Electronics World

APRIL, 1969
60 CENTS

SPECIAL ISSUE

STEREO VERSUS THE CONCERT HALL
IONOSPHERIC-PROPAGATION PREDICTIONS
NEONS IN PHOTOCONDUCTIVE CHOPPERS

FILTERS

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Bare copperweld; 2 conductors parallel, polyethylene jacket with inert gas filled unicellular polyethylene core.

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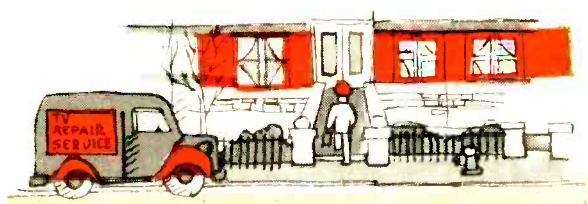

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18 Solid, Bare	Black	.242	78%	17.3	50 100 200 300 400 500 600 700 800 900	1.5 2.1 3.1 3.8 4.5 5.0 5.5 6.0 6.5 6.9	100', 500', 1000' spools.

Don't forget to ask them what else needs fixing.

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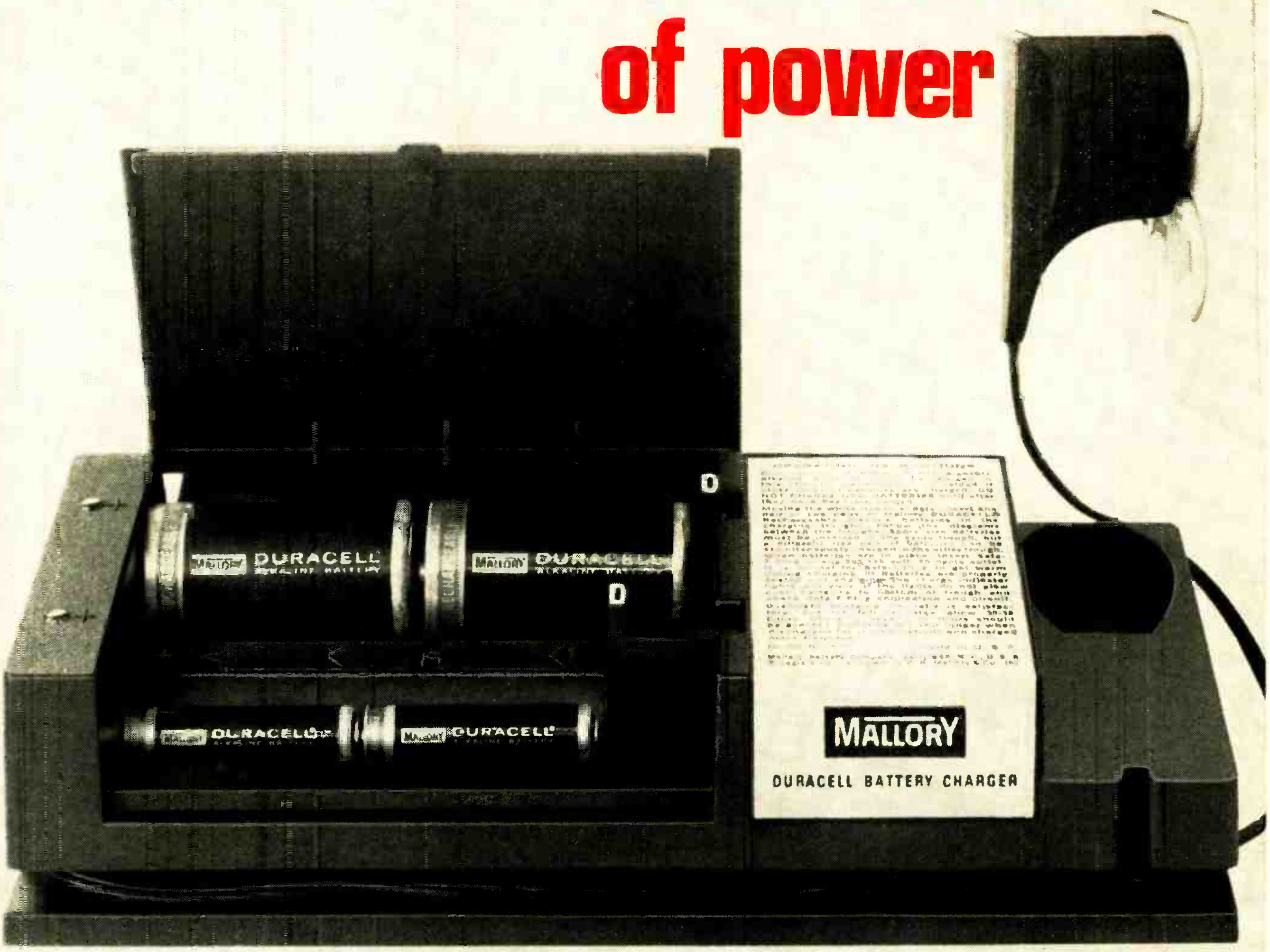
CIRCLE NO. 119 ON READER SERVICE CARD

The restoration of power



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CIRCLE NO. 96 ON READER SERVICE CARD

THIS MONTH'S COVER shows a few of the numerous filter types examined in this issue's Special Section. The LC audio filter (left) made by ESC Electronics Corp. has a 20-kHz center frequency and 20% bandpass. Damon Engineering supplies the 4-resonator crystal filter (center) to the Navy for their Talos guided missile system. The nineteen-element S-band interdigital bandpass (bottom) by Microlab/FXR is used in ECM systems while the Collins Radio mechanical filters and Clevite's ceramic filter (top center and right) are used in military radio sets to provide secure communications. In sensitive equipment, engineers often use Sprague RFI/EMI filters (right) to pass signals through a chassis. The Linear Networks low-pass filter also has many uses. Photo by Dirone Denner.

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Electronics World

APRIL 1969 VOL. 81, No. 4

CONTENTS

MONTHLY FEATURES

Electronics World: Published monthly by Ziff-Davis Publishing Company at 307 North Michigan Ave., Chicago, Illinois 60601. One year subscription $6.00. Second Class Postage paid at Chicago, Illinois and at additional mailing offices. Subscription service and Forms 3579: Portland Place, Boulder, Colorado 80302.

COMING NEXT MONTH

SPECIAL FEATURE ARTICLE:

RADIO MIRRORS

A big problem with active repeater stations has been reliability and maintenance costs. But passive repeaters, in many instances, do the same job cheaper with a whole lot more constancy. In many areas, radio mirrors are being used by telephone companies to carry voice and data. Our lead article goes beneath the surface to discover why this is as it is.

DOLBY NOISE-REDUCTION SYSTEM
Learn what audio engineers are doing to obtain quieter master tapes with greater dynamic range than ever before.

FORD'S NEW SPEED CONTROL
An electronic memory and computer keeps '69 Fords cruising at any desired speed.

SELECTING A TAPE RECORDER
Know what's required for a really efficient tape recorder? This article lists specifications for buyers who want the most for their money.

ATOMIC RADIATION
The first of a series of articles on what radioactivity is all about. The author explores atomic structure and shows how radioactive isotopes are formed.

DIGITAL IC TIMER
If you really want accurate timing, you need an electronic timer; and the newest timers are made with IC's. This article tells how they can be made more reliable at less cost.

All these and many more interesting and informative articles will be yours in the May issue of ELECTRONICS WORLD . . . on sale April 17th.

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CIRCULATION OFFICE
Portland Place, Boulder, Colorado 80302

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SUBSCRIPTION SERVICE: Forms 3579 and all subscription correspondence should be addressed to Electronics World, Circulation Department, Portland Place, Boulder, Colorado 80302. Please allow at least six weeks for change of address. Include your old address, as well as new—enclosing if possible an address label from a recent issue.

EDITORIAL CONTRIBUTIONS must be accompanied by return postage and will be handled with reasonable care; however publisher assumes no responsibility for return or safety of art work, photographs, or manuscripts.

ELECTRONICS WORLD (April, 1969, Vol. 81, No. 4). Published monthly at 307 North Michigan Avenue, Chicago, Illinois 60601, by Ziff-Davis Publishing Company—also the publishers of Airline Management and Marketing, Boating, Business & Commercial Aviation, Car and Driver, Cycle, Flying, Stereo Review, Modern Bride, Popular Electronics, Popular Photography, Skiing, Skiing Area News, and Skiing Trade News. (Travel Weekly is published by Robinson Publications, Inc., a subsidiary of Ziff-Davis Publishing Company.) One year subscription rate for U.S., U.S. Possessions, and Canada, $6.00; all other countries, $7.00. Second Class postage paid at Chicago, Illinois and at additional mailing offices. Authorized as second class mail by the Post Office Department, Ottawa, Canada and for payment of postage in cash.

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☐ ☐ ☐ 420-5/IC

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Address ____

City ____ State ____ Zip ____

☐ Check here if, in addition, you want to receive the Columbia 8-Track Tape Cartridge Player for only $19.95. Enclose your check or money order for $19.95 as full payment. (Complete satisfaction is guaranteed or your money will be refunded in full.) You'll be billed $5.95 for your first three cartridges (plus a mailing and handling charge), and you merely agree to purchase as few as twelve additional cartridges during the coming year at the regular Service price. (Be sure to indicate in the boxes above the three cartridges you want.)

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Signature ____

CIRCLE NO. 115 ON READER SERVICE CARD

news

Electronics Technicians . . .

need a broader base if they are to keep ahead of the game. Apparently, electronics in all types of industries is growing so rapidly that future technicians would fare better if their education were less specialized.

At a recent symposium on technological education, sponsored by the Frontiers of Science Foundation of Oklahoma, Patrick B. Lyons, General Manager of *Western Electric's* Oklahoma City Works, said, "We have a greater need for technicians and engineers who have a strong general theoretical foundation." He would like to see changes in education techniques which would produce a more "flexible" employee at the technician level. Behind it is the idea that broader-based technician training will keep employees from finding their jobs obsolete as technology advances.

Linear Device . . .

sales are exploding and will probably pass the moon on their way to a new high late this year. Previously, high development costs and poor markets for volume business have served to brake the push into the home entertainment market. But all that is in the past. Recently, the use of linear IC's has been cast in a new light. As an example of what a linear IC can do, consider *H. H. Scott's* new stereo receiver for which *Motorola* integrated all of the multiplex section with a monolithic signal demodulator (ELECTRONICS WORLD, Feb. 1969, page 34). The tiny chip replaces a 3 × 5 inch PC board. A *Motorola* IC preamp is also used in the set, along with other IC's in the i.f. strip and tuning indicator.

As it looks now, new linear IC designs will soon play as big a role in the entertainment electronics market as discrete semiconductors do now. In fact, the semiconductor industry has indicated its willingness to develop circuits which can meet the general requirements of specific equipment.

By the way, *Motorola* and *Scott* have an agreement which bottles up the supply of the *Motorola* IC demod for six months. After that, the monolithic chip is supposed to be available to all comers for about $3 apiece.

When Intelsat 3 . . .

achieved synchronous earth orbit over the Atlantic, it made it possible to lower tariffs for overseas television transmission. Accordingly, the *Communications Satellite Corp. (Comsat)* has asked the FCC for permission to lower rates by 40 percent and to eliminate extra charges for color-TV. By reducing rates, they expect to double the volume of transatlantic television.

To illustrate the magnitude of the reduction, *Comsat's* present 10-minute initial period charge for a television transmission (video and audio) on the United States-to-Europe routes is $1100 for a black-and-white transmission and $1375 for a color transmission. Under the proposed new rates, the charge would be $660 for either black-and-white or color. For each additional minute the charge is $30 for black-and-white and $37.50 for color. The proposed new charge is $18 for either.

What do all these rate changes mean to the American consumer? Well, it could mean better programs with more of the best in European art and theater being shown. It'll also make it easier for them, the Europeans, to take in our cultural and athletic endeavors.

Incidentally, as this column was written, two communications satellites were launched and orbited—one commercial and one military. The successful orbiting of the commercial satellite over the Pacific probably means that *Comsat* will press the FCC for similar rate reductions. The military satellite is to test a tactical system that would link units in the field and on ships and aircraft.

Radioteleprinters . . .

may one day be standard equipment in police cars of many major cities. For some time the City of Miami Police Department has been experimenting with a new radioteleprinter under a special permit from the FCC. So far, the FCC has poked along trying to figure out how to best regulate mobile radioteleprinters. Meanwhile, many interested law enforcement agencies, state communications advisory boards, and industry associations have been smothering the FCC with memoranda saying how much they like the system.

In many big cities, there are times when so many police radio transceivers are on the air that reception is garbled and difficult. Teleprinters cut the "time" needed for long involved descriptive transmissions and eliminate errors in copying the information or the necessity for repeating the message if the officer should be out of the vehicle at the time it was first sent.

At present, the FCC has restricted teleprinters to 10 pairs of channels in the 450-470 MHz band. Most potential users, however, are pressing for authorization to use teleprinters on all frequencies in all available bands. Conceivably. this would make installation of the system easier and less expensive.

Community Radio Watches . . .

get backing from big business, particularly *General Motors* and *Motorola Communications*. The radio watch program, which began in 1966, has become one of the country's largest and most widespread plans for encouraging citizen cooperation in the fight against crime. Nearly 700 cities and towns have adopted it. Over half the cities with populations over 100,000, including New York, Detroit, Chicago, Baltimore, Atlanta. San Francisco, and Washington, D. C., have enrolled.

In each city, the program is usually directed by the mayor who asks individuals and companies with two-way radio-equipped vehicles to act as eyes and ears for the police. In most cities, drivers observing accidents, fires, crimes in progress, suspicious persons, etc. report to their base stations who, in turn, notify the appropriate authority by telephone. In Detroit, the CB Radio Driver Aid Network is equipped with *GM* mobile CB transceivers. Network drivers patrol the Lodge Freeway and report, through remote receivers located in strategic spots, to a single base station.

At present, over 46,000 business firms are participating in Community Watch programs, keeping a quarter of a million drivers on the alert for real or potential trouble. Being so short of men, most police departments welcome the help. It fills in many of the gaps caused by lack of personnel. All without cost to the taxpayer.

Welding . . .

has been lifted from the realm of "just another craft" to a fine-art status by the telescoping size of electronic components. First, tungsten-inert gas welding (TIG) was developed in the 1940's for working with hard-to-weld materials such as aluminum and magnesium. Then the plasma needle arc-welding technique came along. This method was particularly useful for welding printed-circuit boards and transistor elements. Of course, the latest method to find favor is the laser welding system.

Two improved arc-welding systems have recently been developed by *Air Reduction* and the *Linde Division* of *Union Carbide*. The *Airco* system, called "Pulsed-Arc 3," operates at either 60 or 120 pps at variable pulse widths of 0.8 to 5 milliseconds. According to the company, control of pulse width and frequency makes it possible to obtain high-quality welds on thin stock at low amperage.

The *Union Carbide* system is a 100-amp plasma needle arc type which is capable of TIG and stick electrode welding. Initially developed for welding pieces 0.001 to 0.050 inch thick, it can also work with materials up to 0.125 inch thick.

Some Thoughts . . .

about things going on. . . . *RCA* has set up a new hybrid microelectronics laboratory in Van Nuys, Calif. to assist its engineers in designing advanced electronics warfare systems, military aviation equipment, and other product lines. . . . Electronic Industries Association says semiconductor sales were up 40% in 1968. . . . Europe's newest and largest space link went into operation early this year. Goonhilly 2 was built by *The Marconi Company* for the British Post Office. It can carry up to 400 telephone circuits and a television program simultaneously. Operating through the Atlantic Intelsat 3 satellite, it carries more traffic than all the translantic cables and the original Goonhilly space link put together. . . . Fluidics promises to be a cheap substitute for electronics in many jobs. . . . *Radiation Inc.* of Melbourne, Fla. claims that its display of radiation-hardened IC's shown at the IEEE Convention were the first commercially available. . . . The State Department and the Electronic Industries Association joined in protesting the common electronic component and equipment standards being drawn up by Great Britain, France, and West Germany. They fear the new standards could mean a reduction of almost 35% in American electronics exports to those countries. . . . A recent study by the Engineering Manpower Commission (Engineers Joint Council) showed small companies most likely to have engineers in top R & D spots. . . . Last of the XB-70 super-bombers is safely tucked away in the Air Museum at Wright-Patterson Air Force Base. The 2000 mi/h research plane was crammed full of sensitive electronic gear up to the very end, measuring clear air turbulence and doing stress analysis. ▲

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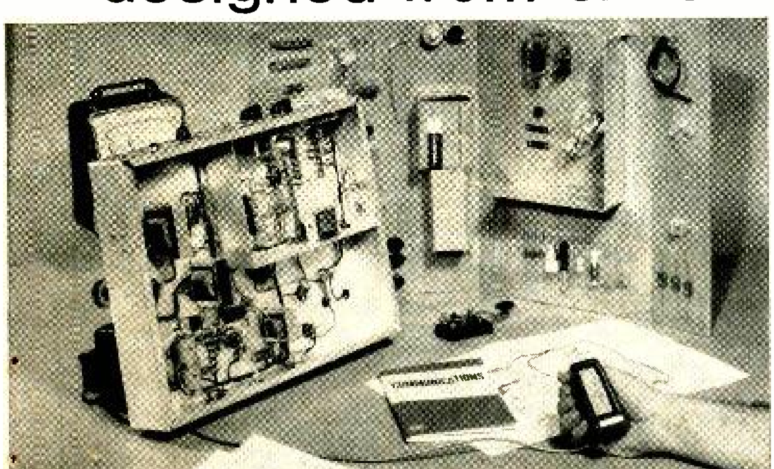

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CIRCLE NO. 82 ON READER SERVICE CARD

By FOREST H. BELT /Contributing Editor

Color-TV in the News

You'd think something as well established and old-hat as color television would quit making news. But popularity and continued growth keep things alive. More than 20 million homes now have color receivers —35% of the TV audience. By the end of 1970, it's safe to expect 50% or more of the U.S. television viewers to watch on color sets.

The market is changing, too. More portables are being built and sold now. The total number of color sets in use is rising faster than the number of homes with color. That bears out a recent statement by B. S. Durant, chairman of *RCA Sales Corp.*, that color-set owners buy second color sets much more quickly than they did their second black-and-white. Color-TV seems to be the only consumer instrument with a sizable second-unit market long before saturation of first purchases.

Checking Out the Consumer

The government isn't the only one examining what makes the American consumer tick. Two companies —*RCA Sales Corp.* and *Sylvania*—have announced studies of the buyer and user of entertainment goods. Conversation with officials of many firms discloses strong interest in how and why consumers buy these days. Changes in population distribution, in spendable income, in personal tastes, and even in the age of the major buying population—all affect sales and design trends for the next few months and years. Alert companies have always been sensitive to consumer likes and dislikes. Now, market tests and consumer research promise the buying public an even larger role in deciding next year's features.

This also opens up an avenue of influence for the service technician; he is a front-line contact with the home-entertainment consumer, and most manufacturers realize it. More and more set-buyers are sensitive to servicing and repair costs and availability; technicians can help or hinder the reputation of a set-maker by saying how easy (or not) a model is to service.

Down with the FCC!?

The Federal Communications Commission reaps its share of abuse (some commissioners and staffers think it gets more than its share). Now a series of bills, introduced by Representative John Dingell of Michigan, is aimed at drastically changing or entirely abolishing the FCC. The mildest of the bills, H.R. 3059, suggests the Commerce Department study the functions of the Commission and make suggestions to Congress. Another bill recommends the FCC, which is an independent agency, be put into the Commerce Department. The tough bill, H.R. 3058, wants to eliminate the FCC and establish three new agencies: one to regulate broadcasting; one to regulate common-carrier and satellite communications activities; and one to handle frequency allocations for all except safety and special services. Allocations for safety and special services would be made by the Transportation Department. To so fragment the duties of making sense of our already tangled communications setup doesn't sound much like improvement; the bureau or agency that developed the most powerful staff could easily hog the authority.

New Name for "Servicemen"

The men who repair the nation's home-entertainment electronics have gained another name. The National Alliance of Television and Electronic Service Associations suggests that they be called "electronicians." This is in connection with a revised and updated code of ethics each would-be NATESA electronician must subscribe to. Similar names have been made up in the past. Most recent that come to mind are "electronist" and "electronicist." Further back, the terms "radiotrician" and "teletrician" were used by graduates of *National Radio Institute*.

None of them caught on, mainly because they don't roll easily off the tongue. Repeated surveys of service people throughout the country have revealed an almost unanimous preference for "service technician" as a title.

NATESA announces another service. From now on, the association will accept complaints from customers of its members. If the association decides the member is at fault (a fellow member decides), he must pay for service needed to correct the complaint. If he doesn't pay the invoice, says Frank Moch, executive director of NATESA, his membership *can* (not *will*) be revoked. Any customer in error will be given an explanation. No promotion of the "NATESA Electronician Certification" program to the general public is foreseen; the word will be spread to customers by NATESA members.

Urethane Cabinets . . . To Come

A plastic you can hardly distinguish from wood will be turning up in next year's home-entertainment cabinets. It's urethane. It isn't less costly than wood, at least not yet, but it can be molded into imaginative shapes more easily than wood—and into many shapes wood can't even approach. First uses of urethane will look ordinary, but don't be surprised if some odd-looking designs creep into the lines late next year. Designers see a field day in possibilities, but of course they're limited to what the public will accept.

Service Technician Licensing

There's quite a bit of activity in legislatures regarding licensing of service shops or people. Consumer criticism is blamed for reviving efforts at licensing technicians in New York State. Similar bills have been defeated three times, and some proponents of the present bill voice little hope it will be passed this year.

New Jersey and Kansas have laws before the legislature, and one may have been introduced in Pennsylvania by press time. An important part of both bills is a provision for a written receipt giving the technician's name and address and an itemized account of parts used and labor performed. Most laws also provide for an examination to prove competence of technicians.

A bill in the Kentucky General Assembly failed to pass in 1968, but another is being readied for the 1970 session. And in Indiana, where licensing has been in effect since 1967, a repealer has recently been dropped into the legislative hopper.

TV From the Moon

It's fun to conjecture what will happen years hence in an industry that grows as rapidly as electronics. We've seen brief television from Apollo 8 near our only natural satellite—the Moon. Our first astronauts to land there in a few months will probably give us the first lunar TV origination. Is it possible they will leave behind, on some future trip, a device to make world-wide telecommunications easier?

An example: a corner reflector to collect and beam back laser rays efficiently. Bandwidth of a laser beam is exceptionally broad. A lot of TV and voice channels could, with critical aiming and timing, be transmitted using the moon as a space-located repeater. In later years, of course, similar facilities can relay transmissions to and from the deeper reaches of space.

Electronics from Elsewhere

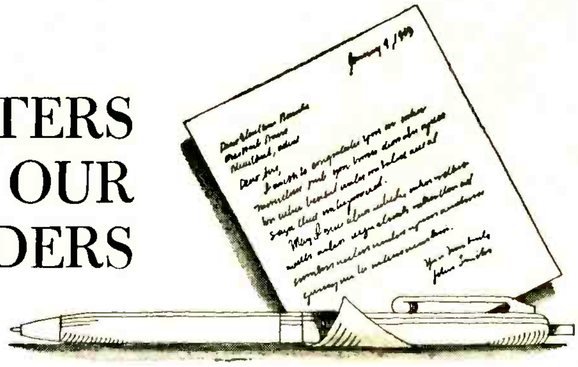
Of the $5-billion worth of consumer electronics equipment bought in the United States last year, about $500-million worth came from other countries. Most of it was from Japan. Despite "dumping" charges (selling in the U.S. cheaper than at home), as yet unproven, imports of Japanese equipment will probably rise significantly this year. Chief import expected to boom in 1969 is color-TV; imports of color sets doubled last year. This year's parade may be led by *Sony's* color set with the Trinitron CRT. All this is in spite of a TV-set price hike by Japanese manufacturers.

Less than 10% of consumer electronic imports come from countries other than Japan. Taiwan ships quite a few black-and-white sets to this country, and the number will grow as U.S.-owned plants there continue raising production. Canada sends in car radios under a duty-free trade provision. Hong Kong is a source of thousands of low-cost AM transistor radios. Mexico has begun making sets for U.S. consumption, and is sure to make more as facilities are completed.

Flashes in the Big Picture

Computer helped *Admiral* develop color picture tube for 11-inch portables; claim resolution far better than that of present color CRT's. . . . Federal Trade Commission says number of solid-state devices cannot be used in advertising transistor radios unless the number refers to working transistors; demands schematics for proof; prohibits parallel transistors from being counted as more than one. . . . South Africa gets TV by 1972. . . . Congress is again considering bill (H. R. 2113) requiring all radios shipped in interstate commerce to be AM-FM. . . . *Sylvania* still hasn't found any rush to buy its quick-warmup 12-inch black-and-white CRT for solid-state TV sets. . . . National Electronic Associations plans July 23-27 convention is Waterbury, Conn.; judging from past, it is a grand affair for service technicians *and families.* ▲

LETTERS FROM OUR READERS



OUR JANUARY ISSUE

To the Editors:

The "New Approach to Color-Organ Design" in the January, 1969 issue comes with great relief and a hearty welcome from some of us audiophiles. There is no better or cheaper way to obtain frequency discrimination than by feedback. How come nobody thought of it before? Many thanks to Engineer J. J. Powell and to ELECTRONIC WORLD.

ANTHONY ROCCO
Bonita Springs, Fla.

To the Editors:

I am writing to commend you and Mr. Don Steinbach for his recent articles on "IC Frequency Dividers and Counters" in the Dec. and Jan. ELECTRONICS WORLD. These two articles were very well written and easy to understand.

BOB SHAW
Garland, Texas

* * *

RFI DUE TO C-D IGNITION

To the Editors:

I have recently installed Citizens Band radios in a 1965 *Corvair* and a 1967 *Pontiac*. In both cars the use of a *Delta* Mark 10 C-D system *reduced* ignition interference by a significant amount. In fact, this was the only reason for putting one on the *Corvair*. There was an increase of noise noticed in the broadcast radios of both cars. However, this is noticed at high gain settings for distant stations; it does not interfere with local stations so no attempt has been made to correct this.

HARRY H. WADE, JR.
Huntsville, Alabama

To the Editors:

I have used a *Delta* Mark Ten C-D ignition for four years in a 1964 *Chevelle* 283, and for two years in a 1966 *Olds* Cutlass 330, with trouble-free and excellent engine performance. However, the addition of the C-D system definitely increased ignition noise in the AM radios of both cars.

The *Olds* Cutlass is also equipped with a CB radio and a v.h.f. receiver. The CB radio, particularly, was seriously degraded. I made some improvement by incorporating resistor-type spark plugs in addition to the standard *GM* resistor-type harness. However, even with these provisions, the CB squelch circuit is inoperative and clear-channel range to my base station is degraded.

CORWIN A. HANSEN
Kensington, Md.

To the Editors:

In reference to your query in the December "Letters" column about RFI from C-D ignition systems, I had that very problem.

