAs PIN Diodes

These diodes have high carrier mobility resulting in low series resistance and fast switching speed. Low I region carrier concentration provides near zero bias punch through. Switching speeds are in the low nanosecond range. **M/A-Com Semiconductor Products, Inc., Burlington, MA. INFO/CARD #122.**

Spread Spectrum Gold Code Generator

This system generates pseudorandom sequences that are useful for developing and testing spread spectrum and conventional data communication systems. It consists of two linear recursive sequence generators that operate synchronously up to 25 MHz. The feedback pattern, sequence starting point and sequence length of one generator can be set independently of the other. **New Wave In-**

You've waited a long time for

For too many years, if you needed a cost-effective 2 GHz signal generator, you had to settle for clumsy, clunky Klystron-based units. Many of which have been around since the last World War.

To achieve any accuracy you needed a counter to set frequency. Then it would drift. And such primitive technology necessitated high maintenance costs.

Of course you could opt for the precision of a synthesizer. It only takes $20,000 or more.

At last, a true alternative.
The Wavetek Model 2520 puts these past technologies and problems far behind you.

Now you can have a 2.2 GHz synthesized signal generator with all the features and convenience of the popular 1 GHz synthesizers. But, remarkably, at the price of an old-fashioned Klystron generator.

2.2 GHz for under $8,000.
You've come to expect a lot of performance from your 1 GHz signal generator. Now you can have that same affordable, effective performance in a 2.2 GHz generator with *no compromises.*

Frequency range down to 200 KHz +13 dBm output power.* Excellent spectral purity. Near field RFI typically <0.1 microvolt. Fast and precise setting of frequency to 10 Hz resolution by keyboard or


RADIO
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SERVICE
Level
0000
13.0
dBm
9
6
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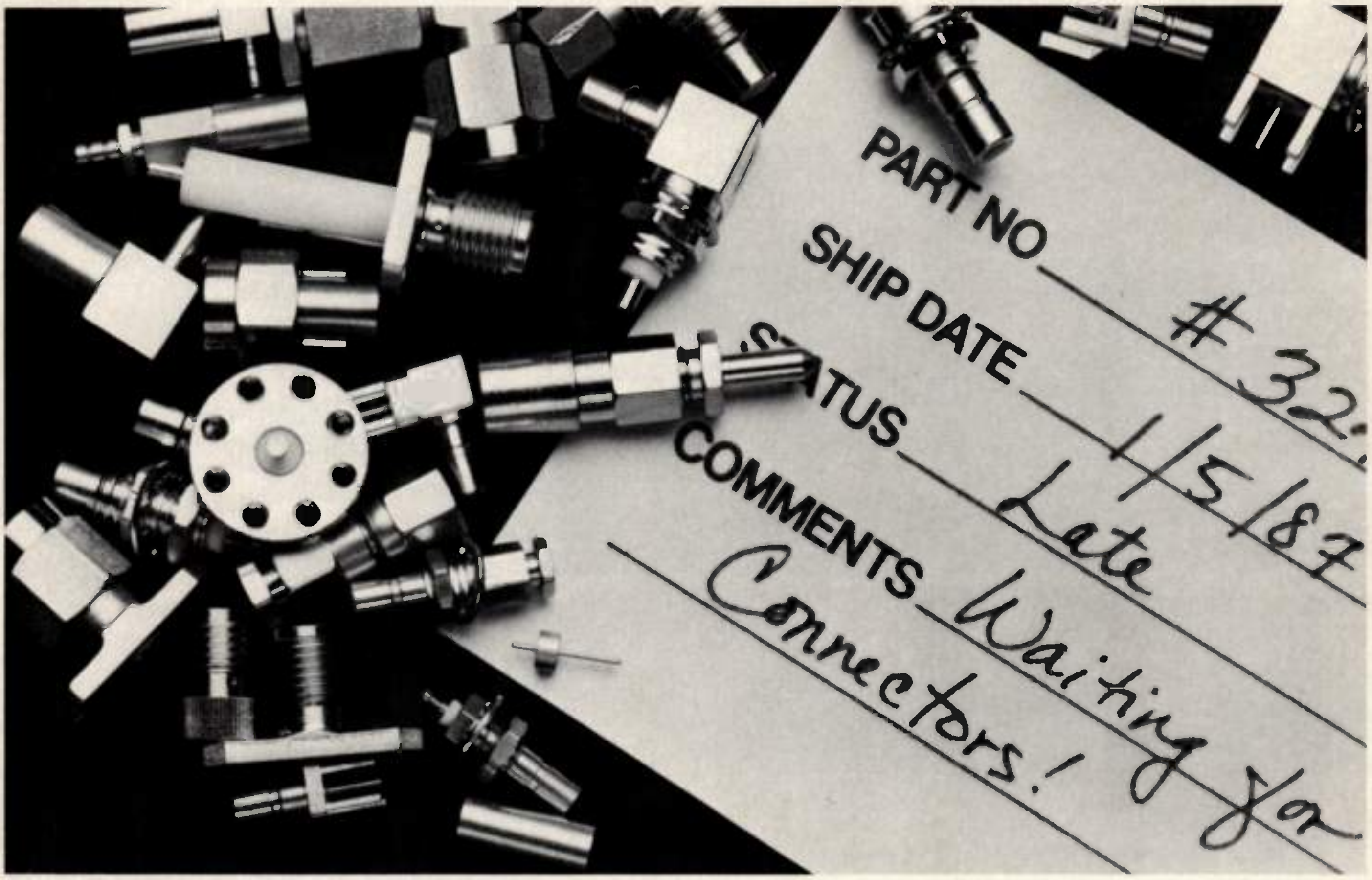
+/-
MHz
mV
kHz
uV
%
dBm
RF
ON/OFF
RF Out
Meissner