I built and installed my own C-D system in my '66 *Ford* and found RFI on the broadcast radio. I proceeded to run separate ground braids from the engine block, exhaust pipe, muffler, and tail pipe to the car body. This cured it completely.

The exhaust system, being held by clamps in rubber, apparently acted as an antenna.

VIC HENDERSON
Toronto, Ont.

From the letters we have received, the installation of a C-D system sometimes increases ignition interference but sometimes reduces it, especially on non-broadcast-band AM receivers. In any case, it appears that the usual grounding and shielding interference-suppressing techniques that have always been recommended for ignition interference work equally well with C-D or standard systems.—Editors

* * *

DIFFERENTIAL TRANSFORMERS

To the Editors:

While I find most of the articles in ELECTRONICS WORLD interesting, the one by Mr. Silver on "Differential Transformers" in the December, 1968 issue was particularly so because of possible application in my business. The only problem is that there was no list of manufacturers whom I could contact for specs, prices, etc. From another publication, I have learned that the *Lockheed Electronics Company* and *Schaevitz Engineering* supply these devices, and if you could send me the names and addresses of a few more it would be appreciated.

In Fig. 13 of this article, the author shows a matched pair of differential transformers in a null-balance circuit with the core of one transformer connected to motion to be measured and the core of the other to a servomotor. As a somewhat less sophisticated approach, wouldn't it be feasible to connect one element of a single transformer, say the core, to the motion to be measured and the case containing the coils to a servomotor?

Incidentally, I believe the circuit shown in Fig. 12 is in error and that the junction between the two capacitors should be connected to the junction of the two secondary coils rather than to the anode of one of the rectifiers.

D. P. McIntire
Asst. Director, Quality Control
U. S. Pipe & Foundry Co.
Birmingham, Ala.

Dear Mr. McIntire:

In response to your inquiry concerning my article, I have listed below several manufacturers of these devices.

Gulton Industries
2524 Wyandotte Rd.
Willow Grove, Pa.

Pickering & Co., Inc.
101 Sunnyside Blvd.
Plainview, N. Y.

Bourns, Inc.
Instrument Div.
6135 Magnolia St.
Riverside, Cal.

With regard to your comments on the null-balance system shown in Fig. 13, it is perfectly feasible to operate a single differential transformer as a null-seeking device. In this approach, the two secondary coils are connected in series-aiding to form a bridge circuit with a potentiometer. As the sensing core is moved from the null position, a voltage is fed to the amplifier and the servomotor adjusts the pot wiper to a new null position. However, the disadvantage of this circuit is that the resolution is not as good as the two matched differential transformers described in the article.

Finally, I would like to thank you for pointing out the error in the diagram of the demodulator circuit shown in Fig. 12.

Sidney L. Silver, Engineer
United Nations-Telecom. Sect.
New York, N. Y.

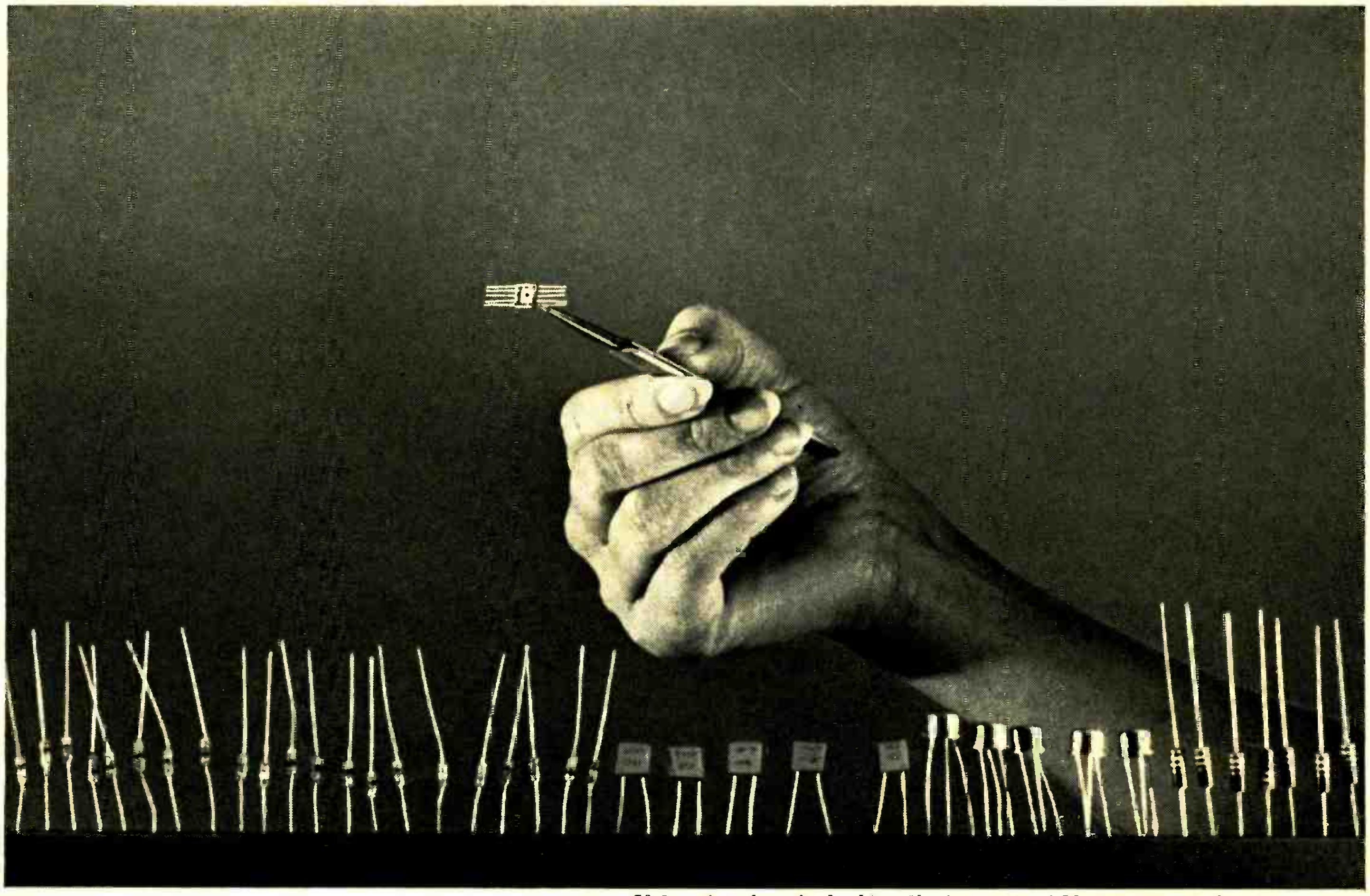
* * *

ELECTRONIC INTRUSION ALARMS

To the Editors:

We read your very interesting and timely articles recently concerning electronic intrusion alarm systems. While your listing of manufacturers was fairly complete, it omitted mention of our firm. We produce "Burgatel" telephone alarm reporting systems.

John L. Menke, Pres.
Technical Innovations
Barnesville, Md. 20703 ▲



50 functions in a single chip. *The functions of 50 separate transistors, diodes, resistors and capacitors can now be performed by the tiny dot in the center of the integrated circuit held by the tweezers.*

The "Chip" ...will it make or break your future job?

THE DEVELOPMENT OF INTEGRATED CIRCUITRY is the dawn of a new age of electronic miracles. It means that many of today's job skills soon will be no longer needed. At the same time it opens the door to thousands of exciting new job opportunities for technicians solidly grounded in electronics fundamentals. Read here what you need to know to cash in on the gigantic coming boom, and how you can learn it right at home.

TINY ELECTRONIC "CHIPS," each no bigger than the head of a pin, are bringing about a fantastic new Industrial Revolution. The time is near at hand when "chips" may save your life, balance your checkbook, and land a man on the moon.

Chips may also put you out of a job ... or into a better one.

"One thing is certain," said *The New York Times* recently. "Chips will unalterably change our lives and the lives of our children probably far beyond recognition."

A single chip or miniature integrated circuit can perform the function of 20 transistors, 18 resistors, and 2 capacitors. Yet it is so small that a thimbleful can hold enough circuitry for a dozen computers or a thousand radios.

Miniature Miracles of Today and Tomorrow

Already, as a result, a two-way radio can now be fitted inside a signet ring. A complete hearing aid can be worn entirely inside the ear. There is a new desk-top computer, no bigger than a typewriter yet capable of 166,000 operations per second. And it is almost possible to put the entire circuitry of a color television set inside a man's wristwatch case.

And this is only the beginning!

Soon kitchen computers may keep the housewife's refrigerator stocked, her menus planned, and her calories counted.

Money may become obsolete. Instead you will simply carry an electronic charge account card. Your employer will credit your account after each week's work and merchants will charge each of your purchases against it.

When your telephone rings and nobody's home, your call will automatically be switched to the phone where you can be reached.

Doctors will be able to examine you internally by watching a TV screen while a pill-size camera passes through your digestive tract.

New Opportunities for Trained Men

What does all this mean to someone working in Electronics who never went beyond high school? It means the opportunity of a lifetime—if you take advantage of it.

It's true that the "chip" may make a lot of manual skills no longer necessary.

But at the same time the booming sales of articles and equipment using integrated circuitry has created a tremendous demand for trained electronics personnel to help design, manufacture, test, operate, and service all these marvels.

There simply aren't enough college-trained engineers to go around. So men with a high school education who have mastered the fundamentals of electronics theory are being begged to accept really interesting, high-pay jobs as engineering aides, junior engineers, and field engineers.

How To Get the Training You Need

You can get the up-to-date training in electronics fundamentals that you need through a carefully chosen home study course. In fact, some authorities feel that a home study course is the best way. "By its very nature," stated one electronics publication recently, "home study develops your ability to analyze and extract information as well as to strengthen your sense of responsibility and initiative." These are qualities every employer is always looking for.

If you do decide to advance your career through spare-time study at home, it makes sense to pick an electronics school that specializes in the home study method. Electronics is complicated enough without trying to learn it from lessons designed for the classroom instead of correspondence training.

The Cleveland Institute of Electronics has everything you're looking for. We teach only Electronics—no other subjects. And our courses are designed especially for home study. We have spent over 30 years perfecting techniques that make learning Electronics at home easy, even for those who previously had trouble studying.

Your instructor gives your assignments his undivided personal attention. He not only grades your work, he analyzes it. And he mails back his corrections and comments the same day he gets your lessons, so you read his notations while everything is still fresh in your mind.

Always Up-to-Date

Because of rapid developments in Electronics, CIE courses are constantly being revised. Students receive the most recent revised material as they progress through their courses. This year, for example, CIE students are receiving exclusive up-to-the-minute lessons in Microminiaturization, Logical Troubleshooting, Laser Theory and Application, Single Sideband Techniques, Pulse Theory and Application, and Boolean Algebra. For this reason CIE courses are invaluable not only to newcomers in Electronics but also for "old timers" who need a refresher course in current developments.

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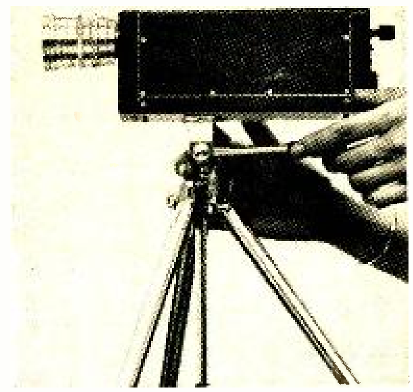
Tiny TV camera *for space and military use is one of the miracles of integrated circuitry. This one weighs 27 ounces, uses a one-inch vidicon camera tube, and requires only four watts of power.*



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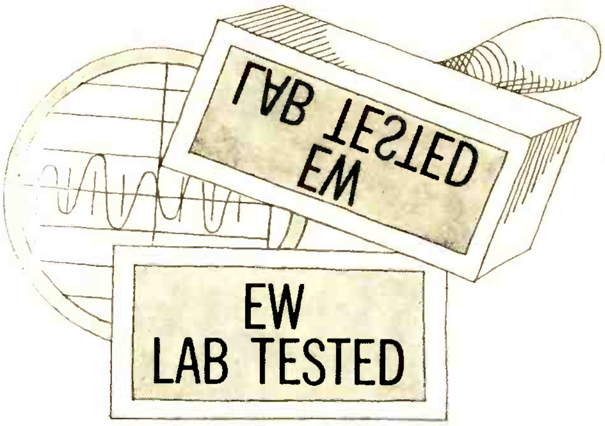


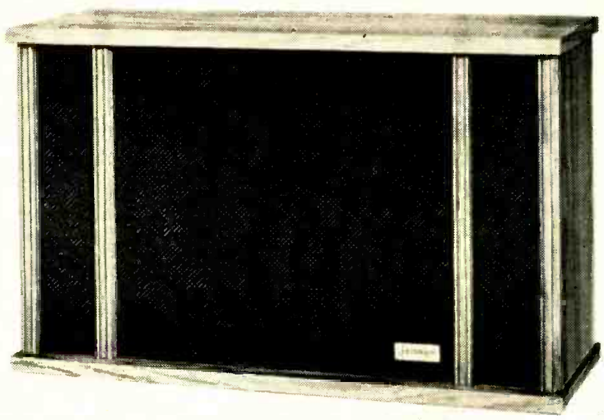
HI-FI PRODUCT REPORT

TESTED BY HIRSCH-HOUCK LABS

Jensen TF-25 Speaker System
Allied TR-1080 Stereo Tape Recorder

Jensen TF-25 Speaker System

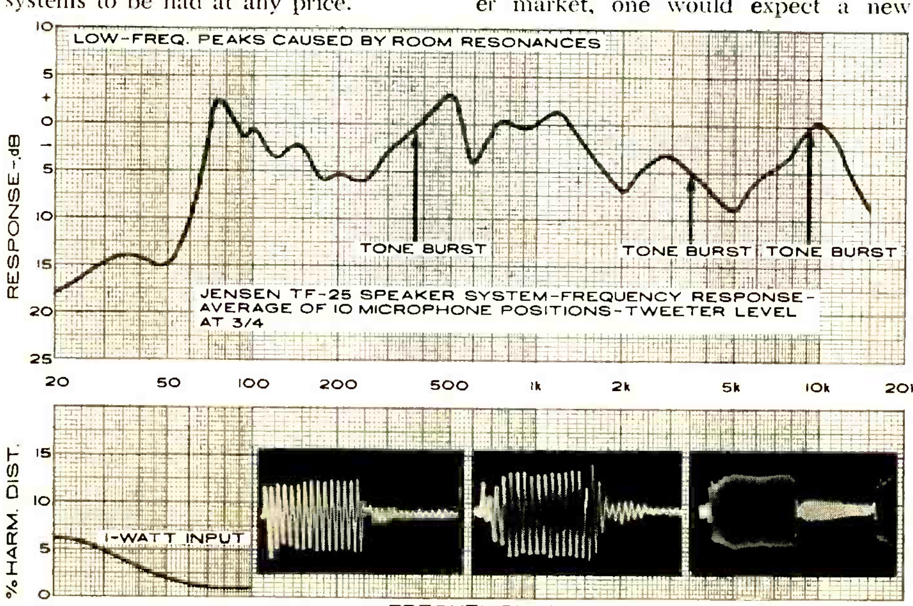
For copy of manufacturer's brochure, circle No. 18 on Reader Service Card.



ONLY a few years ago, speaker systems tended to be priced in two or three distinct classes. Under $50 were a few speakers which claimed high-fidelity qualities, but were usually seriously deficient, usually in low-frequency performance. In the $100 to $130 class were numerous truly high-quality systems, which have always enjoyed wide popularity. The next jump was to the $200 to $250 bracket, which encompassed some of the finest speaker systems to be had at any price.

Gradually, the price barriers have been breached, and we now find a number of excellent speakers in the $50 to $60 class, others between $80 and $90, several in the vicinity of $175, and an increasing number from $250 to $300.

Jensen, long one of the major speaker manufacturers, has naturally kept up with this trend, and has recently entered the $90 price class with its Model TF-25. In the highly competitive speaker market, one would expect a new entry to offer something special in the way of performance. The manufacturer's advertising copy for the TF-25 emphasizes its performance rather than its price, with the glowing adjectives one has come to expect in such advertising. We were, naturally, quite curious to discover for ourselves what the TF-25 could do.



This is a true bookshelf system, by virtue of its 8⅝-inch depth and weight of approximately 22 pounds. The walnut cabinet is 22½ inches wide and 14 inches high, and is styled about as attractively as can be, within the limitations of the bookshelf format. Within it is a 10" high-compliance woofer, with a free-air resonance of 25 Hz and an 8-ohm impedance. Above 3000 Hz, a horn-loaded tweeter takes over. A continuously adjustable control in the rear varies tweeter level from "off" to maximum, and should be set to suit the user's taste. (There is no indication of a "normal" setting.) We found the best balance to be with the control about ¾ advanced.

With the TF-25 mounted on a shelf as in a typical installation, we measured the frequency response at ten locations in the room and averaged the data to obtain a single curve. The response was ±6 dB from 60 to 15,000 Hz, and was quite free from sharp peaks or dips. A slight improvement in apparent flatness could have been made by fully advancing the tweeter level control, but this sounded a bit too bright to our ears. At any rate, the range of adjustment is more than sufficient to suit any need.

The most interesting characteristic of the TF-25 response curve was its sudden drop below 70 Hz. Below 50 Hz, the output was insignificant. However, the low-frequency distortion was exceedingly low (at a 1-watt drive level), amounting to less than 2% at 50 Hz and only 6% at 20 Hz. The latter was at a sub-audible, but measurable, level.

If the low-frequency output fell off more gradually, it could have been compensated to some degree with tone controls, since there was absolutely no tendency for the speaker to break up

or distort when it was "pushed." However, in most cases, we believe that the low frequencies can only be aided by room characteristics and correct speaker placement.

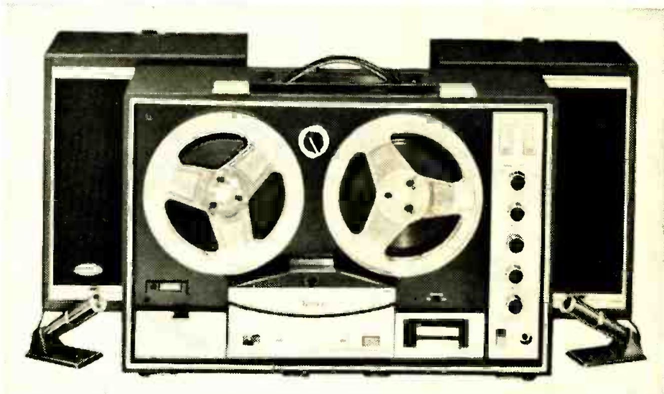
The tone-burst response was good at all frequencies. There was some ringing visible but not to a disturbing extent. Few speakers in the price class of the TF-25 can do better.

Listening tests provided a pleasant confirmation of our measurements. The speaker has a balanced, uncolored sound which can be listened to for hours without fatigue. Interestingly enough, it never seems "bass-shy", but rather has a solid, non-boomy bottom-end response. This is logically explained, since there is little musical program content below 60 Hz, and its output is exceptionally strong and uniform down to that frequency, as well as almost totally free from distortion at normal listening levels.

Our conclusion is that *Jensen* has hit its target squarely with the TF-25. Rereading the advertisements in the light of our experience with the speaker, we can only agree with their statements and claims. TF-25 sells for $89.50. ▲

Allied TR-1080 Stereo Tape Recorder

For copy of manufacturer's brochure, circle No. 19 on Reader Service Card.



ONE of the inconveniences of quarter-track reel-to-reel tape as a medium for home music reproduction is the need to remove and interchange the reels at the mid-point, in order to play all four tracks. Although this is equivalent to turning over a record to play the reverse side, it normally takes considerably more time and on some recorders can be an awkward procedure.

A number of tape recorders have solved this problem, at least during playback, by automatic-reversal systems. These operate on several different principles, such as by sensing an inaudible tone which the user records on the tape near its end, or by electrical contact with a conducting metal foil added to the tape at the point of desired reversal.

Most such recorders are designed to play tape in both directions and have duplicate playback heads which are switched into the circuit in accordance with the direction of tape travel. As a rule, they record only in the normal (left to right) direction, requiring manual interchange of reels at the halfway point while making a recording.

Anyone who has missed a vital portion of a recording while turning over tape reels will appreciate the new *Allied* TR-1080 automatic-reversing stereo tape recorder. The TR-1080 has duplicate recording heads as well as playback heads so that in a fraction of a second the tape can be reversed and recording continued without interruption. The reversal can be performed manually at the touch of a lever, at a pause in the program, so that not even a note will be lost. Subsequently, a piece of adhesive-backed metal foil can be attached to the tape at that point, and in future playing the reversal will occur automatically.

A slide switch on the recorder offers three modes of automatic operation. In "Auto Stop", the tape stops when the foil is contacted, at either end of the tape. In "Repeat", if the foil is installed at both ends of the tape, the tape will play completely through and repeat indefinitely. In "Auto Reverse", the tape plays in both directions and stops after one complete play.

Aside from its automatic-reversing feature, the TR-1080 is a versatile three-speed machine. All transport operation is solenoid-controlled, with two rocker-type switches for normal or fast speed in each direction. A red "Stop" button brings the tape to an instant halt. At normal speed, the tape direction can be changed instantly while recording or playing a tape, without affecting the mode of operation. Signal lights indicate the selected direction of tape travel, even while the tape is stationary. A "Pause" button, with instantaneous release, makes it a simple matter to delete undesired portions of a program from a recording. A speed-selector knob also switches equalization for the speeds of 7½, 3¾, and 1⅞ in/s.

Concealed behind a hinged door on the panel are the two microphone jacks and individual "Record" safety buttons for the two channels. In the rear of the recorder are the high-level "Aux" inputs and the line outputs, which are not affected by the playback volume or tone controls, and a pair of speaker jacks. The recorder is a portable machine, whose two detachable speakers are used as a cover. The cables supplied allow the speakers to be located up to eight feet from the recorder. A compartment in the rear of the recorder stores the input and output cables, speaker cables, line cord, and two dynamic microphones with detachable desk stands, all of these are supplied with the recorder.

The recorder contains two low-powered playback amplifiers, with bass and treble tone controls, and separate volume controls for the two channels. These volume controls also serve as recording level adjustments. A slide switch turns off the speakers while recording or when playing through an external amplifier and speakers. The program may be monitored with stereo headphones through a front-panel jack, even with the speakers turned off. The two recording level meters are illuminated when their respective channels are energized.

A four-position selector switch controls the playback mode, with full stereo operation, or either left or right channel played through both outputs. In its fourth position, the recorder is set up for sound-on-sound recording. Either channel may be copied onto the other, together with any added program material.

The specifications of the recorder proved to be generally very conservative. The over-all record/playback frequency response was rated at 30 to 19,000 Hz at 7½ in/s. We measured it as ±5 dB from 45 to 18,000 Hz. At 3¾ in/s, where the response was rated at 30 to 12,000 Hz, it was measured as ±4 dB from 60 to 11,800 Hz. At 1⅞ in/s the response was rated at 30 to 6000 Hz; it measured ±4 dB from 55 to 5200 Hz. *Scotch* 111 tape was used for over-all response measurements which were essentially identical on both channels and in both directions of tape travel. The playback response at 7½ in/s using the *Ampex* 31321-04 test tape, was +5, −1.5 dB from 50 to 15,000 Hz.

The wow and flutter were rated at less than 0.15% at 7½ in/s, 0.30% at 3¾ in/s, and 0.50% at 1⅞ in/s. The measured wow was 0.04% at 7½ in/s and 0.085% at 3¾ in/s. The flutter was 0.065% at 7½ in/s and 0.09% at

(*Continued on page* 64)

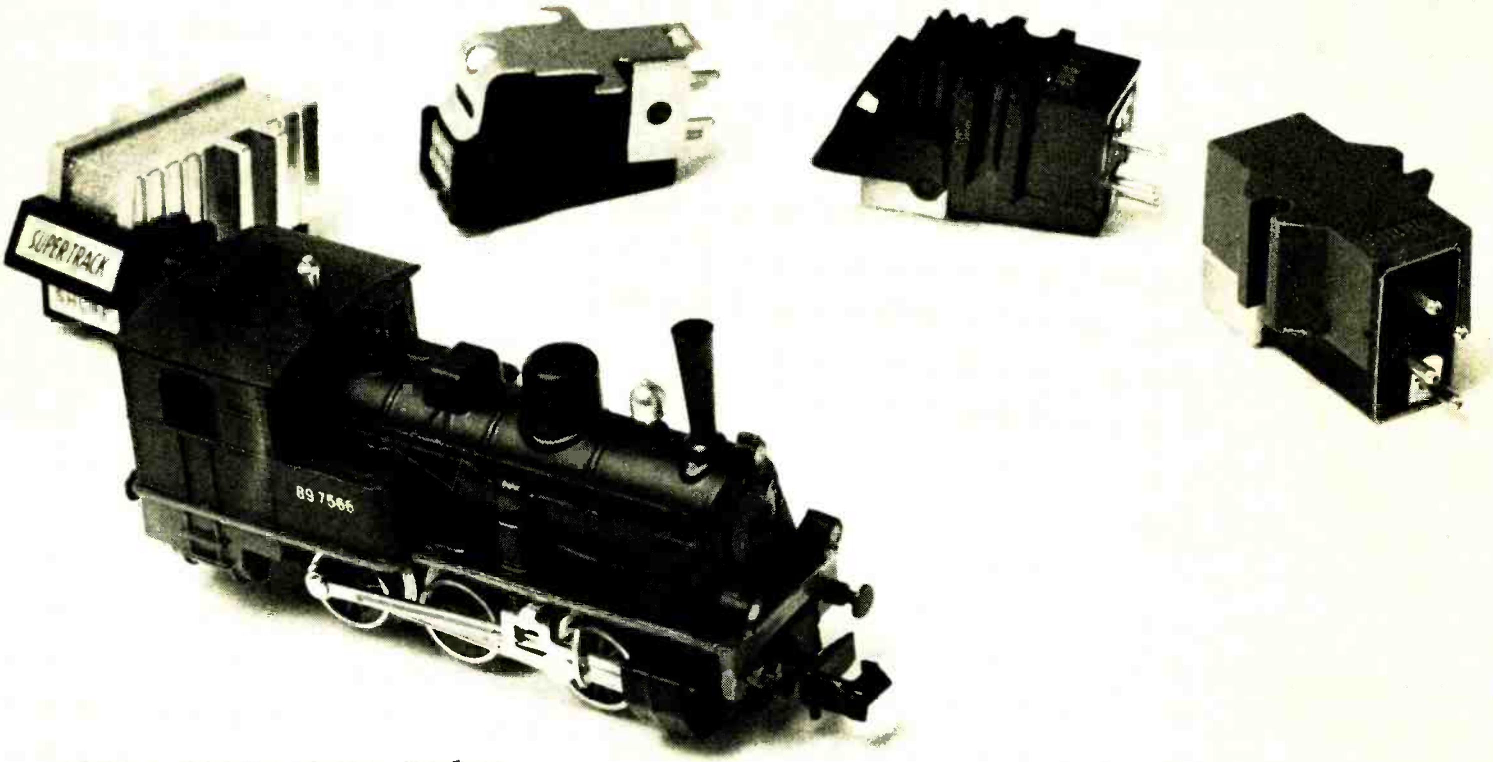


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Fig. 1. Groups of well-formed sunspots (arrows) photographed in February 1956 near the maximum of an 11-year cycle. Ultraviolet radiation during height of solar cycle is sufficient to produce highly ionized F_2 layer capable of supporting radio signals of frequencies up to 50-55 MHz.