SMALL CONNECTORS CAN BE A BIG DEAL

AEP Subminiature Coaxial Connectors

Small connectors can kill a big system if they don't work or aren't there when you need them. AEP can help make sure this doesn't happen to you.

Connectors that work.

Our production standards exceed MIL-C-39012 requirements. 11% of our workforce is in quality control to make sure these standards are met. Need proof? We have shipped 144,000 cable assemblies (with AEP SMB connectors) for the ARC-164 military radio--NO REJECTIONS. We've also shipped almost 150,000 SMA and SMB connectors to a major radio manufacturer--NO REJECTIONS.

Connectors when you need them.

It's easy to get our parts quickly, thanks to our network of stocking distributors and four-week factory delivery of 92 standard items. If you need something unusual, we can generally deliver specials within twelve weeks.

The right connector for the job.

We make hundreds of varieties of SMA, SMB, and SMC connectors--many qualified to MIL-C-39012. Our 7000 series has unequalled performance in microminiature size. Do you need 75 ohm connectors? We make them. You can also save time, trouble, and money by letting us build flexible and semi-rigid cable assemblies for you.

If we sound like the kind of connector supplier you'd like to have, call or write for our 120 page catalogue.

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INFO/CARD 56

struments, San Jose, CA. INFO/CARD #121.**

Attenuator Chips

10 mil thick quartz pads are available in 1 dB increments from 1 dB to 20 dB with solderable backside metalization rated to 325 C. VSWR at 18 GHz is less than 1.3:1 and flatness is ±0.25 dB from 10 MHz to 18 GHz. The 50 ohm chip measures 0.10" × 0.08" × 0.01". **Ion Beam Milling, Inc., Manchester, NH. Please circle INFO/CARD #120.**

RF Distribution Amplifier

Viewsonics introduces their wideband distribution amplifier Models VSA-10-550 and VSA-20-550. Both units cover a frequency range of 50 MHz to 550 MHz. A virtually flat signal gain of 10 or 20 dB can be obtained depending on the model used. Typical noise figure is 7 dB. Input/output impedance is 75 ohms. **Viewsonics, Inc., Syosset, NY. INFO/CARD #119.**

Thin Film Mixers

Model TFX-18075 from Avantek covers .75 to 18 GHz on the RF/LO ports and DC to 0.5 GHz on the IF ports with 8.0 dB conversion loss, 25 dB of LO-RF isolation and 2.5:1 VSWR on the RF and LO ports. They are built with double sided, planar, thin film ceramic substrates and beam lead diode quads. **Avantek, Inc., Santa Clara, CA. INFO/CARD #118.**