IONOSPHERIC-PROPAGATION PREDICTIONS

By H. CHARLES WOOD

The quality of a long-distance communications system depends on the ability of the ionosphere to bend and reflect radio waves back to earth.

SOME radio waves penetrate the ionosphere and fly outward to the stars; others are stopped, bent, and reflected to touch the earth miles away from their origin. Propagation—the movement of electromagnetic (radio) waves through the air, or "ether" as it used to be called—is the means by which wireless communications systems communicate. The distance over which these waves travel is a function of frequency; angle of radiation; and atmospheric noise such as sunspots, aurora borealis, and other solar activity.

This article discusses the various phenomena which must be considered when predicting propagation distances.

Ground Wave and Sky Wave

Engineers agree that radio waves are electromagnetic waves consisting of traveling electrostatic and electromagnetic fields of energy whose lines of force are at right angles to each other in a plane perpendicular to its path. Except for frequency, the electromagnetic field has the same characteristics as light waves—both have a speed of 300-million meters per second, and both are capable of being refracted or reflected. Two types of electromagnetic waves are emitted by a transmitting antenna, one travels along the ground and is called the *ground wave*. The other, referred to as the *sky wave*, travels through the atmosphere and has little contact with the earth along most of its path.

At low frequencies (below 500 kHz), the ground wave is the most important, frequently traveling a thousand miles or more. In the broadcast band, ground waves are received 200 miles or more away over land and perhaps twice that distance over sea water. At higher frequencies, however, the range drops off rapidly. Above 4 MHz, the ground wave is only useful for very short distance communications.

The sky wave leaves the transmitting antenna at various angles of elevation to the earth's surface, ranging from 1 or 2 degrees to 90 degrees, and would travel out into empty space were it not that, under certain conditions, it can be reflected or refracted high in the atmosphere to return to the earth at distances varying from zero to about 2500 miles (4000 kilometers) from the transmitter. By a series of alternate reflections by the upper atmosphere and the earth's surface, electromagnetic waves can be transmitted or propagated around the world.

Ionosphere

The medium which causes the bending or reflection of the sky wave is called the "ionosphere", a region in the upper atmosphere where free ions and electrons exist in sufficient quantity to cause a change in the reflection index. Ultraviolet radiation by the sun is considered to be responsible for producing most of the ions. In the ionosphere, ionization does not change at a uniform rate, that is, proportionate to height, rather the ions form in layers with each layer consisting of a highly concentrated central region, tapering off in intensity above and below this area. Three major layers of ionization exist in the upper reaches of the atmosphere: the "D" region, "E" region, and "F" region, with the F layer being further subdivided into F_1 and F_2.

The D-region, lowest of the ionospheric layers, ranges in height from 30 to 50 miles above the earth. At this altitude the atmosphere is still relatively dense and atoms broken into ions by solar radiation quickly recombine. Here the amount of ionization is directly dependent upon the amount of sunlight. Therefore, it is maximum at noon and almost zero at dusk. In the D-layer, most electromagnetic wave energy (sky waves under 5 MHz) is expended in the form of heat. Thus, the D-layer acts as an absorber with little effect on bending radio waves back to earth.

The E-layer, the second significant ionized layer in the atmosphere, has a mean height of about 65 miles and because it, too, is in an area of comparatively high atmospheric density, ionization varies with the elevation of the sun, much the same as the D-layer, although not to as great an extent. And, also for reasons mentioned previously, a radio wave below 5-7 MHz passing through the E-layer loses a large portion of its power in the form of heat.

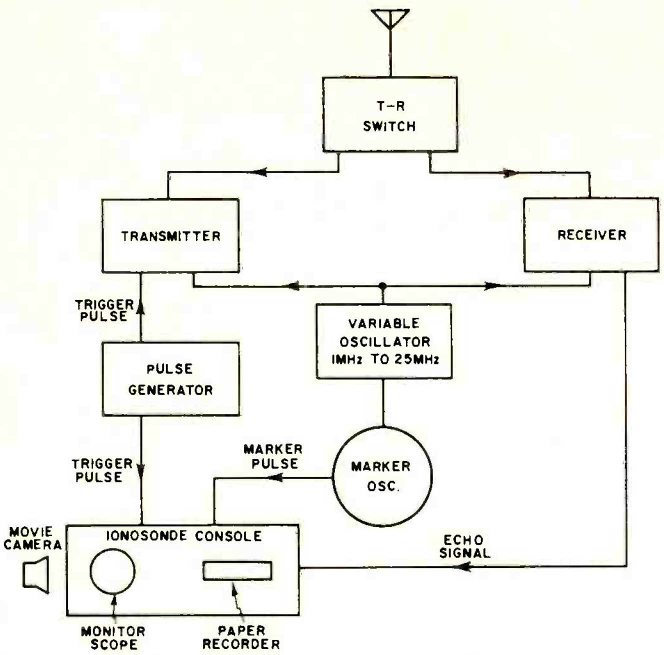


Fig. 2. Block diagram of a typical ionosonde. This radar-type device explores the ionosphere and records the MUF for a specific time of day. There are 150 observatories around the world.

The F-layer, the third and most important ionized area for long-distance short-wave communications purposes, is approximately 150 to 250 miles above the earth. At this altitude, the atmosphere is so thin that electrons and ions are slow in recombining. Ionization reaches a maximum shortly after noon and decreases very slowly to a minimum shortly before dawn. At sunrise, intensity increases rapidly to a maximum within an hour or two. During daylight hours, the F-layer sometimes splits into two distinct areas, called the F_1-and F_2-layers. The F_1-layer is of little importance to radio communications except that it acts as an absorber much like the D- and E-layers and disappears shortly after sunset. The F_2 region of the ionosphere is normally the most important parameter in estimating the performance of a high-frequency transmission but, unfortunately, it is also the most unpredictable of the three ionospheric layers.

The Critical Angle

The amount by which a radio wave is bent in the F_2 region is dependent upon two factors: the density of the ionized layer, and the frequency of the wavelength. The greater the ionization, the more it bends at a specific frequency; or for a specific degree of ionization intensity, the refraction will be greater as the frequency is lowered. It thus becomes apparent that if the ionization is intense enough and the frequency is low enough, a radio wave entering the F_2-layer at a 90-degree angle will be reflected back to earth; conversely, if the frequency is raised or the amount of ionization is decreased, a point will be reached where the refraction will not be sufficient to return the radio wave. Fig. 3 shows a specific radio wave whose frequency is of such a value as to penetrate the ionosphere at a 90-degree angle but is reflected back to earth when the angle is decreased. The angle at which the radio wave begins to bend back toward earth is called the *critical angle*. Fig. 3 also shows low-angled waves being bent back to earth in a *single-hop* propagation. As mentioned earlier, multi-hop transmissions are accomplished by alternate reflections of the electromagnetic wave between the earth and the F_2-layer.

Because long-distance high-frequency radio communications depends upon the ability of the ionosphere to return the radio signals back to earth, it is apparent that predictions of ionization intensities in the various regions of the F_2 and other layers are essential to the calculation of sky-wave circuit (the communications path over which intelligence is transmitted) performance. Predictions of the F_2 characteristics are computed about three months in advance by the Environmental Science Service Administration and published in a booklet called "Ionosphere Propagation Predictions." These predictions, as well as the accompanying isograms which show the maximum usable transmitter frequency for a specific hour of a specific month, are essential tools for the communications engineer. A discussion of the methodology used by ESSA in the compilation of the charts appears later in this article. The mechanics involved in using the charts are beyond the scope of this article; however, they are described in ESSA Handbook #90.

The Optimum Frequency

The complexity of the propagation phenomenon, the diversity of radio programming services, and the fluctuations in traffic density within the high-frequency bands preclude any clear and simple criteria for the selection of optimum frequencies. And because these are elusive factors, a high-frequency communications engineer's job is not an easy one. Since the density of the F_2-layer and its height above the surface of the earth vary with the time of day and the season of the year, and because of the 11-year sunspot cycle (a factor we shall discuss later), it is common practice for communications engineers to select a new set of operating frequencies and time schedules every three months.

In general (within the high-frequency spectrum), radio noise tends to decrease as frequency increases; also, propagation losses become less severe as frequency increases. Therefore, the higher the operating frequency the better the signal-to-noise ratio. However, the frequency can be increased to a point where the critical frequency is exceeded, or where the ionosphere reflection becomes improbable. This point is called the *Maximum Usable Frequency* (MUF). Through the use of the prediction charts and a working knowledge of the geographic variation in the electron density of the F_2-layer, it is possible to predict this upper limit. It would therefore seem to the engineer's advantage to simply operate very close to the MUF. Unfortunately, the high-frequency circuit calculation is not that simple. Because the F_2-layer density changes constantly, it would be necessary to continuously change the operating frequency throughout a 24-hour day—a laborious task to say the least.

If enough is known about the ionosphere to determine the critical angle, etc., at specific frequencies 90 percent of the time, these frequencies are considered adequate as estimates of upper limits for system planning. Selected operating frequencies are approximately 10 percent below the MUF. This minimizes circuit interruptions from irregularities in ionospheric conditions and reduces to a minimum the number of frequency changes required to maintain acceptable continuity throughout the transmission period. This operating frequency is called the *Optimum Traffic Freq.* (OTF).

Because energy absorption in the ionosphere's D- and E-layers increases as frequency decreases (assuming that the transmitter's output power remains constant), the power available at the receiver's input decreases. The atmospheric noise level also increases with a decrease in frequency. These phenomena combine to lower the signal-to-noise ratio and reduce circuit reliability.

When the *required* signal-to-noise ratio (the minimum acceptable level for communications) equals the *available* signal-to-noise ratio, the circuit may be expected to have acceptable quality on half the days within the month. In other words, the probability of satisfactory performance on any given day will be 0.5. The probability of satisfactory signal-to-noise ratio at any given hour is defined as *circuit reliability*. As the available signal-to-noise ratio exceeds the *required* signal-to-noise ratio, circuit reliability increases.

Since the available signal-to-noise ratio decreases as the

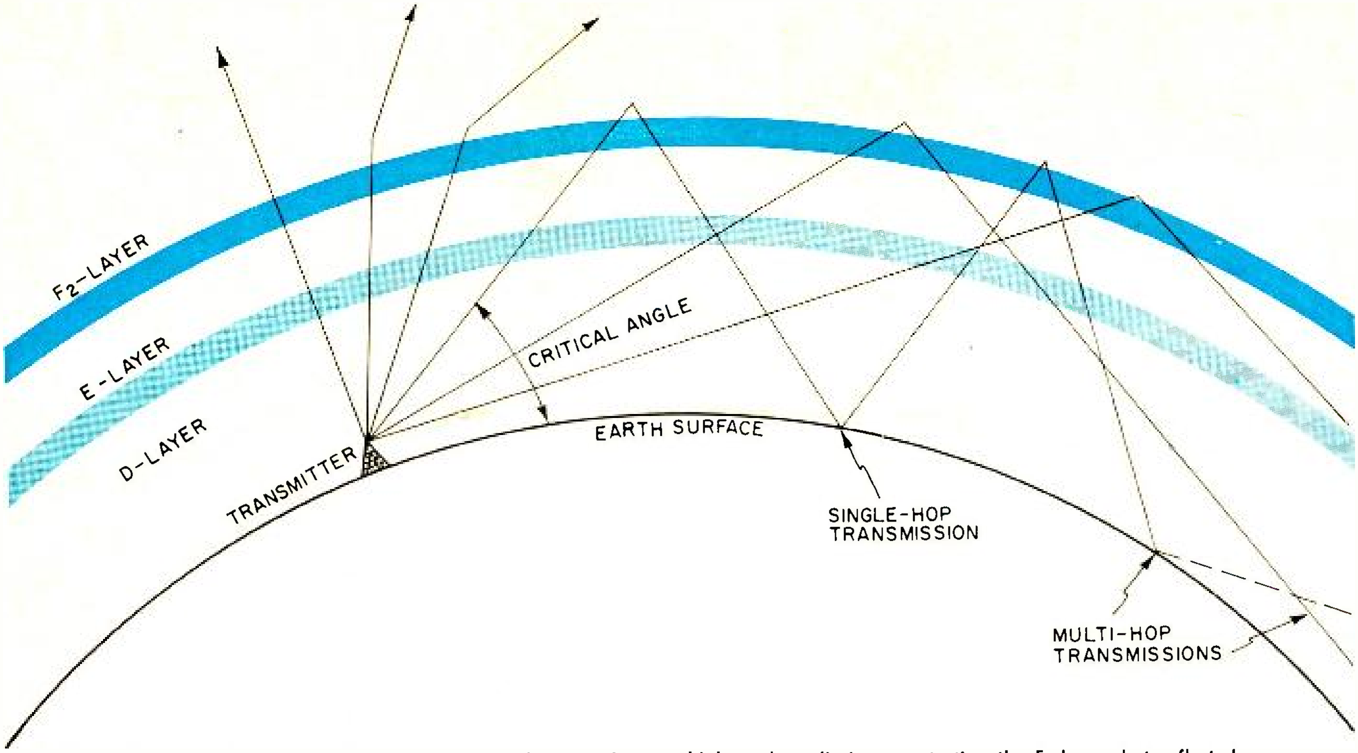


Fig. 3. Typical daytime ionosphere layer diagram showing high-angle radiation penetrating the F_2-layer, but reflected back toward earth as the wave-angle is reduced. All multi-hop transmissions are at wave-angles below the critical angle.

transmitter frequency is decreased, it becomes apparent that a point can be reached where a further reduction in frequency will result in unacceptable circuit reliability. This point is defined as *Lowest Useful Frequency* (LUF). The LUF depends on transmitter power, the factors that determine the path-loss (frequency, season, geographic location), and noise level. Of course, one of the principal factors is D- and E-level absorption and, since their intensity is maximum at noon, LUF is highest at noon. When calculating an operating frequency, the engineer must select one that is above the LUF but not greater than the OTF.

Selection of Frequency Complement

Absolute continuity of any high-frequency radio service is impossible to achieve even if an unlimited choice of operating frequencies is available. For a 24-hour day, frequency complements are based on the concept of *Maximum Feasible Continuity* or that a theoretical increase in circuit continuity will be negligible if additional frequencies are used, but a significant decrease in continuity is possible if fewer frequencies are used. The required frequency complement depends upon the type of circuit used. Communications engineers classify all circuits in two groups: circuits requiring Maximum Feasible Continuity and circuits requiring Moderate Continuity.

Circuits requiring maximum continuity are heavily loaded telegraph and telephone circuits which maintain high traffic at all times. Telegraph circuits in this category are usually operated by high-speed machines which transmit 100 or more words per minute, while telephone circuits generally employ several multiplex channels of a single-sideband system with multi-line terminations at each end. Such circuits usually have large directional antennas and employ diversity reception and high-power transmitters. The standard frequency complement for these circuits assures at least one frequency between OTF and LUF at all times plus two additional frequencies to permit flexible operation in the event of atmospheric disturbance.

When choosing frequencies for this service, the communications engineer selects one high frequency, one low frequency, and one middle frequency. The high frequency is strictly a daytime frequency (computed to be well below the OTF for at least four hours every day during the period the circuit is operated).

The low frequency of the three-frequency complement is exclusively a night channel, and is chosen as the highest frequency for which less than two hours of skip is indicated on the lowest of the OTF curves for the required operating period.

The middle frequency selection is made to maximize the number of hours during which at least one frequency is between LUF and OFT for the required circuit operation.

Circuits requiring only moderate continuity are usually those that provide communications where the needs are sufficiently critical to warrant extension of telephone, cable, or v.h.f. facilities. Many such circuits are used to provide occasional service to remote areas or are operated in situations where occasional delays or traffic slow-downs can be tolerated. The standard frequency complement for these circuits is usually one day frequency and one night frequency.

Therefore, the logical selection for the daytime frequency must be one that will be above the mid-day LUF but far enough below the OTF to give skip-free service to the intended areas. The night-time frequency is chosen as the highest frequency for which less than four hours of skip is indicated on the lowest OTF curve for the operation period.

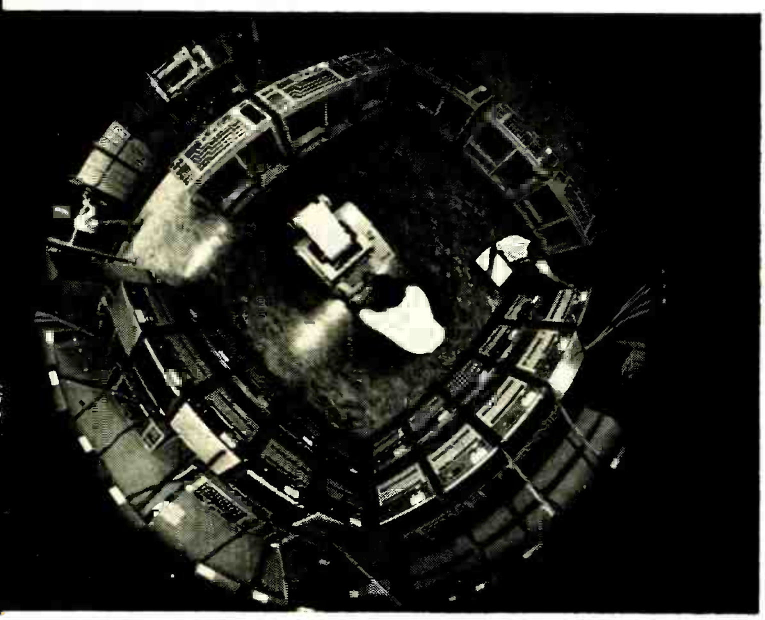
Solar Activity

As mentioned earlier, solar bombardment of the earth's upper atmosphere by ultraviolet rays is the major influence in the production of ionized layers. Because the earth is constantly bathed by these rays, the F_2 layer is always present; however its density and height above the earth changes constantly.

Although a completely satisfactory measure of solar activity is not available, the average number of sunspots over a 12-month period (as observed at Zurich, Switzerland) has formed the basis for much of the radio propagation analysis, and is presently being used as an index of the solar activity. Other celestial occurrences are under study at this time in an effort to improve predictions. (*Continued on page* 67)

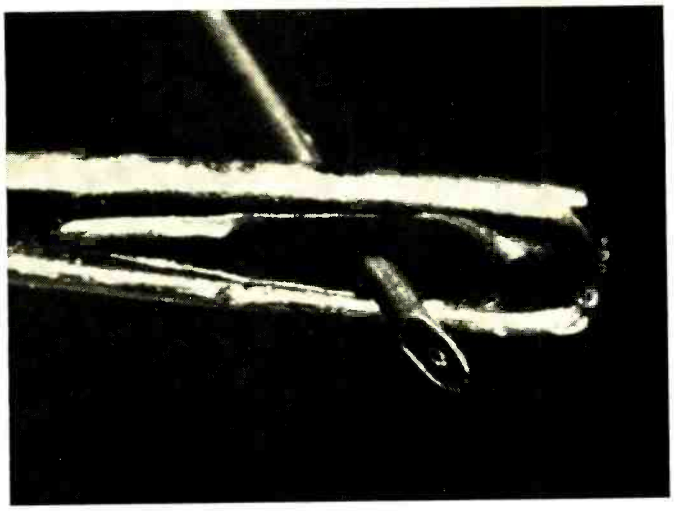
RECENT DEVELOPMENTS IN ELECTRONICS

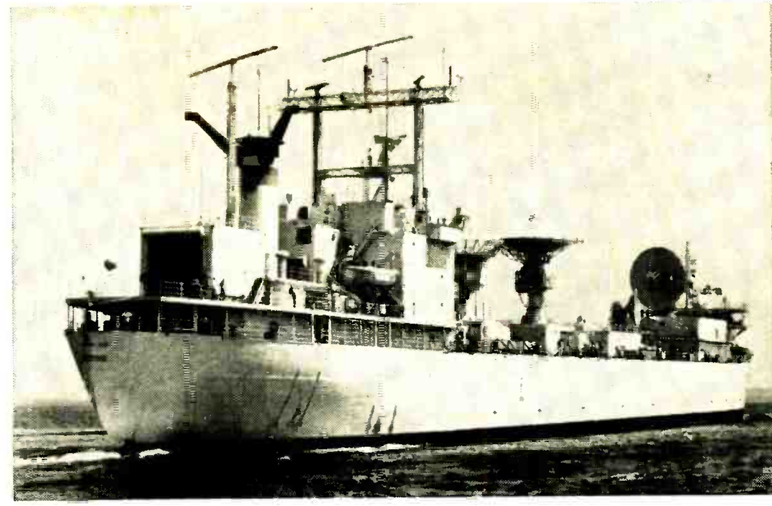
Desk-top Display System for Brokers. (Top left) Although it looks like a portable TV set, the unit on the stockbroker's desk is the display for an information-retrieval system. Now operating at the First Hanover Corp. in New York, the system is one out of a total of 275 such systems that have been installed in 32 financial and brokerage offices throughout the country recently. The system, called Videomaster, is produced by Ultronic Systems, subsidiary of Sylvania. The 12-in video screen displays seventeen specific details on any one of more than 8000 securities and simultaneously monitors any 18 selected securities and reports on their performance. Also, it alerts its operator to special stock situations and displays market summaries, financial news service, and economic background data from computer sources. The keyboard is detachable, allowing flexibility in desk and office arrangements. In addition, the keyboard can function with television-type monitors of any size as well as the unit's own small display screen.



Electronic Telephone Switching System. (Center) This roomful of equipment is able to interconnect more than a million phone calls within a period of 24 hours. Located in downtown Trenton, New Jersey, these telephone "load boxes" automatically dial telephone numbers, hold the connection for the start of ringing, and then disconnect so that another number can be called. The system, recently installed by Western Electric for New Jersey Bell Telephone Co., will, by the end of this year, handle calls of seven central offices that now use older switching equipment. The installer who is shown at the center of the photograph is reading a load report on a teletypewriter.

Electronic Color Scanner. (Left) The technician is comparing an original 35-mm color transparency with a $10\frac{1}{2}$ by $17\frac{3}{4}$-in enlargement produced by a new color scanner. The new unit, part of which is shown in the enlargement itself, can produce and enlarge four color-corrected, continuous-tone color separations for making printing plates in less than an hour. This should shorten deadlines presently set by newspapers and magazines for color printing. The scanner, made by RCA, uses a beam of light to scan the photo transparency at up to 10,000 lines per inch, depending on the enlargement ratio. The high resolution of the scanning beam permits the smallest details to be retained. The light beam is converted into electronic signals which are automatically analyzed, color corrected, and recorded on film. The film is then developed to make four continuous-tone positive or negative color separations, from which the printing plates are made. Portions of transparencies can be enlarged as many as 20 times. In addition, same-size transparent or opaque copy can also be scanned by the unit.





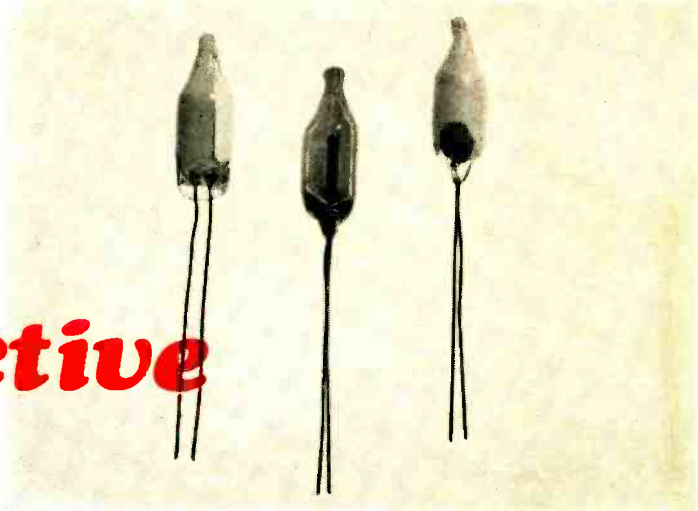
Ultraminiature Coax Cable. (Top left) Small enough to be threaded through the eye of a needle, this fully shielded flexible coax is only 10 mils in diameter (about triple the thickness of a human hair). The inner conductor is gold-plated No. 42 high-strength copper wire, while the outer conductor is a continuous sheath of copper that is electrodeposited on a Teflon dielectric. The new cable, which has been developed by Plaxial Cable Dept., United-Carr, has a 50-ohm impedance. It is expected to be useful in high-density computer circuits, with hybrids and other IC's, and in biomedical applications.

Apollo Tracking Ship. (Top right) With all the current activity in our lunar-landing space program, our five tracking ships, such as this USNS Redstone, are sure to be kept busy in coming months. Each ship contains nearly 445 tons of electronic equipment used for satellite tracking and as communications links. The ships, deployed on the oceans around the world, fill the voids in tracking coverage between the land-based sites. ITT's Federal Electric Corp. provides the technical teams for operation and maintenance of all the electronic equipment.

Computerized Radar for Air Defense. (Center) The Air Force technician is seated before one of eleven display consoles in the dimly lit operations room at Fort Fisher Air Force Station, near Wilmington, North Carolina. The installation is the first of fifteen that will cover the U.S. with a back-up system for our SAGE (Semi-Automatic Ground Environment) defense radar system. The back-up system, called BUIC III (Back-Up Intercept Control) ties together information on all in-flight aircraft from both land-based and airborne radars. A high-speed computer combines the radar signals with weapons status, weather, flight plans, aircraft identification, speed, altitude, and course, and displays all this information to a surveillance officer or weapons director. The back-up system takes over in the event of a SAGE failure. Fort Fisher covers the Atlantic Coast area, from Atlantic City, N.J. to Savannah, Georgia.

High-Temperature Rectifiers. (Below right) Silicon carbide rectifiers have been developed that operate at temperatures up to 1000°F and will survive at almost twice that. In contrast, the usual silicon diode stops rectifying at 450°F. Silicon carbide units have been made by Westinghouse Astronuclear Laboratory that will handle up to 10 amperes with reverse voltages of up to 300 volts. The new laboratory rectifiers are inert in most atmospheres and they are also highly radiation resistant.

Neons in Photoconductive Choppers



Side-looking A083 lamps have 180° of their circumference coated with a highly reflective white coating.

By G. S. TALBOT / Leeds & Northrup Company

Photoconductive choppers, which are being widely used for electro-optical switching, favor neons because of their sharp breakdown characteristics.

PHOTOCONDUCTIVE choppers are gaining popularity in electronic circuitry for electro-optical switching because they have extremely low noise levels and can be electrically isolated from other parts of the circuit. While either incandescent or neon lamps can be used in the design of choppers, the inherent breakdown characteristics of the neon, which provide for a sharp threshold of light when ignited, make the neon a good choice for switching applications.

In addition, since the photoconductive chopper is supplied in an encapsulated package, it is essential that the lamp have a long life. Neons, characteristically, operate for 25,000 to 30,000 hours. Obviously, when the lamp is not on, it is not consuming any of its lifetime, and thus the *service* life of the chopper will be many times the 4 to 5 years of its operating life.

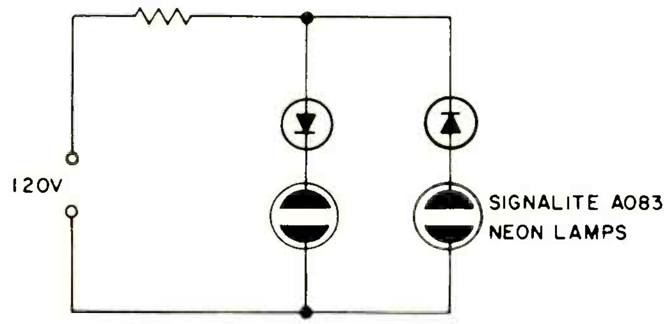


Fig. 1. Providing alternating illumination in photochopper.

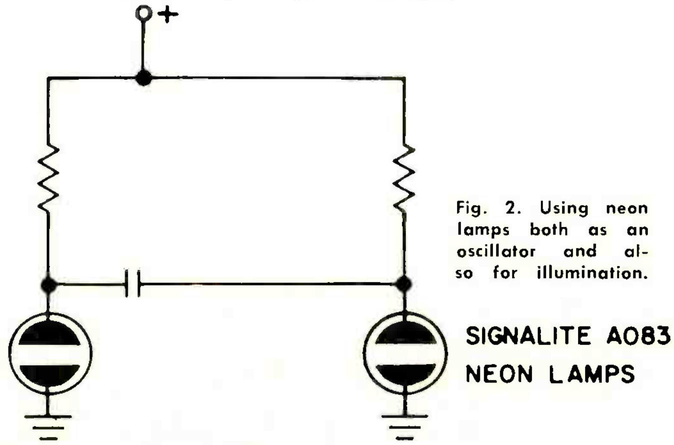


Fig. 2. Using neon lamps both as an oscillator and also for illumination.

For years, choppers of various types have been the standard method of converting low-level d.c. to a form of a.c. for more convenient amplification and utilization. Until recently, most of these have been electromechanical relays or vibrators driven by line frequency. To overcome some of the limitations inherent in the electromechanical design, various new approaches have been tried, among which are magnetic modulators, diodes, transistors, and most recently, FET's and MOST's. Analysis of these various types reveals that while each has certain advantages, each is also subject to certain limitations.

The electromechanical chopper is a true "on-off" switch with effectively infinite resistance when open and zero resistance when closed. However, as a mechanical device it is subject to contact bounce and contact contamination. Contact and spring materials must be selected to avoid spurious thermoelectric and/or contact potentials. Other factors which must be considered when using electromechanical choppers are phase lag caused by carrier coil inductance, sensitivity of the contact configuration to the carrier coil magnetic field on very low-level signals, and capacitive coupling between the signal circuit and the carrier circuit when high common-mode voltage rejection capability is required.

Diodes and diode bridges have been used in modulators for a generation or more (carrier telephony). More recently, transistors and their successors in the more exotic solid-state realm have been applied to this function. However, solid-state modulators generally do not offer the high isolation afforded by electromechanical choppers; nor do they provide the zero and infinite resistance limits.

An ideal modulator would generate no signal of its own and its a.c. output would be zero with no input signal. Signal output in the absence of an input signal is called "offset." In component descriptions, offset is usually defined as the signal required to bring the modulator output to zero. Offset is an error signal. However, if it is constant, it can be compensated for in the equipment and its effects eliminated.

Solid-state modulators, which include non-linear junctions, are generally prone to offset. Moreover, the magnitude of this offset is a function of the junction temperatures. Uncompensational offset puts a lower limit on the level of signals which may be detected and measured. The offset generally associated with solid-state modulators is in the range of a few to tens of microvolts. (Many industrial low-level d.c. applications requiring modulation are in temperature measurements by thermocouples, and a 10-microvolt offset corresponds to 1° C for a platinum-to-platinum rhodium thermocouple. This is an acceptable error in many industrial control processes.)

The intermittently illuminated photoconductor is the basis for the electro-optical photochopper. These choppers offer good electrical isolation between the signal and carrier circuits since the only coupling is optical. Electrostatic shielding between the pulsed neon light source and the photoconductor prevents capacitive coupling between the lamp and the photoconductive element in the signal circuit.

The alternating illumination required for the s.p.d.t. photochopper may be obtained in a number of ways. When power-line frequency is the carrier, the simplest method utilizes two neon lamps, Type AO-83, (*Signalite, Inc.*, Neptune, N.J.) operated on alternate half cycles (see Fig. 1). Other carrier frequencies may be generated by separate oscillators or by using a two-neon-lamp relaxation oscillator wherein the neon lamps act as both oscillator and illuminating lamps. See Fig. 2. If two additional cells are photocoupled to these neon lamps and used as a demodulator (synchronous rectifier), the carrier frequency may be selected (within the frequency capabilities of the neon lamps, the photocells, and the amplifier) to provide greatest immunity to power-line and other extraneous pickup sources.

When using photoconductive choppers in electronic circuitry, it is essential that the performance of each unit be uniform with every other. Selection of both the photocell and the neon lamp is critical in this respect. In our applications we require neon lamps, for example, which have highly uniform and constant maintaining voltages, and which exhibit no tendency to flicker when operated by a current low enough to insure the 25,000-hour minimum life.

The s.p.s.t. and s.p.d.t. photochoppers discussed here are designed to operate with good efficiency into a wide range of circuit impedances in various circuit configurations, including full-wave transformer inputs. The s.p.s.t. unit is a tubular design consisting of a neon lamp and a cadmium-selenide photocell. They are encapsulated so that the photocell is activated by light emitted from the end of the neon lamp. The s.p.d.t. unit is a flat-package plug-in design consisting of neon lamps, an internal lamp circuit, and cadmium-sulpho-selenide photocells.

The *Signalite* neon lamps for this unit have 180° of their circumference sprayed white to increase their effective brightness (see photo on opposite page). Both models are designed for 60-Hz operation.

An application for the s.p.d.t. unit is shown in Fig. 3. This chopper-stabilized amplifier reduces the drift of the main a.c.-d.c. amplifier to a very low level. The a.c. signals are coupled through *C1* to the main amplifier. The d.c. signals are amplified by the chopper amplifier and fed directly to the main amplifier. The gain of the chopper amplifier corrects the inherent drift to the main amplifier.

In Fig. 4, the s.p.d.t. chopper replaces a conventional electromechanical chopper in a typical low-level, d.c. servo amplifier circuit. The 60-Hz switching circuit for the neon lamps is an integral part of the chopper package.

The drive circuit (U.S. Pat. 3,283,157, D.E. Blackmer) is 120-V, 50-60 Hz. The initial resistor and the two capacitors serve to adjust the phase of the chopped d.c. in the signal circuit to match the phase of the a.c. line. The

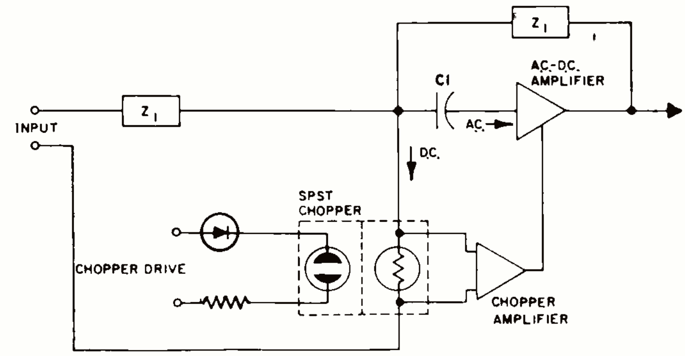


Fig. 3. A s.p.s.t. photoconductive chopper used in a high-gain chopper-stabilized operational amplifier.

two resistors in series with the neon lamps, control the lamp current to provide extended life. These resistors are so chosen that flickering of the lamps will not take place.

Only one lamp fires at a time. The second lamp is shorted out by its parallel rectifier which charges its associated capacitor during the half cycle that it is forward-biased.

When the line polarity reverses at the beginning of each of the succeeding half cycles, each rectifier reverses its bias condition.

The rectifier in parallel with the second lamp now becomes reverse-biased and its associated capacitor discharges in series with the line through the second neon lamp. In the meantime, the original lamp is turned off because its paralleled rectifier is forward-biased and charges it associated capacitor.

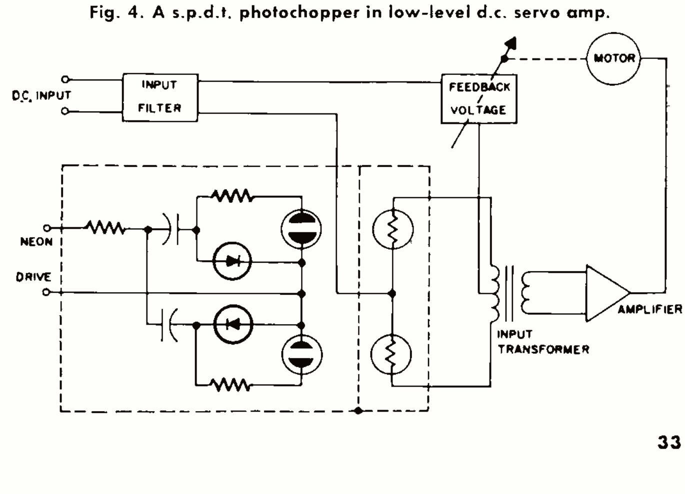
This circuit serves to turn on each photoconductive cell alternately for almost 100% of each half cycle. Furthermore, it provides maximum lamp brightness at the beginning of the cycle to reduce the turn-on time of the photoconductive cell to a minimum.

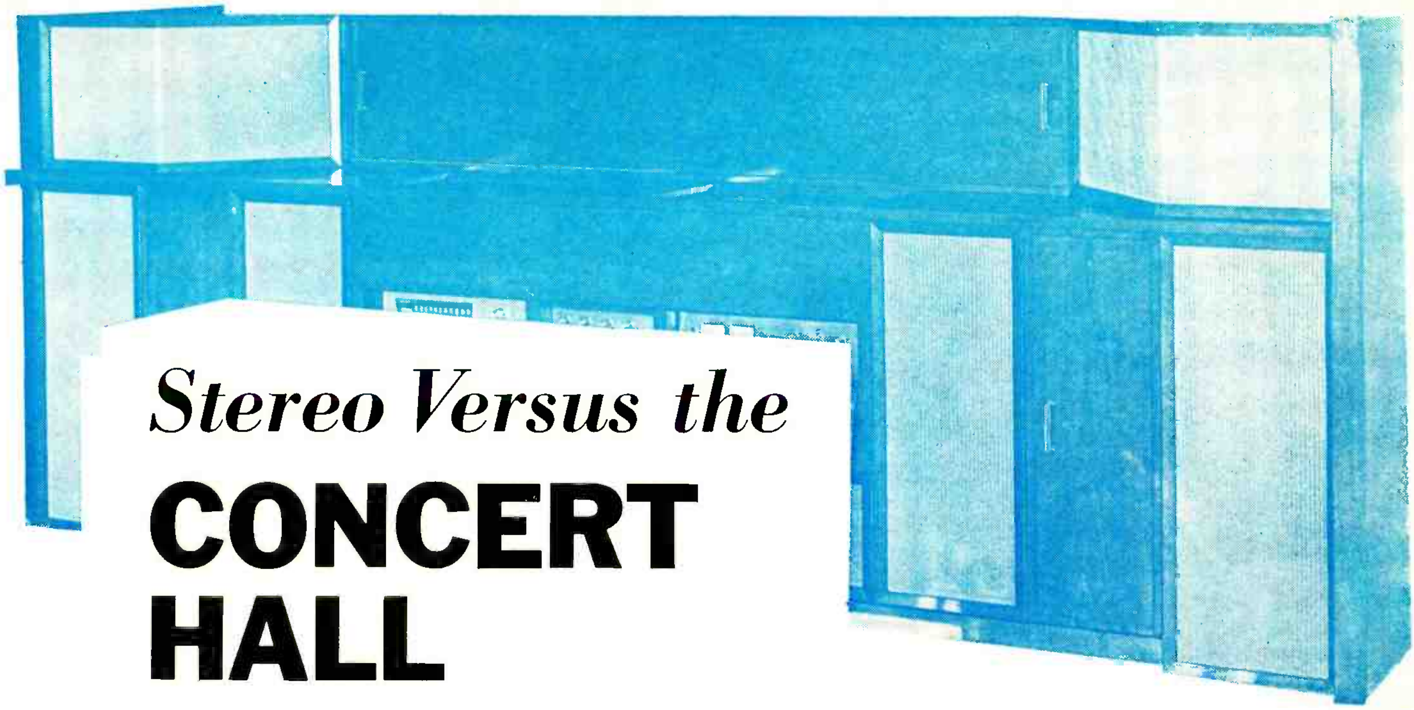
As each photoconductive cell alternately reduces its resistance, a current flows alternately in opposite halves of the primary of the input transformer, in synchronism with the line-voltage phase. The phase of this alternating current differs by 180 degrees when the direction of current between the input and the feedback is reversed. Likewise, the a.c. current which flows in the upset transformer's secondary winding reverses phase when the primary current is reversed.

The signal circuit is isolated from the drive circuit by a transparent gold coating on the inside of the photocell glass (U.S. Pat. 3,283,237, Williams and Polster).

There are many applications for photochoppers including series modulation, series-shunt circuitry for low-frequency applications, modulation and demodulation, in regulated power supplies, sequential switching, and so on. The long life, low noise, and small size of these photochoppers, as well as their greater stability against mechanical shock and vibration, make them an ideal component in many and varied applications. ▲

Fig. 4. A s.p.d.t. photochopper in low-level d.c. servo amp.





Stereo Versus the CONCERT HALL

By L. D. HARMON and D. J. MacLEAN

Author Harmon's elaborate home stereo system.

Stereo, like any other reproduction process, has its limitations. By knowing what they are, listeners can often improve their living-room "concert halls."

SOUND recording and reproduction have improved enormously over the past ten years; many of today's home music systems are considerably better than most professional installations of the mid-fifties. Indeed, some of the best domestic music "shrines" have fantastic impact. The stereophonic sound they produce speaks with authority, distortion is vanishingly low, individual instruments are crisply localized in space, dynamic range is large, and noise is practically nonexistent.

Yet, as splendid as such installations are, they fall far short of replacing the "live" listening experience. Coming home immediately after a real concert and turning on one's favorite home music system may lead to acute disappointment. Why?

In what follows, we shall point out some of the deficiencies in stereo sound reproduction and discuss how to hold such deficiencies to a minimum. Our intent is not to provide a detailed panacea for relieving hi-fi ills, but rather to point out interesting and useful-to-know aspects of stereo reproduction that are not often discussed.

Distortion—Amplitude, Phase, Frequency

Why can considerable distinctions be perceived between the best sound-reproducing systems and the live performance? There are half a dozen or more contributing factors. For one, there are several kinds of distortions, such as amplitude, phase, and frequency, which are introduced in both the recording and reproducing process.

Amplitude distortion includes the old, familiar harmonic and intermodulation kinds—where spurious tones (not present in the original signal) are generated. Although these distortions in amplifiers are now "vanishingly small," they still are not zero. And when all the harmonic and intermodulation distortion products from the recording microphone to the loudspeaker are added up—including disc-recording apparatus, recording material, and phonograph cartridge—the total can easily reach 4 to 5 percent, and the ear knows the difference.

Somewhat more subtle is phase distortion where the relative times of the many complex frequency components are not accurately preserved. The causes of phase distortion vary from phase shift in amplifiers to delays owing to different transmission path lengths in multiple-speaker arrays. It is commonly believed that the ear is relatively insensitive to phase distortion, but psychophysical experiments conducted several years ago by M. R. Schroeder at *Bell Laboratories* clearly showed that phase differences *can* be detected. Surely then, part of the departure from ideal realism in sound reproduction resides here.

Frequency distortion simply means non-uniform response over the entire spectrum that the ear perceives. That is, some tones are reproduced at higher or lower levels than others. Although amplifiers are relatively good in this respect, the terminal transducers are not ideal. Some phonograph cartridges and most loudspeakers, for example, are considered excellent if their response lies between plus and minus 3 dB. But this means a power range of 2:1, or 100 percent.

Loudness, Noise, and Room Coloration

There are still other factors that distort reality. One is that of over-all level or loudness. We know from "live" experience how loud a symphony orchestra or a chorus should be. If this level is not reached in the reproduced listening environment (and it rarely is), then it is not easy to convince the ear that the orchestra or chorus actually *is* in the living room.

Level compression provides yet another difficulty. Owing to the dynamic limitations of both the recording and reproduction equipment, most signals are compressed. Not only orchestras but single instruments suffer. For instance, part of the "bite" of a trumpet stems from brief but large transient waveforms. When this sharp spike is squashed by a recording limiter, the piercing quality suffers, as does the illusion of reality.

Noise, of course, also helps destroy realism. The distraction of record tics and pops and tape hiss makes it hard to believe the original source is present.

Then there is the matter of acoustic environment or "room coloration." Every room has its own influence on sound produced or reproduced within it—due to selective frequency absorption, reflection, and reverberation. These properties profoundly influence the sounds that reach the ear, and even an untrained listener easily hears the differences among the acoustics of concert halls, cathedrals, living rooms, and bathrooms. Now when sounds produced in a huge concert hall (and recorded with those acoustics) are reproduced in a 15 x 20 foot room, the ear knows something is not quite cricket.

Additionally, the acoustical properties of the listening environment are superimposed on the recorded room acoustics. The result is a melange which once again is quite noticeably (perhaps subconsciously) a put-on.

An even more subtle form of distortion arises from the vagaries of recording techniques, notably microphone placement. In the concert hall experience, the listener's two ears, spaced about 6 inches apart, sample the total sound field at one particular location. The ideal re-creation of that sound field is the goal of honest stereophony. (We exclude here "ping-pong" stereo, inside-the-piano microphony, "reprocessed" mono and other *ersatz* procedures.)

Microphone placement techniques range from the use of two vertically stacked units pointing in different directions, to twenty or more mikes scattered throughout an ensemble, picking up individual instruments. There are advantages and disadvantages to each, but none yet approaches the ideal re-creation of signals that effectively places the listener's head back in the concert hall, acoustically speaking.

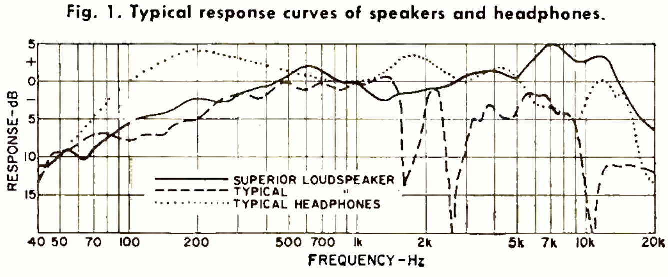
Some Partial Remedies

Fortunately there are many partial remedies to each of these problems; and, in fact, some stereophonic systems sound fabulously good (at least if they are not directly compared with a live performance). Perhaps the poor absolute auditory memory most of us have is responsible for a lot of our satisfaction. The psychologists call this *adaptation*. After a short time, our nervous systems adapt to a particular kind of input and accept it as the norm. Another way of saying this is that one quickly gets used to the kinds of sounds that come out of loudspeakers. Only with relatively rapid A-B comparisons are differences between two kinds of sound well perceived.

It is axiomatic that the weakest element in almost every sound reproduction system is the loudspeaker. There are few if any cheap, royal roads to glory—and loudspeakers are no exception. Really good sound quality is difficult to achieve, and the consequent design and manufacture simply cannot be inexpensive.

Few listeners will tolerate headphones for extended listening or prefer them to speakers. However, an intriguing fact is that many modern and relatively inexpensive headphones are superior in response to a large number of loudspeakers. Typical response curves illustrating this point are shown in Fig. 1. Since headphones are by their very nature small, their lightweight moving elements permit good high-frequency response. And for low frequencies, snugly fitting phones act as pistons to compress air in the ear cavity; they do not have the difficult job of radiating sound into large volumes as do loudspeakers.

Fig. 1. Typical response curves of speakers and headphones.



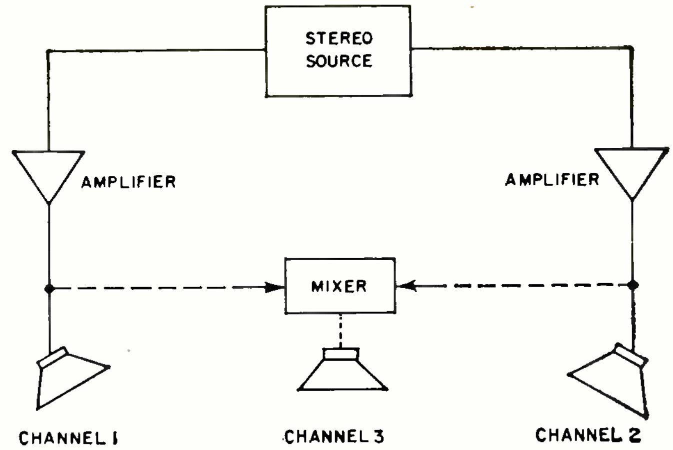


Fig. 2. Adding a third channel for the "hole in the middle."

But with headphones, the auditory space and all the sound images move around with the listener's head—a most unrealistic experience. Further, sounds are perceived as being close to or even inside one's head.

An interesting question arises regarding the number of stereophonic channels required for adequate reproduction. Various tests by many researchers in the past tend to agree that at least three channels are needed. However, since the industry has compromised on two channels, the suggestion is often made that a third or fill-in channel be added, not having an independent channel signal but using parts of the existing left and right signals (as shown in Fig. 2). This is claimed to fill in the "hole-in-the-middle" and to provide solid image placement (a tuba right there just to the left of the bassoon).

Surprisingly, a properly balanced 2-channel speaker system does not exhibit a hole in the middle, and image placement can be excellent. But this requires two sets of speakers to be essentially identical. If the acoustic output of one side departs from that of the other by more than 2 dB at any one frequency, then the perceived image of an instrument will shift from side to side whenever its spectral output lies principally in the region of the imbalance.

Sound Localization

One important aspect of stereophonic perception is the listener's ability to localize sound sources. Obviously, if one speaker is switched off during a stereo presentation the intended spatial effect is lost. The sounds coming from the remaining speaker are identified as emanating from its general location but the sonic spread is missing.

Suppose that a listener is sitting equidistant from two loudspeakers. The program material is not stereo but mono presentation. The gains are adjusted for equal outputs from the loudspeakers. Where does the sound apparently come from? The majority of people will say "at a point (area) directly in front of me," that is, between the two loudspeakers. Each ear is picking up the same auditory signal at identical intensities. From past behavioral experiences the listener is deceived into believing a new source is present half way between the two actual sources.

If the intensity from one or the other loudspeaker varies, the image (source) apparently moves toward the louder speaker (see Fig. 3). This illusory effect continues if the intensity increases until the image is centered at that one loudspeaker. In this case, the stronger source takes precedence.

However, there are additional factors to consider. Suppose a time delay were introduced into one channel while the levels were again adjusted for equal loudness from

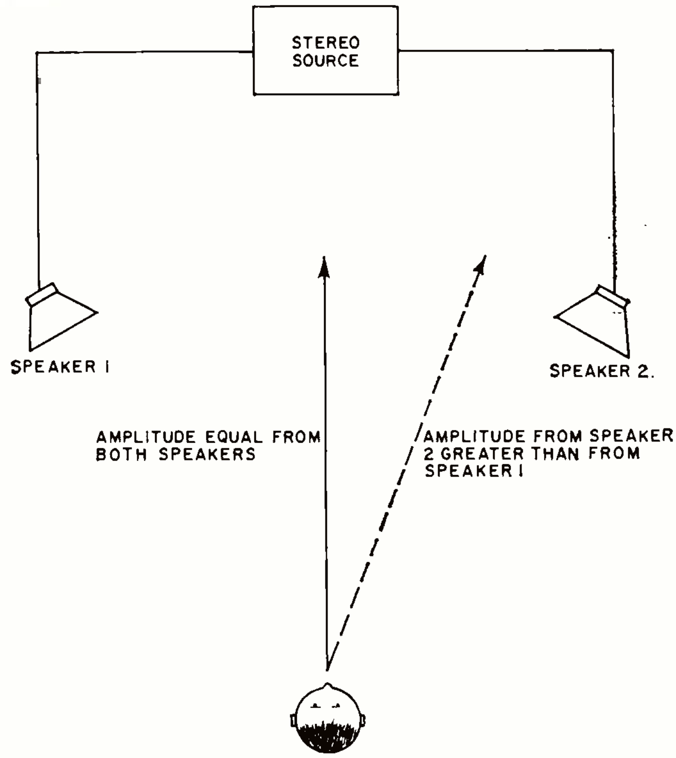


Fig. 3. Auditory image shifts toward the louder speaker.

each loudspeaker. If the delay were sufficient, that is, several milliseconds, the image would again shift—this time toward the undelayed speaker. System delays of this magnitude are uncommon; however, if the listener shifts his position toward one or the other loudspeaker, a similar effect takes place (roughly one millisecond per foot). The sound from the more distant speaker takes longer to reach the observer; therefore, a time delay takes place. As a result, the sonic image shifts toward the closer (less-delayed) speaker.

For unadulterated stereo in a typical listening situation, the listener must preserve his head position to within a few inches to make these shifts negligible. It is not to be inferred by this that all is lost if the listener does not have his head clamped in an exact equidistant position. We are all aware that the general enhancement offered by stereo is quite acceptable over distances far in excess of a few inches. Again, our tolerance for less than perfect effects is relatively enormous.

Phasing of Loudspeakers

One of the most troublesome problems in assembling a stereo system from components is the proper phasing of the loudspeakers. Sophisticated methods employing oscilloscopes are not always available to the audiophile. A very old, inexpensive method involves using a flashlight battery and observing the direction of cone motion with respect to the applied polarization. This technique presumes that the speaker cones may be observed and that the rest of the system is properly phased.

A very simple method that the authors have used is to move the speakers as close as possible to the ears (much like earphones) and simply listen. If all components including the loudspeakers are in phase, the sound will appear to be in front of the observer; if out of phase, the sound seems to originate inside the head. (*Also, the in-phase speakers will produce a fuller, bassier sound compared to out-of-phase speakers, which will sound lower in level and "thinner."—Editor*). Moving the speakers close-in is essential only where the room is fairly reverberant. In a "dry" or "dead" room, the effect may be realized simply by standing midway between the sound sources. This test is best accomplished using a monophonic record or tape as the source material; however, stereo material with an abundance of correlated left and right material may be used.