Phased Array Bragg Cell

Crystal Technology offers a phased array Bragg cell made from gallium phosphide (GaP). The Model 41000LG-PA has a center frequency of 1 GHz and a diffraction efficiency of 70%/W at 830 nanometers. Its applications include high frequency spectrum analysis. **Crystal Technology, Inc., Palo Alto, CA. Please circle INFO/CARD #117.**

High Frequency Amplifier

Signetics Corp. unveils the NE/SA5204 wide band high frequency amplifier. A unique feature of this device is its ability to reflect a load impedance to the input for both 50 and 75 ohm systems. The second and third order of intermodulation intercepts are +24 dBm and +17 dBm, respectively, at 100 MHz. **Signetics Corporation, Sunnyvale, CA. Please circle INFO/CARD #124.**

RF Power Amplifier Analysis and Design

The CAED (Class E Amplifier Design) program computes the steady state repetitive time domain waveforms in a switching mode RF power amplifier circuit of class E topology. The DC power input, RF power output, power losses and power efficiency is calculated. The computation takes about 1/2 second on the IBM AT or 2 seconds on the IBM PC or XT. CAED can also optimize the design automatically. It performs a series of circuit analyses, adjusting component values automatically to maximize the efficiency. The software is priced at $2000. **Design Automation, Inc., Lexington, MA. INFO/CARD #182.**

Filter Synthesis Program

Webb Laboratories introduces Filsolve 1.0. It performs synthesis of lowpass, high pass and bandpass filters in Butterworth, Chebyshev, maximally flat time delay and equal ripple time delay realizations. Also available from Webb is demonstration software on Syscad and Transcad. **Webb Laboratories, North Lake, WI. Please circle INFO/CARD #181.**

Simulator Integration Kit

SimKit is a simulator integration kit used to combine the Analog Workbench design environment with simulators and model libraries. It includes simulator interface software, documentation and an example Spice 2G.6 connection. **Analog Design Tools, Inc., Sunnyvale, CA. INFO/CARD #180.**

CAE/CAD for Designing with SMD's

Aptos System introduces a PC based design system using surface-mount components. The software library includes small outline packages (SOIC), plastic leadless chip carrier (PLCC), leadless ceramic chip carriers (LCCC), small outline transistors (SOT) as well as five types of outline capacitors and six types of outline resistors. **Aptos Systems, Scotts Valley, CA. INFO/CARD #179.**

Remote Site Monitoring

Tektronix announces Remote Site Monitoring Software (RSM). It was developed to merge the power of the Tek 490P series portable and 2750P series laboratory spectrum analyzer with IBM PCs or compatibles. The package simplifies control and data analysis of instruments at remote sites. It gives the user the ability to connect two PCs by phone with the remote PC connected to a Tektronix programmable spectrum analyzer. The user can control operations of the remote PC or can acquire data from the remote spectrum analyzer. **Tektronix Inc., Beaverton, OR. INFO/CARD #178.**

Mathematical Applications Packages

NSC introduces two software packages that support digital signal processing applications for the HPC family of 16 bit CMOS microcontrollers. One package implements a floating point routine and the other is a fast fourier transform program. The floating point package is a single precision implementation based on the IEEE standard for binary floating point arithmetic with several differences to accommodate the architecture of the HPC. The fast fourier transform program is set up to do FFTs of 2, 4, 8, 16, 32, 64, 128 and 256 inputs or bytes and can be easily modified to work with higher lengths. **National Semiconductor Corp., Santa Clara, CA. INFO/CARD #177.**

rf literature

Power Electronics and Software Catalog

Bloom Associates has released their 1987 catalog of Power Electronics Books and Software. Twenty-one books and 25 software titles are included. **Bloom Associates, Inc., San Rafael, CA. INFO/CARD #175.**

Power MOSFETs Described In Data Book

The 1987/88 SIPMOS components data book from Siemens Components contains product innovations, expansions and improvements in the SIPMOS (Siemens Power MOS) small signal and power transistor product lines. It includes 150 product types with general technical and mounting information as well as complete device parameters and characteristics. In addition, the catalog contains a survey of types, selection, guides and an industry cross reference. Individual data sheets are included. **Siemens Power Semiconductor Division, Santa Clara, CA. INFO/CARD #174.**