An interesting experiment was conducted in the *Bell Laboratories* free-space room to demonstrate dramatically the in- and out-of-phase phenomena. R. L. Hanson used a conventional stereo system for the source but with the loudspeakers purposely 180 degrees out of phase with each other. An observer standing anywhere on the line midway between the speakers experienced the startling sensation that the entire orchestra was stuffed inside his skull. To enhance the already unnerving experience, one of the speakers was hung pendulum-fashion so that it could move forward or backward from its normal resting position. When this was done, the sound would drift laterally through the head and on out one of the ears, depending on the relative position of the moving speaker.

This is an auditory deception similar to some of the dynamic optical illusions. It dramatically drives home the effects of the localization parameters of delay and intensity that play such an important role in stereo perception. In using a free-space room, which is essentially devoid of reflections (echoes), the sensation was magnified beyond the point that would normally be encountered in the average living room.

The Listening Room

While on the subject of speakers and acoustics, let's look at a rather interesting point regarding listening rooms. Since the acoustical properties of a typical living room are generally far from ideal, the question arises as to whether the amplifier-speaker system should be compensated accordingly. For instance, if a room has considerable acoustical absorptive material, the high frequencies may not be received as well as the lows in different parts of the room. It might seem reasonable to boost the treble response of the system so as to balance out the room characteristic and so end up with "flat" response.

In our experience this is a very unsatisfactory procedure. The ear "knows" the room; speaking voices, footsteps, clinking glasses all cue us as to the actual acoustical environment. Consequently, if we anticipate hearing a piano, for example, at the far end of this room, we somehow expect to hear the unbalanced spectrum; this constitutes the real, live acoustic experience. If we receive a compensated, "flat" transmitted auditory image, it sounds unnatural in that room. Furthermore, the acoustical characteristics of the room will vary from one place to another, and so no one compensation is possible.

We believe that generally the most satisfactory procedure is to get the reproducing system as flat as possible. This means, ideally, that it will produce a piano sound as though the piano were at that place. Then if the acoustical properties of the room are less than ideal, the room itself should be modified.

The chain of events from a sound source to the ears of a perceiver is long and complex. An interesting but simplified description of these events is as follows: A vibrating membrane (for example a reed, sounding board, or drumskin) sets air molecules in motion; this in turn causes a new membrane (microphone) to vibrate, which sets electrons in motion. Eventually, through one or another of the complicated reproducing processes, a loudspeaker membrane is set in motion; this in turn once more moves air molecules finally to vibrate another membrane, the eardrum.

That any useful degree of fidelity can be preserved through such an involved chain is astonishing. Yet, despite all the problems we have mentioned, the eardrum is made to vibrate fairly faithfully with respect to the original air-molecule vibrations. And the fidelity is constantly improving. ▲

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Importance of Filters

By A. H. SEIDMAN/Contributing Editor

Once the image-parameter method was the only good approach to filter design. Now it is modern network synthesis and computers which guarantee better products.

A FILTER is a frequency-sensitive component which is able to pass, with minimum attenuation, a select range of frequencies while suppressing the transmission of unwanted frequencies outside this band. Applications of filters are numerous, covering frequencies from less than a hertz in seismology to gigahertz in microwave work. Most filters are custom-made and some five-hundred companies are competing for a market currently estimated to be $40 million annually and promising to double by 1972.

Because of the widespread use of computers, filter technology in the past few years has come into its own as a sophisticated specialty. Nearly any filter can be designed using a computer. Computerized sensitivity studies of such items as component tolerance, "*Q*", and environmental factors help in designing a practical filter that is reliable and meets specifications. Because of the complexity of modern technology, filter requirements have become more sophisticated than they were a decade ago when the engineer could design his filter by using suitable tables.

Today, a special brand of expertise is required. There are filter specialists who design and make filters to satisfy the particular customer requirements. There are filter houses which can provide any filter design, using lumped, distributed, or other components. But many others tend to specialize and offer only crystal, ceramic, mechanical, or microwave filters. In general, except for relatively simple designs, it seldom pays an engineer to design and build a filter in house. More important is how he selects and specifies filters. This Special Section outlines these techniques.

What's Available?

If one were able to build the *ideal filter*, its characteristics would be as shown in Fig. 1. The *passband* has unity gain, permitting signals in the range of frequencies defined by f_2-f_1 to be transmitted without any attenuation. In the region outside the passband, referred to as the *stopband*, 100 percent suppression of frequencies is obtained. The transition from the pass- to stopband or *vice versa* is over zero frequency (instantaneous). And an examination of the phase characteristics shows that the phase shift changes linearly with frequency in the passband. Actually, filters do not possess zero attenuation in the passband and suppression in the stopband is not infinite. Furthermore, the transition between bands is gradual and the phase shift is nonlinear.

The filter designer must approximate ideal filter characteristics as closely as possible with combinations of passive elements like inductors and capacitors (*LC* filters); with resonant transducers (crystal, ceramic, and mechanical filters); combinations of an amplifier and passive components (active filters); and, at microwave frequencies, distributed, cavity, and strip-line filters. These subjects are explored in depth in the remaining articles of this Special Section.

In terms of frequency discrimination properties, there are four distinct types of filters: *low-pass, high-pass, bandpass*, and *band-reject* types. Typical amplitude and phase-shift response curves for the filters are given in Fig. 2.

Low-pass filters pass frequencies from zero to a higher or *cut-off* point. In general, an *RC* integrating network is considered a low-pass filter. On the other hand, high-pass filters attenuate frequencies below a specified cut-off point, passing all other frequencies beyond this point unattenuated. Examples of high-pass filters are the simple *RC* differentiating network and the waveguide used at microwave frequencies. In both cases, the cut-off frequency is taken at the −3 dB point.

The bandpass filter passes a group of frequencies between specified lower- and upper-cut-off frequencies. Typically, bandpass filters are used in the i.f. stages of a receiver. The band-reject filter can be thought of as an upside-down bandpass filter, rejecting frequencies between the cut-off points and passing all other frequencies without attenuation.

Filter design is based on mathematics and modern network synthesis. In the past, filter design was based on the image-parameter method, where a lumped network is described in terms of a distributed network, like a transmission line. Today, however, the polynomial method,

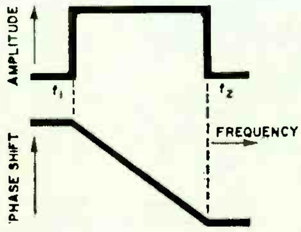


Fig. 1. "Ideal", and unobtainable, filter characteristics. Compare this graph with those for practical designs, Fig. 2.

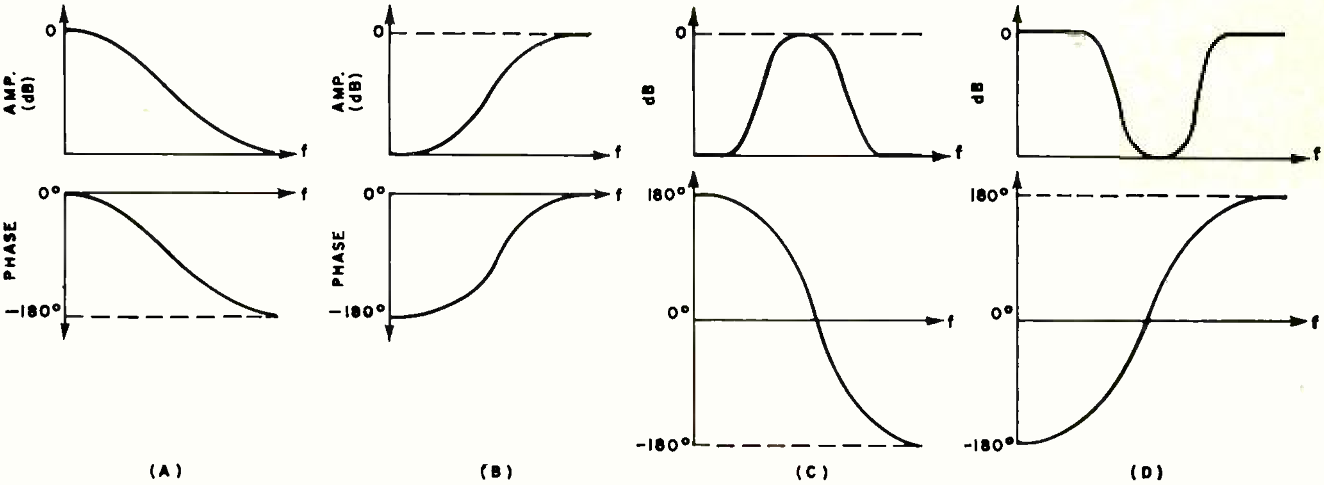


Fig. 2. Characteristics of four basic filters using LC elements. (A) Low-pass, (B) high-pass, (C) bandpass, and (D) band-reject.

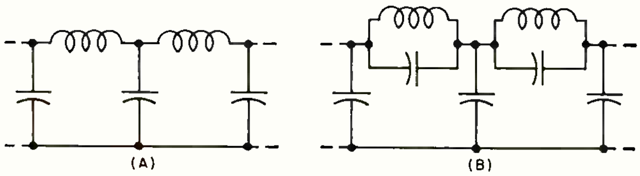


Fig. 3. (A) Butterworth and Chebyshev, (B) elliptic filters.

also called the exact or insertion-loss method, is usually the basis of filter designs. This method tackles the filter as a lumped-parameter system and deals directly with the various parameters that characterize the filter. Its drawback is the inordinate amount of work required to obtain values for the filter elements; this labor means nothing, however, when calculations are computerized.

A number of classic filter designs have evolved, using *LC* sections. To gain some insight into what may be expected of filters, three of these structures will be examined briefly: the Butterworth, Chebyshev, and elliptic filters. Their basic forms, using the low-pass filter as an example, are shown in Fig. 3.

The Butterworth filter, also referred to as a maximally flat filter, is characterized by a relatively flat response and no ripple in the passband. The *roll-off*, that is, the decrease in gain beyond the cut-off frequency, approximates −18 dB per octave for a section. In terms of mathematics, the filter is simple to handle, having fair phase and good amplitude response. Actually, however, its cut-off frequency is poorly defined, making it unsuitable for applications demanding a uniform transmission of frequencies in the passband and fast roll-off.

The Chebyshev filter has a sharper cut-off than the Butterworth, but exhibits ripple in the passband; the ripple is 0.1 to 3 percent, or greater, of maximum signal amplitude. If one can tolerate greater ripple, a trade-off is possible to obtain sharper cut-off. The Chebyshev filter provides a relatively constant amplitude in the passband.

Sharper cut-off than that obtainable with either the Butterworth or Chebyshev filters is realized with the elliptic filter. But, besides having ripple in the passband, the elliptic filter also exhibits ripple in the stopband. Of the three filters, the elliptic generally provides the best performance with a minimum number of filter sections. Other classical *LC* filters are the Bessel and Gaussian types. Mechanical, crystal, and active filters can also exhibit characteristics similar to LC filters.

Our discussion of filters has tacitly assumed ideal components—a convenient fiction that serves to simplify the many calculations in synthesizing filters. To account for real lossy components, like inductors and capacitors, a technique called *predistortion* is used by the experts. Expected changes in filter performance, owing to lossy components, are included in the evaluations of polynomials used to describe filter operation. When done on a computer, the task is relatively easy.

Filter Terminology

We have already alluded to some of the terminology, like passband, stopband, and roll-off, that is peculiar to filters. To specify filters, the engineer must be sure what he is talking about. In this section we shall consider definitions of terms used to characterize filters, as used by industry and the military. Wherever appropriate, test circuits employed in establishing some of the definitions will also be examined.

Insertion loss indicates how effective attenuation of signal frequencies is in either the passband or stopband of the filter. A test circuit for measuring insertion loss is shown in Fig. 4. Z_S and Z_L are the source and load impedances, respectively; their values must be stated when specifying the insertion loss of a filter. With the d.p.d.t. switch in position 1, the filter is removed from the circuit. Voltage ($E1$) across load Z_L, is measured for the frequency or range of frequencies of interest. When the switch is thrown to position 2, the filter is in the test circuit and voltage $E2$ is recorded (for the same range of frequencies used in the previous measurement). Insertion loss (IL in dB) is defined as: $IL = 20\ log_{10}\ (E1/E2)$.

Discrimination is a useful criterion for comparing the attenuation in a filter between a chosen reference frequency, usually the frequency corresponding to maximum output voltage, and a second frequency, often in the stopband. The test setup used is the same as that for measuring insertion loss, with measurements of insertion loss made at the reference frequency and the second frequency. The algebraic difference, in dB, in the two measurements yields the discrimination, designated *alpha:* $\alpha = IL_{(\text{ref freq.})} - IL_{(\text{second freq.})}$.

The *cut-off frequency* is the frequency at which the maximum specified insertion loss occurs in the passband. Typically, it is −3dB, but it can be any selected level.

Because roll-off from the pass- to stopband is gradual, a *transition region* exists. This region may be specified as the difference between the cut-off frequency and the frequency corresponding to the minimum value of insertion loss in the stopband.

Two terms used to characterize bandpass filters are *shape factor* and *percent bandwidth*. A typical amplitude response curve for a bandpass filter is shown in Fig. 5A. Shape factor is defined as the ratio of bandwidths between two specified values of insertion loss in the passband. Often the −6 dB and −60 dB points are selected; assuming this to be the case, the shape factor is *Shape factor* = $BW_{(-60\ dB)}/BW_{(-6\ dB)}$. Percent bandwidth is defined as: $\%BW = (f_H - f_L \times 100\%)/\sqrt{f_H f_L}$, where f_H and f_L are the upper and lower −3 dB frequency points, respectively.

Ripple in the passband or stopband can be cited either in dB or percent.

Except for the ideal filter, the *phase-shift response* of filters is nonlinear. A useful measure of the nonlinearity is the phase slope obtained by drawing a line tangent to the phase-shift curve at the frequency in question (see Fig. 5B). A triangle is drawn and the phase slope, in seconds is defined as: *Phase slope* = $\Delta\theta/\Delta\omega$.

Group delay is the delay of frequencies transmitted through the passband. If the delay is *flat*, all frequencies are delayed by the same amount. Group delay is equal to the phase slope at a stated frequency.

The *transient response* of a filter is its response to a step function. In practice, the step is approximated by a low-frequency square wave. The output response of the filter will appear as a damped sinusoid having a maximum overshoot and ringing. Where the transient performance of filters is important to the application, a figure of permissible overshoot and ringing should be specified.

Output and *input impedance* of a filter at various frequencies may be determined with the test setup of Fig. 6. Source E_s is a variable frequency source; the filter is terminated in a specified impedance. By definition, the magnitude of the input (or output) impedance is the magnitude of the impressed voltage $|E_1|$ across the filter, divided by the magnitude of the input current. Because current meters tend to be inaccurate at higher frequencies, the input current is determined by measuring the voltage magnitude $|E_R|$, using an off-ground or battery-operated meter, across resistance R. The input (or output) impedance, Z, is: $Z = |E_1/E_R|(R)$.

At the outset the engineer should have a good idea of what the filter he needs is expected to do. He should know, for example, what the filter characteristics should look like, temperature range of operation, and the impedance terminations the filter will see when installed in the circuit. To assist the engineer, some companies provide nomograms, charts, or graphs to enable him to specify a filter. Sales and applications engineers are also available to help the engineer arrive at a realistic filter specification. What *must never be done* is to overspecify; overspecification results in higher costs and bulkier filters.

Filters come in many forms other than *LC* (or *RC*) structures. As described in the following articles, filters using mechanical transducers, like ceramic and crystal, offer interesting design opportunities; at low frequencies, the active filter can be a possible choice. The engineer should investigate all possibilities before making his final selection.

What are some things the filter designer must know to ensure that you, the engineer, will get the most filter for your dollar? He must know the magnitude of signals to be applied to the filter and their waveshape. If high-amplitude signals are present, power levels may become a significant consideration which could lead to larger, heavier, and costlier units. For this reason, filters should be used in low-level stages.

If the waveshape is appreciably nonsinusoidal, the transient response becomes important; this requires the specification of values of permissible overshoot and ringing. If the filter is going to see d.c. levels in addition to the signal, this must also be stated in the filter specification.

All filters exhibit a nonlinear phase shift and a varying phase slope. In applications like data transmission systems, where a constant phase slope over some specific operating region is required to ensure flat group delay, this condition must be specified. A constant phase slope requirement will raise filter costs; therefore it should be specified only if absolutely essential.

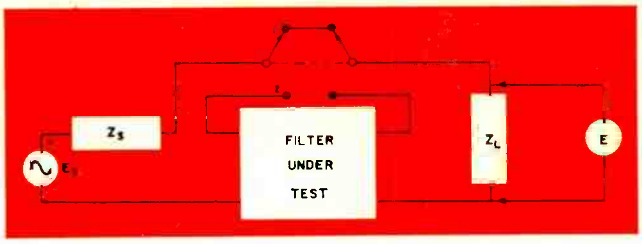


Fig. 4. Test circuit for measuring insertion loss of filter.

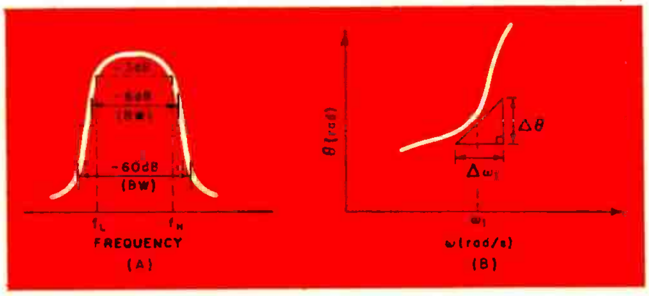


Fig. 5. (A) Defining shape factor and percentage bandwidth. (B) Determining the phase slope of the filter. See text.

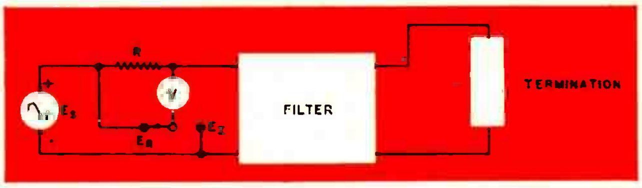


Fig. 6. Procedures for measuring impedance of a filter.

As previously stated, early filter designs used the image-parameter method, where equal source and load impedances are considered essential for optimum filter performance. But today, thanks to the computer, the polynomial method is generally used to synthesize filters. With this technique, the actual source and load impedances the filter sees when placed in the circuit are the significant parameters. If parallel operation is necessary, as in some telemetry applications, this should be made known to the designer so he can consider the stop-band impedance characteristics of the filters as well as minimize interactions between the parallel combination.

The maximum ripple that can be tolerated in the pass- or stopband should be specified. Achieving low ripple often entails more filter sections and high-"*Q*" components, resulting in greater filter costs. For these reasons, an engineer should never overspecify but determine realistically how much ripple he can "live with."

A realistic appraisal of environmental conditions under which the filter will operate is a worthwhile undertaking. A wider temperature range than needed could mean that highly stable components would be required, again resulting in higher filter costs. In addition, excessive shock and vibration requirements increase costs and lead to bulkier filter designs.

A number of companies offer brochures relating to filter operation and design. A sampling of some that may be of interest to the reader are: "Wave Filters: Their Design and Specifications" by *ADC Products Inc.*, Minneapolis, Minn. *Burr-Brown* of Tucson, Arizona has a well-written booklet, covering active filters, entitled "Handbook of Operational Amplifier Active *RC* Networks." Crystal filters are treated in "Recent Developments in Crystal Filters" issued by *Damon Engineering Inc.*, Needham Heights, Mass. For military applications, MIL-F-18327C (May, 1966) is a general specification for filters. ▲

The author received his BSEE in 1960 and has done graduate work at the Polytechnic Institute of Brooklyn. He joined the company in 1965 as head of the filter design department. Since then he has written numerous digital computer programs on LC filter design and analysis and is doing research on new types of LC filters. He is a member of IEEE, the Professional Group on Circuit Theory.

LC Filters

By STEPHEN ROSENFIELD/ Senior Engineer, ESC Electronics Corp.

Are LC filters sophisticated enough to fulfill the needs of today's complex systems? Yes, but you need a specialist who knows filters and a computer which designs intricate LC networks quickly and inexpensively for the job.

TAKE an inductor and add a capacitor; tie them together and you have a system which can store power and filter out noise. *LC* networks, which incidentally should be called *RLC* filters since all passive electrical components contain resistance, are first cousins to *RC* filters which most engineers at one time or another have designed with traditional resistors and capacitors. As a matter of fact, *RC* filters are fairly well standardized—their design formulas are found in many textbooks. *LC* networks are by comparison difficult, and a more sophisticated approach is needed. To some degree, the difficulty in *LC* filter design is directly due to the inductor's design which is in itself an art. For any particular frequency at which a specific inductance value is specified, there are literally hundreds of possible inductors which could be used in the application. In reality, there are only a few optimum choices.

One more thing about *LC* filter design. There are many textbooks and magazine articles which purport to give design information. However, engineers or technicians who require filters should be advised not to design their own networks. An engineer who designs his own *LC* filter usually finds that he could have specified his requirements to a filter specialist and paid much less for a lot more.

The Art of LC Filter Design

All kinds of filters, such as crystal, mechanical, and ceramic (which we can refer to as secondary types), have evolved from the primary *LC* type. Designers of these secondary filters always make use of *LC* filter analysis to help explain the operation of their networks. For most parameters in the secondary filter system, there exists an analog which relates to either an inductance (self or mutual) or a capacitance in the primary *LC* filter system. As a matter of fact, if this were not true, little could be done in the way of analyzing these types of filters mathematically.

Perhaps the degree to which *LC* filters can be analyzed mathematically explains the degree to which the filters have grown in sophistication. In no other type of filter can the specialist control so many parameters.

For example, we are able to provide *LC* filters with a group-delay constancy of 1% in the passband coupled with an ability to provide extreme selectivity. We can design *LC* networks which will shape a given signal and stabilize the response to within a few tenths of a dB over an extremely wide temperature and input voltage range. Each year new *LC* filter capabilities are realized and the end is not in sight.

LC filter design has become so sophisticated and competitive that filter designs must be carefully analyzed by digital computers. The digital computer is a necessity, not a luxury.

Some filter manufacturers have devised computer programs which will: (1) design a complete filter network from customer specifications, (2) analyze a completed design—tells the engineer whether or not the filter meets all specifications and whether or not it operates efficiently at the extremes of the component tolerances, and (3) optimize an initial filter design. Here the computer picks the best *L* and *C* values in a particular branch of a network, giving the filter design engineer a truly optimal network for a given number of inductors and capacitors.

The time required—from specification of the filter to delivery to the customer—has been greatly reduced by computer processing. Many filter manufacturers are able to give cost quotations within 24 hours after receipt of the specifications. Design work is so rapid that often filter deliveries can be made in a few days or at most a few weeks. In the past, it often took months, or perhaps even longer for an engineer to receive the required filter.

In the past, most filter companies offered catalogues or brochures showing the many filters kept in stock. For example, many types of *LC* filters such as telegraph and tone-channel networks have been standardized by the electronics industry, that is, these units have fixed bandwidth, attenuation, and input and output impedances. Low-pass filters with particular cut-off frequencies and given impedance levels were also stocked by some manufacturers. Some companies continue to stock these items but, based upon the author's experience, the need for the off-the-shelf unit has greatly diminished. For example, if the engineer thinks he saves money by buying an off-the-shelf item, he should consider his decision carefully.

Despite the growth of active filters, which in years past have threatened to "push *LC* filters out of existence," *LC* filters have grown in direct proportion to the expansion of the entire electronics industry. But, more and more sophisticated engineers and technicians realize that filters should be designed by specialists.

LC Filter Characteristics

The *LC* filter user should know something of the characteristics of various types of units so that he may know if it is feasible to get a filter that meets his needs. We will concentrate on the specific shape of the filter's characteristic, including parameters like group delay, amplitude response in the passband, out of the passband (or stopband), and in the transitional area between. We will also summarize the transient response of several families of *LC* filters.

Essentially, the several families of filter characteristics can be grouped and represented by a low-pass network. Bandpass, high-pass, and band-reject designs are related to the low-pass case by simple frequency transformations. Within the general characteristics of each family, the rate of attenuation outside the passband is set by the number of poles (directly related to the number of inductors and capacitors within the filter).

Fig. 1 shows the amplitude and group-delay characteristics of Butterworth, Chebyshev, and Bessel filters while Table 1 summarizes their respective rise times and overshoot.

Butterworth filters are derived on the assumption that behavior at zero frequency is far more important than behavior at any other frequency. In this way they are similar to the classical image-parameter filters. As a matter of fact, a three-pole Butterworth filter is identical to a three-pole image-parameter type. This d.c. approximation leads to a class of filters with good phase response and good amplitude response but poor characteristics around the cut-off frequency (the 3-dB point). The Butterworth function is unsuitable for applications that require transmission of frequencies in the passband and sharp rise at cut-off. As Table 1 shows, overshoot increases with the number of poles in the Butterworth filter.

Chebyshev filters are derived on the assumption that all frequencies in the passband are of equal importance. The Chebyshev function is useful in applications where the amplitude is of primary concern. This family gives a more constant attenuation in the passband than the Butterworth type and gives much greater attenuation in the stopband. Unfortunately, Chebyshev filters offer little improvement in decreasing the size of overshoot.

Bessel, also known as Thompson filters, achieve their excellent phase linearity at the expense of the slow rate

No. of Poles (N)	Rise Time (sec)			Overshoot (%)		
	Butter-worth	Chebyshev (.5 dB ripple)	Bessel	Butter-worth	Chebyshev (.5 dB ripple)	Bessel
2	2.2	1.6	2.7	4	2	0.4
3	2.3	2.4	3.1	8	6	0.8
4	2.4	2.7	3.4	11	9	0.8
5	2.6	3.1	3.6	13	11	0.8
6	2.7	3.2	3.8	14	12	0.7
7	2.9	3.3	3.9	15	12	0.7
8	3.0	3.5	3.9	16	13	0.6

Table 1. Rise times and overshoots of typical filter types.

at which signal amplitude decreases in the stopband. They can pass rectangular pulses with little overshoot (Table 1), negligible over-all distortion of shape, and the time delay is almost constant with frequency for passband signals. They are well suited to pulse-modulation systems and applications where minimum deterioration in pulse transmission is required.

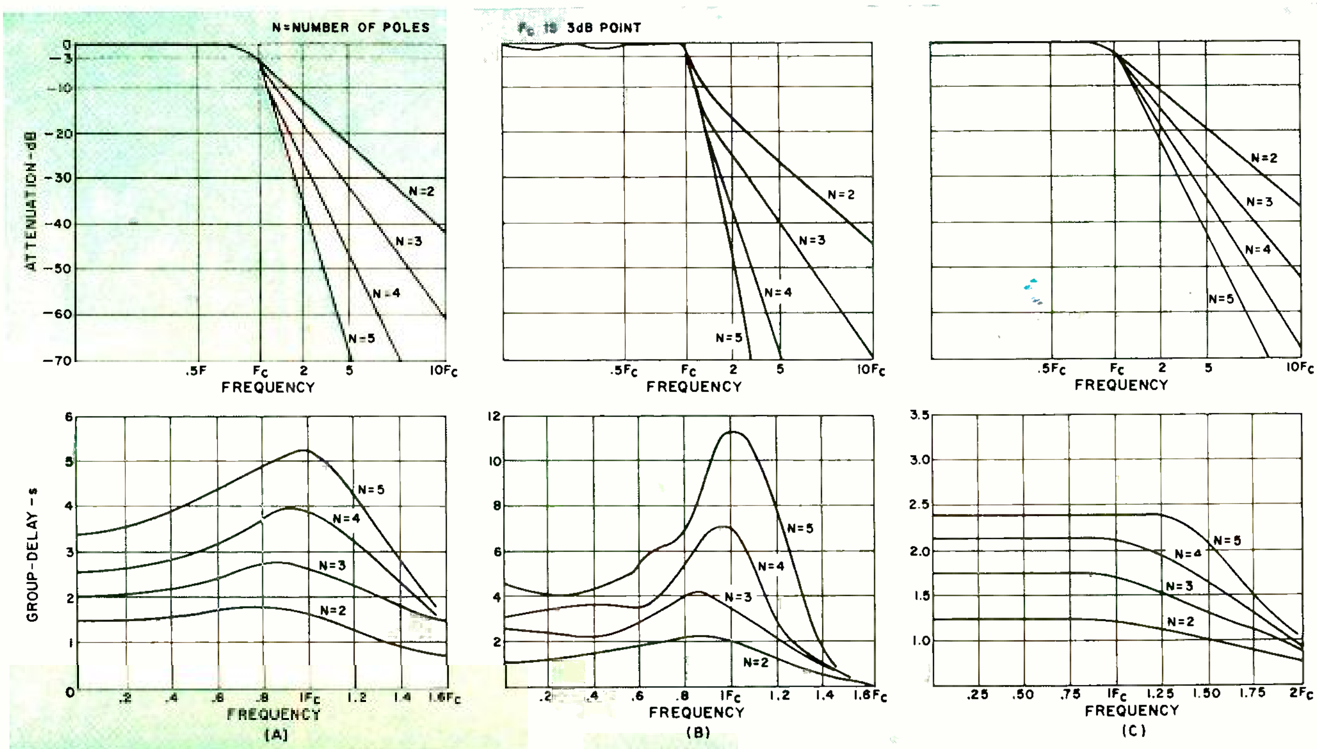
Some other filter types, not illustrated here, attempt to combine the characteristics in which each of the three already described filter types excels. The Transitional Butterworth-Thompson (TBT) is well defined by its name. It is used where somewhat greater attenuation is needed than that which the Bessel offers, and somewhat more overshoot can be tolerated than that which the Butterworth allows.

Optimum-L filters combine good selectivity with a uniformly changing phase characteristic. There is less attenuation than in the Chebyshev filter but also less time delay over a greater bandwidth, therefore better transient response. They are useful in phase-angle modulated systems.

Where amplitude is of prime importance and stopband and passband ripple are allowable, the most efficient type of filter characteristic is the relatively new elliptic type. For any given number of poles, these filters provide the most efficient amplitude *vs* frequency characteristics of any type. Unfortunately, their group-delay and overshoot characteristics are poor and difficult to predict. See Fig. 3.

Fig. 4 shows the network configuration for Butterworth,

Fig. 1. Attenuation and group-delay characteristics of the (A) Butterworth, (B) 0.5-dB Chebychev, and (C) Bessel filter systems.



Chebyshev, and Bessel filters. Fig. 5 is an elliptic filter schematic.

The "Interface" Problem

For an efficient filter to be designed, there must be honest and knowledgeable communications between the requesting engineer or technician and the filter designer. First, the engineer must know why he wants a filter. He must know the waveforms in his system, what he wishes to change, and what characteristics he wishes preserved, and he must know what frequencies must be eliminated. Therefore, the engineer must analyze his waveform and know why it is the way it is. Even if the filter designer knows something of the system's function, he is really an expert only within his own domain, and hence must be presented with information on circuit conditions.

At an early point in the specification of the filter, the engineer must decide what type of filter he needs. Does he need an *LC*, mechanical, or crystal filter? To aid the engineer in his choice, a chart of frequency *vs* percentage bandwidth ranges is shown on page 44 of this section. (Note these are approximate and should serve only as a casual guide. Certain filter manufacturers may take issue with these limits.)

Assuming that the specifying engineer knows the composition of his waveform and what changes he wants the filter to make, he now should specify a filter with the minimum requirements that meet his objectives. Overspecifying or underspecifying a filter may ultimately lead to an impractical design or a costly or time-consuming mistake.

Based on our company's experience in designing *LC* filters, it is quite obvious that the specifying engineer tends to overspecify selectivity while overlooking other parameters that may be critical to his needs. To alleviate some of these problems, some suppliers have prepared detailed questionnaires which the filter user completes and returns to the designer. Very careful thought has gone into the preparation of these forms and we will go over a typical questionnaire item by item (see Fig. 2) to help clarify the "interface" problem—the communication between user and supplier.

1. Filter Type: Here the word "type" refers to low-pass, high-pass, bandpass, or band-reject. It should be obvious to the filter user the type he requires.

If his signal is d.c. or some frequency which will suffer from harmonic interference, he needs a low-pass filter. If his information is in a restricted band above d.c. and signals are interefering on both sides of the band, he needs a bandpass type. Where a network has a limited band of signals to be eliminated (above d.c.), the user may require a band-reject network. A subharmonic problem is generally taken care of through the specification of a high-pass filter.

We have simplified the explanation of the differences among filter types, but, in addition to these "simple" cases, there exists a myriad of other applications.

For example, filters may be used to separate signals into discrete bands of frequencies so that information can be sent efficiently through transmitters which have limited bandwidths (see Fig. 6). Upon reaching a receiver, the separate signals are recombined to produce the intelligence. A group of bandpass filters composed of contiguous frequency passbands are connected with inputs in parallel. The information is separated into frequency-limited bands and sent to different outputs. A similar group of filters on the receiving end, with outputs in parallel, will combine the separate bands and restore the signal to its original information capacity. Here the user must supply the filter designer with specifications for each group of bandpass filters which work together to accomplish the required function.

Many other functions, too numerous to be covered here, can of course be accomplished through the use of low-pass, high-pass, bandpass, and band-reject type filters.

FILTER QUESTIONNAIRE

FIRM NAME ______ DATE ______

ADDRESS ______

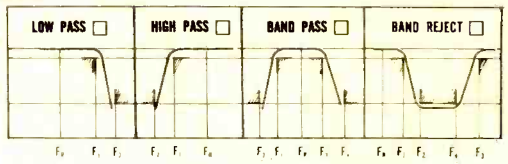
ATTENTION OF MR. ______ DEPT. ______

PHONE ______

PLEASE PROVIDE AS MUCH OF THE FOLLOWING INFORMATION AS POSSIBLE:

ELECTRICAL SPECIFICATIONS

1. FILTER TYPE (CHECK ONE)



a. ATTENUATION CHARACTERISTICS (REFER TO DIAGRAM ABOVE AND FILL IN FOLLOWING)

F_r (REFERENCE FREQUENCY) ______, INSERTION LOSS ______ db MAXIMUM

F_1 ______, Attenuation ______ db Maximum

F_2 ______, Attenuation ______ db Minimum

F_3 ______, Attenuation ______ db Maximum

F_4 ______, Attenuation ______ db Minimum

b. MAXIMUM PASSBAND RIPPLE ______ db

2. IMPEDANCE Z Source ______ Ω Z Load ______ Ω

3. SPECIAL PHASE OR TRANSIENT CHARACTERISTICS (IF ANY) ______

4. VOLTAGE LEVEL ______

5. TEMPERATURE RANGE

a. Operating ______ °C To ______ °C

b. Storage ______ °C To ______ °C

6. APPLICATION AND DESCRIPTION OF CIRCUIT ______

MECHANICAL SPECIFICATIONS

7. PREFERRED CASE MATERIAL: Metal ☐ Molded ☐ Other ______

8. MAXIMUM OUTSIDE DIMENSIONS ______

9. TERMINAL TYPE AND LOCATION ______

10. QUANTITIES REQ'D ______

REMARKS ______

Fig. 2. Typical questionnaire designed to aid the filter specialist in devising the right filter for the customer's needs.

After the decision as to "type" has been made, the amount of selectivity needed must be expressed quantitatively as in Item 1a in Fig. 2. This is generally done in terms of the maximum dB of attenuation allowable within the passing region or passband, and a minimum amount of loss needed in the attenuating region of stopband. Here, again, we stress the need for an honest evaluation on the part of the user of his requirements. This enables the filter to be manufactured in the most efficient and economical configuration. A simple example of overspecification of selectivity follows:

Suppose an engineer wishes to suppress the seventh and higher harmonics of a 1-kHz square wave in order to slow down the waveform's rise time. The filter specifier may decide arbitrarily that if the 7-kHz and higher components of the signal are attenuated 60 dB, his problems are solved. He fills out Item 1 of the questionnaire as follows:

(*a*) F_r reference frequency 1-kHz insertion loss 1 dB max.

F_1 5-kHz attenuation 3 dB max. (He wishes to pass frequencies up to harmonic five, allowing a 3-dB maximum loss at 5 kHz.)

F_2 7-kHz, 60 dB minimum.

(*b*) Maximum passband ripple ±1 dB.

This looks simple enough, but let's examine this more closely.

If the user remembers that the Fourier series shows harmonic number seven of the square wave is already 1/7th of the first harmonic, or 17 dB below the 1-kHz fundamental, he really needs 60—17 or 43 dB attenuation to produce the required result. A filter which produces 60-dB attenuation at 7 kHz (with 17-dB attenuation wasted) costs more to produce than a filter with the acceptable attenuation of 43 dB.

On the other hand, there may be more subtle problems in deciding the amount of attenuation allowed in the passband. It is easy to say "let harmonic number five (5 kHz) come through the filter with no more than 3-dB attenuation," it is more difficult to explain why.

2. Impedance: This information seems obvious. The user, after deciding where the filter is to be used, notes the input and output impedance (Z_{source} and Z_{load}, respectively). The problem here is that the circuit impedance could vary with frequency. Most filters will cause distortion if the input and output impedances are not constant. If the filter design engineer is informed of this impedance variation he might be able to design around it. In this way, some circuit troubles may be avoided when the filter is inserted into the system.

Too high or too low a design impedance can make filter design unrealistic. A filter that must operate at 10 MHz at an impedance of 100,000 ohms may possess 1-millihenry inductors and 1-picofarad capacitors, a poor combination. Perhaps the filtering should be done in another part of the circuit where impedance values are more compatible.

3. Phase and Transient Characteristics: Filter specifiers seem to be more ignorant of phase shift and time-delay requirements than of any other parameter. In the past, where amplitude modulation was the primary method of information transmission, it was not important for the engineer to be concerned about phase and time delay. Now the complexity of modern signals through the newer modes of signal processing, such as frequency, pulse, and continuous-wave modulation, forces the well-informed engineer to reckon with these variables.

Suppose we are dealing with a pulse transmission system where the requirement is that the output pulses have the same shape and separation as the input pulses except for a time delay $T = T_2 - T_1$, as shown in Fig. 7A. It is clear that a filter with a long rise time is not suitable because the pulses would "smear" over each other, as seen in Fig. 7B. The same can be said for long settling times. Obviously, the best filter for the pulse transmission system is a constant-delay filter with small rise and settling times.

Engineers working with pulses may appreciate the term "overshoot" more than certain other engineering types. In color-TV transmission, too much overshoot causes the TV picture to have an excessive mount of blue haze, not the most satisfying color for human skin tones. Fig. 8 defines overshoot.

A word of caution should be given here. The author has stressed the significance of understanding phase shift and time delay, and has given examples of their effect on the user's system. If, however, special phase-shift or transient characteristics are not needed, it would be unwise for the filter user to specify them. Their specification will ultimately require a more costly filter.

4. Voltage Level: Linear networks of which *LC* filters are a part, generally remain stable with voltage and power. But any linear network will saturate when loaded by too high a signal. It is especially important for the filter designer to be aware of the incoming voltage swing when specifying low-frequency filters below 5 kHz. At low frequencies, inductors tend to saturate more than at higher frequencies due to increased hysteresis losses.

High dynamic ranges of voltage may be critical if the filter has been specified to have a high degree of stability. The filter specialist has at his disposal, components such

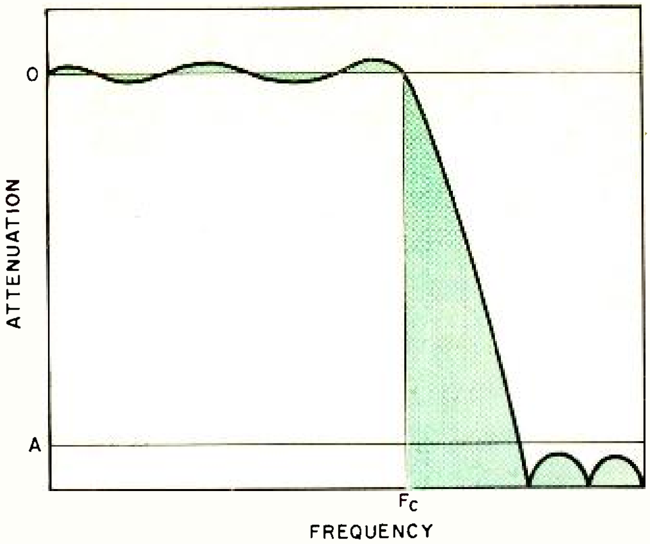


Fig. 3. Elliptic filter characteristic attenuation showing occurance of ripples in the passband and stopband.

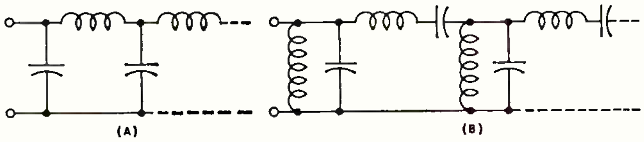


Fig. 4. General network configurations. (A) Low-pass and (B) bandpass for Butterworth, Chebychev, Bessel filters.

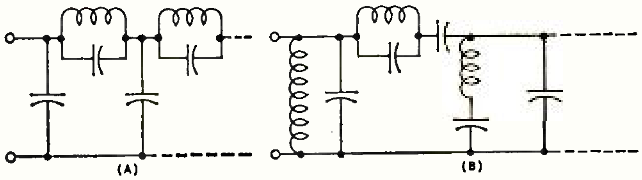


Fig. 5. (A) Low-pass and (B) bandpass elliptic filter circuits.

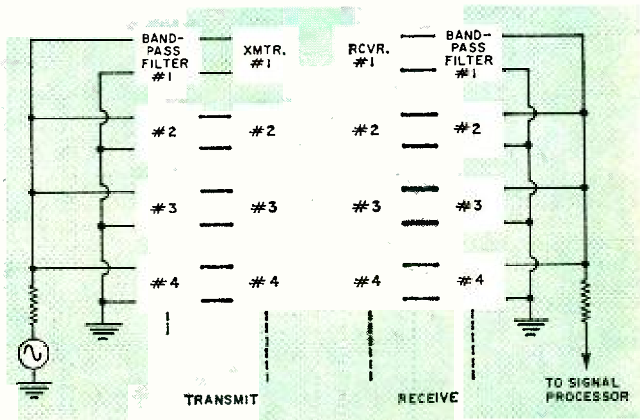
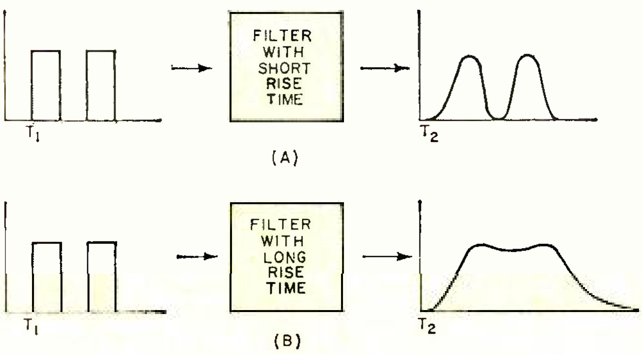


Fig. 6. Contiguous bandpass filters separate, combine signals.

Fig. 7. In most pulse transmission systems, short rise time filters are better (A). Long rise time filters smear the pulses (B).



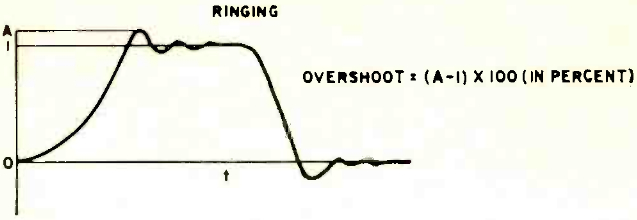


Fig. 8. How to calculate the degree of overshoot.

as thermistors and varactors which are able to compensate for input variations. But he can only compensate, when the user informs him of the system's conditions.

5. Temperature Range: All capacitors and inductors vary (in value) over a temperature range. Ambient temperature and the range of temperature variations are frequently inadequately specified. A probable reason is that although users are aware of the temperature problem, they care little about it, and shift the responsibility to the component supplier. Often, a filter user will arbitrarily enter the operating temperatures as −55° C to +125° C thereby covering himself for any error he may have made in predicting the actual range. The restrictions now placed upon the filter supplier are numerous. He cannot use certain types of capacitors such as polystyrene and ceramic, he must eliminate certain encapsulating compounds, and he must completely stop the use of certain inductive devices such as ferrite pot-cores with small air gaps. All this is the consequences of a wide temperature range.

With all these restrictions, the filter specifier must now pay a price for the extra design time and more costly components which require temperature compensation. A filter specialist is able to compensate for temperature changes easily, but why compensate when it really isn't necessary.

6. Application: This part of the questionnaire is an aid to the user who is not exactly sure his specifications are correct. Sometimes this added data helps the designer understand the user's needs.

Mechanical specifications, Items 7 through 10, are obvious and require no comment.

What's Ahead

Through the use of the digital computer, new families of *LC* filters have been built that have never previously been thought possible. Now, the computer is the top tool of the filter design engineer. Through computer usage, the price of *LC* filters has been slashed. Prototyping costs have also dropped substantially in recent years and appear to have a tendency to continue doing so. Innovation and experimentation are not expensive any more and the filter designer does not have to build the physical filter to prove his design. A mathematical model of the filter is, instead, analyzed by the computer, and only after careful study, with many alternate designs weighed, is the filter released to the shop for construction. The actual computer time has not been days or weeks, but seconds to minutes.

LC filters, which cover the widest of frequency ranges have been used in more networks than any other type of filter. In all probability, these filters will continue to increase in range. This is in part due to the new components such as ceramic chip capacitors, which cut package sizes, and new inductive devices. ▲

PRACTICAL OPERATING LIMITS FOR FILTERS

THE frequency and percent bandwidth limits for the different filters shown in the diagram are representative over-all figures. For example, it should not be inferred that for a crystal filter operating at a center frequency of 10 MHz, all percent bandwidth values listed are realizable. Design trade-offs must be made to obtain physically realizable and economical units. Because the r.f. interference filter is an example of an application rather than a type, it is not included in the frequency diagram.

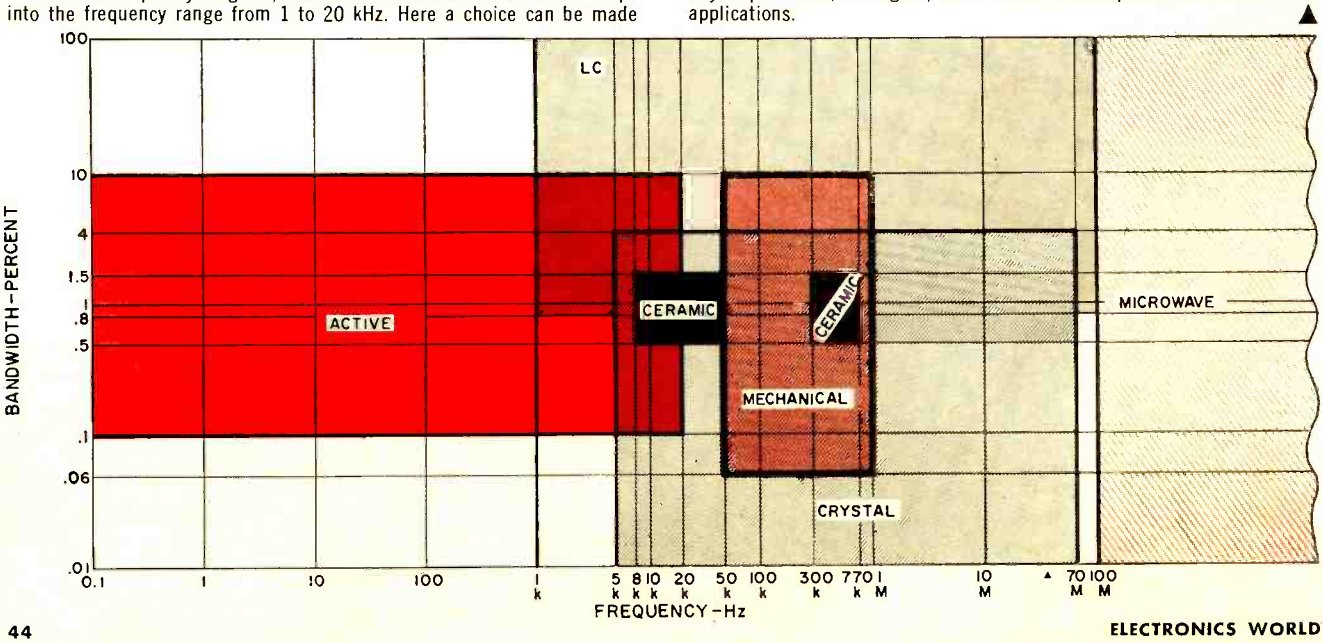
From 1 kHz to 100 MHz the LC filter covers the largest area of frequency spectrum and percent bandwidth. At very low (less than 1 kHz) and at very high (greater than 100 MHz) frequencies it is nearly impossible to fabricate LC filters with either useful electrical characteristics or small physical dimensions. At frequencies less than 1 kHz, inductance values and physical dimensions become excessive. The active filter, using reasonable values of RC elements and an operational amplifier, can provide filtering at frequencies less than a hertz.

For frequencies greater than 100 MHz, discrete LC structures fail as filters because of parasitic capacitance and inductance. Microwave filters composed of distributed elements such as transmission lines, waveguides, and comb structures are used at the higher frequencies.

From the frequency diagram, it is evident that the active filter overlaps into the frequency range from 1 to 20 kHz. Here a choice can be made among a number of different filter types. Various factors, including percent bandwidth, temperature, shape factor, and cost, influence the selection of a particular filter type. For percent bandwidths greater than 10, an LC filter is required. If signal power gain is needed, this can be obtained only from an active filter. A crystal filter may be the best choice if a shape factor on the order of 2:1 is required. If the filter has to operate at a temperature of 125° C, it may be most economical to choose an LC filter.

Generally, ceramic filters are restricted to two frequency slots: 8 to 50 kHz and 300 to 770 kHz. The reason is that ceramic elements, being piezoelectric in nature, resonate in these frequency ranges (broadband ceramic filters operating at center frequencies of 4.5 and 10.7 MHz are also available). In general, ceramic filters exhibit a reasonably good shape factor and are economical. At temperatures greater than 85° C, however, frequency shift becomes excessive for many applications.

Mechanical filters are obtainable with shape factors as low as 1.2:1, making them excellent devices where sharp selectivity is required. Crystal filters are well suited for narrow-band applications. Monolithic crystal filters housed in a TO-5 package are ideal for integrated circuits. With computer synthesis, the LC filter can be made to satisfy just about any requirement, but again, cost and size are important factors in some applications. ▲



The author joined Microlab/FXR in 1959 and in his present position is responsible for the coordination of all filter and custom product design and development contracts. Prior to joining the company, he was associated with ITT Federal Laboratories where he was involved in the development of communications and radio navigation equipment. He received his BSEE from Lafayette College in 1958 and an MSEE from Newark College of Engineering in 1962. He is a member of the IEEE and the IEEE Professional Groups on Microwave Theory and Techniques and Circuit Theory. He is also a member of Tau Beta Pi and Eta Kappa Nu honorary groups.

Filters for Microwaves

By ROBERT FELSENHELD, Jr./ Engineering Manager, Microlab/FXR

No new breakthroughs; just better made parts. Here's what the system engineer should consider when choosing a new microwave filter design.

MICROWAVE filters are unique. The frequency spectrum they cover is quite large, overlapping into the area of lumped-constant filters at the low end and into the "millimeter wave" region at the upper end. There is some confusion because most engineers and scientists cannot agree where the microwave frequency spectrum really begins or ends. For traditional reasons, however, and probably for reasons developed by the industry itself, the practical microwave region starts at 100 MHz and runs up to frequencies in excess of 18 GHz.

Types of Microwave Filters

Microwave filter types include high-pass, low-pass, and bandpass units whose bandwidths range from a fraction of a percent to an octave or even more; narrow- and wide-band band-reject types; elliptic function filters with extremely steep rates of rejection; complementary filter pairs; continuous channel diplexers; combination networks to act as channel separating and multiplexing devices; lossy wall and mode suppressing filters; directional filters which have the properties of directional couplers but exhibit bandpass and band-reject characteristics depending on which ports are chosen as input and output; and filters used for phase correction networks and delay lines. Types and applications are a never ending list.

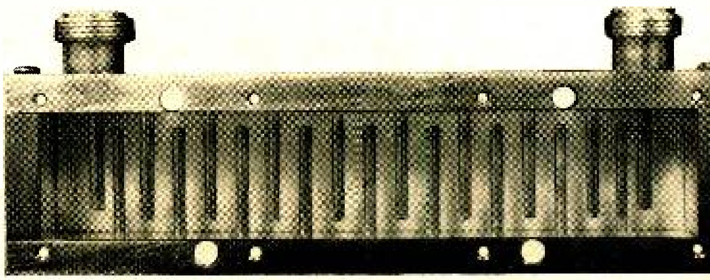
What Makes a Microwave Filter?

Anyone who has worked in the lower frequency regions or with an FM or TV tuner knows the problems that can be encountered due to stray capacitances or excessive component lead lengths. Microwave filters overcome these difficulties somewhat by the use of distributed rather than lumped elements. Thus, the microwave filter engineer uses transmission line lengths and characteristic impedances rather than commercial capacitors and coils as the elements of design. In the v.h.f. and u.h.f. regions, there is overlapping and some combining of the lumped-element and distributed-element design. These filters are classed as "hybrids." At higher frequencies almost all filters are constructed of parts made on lathes and milling machines.