Crystal Filters and Oscillators Brochure

PTI introduces a 16-page brochure on its line of crystal filters and oscillators. The monolithic and discrete filter line includes linear phase and spectrum clean-up filters and phase/amplitude matched filter sets. A line of ovenized, temperature compensated and voltage controlled oscillators is featured. **Piezo Technology, Inc., Orlando, FL. INFO/CARD #157.**

Short Form Catalog

Available from Krohn-Hite is a short form catalog that highlights their line of amplifiers, distortion analyzers, filters, function generators, oscillators and phasemeters. **Krohn-Hite Corporation, Avon, MA. INFO/CARD #172.**

Microwave Detector/Limiter Brochure

The 28 page brochure presents information on TRW's planar tunnel diode detectors, Schottky diode detectors and limiters. Included are specifications, performance curves, outline drawings, application information and a detector selection guide. **TRW Microwave, Inc., Sunnyvale, CA. INFO/CARD #171.**

RF Selector Guide

Motorola's 4th edition RF selector guide features product categories which include RF power TMOS FETs, RF power bipolar transistors, RF small signal transistors, bipolar NPN/PNP transistors and hybrid amplifiers. The guide also includes a section on recommended lineups to achieve output power levels required in many typical applications. **Motorola, Inc, Phoenix, AZ. INFO/CARD #170.**

Crystal Oscillator Catalog

It features AT-cut quartz crystals from 5 MHz to 150 MHz and crystal oscillators up to 1 GHz. Oscillators are available in temperature compensated (TCXO), ovenized (OCXO) and voltage controlled (VCXO) designs. **EG&G Cinox, Cincinnati, OH. INFO/CARD #169.**

Application Note for EMI Measurement

An application note entitled Broadband Correction Factors is available from Eaton Corporation. It reviews the differences between narrowband and broadband signals, the relationship of bandwidth to measurement levels when measuring different types of signals, and tips for converting measurements from one bandwidth to another bandwidth when doing MIL-STD 461 testing. **Eaton Corporation, Electronic Instrumentation Division, Los Angeles, CA. INFO/CARD #168.**

rf literature *Continued*

EMI Shielding Handbook

The EMI shielding engineering handbook offers solutions to electronic packaging problems. In addition to Chomerics line of shielding products (conductive elastomers, wire mesh gasketing, conductive compounds, cable shielding products, shielded ventilating panels, shielded windows, engineered laminates, and thermal interface materials), the handbook includes a section devoted to value and risk, specification control, quality acceptance criteria, and corrosion prevention. **Chomerics, Inc., Woburn, MA. INFO/CARD #163.**