In the past ten years, microwave filters have undergone a vast change. The major stimulus to this change has been the tremendous activity generated toward what is called "modern network theory" as opposed to the older and more pragmatic "image parameter" method of design. Modern network theory has not only made possible practical bandpass, low-pass, high-pass, and band-reject filters to more optimum specifications, but also has led to a variety of new types and configurations. Two examples of distributed-element bandpass structures are shown in Figs. 1 and 2. Fig. 1 is a 19-resonator interdigital filter constructed of alternately shorted round-rod quarter-wavelength resonators in a metal housing. Fig. 2 is a five-resonator comb-line device constructed of parallel-coupled, capacitive-shortened rectangular resonators in a metal housing. In both cases, the filters could have been constructed from round rod, rectangular rod, or strip-line. For the interdigital filter, each rod or resonator is the microwave equivalent of a low-frequency "tank circuit." For the comb-line filter, the same is true, except the input and output bars act as transformer sections, not resonators. These are only two examples of devices which are popular in microwave systems.

Other technologies, the call for miniaturization, and economic pressures have all influenced microwave filter technology. Some filters can be fabricated using printed-circuit strip-line techniques. A strip-line filter is, in itself, not a type of filter but a type of construction. Many types of microwave filters can be constructed in printed strip-line, but most strip-line filters are of the moderate and wide-band bandpass type. Printed strip-line filters are designed utilizing distributed elements, as were the comb-line and interdigital previously discussed. But printed strip-line elements more often take the form of open or short-circuit

Fig. 1. A 19-resonator interdigital filter made of alternately shorted quarter-wavelength rod resonators in metal housing.



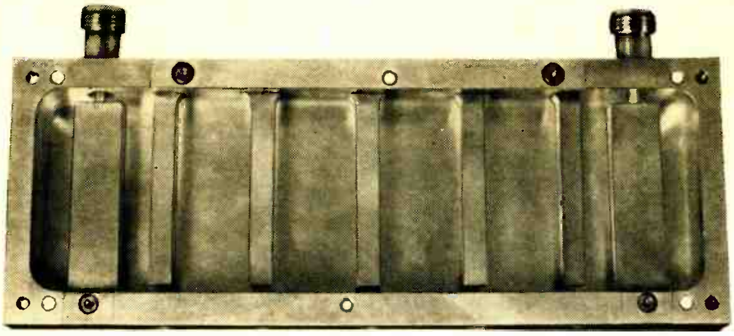


Fig. 2. Five-resonator comb-line filter using capacitance tuning.

quarter-, half-, or three-quarter wavelength stubs of varying widths. Typically these stubs are interconnected by quarter-wavelength coupling lines to yield the desired design characteristic. Recently, printed strip-line filters have replaced their fabricated, thick-strip predecessors in some system applications, but printed-circuit filter components probably account for less than five percent of all microwave filter component applications. Strip-line filters are more often used with other printed-circuit devices such as directional couplers, mixers, hybrids, etc., where all the components may be integrated and reproduced on one circuit board. Two major drawbacks to printed-circuit filters (and possibly the reasons why they are not used as much as one might think) are bandpass insertion loss and temperature instability. These factors are dependent on the nature of the filter, and upon the resistive losses and thermal characteristics of the dielectrics of the copper-clad materials which are presently available in the industry.

Helical-line filters have become quite popular below 1000 MHz because the slow-wave property of the helix (it takes r.f. energy longer to travel circularly along a helix than along an equivalent length of coaxial transmission line) permits length and volume savings on the order of three times or more. Fig. 3A shows a typical four-resonator helical tubular bandpass filter. The design is "hybrid" in nature. The "coils" are actually distributed elements which have been precisely calculated as lengths of helical transmission line.

Each helix is soldered to two adjacent shunt bead capacitors which have predetermined values and are calculated as dielectrically loaded concentric coaxial cylinders. These two capacitors and one helix form one resonator. The resonators are coupled to one another through dielectric spacers which are located between the faces of adjacent beads. The input and output capacitors are shunt elements. The lumped-element equivalent circuit diagram is shown in Fig. 3B. Because of this configuration, helical tubular bandpass filters have a steep (slope) rate of rejection at the upper frequency cut-off point and a reduced rate on the lower frequency rejection slope. A filter such as the one illustrated is typically about four inches long and one-half inch in diameter at 400 MHz.

YIG filters are a newer type of filter which finds application in some systems. Yttrium iron garnets are used to construct miniature cavities (YIG filters) which can be electrically tuned over octave bandwidths.

Some Microwave Filter Characteristics

Microwave filters have some special characteristics and exhibit some phenomena not normally associated with filters at other frequencies. This is true despite the fact that the design theory is exactly the same as that used at all other frequencies. Most coaxial systems are 50-ohm systems, therefore most coaxial filters quite naturally are specified with 50-ohm input and output impedances. Some v.h.f. systems are 72 ohms or 93 ohms. On the other hand, waveguide filters are not normally specified by impedance, but rather by waveguide size. Thus the typical two-section cavity shown in Fig. 4 would be specified to work over a frequency range in WR-137. This is because the true impedance of the waveguide is not constant but varies with frequency and therefore is not a practical parameter.

"Q", or unloaded "Q" is not usually a problem in microwave filters. The geometries, configurations, and boundaries required by microwave structures usually assure a reasonable "Q" is available. In the worst cases, insufficient "Q" will be translated into an undesired passband insertion loss. In multi-resonator filters, "predistortion loss" associated with finite "Q" and predictable as a function of phase slope or group time delay will cause additional transmission losses at passband edges.

Temperature drift can be a problem with microwave filters, particularly with narrow-band cavity devices. These filters are typically used as preselectors in microwave receivers. Cavities are normally temperature-compensated in the mechanical design or constructed of relatively temperature stable materials such as invar, a nickel-steel alloy. Moderate or wideband devices do not demonstrate as much deterioration of performance or frequency drift in severe temperature environs except possibly in systems which require a high degree of absolute and relative phase and group time delay stability.

As was previously stated, microwave filters are designed from the same basic theory as all other resonant devices, and therefore tabulated information about rejection curves, shape factors, passband ripples, "Q", phase, insertion loss, etc. is also applicable to all microwave filters.

How to Select & Specify a Microwave Filter

It is important for an individual who selects and specifies a microwave filter to recognize the special properties of certain filter types. For example, low-pass microwave filters may or may not be required to pass signal from d.c. to some cut-off frequency, f_c, but the stopband must have some finite upper limit, *i.e.*, six to ten times f_c. The upper limit of the reject band will, therefore, not extend to infinite frequency.

Microwave high-pass filters have rather special properties. In fact, there is no such thing as a true microwave high-pass filter! This is due to the distributed nature of the elements. A microwave high-pass filter is actually a wideband bandpass filter or pseudo-high-pass filter. Thus, although the band may reject d.c. to some desired frequency, the actual passband will extend from some cut-off frequency, f_c, to some other finite frequency, f_h, but does not

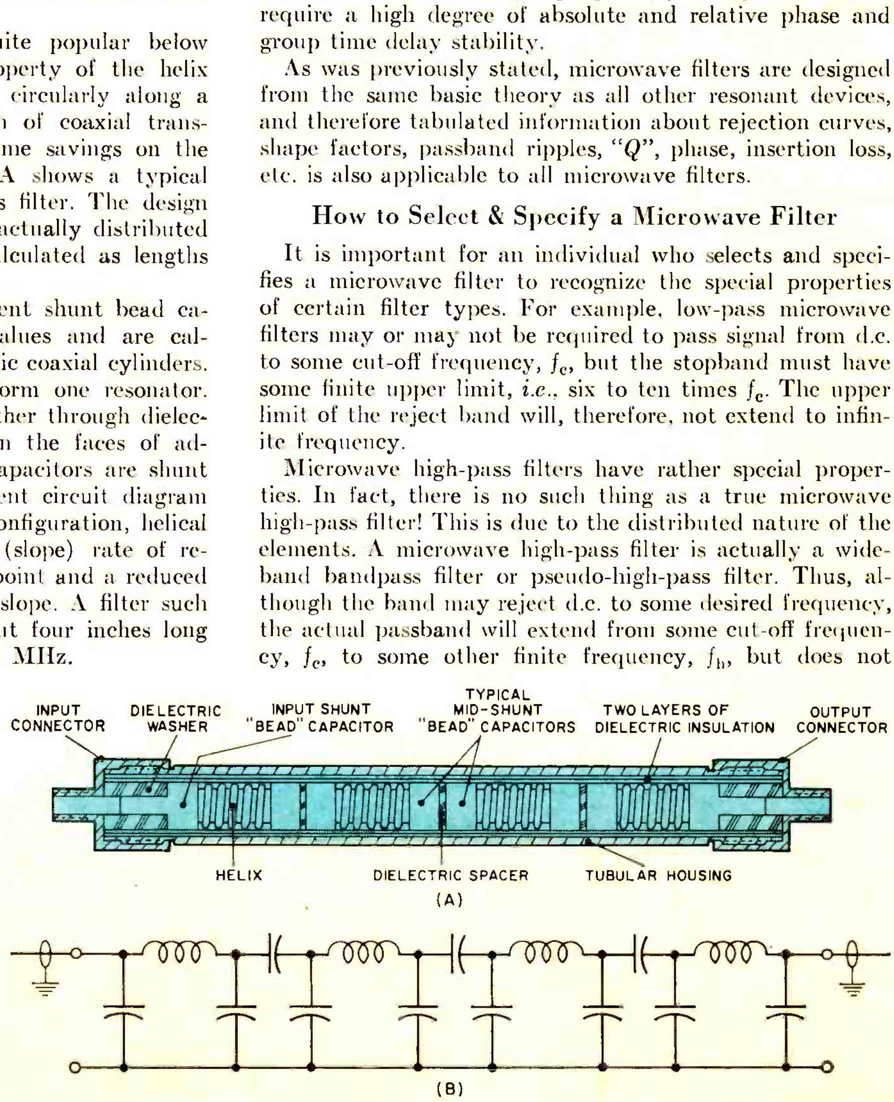


Fig. 3. This hybrid filter (A) and its equivalent circuit (B) is typical of helical tubular band-pass types.

continue indefinitely to some higher operating frequency.

Waveguide filters can cause problems because each standard waveguide range covers only a relatively small portion of the frequency spectrum, or a useful frequency range of roughly thirty percent. On the low side, the waveguide itself cuts off and behaves like a high-pass filter. Above the useful range, energy propagates in modes other than the fundamental TE_{10} mode, and thus structures which are designed to work within a given waveguide range are only useful in or below that range. A waveguide band-reject filter will not pass frequencies below the waveguide's cut-off point even though it may yield the desired "notch" and close-in passband performance.

Microwave filter users should be aware of the limitations of typical coaxial and strip-line structures. Filters such as those shown in Figs. 1 and 2 are designed using distributed techniques and, in general, these structures become periodic with frequency. Typically, microwave bandpass filters constructed with quarter-wavelength resonators exhibit additional passbands at odd harmonics of their center frequencies. Bandpass filters constructed of half-wave resonators exhibit additional passbands at all harmonics. Low-pass filters or elements are often used in conjunction with bandpass structures to eliminate harmonic problems. Coaxial and strip devices can also exhibit mode problems (*i.e.*, spurious responses in their reject bands) when the dimensions of their structures become significant compared to a wavelength at some higher frequency. A good filter designer will consider these problems, based on the specification given.

Fortunately, all microwave filters irrespective of their type—low-pass, bandpass, band-reject, etc.—are defined essentially by the same parameters. Thus, the nomenclature or the specification of parameters becomes relatively simple. The characteristics relating to the theoretical design or method of synthesis is something for the microwave engineer to know, understand, and use, but are not necessary knowledge for the systems engineer (except in sophisticated or very special applications). Thus, the non-filter designer need not be fretful if such terms as Chebyshev, Butterworth, Butterworth-Thompson, Cauer, elliptical, or Gaussian-type responses seem foreign to him. Essentially, the microwave filter user must know "what frequencies are to be passed and what frequencies are to be stopped, how much loss is allowable in the passband and how much rejection is required in the stopband." More specifically, the applicable electrical parameters can be set forth by the following:

1. *Passband frequency range*
2. *Passband insertion loss*
3. *Passband v. s. w. r. and/or amplitude ripple*
4. *Average power*
5. *Peak power*
6. *Impedance*
7. *Stopband frequency range*
8. *Stopband rejection*
9. *Phase*
10. *Group time delay*

The last two characteristics were placed at the end purposely because they are only significant in certain short, fast-rise-time pulse and narrow-band FM systems. The list neglects two significant parameters not controlled by the filter designer—the source and load impedances. Uncontrolled source and load impedances can degrade filter performance and cause voltage breakdowns in a perfectly designed filter. A v.s.w.r. of 1.3:1 for components or networks adjacent to the filter should give good results.

Make or Buy Your Filter?

Much pressure is being put on systems engineers to design their own filters. At first glance, there seems to be some valid reasons for this. Miniaturization requirements and the advent of integrated circuits for the computer and aerospace industries have caused all technologies to be looked at in other than traditional ways. Strip-line circuitry has shown the obvious possibility of eliminating connectors between networks or components. System sophistication has increased the communications and interface difficulties between contractors and vendors. And, tons of handbook material have been published about microwave filters in the past several years.

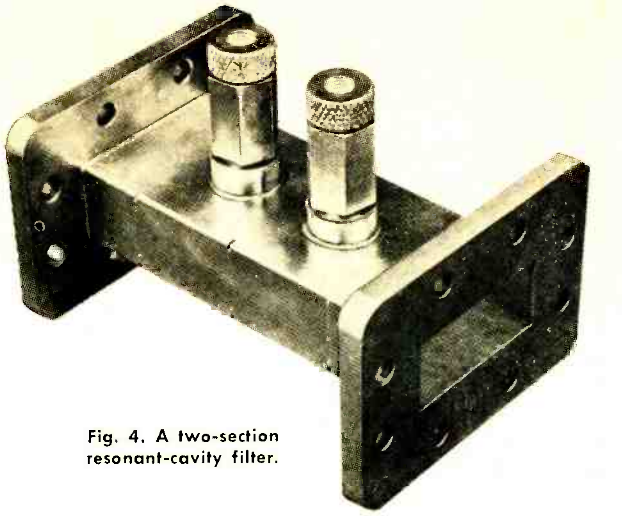


Fig. 4. A two-section resonant-cavity filter.

But, a filter should be made in-house only when the proper engineering ability is available, and then only if there are complementary pragmatic skills available to take over where the handbooks and theorists leave off. On the other hand, buying a microwave filter is relatively easy. There are many companies which specialize in microwave filters and have the facilities to provide certain types of filters as catalogue or near-catalogue items. At the very least, they can advise on feasibility based on specifications. Thus, the answer is obvious. It's usually easier and cheaper to buy filters.

The prices of microwave filters depend on the type, the complexity, and the environmental conditions under which the filter must operate. Typically, tubular filters require less machine and fabrication time and therefore are normally less expensive than other filters. Tubular low-pass filters of transmission-line or helical construction sell for just under \$50 to \$300. Tubular high-pass and bandpass filters cost between \$100 and \$400. Basic waveguide cavity filters may be priced from \$250 to \$500, but higher-order-mode waveguide devices can cost \$3000. The comb-line and interdigital filters fall in the \$250 to \$500 category. Tunable coaxial preselectors may cost as much as \$750. Printed strip-line filters may cost between \$50 and \$200, in quantity, after the initial photography and artwork costs have been amortized. Incidentally, this pricing information is given as a guide and the reader should realize actual costs are based on a particular specification.

Future Developments

It is doubtful that revolutionary microwave filter breakthroughs will be made in the next year. The trend will continue toward miniaturization compatible with 3-mm connectors through the use of smaller or printed structures. The development of low-loss, high-dielectric materials should also continue, and there should be increased use of helices and other slow-wave structures. The big breakthrough will come when microwave transistors become readily and economically available and can be utilized as a reliable basic building block in new hybrid or integrated-circuit active microwave filters. Until that time, microwave filters will probably remain essentially as we know them today. ▲

The author is an electrical engineering graduate of the Massachusetts Institute of Technology and a member of the Institute of Electrical and Electronics Engineers. He also serves as Chairman of Committee P.3.6 on electric wave filters of the Electronic Industries Association.

R. F. Interference Filters

By BENEDICT ROSEN / Asst. Manager, Filter Div., Sprague Electric Co.

Modern electronic devices with low power levels and high sensitivities require improved EMI filters. The challenge for the filter designer is to develop smaller components and to improve packaging techniques.

ALMOST every new electronic device demands a place in the frequency spectrum free from interference of all others. And, the great majority of these new components are more sensitive to "noise" than their predecessors. In many cases, electromagnetic interference (EMI) filters are called upon to protect complex systems, such as missiles and computers as well as simple electronic devices, from performance degradation due to outside electromagnetic interference and to keep unwanted radiation "inside" away from other sensitive circuits.

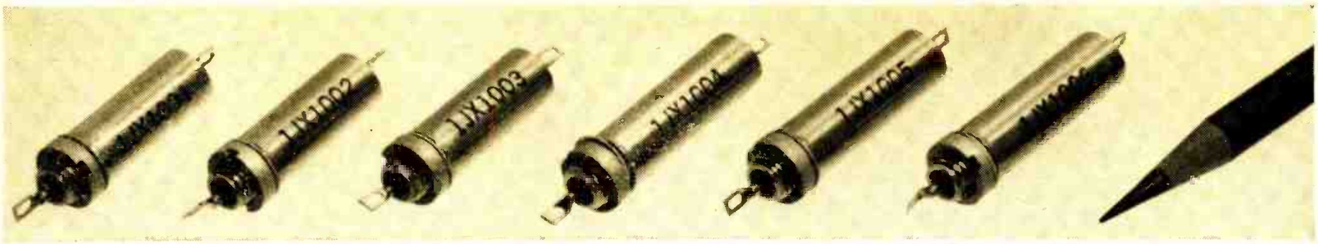
Filters are available in an almost infinite variety of shapes and sizes. Extremely large power-line filters are used in shielded rooms to protect communications equipment from transients. On the other hand, subminiature filters have become commonplace. These tiny devices are able to fit into the head of a multi-pin connector with 50 or more of the units requiring less than one square inch of space. In both filter types, all kinds of capacitors—paper, film, electrolytic, and ceramic—and inductive elements—ferrites, powdered iron, etc.—are utilized in the construction. The selection of the proper capacitor-inductor unit is, of course, entirely dependent on the intended application. A small ceramic feedthrough device may cost as little as 50 cents; the price of some high-current power-line filters runs as high as $1000. A typical single-line, 1-to-5-ampere, 200-V d.c. or 117-V a.c. filter sells for $2 to $10 in large quantities. These are generally manufactured in a cylindrical configuration and are by far the most widely used EMI filters. Size is pretty much a function of both currrent and voltage—increasing with thicker dielectrics for higher voltage ratings and larger core volumes for higher currents.

In general, most of the smallest and lightest interference control filters used in military and industrial electronic and electric equipment are packaged in cylindrical-shaped cans. This design uses to advantage the natural shape of the rolled capacitor sections and the toroidal inductors which form the filter. In addition, the design facilitates mounting the units on panels, or with threaded necks, on bulkheads. The feedthrough characteristics of this class of component enhances filter effectiveness by eliminating mutual coupling between input, or noise source, and the output terminals.

Stability

Most filters which use film capacitors are relatively stable with voltage, and temperature. However, insertion loss varies with frequency and current. Current instability is due almost entirely to the change in permeability of the core material with saturation. This phenomenon is well known and is exhibited, to some degree, by all inductors which use magnetic material. Frequency instability, on the other hand, is a result of changes in component impedances with frequency and other distributed parameters. An "L" circuit filter, for example, will generally have dips in its insertion loss curve somewhere between 1 and 100 MHz, depending on the resonant frequency of the coil.

Temperature and voltage stability have become significant additional considerations with the newest line of interference filters—those containing ceramic capacitors and ferrite inductors. Both ceramics and ferrites are susceptible to temperature fluctuations. In addition, the ceramic capacitor is the first shunt element used in EMI filters which exhibits a substantial voltage instability. This characteristic presents a potentially serious problem since some widely used components show variations in insertion loss of as



Some typical subminiature electromagnetic interference filters. Low-pass filters like these are used on low-voltage power and control lines where the low impedance of the power source must be maintained. Many manufacturers have found that their small size, light weight, and high performance are particularly suited for use in high-density packaging applications.

much as 15 to 20 dB over the specified operating voltage and temperature range.

Impedance

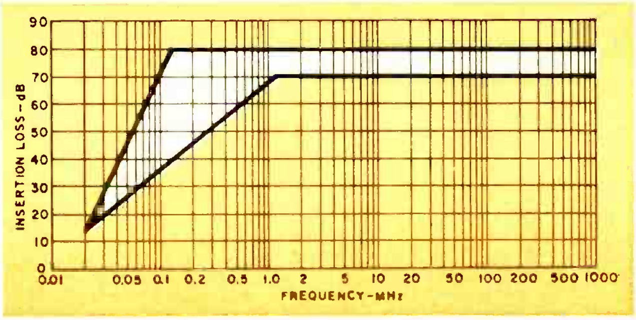
Typically, interference filters are measured in a system where both the input and output impedances are 50 ohms. This 50-ohm system is not too far from real life at high frequencies (for our purposes here, we are considering frequencies above 10 MHz high frequencies), but at frequencies up through the low megahertz region, the real terminating impedance can be almost anything. The reactance of a line, for example, varies continuously from positive to negative as a function of frequency.

Since manufacturers' catalogues generally describe the performance of interference filters in a 50-ohm system, selection of parts on this basis alone cannot help but result in problems. There are, however, several general rules which, if followed, can reduce the hit-or-miss aspects of filter selection. If the installation in which the unit is to be used is a low-impedance capacitive system, an inductor facing this impedance would be desirable. Obviously in this situation a capacitive input filter would be of little value since the input capacitor is in parallel with the system capacitance. On the other hand, the effects of even a small inductor at 100 kHz will be significant. Conversely, if a system is inductive, it would be helpful to have a capacitor facing this high impedance.

Filter selection can be further complicated if the suppression of switching transients is required. Sometimes the addition of a shunt capacity to a circuit amplifies the signals it was intended to suppress. This characteristic is due to stored energy in the capacitor being discharged and creating large current loops which normally would not have existed.

The assumption that a filter which provides 60-dB attenuation at 150 kHz in a 50-ohm system reduces interference in the system by that amount is, more often than not, erroneous. Most filter manufacturers, however, have personnel who are able to assist system designers and provide general filter-application guidelines. The major point, however, is that insertion loss cannot be assumed from a list of specs published in a catalogue. Proper consideration must be given to the system's characteristics.

Once a filter which performs a desired function is specified, it is important that the same circuit configuration and approximate values be used in subsequent devices to assure system continuity. From the standpoint of cost and size, it is equally important that only necessary performance characteristics be specified. For example, if filtering is only required from 100 kHz through 1000 MHz, it is usually unnecessary to incorporate feedthrough capacitors. Less expensive capacitors and manufacturing processes will provide adequate performance. Also, unless lower frequency characteristics are actually needed, very high premiums in size, weight, and cost will result if attenuation within this range is also specified. In installations requiring low-frequency performance, it's desirable to use polarized electrolytic capacitors. This allows a much smaller package to have the same performance as a unit using conventional paper, ceramic, or film capacitors.

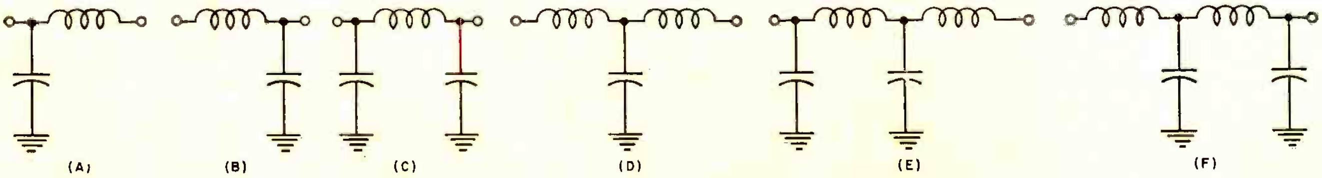


The minimum full-load insertion loss characteristics of subminiature EMI filters are measured in accordance with MIL-STD-220 and usually fall within the band shown in diagram. Ideally, the loss characteristic is flat, however components resonating at specific frequencies cause some dips and peaks.

Another factor in the cost *vs* size battle between the product designer and product user relates to the specification of voltage, current, and temperature ratings. It is quite common for users who will need 2-ampere circuits to specify three or four amps as a safety margin. The cost and size for this luxury increase significantly, and are certainly out of proportion to the end result when the design capabilities of the manufacturer and his safety margins are considered. In order for a supplier of filters to minimize cost, weight, and size and yet provide the desired filter, the user should specify as nearly as possible his actual requirements in terms of insertion loss, current, voltage, and temperature ratings, and, if possible, the general circuit configuration in which the filter is intended to be used. As an added benefit, the user obtains the needed component quicker.

In general, r.f. interference filters are conservatively rated with respect to voltage and current. Thus, they are widely used in military equipment where continuous operation within a specified ambient range is a must. ▲

Here are electrical circuits of subminiature electromagnetic filters shown in photo above. The two L filters are found in parts 1JX1001-1002, respectively. Part 1JX1003 has a pi network (C) while T network (D) is found in part 1JX1004. Remaining double-L configurations (E, F) are found in parts 1JX1005-1006, respectively. The pi and L circuits handle 0.5 A; T and double-L, 0.4 A.



The author received his B.S. from Moore School of Electrical Engineering, University of Pennsylvania, in 1950 and his M.S. in electrical engineering from MIT in 1952. From 1952 to 1960, he was a staff member of MIT's Research Laboratory of Electronics, participating in the development of missile guidance and electronically scanned radar systems and in the design of a satellite gravitational red-shift experiment. He has been with Damon since 1961 where he has been active in the design of quartz crystal devices. He was named to his present post in 1968 and is now engaged in the development of monolithic piezoelectric devices. He is a member of IEEE, Eta Kappa Nu, Sigma Tau, Tau Beta Pi, and is an associate of Sigma Xi. He holds a patent in the area of phased arrays employed for missile guidance.

Crystal Filters

By ROBERT L. KENT/ Engineering Manager, Electronics Div., Damon Engineering, Inc.

Like other electronic components, crystal filters shrank physically when performance and reliability improved. They offer users the maximum in stability and selectivity; are favored in military, commercial applications.

IN the beginning, crystal filters could only be used in equipment where size and weight were of little consequence. After World War II, weight and volume went down while performance and reliability went up an order of magnitude. Now there is a monolithic crystal filter which again cuts size and costs, has greater reliability, and better temperature stability.

Crystal filters are used wherever the bandwidth occupied by a desired signal is no more than a few percent, preferably no more than a few tenths of one percent, of the operating frequency. Extremely narrow bandwidths are attainable because of the inherent high "Q" of the quartz resonator. A "Q" of 100,000 is as readily obtainable with a quartz crystal at 10 MHz as a "Q" of 100 with an LC resonant circuit.

High-frequency crystal filters have made a major impact on h.f. narrow-band communications. System performance characteristics have been improved and complexity reduced through the use of single-conversion receiver designs employing crystal filters. A more recent application is in the area of frequency synthesis, where crystal filters are used to clean out spurious signals caused by mixing and other non-linear synthesis operations.