Vector Modulation Applications

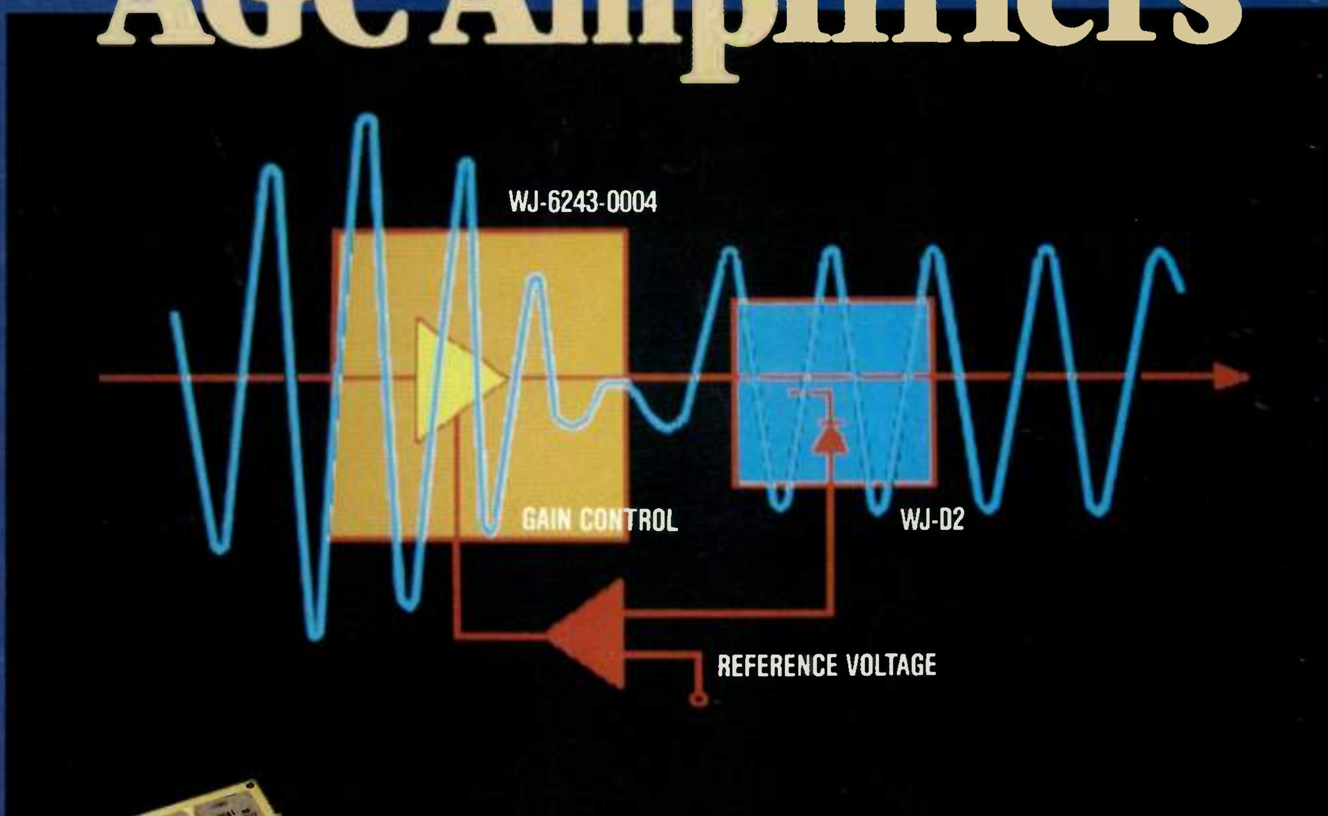
Coherent Pulsed Tests for Radar and EW Systems is an application note that describes methods for testing the microwave and IF portions of equipment using vector modulation equipment and principles. It covers vector fundamentals, basic receiver tests, AM-PM and AM-AM considerations and standard tests for complex signal processors. **Hewlett-Packard Company, Palo Alto, CA. INFO/CARD #173.**

SMT Quartz Crystals Bulletin

This bulletin describes chemically milled miniature AT quartz crystals (10 to 30 MHz) for Pierce, Colpitts, and series oscillators. They are available in rugged, hermetically sealed miniature ceramic packaged with standard leads or with leadless contact for surface mounting by vapor phase, infrared solder or wave soldering at 260 C for 20 secs. **ETA Industries, Inc., New York, N.Y. INFO/CARD #161.**

Ad Index

AGC Amplifiers



- High Gain
- Wide Attenuation Range
- Available in MULTIPAC™ Housings With and Without Connectors

AGC Amplifiers (Guaranteed at +25°C)

Frequency (MHz)	Model	Description	Gain[1] (dB) (Min.)	Noise[1] Figure (dB) (Max.)	Power[1] Output at 1-dB Comp. (dBm) (Min.)	Attenuation Range (dB) (Typ.)	3rd-Order[1] Intercept Point (dBm) (Typ.)	VSWR In/Out (Max.)	DC Volts (Nom.)	DC mA (Typ.)
5-500	6243-0001	G1/RA89/G1	20.0	7.5	+17.5	50	+15	2:1	15	169
	6243-0002	RA89/G1/RA89	47.5	5.0	+20.0	25	+20	2:1	15	293
100-2000	6243-0003	G30/RA36/G30	15.0	10.5	+8.0	40	+15	2:1	15	105
	6243-0004	RA36/G30/RA36	40.5	7.0	+11.5	20	+19	2:1	15	180
1000-2000	6243-0010	G30/RA43/G30	11.0	9.5	+6.0	40	+16	2:1	15/5	20/155
1000-4000	6243-0005	G40/RA43/G40	11.0	9.5	+6.0	40	+16	2.2:1	15/5	24/155
	6243-0006	RA43/G40/RA43	32.5	6.0	+9.5	20	+19	2:1	15/5	12/140

Note: 1. Low-loss state.

For more information on these excellent products, contact the Watkins-Johnson sales office in your area or telephone Components Applications Engineering in Palo Alto, California at (415) 493-4141.

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