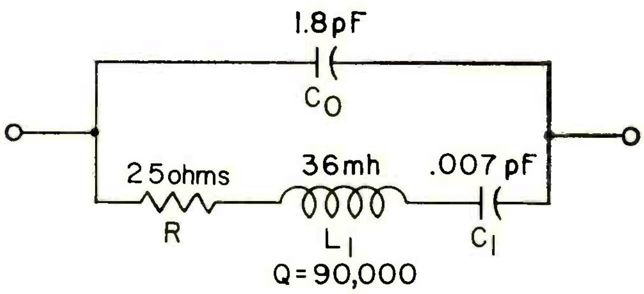
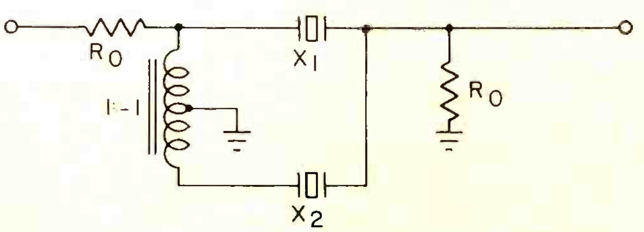


Fig. 1. The equivalent circuit of a 10-MHz quartz crystal.

Fig. 2. The unbalanced half-lattice uses two crystals and is building block for more complex filter configurations.



What Users Should Know

Before discussing "why" and "how" an engineer should select and use a crystal filter, it is worthwhile to examine very briefly some filter designs. As previously stated, crystal filters are narrow-band devices. They are used to select, or reject, a very narrow frequency band out of a broad spectrum. Quartz crystals provide the required selectivity when used in resonant circuits in conjunction with capacitors and inductors.

The most common equivalent electrical circuit of a quartz crystal is shown in Fig. 1. Shunt capacitance, C_0, limits the bandwidth. Similarly, the series resistance, R, along with temperature stability, places a lower limit on practical bandwidths.

To obtain a symmetrical attenuation characteristic in a crystal filter, the shunt capacitance of the crystals is often "balanced out" by means of bridge networks. The unbalanced half-lattice (Fig. 2) is commonly employed for this purpose, and becomes the building block with which more complex crystal filters are assembled.

Table 1. Shape factors for Butterworth (maximally flat) filters.

NO. OF RESONATORS	SHAPE FACTOR (60 dB/3 dB)
2	31.6 :1
3	10.0 :1
4	5.65:1
5	4.00:1
6	3.16:1
7	2.70:1
8	2.37:1

CENTER FREQ. (MHz)	3-dB BAND-WIDTH (kHz)	SOURCE & LOAD RES. (kohms)
4.0	0.5	1.0
4.0	2.0	3.9
9.1	2.5	1.8
10.7	7.0	1.5
10.7	16.0	3.9
21.4	7.0	0.36
21.4	16.0	1.0
30.0	10.0	0.25

Table 2. Typical terminations for monolithic crystal filters.

A six-crystal filter is shown in Fig. 3. Note that a single "hybrid" transformer can serve two of the filter sections.

The number of crystals which the filter uses is usually determined by the "shape factor," *i.e.*, the required selectivity. The shape factor is a ratio of bandwidths measured at two different attenuation levels, such as −60 dB and −3 dB. The shape factors for Butterworth (maximally flat) filter designs are listed in Table 1. Other designs optimize such characteristics as group delay uniformity or phase linearity for a specified shape factor or the number of resonators.

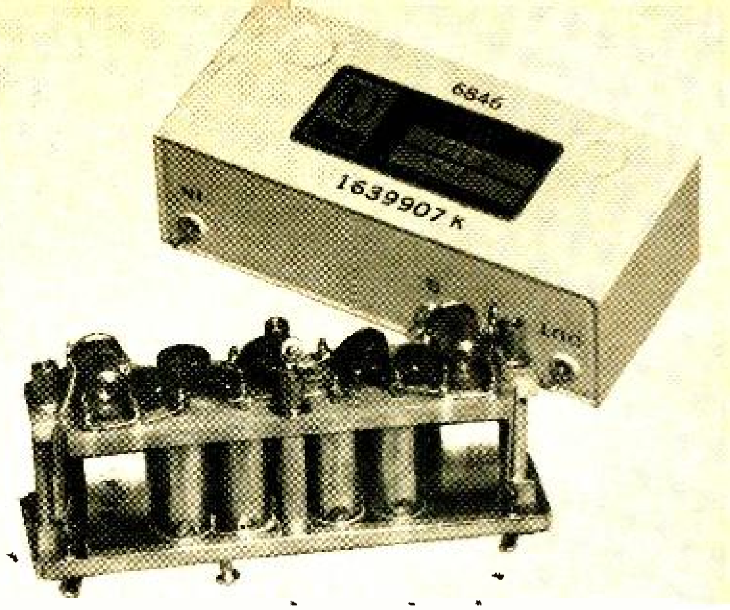
The range of 3-dB bandwidths obtainable with high-frequency (1-36 MHz) fundamental-mode crystal filters is typically 0.005 percent to 2.0 percent of center frequency. Best performance and lowest cost are obtained by favoring fractional bandwidths between 0.01 percent and 0.5 percent.

Monolithic Crystal Filters

Conventional crystal filters are composed of discrete crystal resonators, inductors, and capacitors with their electrical interconnections. In a monolithic crystal filter, the electrical coupling components and connections are replaced by an elastic coupling medium, namely the quartz plate itself. A monolithic filter consists of a single wafer of crystalline quartz into which are deposited two or more pairs of electrodes, as shown in Fig. 4. Each region between a top and bottom electrode becomes a resonator, with the area of vibrational activity extending outward for a small distance beyond the electrode region. The degree of elastic coupling between adjacent resonators is a function of the distance between electrode pairs.

The monolithic filter works this way: A vibration is set up (piezoelectrically) across the crystal's input resonator by the application of a high-frequency electric field. This vibration is coupled elastically to successive resonators until it finally reaches the output resonator. There, the mechanical vibration is transformed by the piezoelectric effect back into electrical energy.

The electrical characteristics of monolithic crystal filters are comparable to those of their conventional ancestors. The size and complexity are much reduced, however, resulting in a device that is more reliable and costs less. At 21.4 MHz, for example, a four-resonator monolithic filter housed in a low-profile TO-5 transistor case occupies only 1/60th of a cubic inch and can be bought in large quantities for less than $10 each. By employing these devices with other integrated circuitry, a complete high-gain narrow-band monolithic i.f. amplifier can be packaged in a volume of 1/3 cubic inch.



A conventional 4-pole crystal filter used in Talos missile system, with a center frequency of 2.5 MHz, 1.5-kHz bandwidth.

Considerations Affecting Cost

The cost of a crystal filter can range from less than ten dollars to several hundred dollars. The major factors determining price are:

a. Quantity required—the multiplicity of parameters makes standardization of models impossible, with few exceptions. The engineering cost associated with a new design is normally amortized over the number of units purchased.

b. Complexity (number of crystal resonators)—determines assembly and alignment time as well as materials cost.

c. Degree of difficulty and special testing requirements—by avoiding the extremes shown on design charts, and by limiting the specification requirements to what is really needed, this cost element can be minimized.

Choosing the Filter

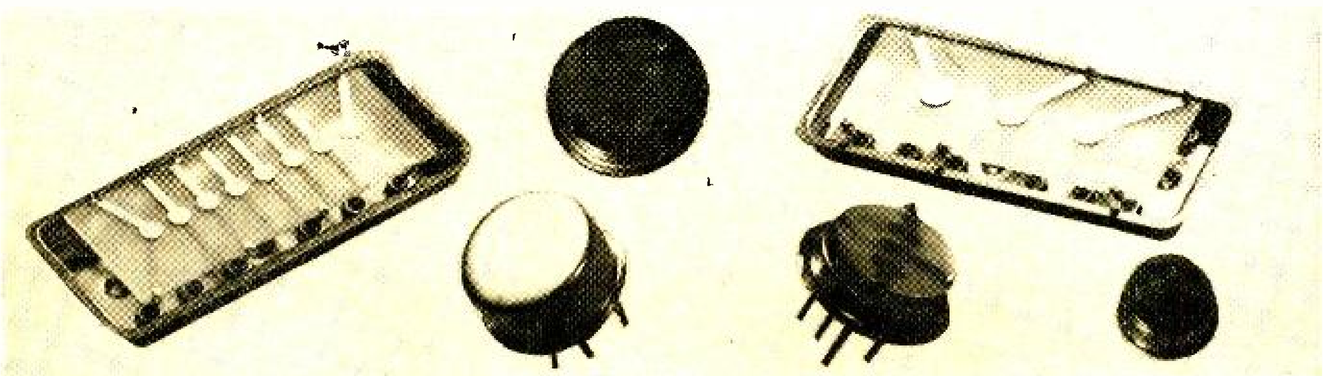
A rather common error in the design of electronic systems that employ sophisticated components is to leap first and look later. If the salient characteristics and limitations of the major components can be borne in mind from the earliest phases of the design, a better and more economical system will result.

Therefore, a designer who is planning to employ crystal filters in his system should consider the following areas:

a. Fractional Bandwidths:

For best performance and lowest cost, choose intermediate frequencies so that the required bandwidths fall between

An assortment of monolithic crystal filters covering the frequency range of 3-30 MHz and bandwidths of 500-15,000 Hz.



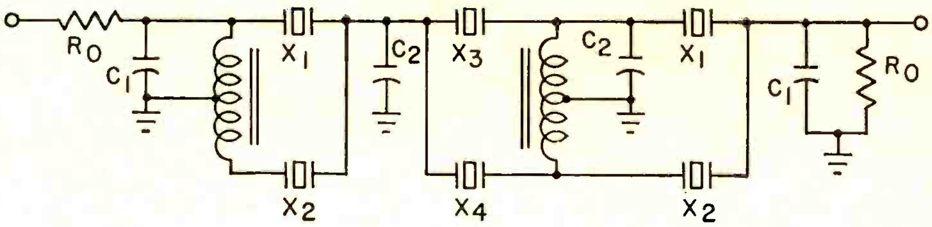


Fig. 3. A single hybrid transformer can be used to serve two filter sections in this circuit.

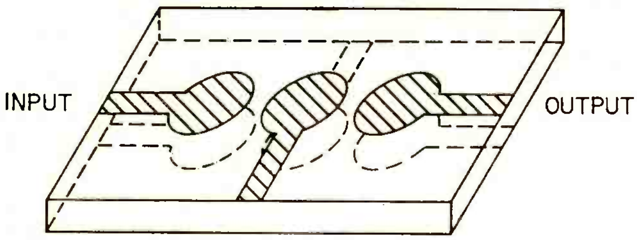


Fig. 4. Monolithic filter consists of a single quartz wafer on which two or more pairs of electrodes are deposited.

0.01 percent and 0.5 percent of center frequency. At frequencies from 35 MHz to 70 MHz it is necessary to employ third-overtone resonators, and the bandwidth limits become 0.005 percent and 0.05 percent of center frequency. Overtone crystal filters are more costly than fundamental-mode filters; moreover, it is usually possible to obtain the same bandwidth at a lower center frequency with fundamental crystals.

b. Stability with Time and Temperature:

Quartz crystals are extremely stable devices. Typical aging rates of high-frequency filter crystals are 5-10 parts per million per year. The variation of frequency with temperature is typically (maximum) ±10 parts per million from 0°C to 50°C, or ±20 parts per million from −40°C to 100°C. For bandwidths greater than 0.1 percent of center frequency, the effects of other discrete components upon the aging and temperature characteristics can be greater than effects of the crystals themselves. The system configuration and filter bandwidths should be chosen to minimize the effects of time and temperature upon system performance.

c. Filter Terminations:

Conventional (non-monolithic) crystal filters normally contain tuned transformers and inductors, making it a simple matter for the filter designer to shift from the characteristic terminating impedance of the filter to whatever value the user chooses to provide. There are, however, several points worthy of consideration in this regard:

1. If a pure resistive termination is specified, the shunt capacitive reactance should be at least ten times greater than the terminating resistance. 2. A tolerance of ±5 percent on the terminating impedance is normally required in order to obtain best performance. If this is inconvenient for the user to provide, resistive padding can be incorporated into the filter. The result is an increase in insertion loss. 3. A reactive terminating impedance, such as 20 picofarads in parallel with 50 ohms, can usually be accommodated in the design. At 30 MHz, for example, a capacitance in parallel with 50 ohms might be specified as 20 ±10 pF, since 10 pF has a reactance of about 500 ohms. 4. At frequencies above 10 MHz it is generally desirable to specify a low terminating resistance such as 50 ohms. This minimizes the detuning effects of parasitic capacitance. 5. Monolithic crystal filters usually do not contain tuned inductors or transformers. In order for the user to exploit fully the size and cost advantages of the monolithic filter, he must design external circuitry to present the terminating impedance required by the filter. Typical values of terminating resistance for monolithic filters are given in Table 2. The impedances shown are for filters operating in the h.f. band.

d. Other Specifications:

1. Shape factor, more than any other characteristic, determines the number of resonators required. A Butterworth (maximally flat) design provides 6 dB attenuation at twice the 3-dB bandwidth for each independent resonator, or pole. A six-pole Butterworth filter, for example, would yield a shape factor from 36 to 3 dB of 2:1. A Chebyshev (equiripple passband) design will be steeper in cut-off, while a Bessel (maximally flat time delay) design will provide a considerably more gradual attenuation characteristic. 2. Rejection of spurious responses. Inharmonic overtone responses of filter crystals can produce undesired "spurs" at frequencies removed from the passband. Spurious responses generally appear in wider bandwidth filters, especially those comprising only one or two cascaded sections. Inharmonic overtones of high-frequency crystals typically occur at frequencies 1-3 percent above the fundamental resonance. This fact can sometimes be advantageous in the selection of a local oscillator frequency. 3. Ultimate attenuation (approximate rule of thumb): narrow crystal filters—30 dB per section; wider crystal filters—20 dB per section; monolithic filters—20 dB per resonator below 10 MHz, 15 dB per resonator above 10 MHz. 4. Insertion loss: 1 dB to 6 dB, increasing as either the upper or the lower bandwidth limit is approached. 5. Ripple in passband: typically ±0.5 dB over wide temperature ranges; 0 dB for rounded-nose (Gaussian or Bessel) types. 6. Volume: conventional crystal filters—1-24 cubic inches. Size increases with number of resonators and with decreasing frequency. Monolithic filters—see Table 3.

Table 3. Case sizes for monolithic crystal filters.

CASE TYPE	VOLUME (cu in)	NO. OF RESONATORS	LOWEST FREQ. (MHz)
TO-5	0.016	2-3	15
		2-4	20
TO-8	0.07	2-4	8
		4-6	20
Flat Pack	0.4	2-4	3
		4-6	6
		6-10	10

Looking Ahead

Within the next five years, manufacturing techniques will be developed for large-scale production of sophisticated monolithic quartz filters. Commercial usage of monolithic filters in home entertainment and ham radio will become economically feasible, resulting in a large market for the devices.

Because of its small size, the monolithic filter will be treated more like a miniature integrated-circuit module than a complex subassembly. Unit prices as low as $3-$4 are not inconceivable.

Another area of increasing interest is the use of new piezoelectric synthetic crystal materials in filters. Zinc-oxide and other metals are currently being explored as possible resonator materials. The attraction of these materials stems from the fact that greater piezoelectric coupling coefficients exist than with quartz. Sophisticated filters with fractional bandwidths of 1-10 percent could then be achieved in the high-frequency range, closing the gap that currently exists between quartz crystal devices and *LC* filters. ▲

The author joined Clevite in 1958 as Sales Engineer for the Piezoelectric Division, subsequently moving to the Brush Instruments Division of the firm. He rejoined the Piezoelectric Div. in 1965. He received his BEE from the University of Detroit. During World War II he served as Communications and Navigation Officer with the Navy in the Pacific.

Ceramic Filters

By REG ZIMMERMAN / Clevite Corp.

Filters like these are a "must" for high-density packaging. An extremely high performance level and rugged construction boost equipment efficiency.

THE trend in military and commercial communications equipment for minimized components using IC integration has created a demand for extremely small filters that are rugged, reliable, and have relatively high sensitivity.

Filters made of ceramic, the newest material for the fabrication of bandpass filters, have these characteristics. For example, a filter with seventeen high-"Q" tuned circuits for bandwidth ratios of 1.1 to 1 from 70 dB to 6 dB attenuation can be packed in a 0.312-inch diameter tube less than 1.6 inches long.

The uniqueness of the ceramic filter results from the properties of the lead zirconate-lead titanate resonators. These resonators have a mechanical "Q" of 450 or 1600, depending on the particular composition. In addition, ceramic resonators are piezoelectric—by bending, squeezing, and twisting, the material directly converts mechanical movement to electrical energy. By reversing the process, it converts electrical energy into mechanical movement. The high electromechanical coupling provides wide-band filters with low insertion loss.

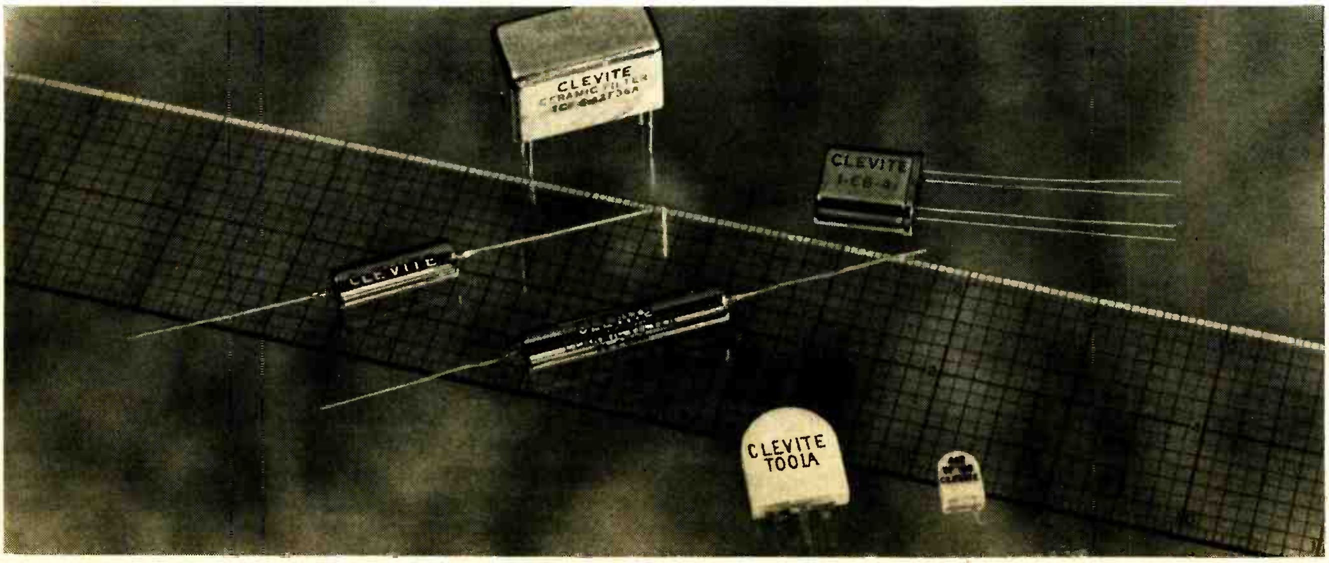
Typically, ceramic disks which measure about 0.2 inch in diameter by 0.010 to 0.040 inch thick resonate at 455 kHz.

How Do They Compare?

Ceramic Filters: Ceramic filters have been developed to operate at frequencies from 40 Hz to 10.7 MHz. As was mentioned earlier, ceramic resonators have "Q's" of 450 and 1600. The higher "Q" materials make narrower bandwidth filters feasible. Higher "Q" materials also reduce insertion loss.

The stability of ceramic is 0.2% of the center frequency from −40°C to +85°C. This is equivalent to the best grade of *LC* filters, but not as good as mechanical or quartz filters. This can be offset by two design techniques. First, due to the steep sides of ceramic filters, the 6-dB bandwidth can be widened to allow for temperature change. Second, since the

Fig. 1. These ceramic filters operate from 9 to 50 kHz and from 300 to 770 kHz. They are ideal for high-density packaging.



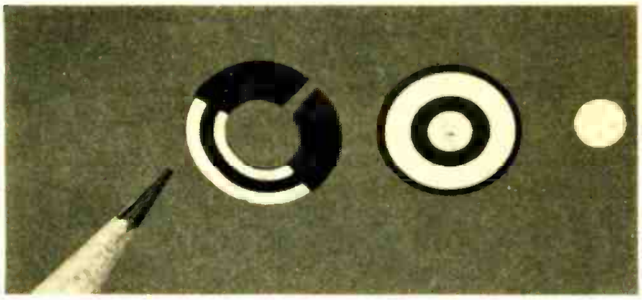


Fig. 2. A group of resonators. (Left) resonates at 9 kHz, (center) at 167 kHz, and small one on the right at 455 kHz.

frequency change with temperature is a percentage of the center frequency, lowering the center frequency will reduce frequency shift. Thus, a 500-kHz ceramic filter has the same stability as a 15-MHz quartz filter.

LC Filters: LC filters can be used over a wide frequency range, but their limiting factors are temperature stability (dependent on core material) and "*Q*". In general, "*Q*" (c.f.) / 3 dB (bandwidth) is less than 100 for *LC* filters. Powdered iron cores have good stability but low permeability, lowering the "*Q*" of the inductor. Ferrite cores, on the other hand, offer higher permeability but at the expense of temperature stability. Also, low-frequency filters require large cores, thus increasing weight and size. One more point, the low "*Q*" in *LC* filters produces a filter with a higher insertion loss when sections are cascaded to steepen the sides of the passband.

Mechanical Filters: Mechanical filters have a "*Q*" of 7000 and excellent temperature stability. These properties favor narrow-band filters (less than 1%) such as single-sideband filters. However, the mechanical filter requires a transducer to convert electrical energy to mechanical energy and another transducer to reconvert the mechanical energy to electrical energy. This, in turn, increases insertion loss.

Quartz Filters: Quartz filters have "*Q's*" ranging from 50,000 to 100,000. Their temperature stability is excellent, but they are generally more expensive than *LC* or ceramic filters. Bandwidths are usually limited to less than 1% of center frequency unless broadbanding inductors are used. However, competitively priced products are available at 10.7 MHz.

Three Designs

Currently, three resonator designs are used in manufacturing the filters shown in Fig. 1. The split ring shown in Fig. 2 resonates at 9 kHz but it can be tuned to 50 kHz by widening the slot. This thin disk, which has an inductance value equivalent to about 50 henrys, vibrates at its resonant frequency by the expansion and contraction of the slot.

The center thin disk vibrates radially at its overtone frequency, popularly 455 kHz. If operated in its fundamental mode, it would vibrate at 167 kHz. Differences in the electrode area on a given disk result in an impedance transformation so that the filters of this type can replace the common i.f. transformer, yielding higher "*Q*", smaller size, greater temperature stability, and greater selectivity.

The small-sized disk (at right) is the basic resonator used for oscillator control and for ladder filters. It utilizes the radial mode of vibration, *i.e.*, it expands and contracts radially. Its resonant frequency is determined by its diameter.

A fully electroded disk has an overtone at 2.3 times its fundamental frequency which can be suppressed or enhanced by varying the area the electrode covers. The center of the disk is a vibrational node point. Electrical connections are made by pressure contacts at the center of the disk. The equivalent circuit and the curve of impedance *versus* frequency are shown in Fig. 3.

In single-resonator circuits, the equation for the 3-dB bandwidth point is $B = f_o/Q_L$ where f_o is the center frequency and Q_L is the loaded "*Q*".

Single resonators can be used to control oscillator frequencies or to replace emitter-bypass capacitors and sharpen the frequency response of transistor radio receivers.

Generally, two or more resonators are required to develop the desired bandpass characteristics. The basic two-resonator circuit and its electrical equivalent circuit are shown in Fig. 4.

The two-resonator section is referred to as an *L*-section. Assuming 455-kHz is the desired f_o, by tuning the low-impedance point (f_r) of the series resonator and the high impedance (f_a) of the shunt resonator to f_o, the minimum signal attenuation will be at f_o. Likewise, the points of maximum signal attenuation will be at f_a of the series resonator

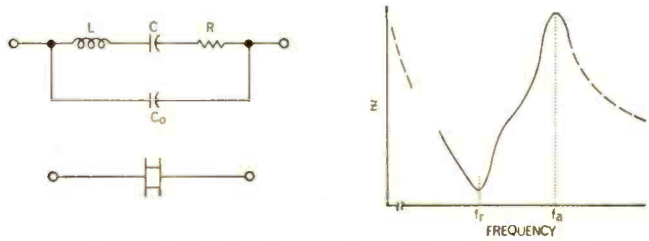


Fig. 3. Circuit and performance curve of ceramic resonator.

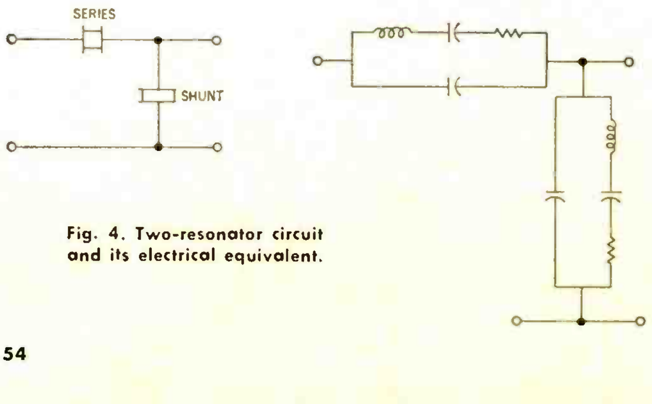


Fig. 4. Two-resonator circuit and its electrical equivalent.

Table 1. Specifications and applications of resonators.

6-dB Bandwidth Range at f_o	Bandwidth Ratio (60 dB/6 dB)	Stop-band Rejection (dB)	Typical Applications
17-DISK			
2 to 85 kHz at 455 kHz	1.4 to 2.5 (depending on bandwidth)	60	Military receivers, missiles, commercial airline receivers
9-DISK			
6 to 40 kHz at 455 or 500 kHz	2.0	50	Military walkie-talkies, aircraft communications, aircraft navigation, transceivers (AM & FM), loran
TUNED CIRCUIT PLUS 4-DISK			
4 to 12 kHz at 455 kHz	2.5 to 3.0	60	Sideband receivers, AM & FM receivers & transceivers
TUNED CIRCUIT PLUS 6-DISK			
30 to 35 kHz at 455 kHz	1.8	60	Aircraft communications, navigation transceivers
SPLIT-RING RESONATOR			
2% of f_o at 9 to 50 kHz	6.5 (for 20 dB/6 dB)	25	Sonar systems, radar systems, v.l.f. receivers, drone control
SPLIT-RING RESONATORS			
1% of f_o at 9 to 50 kHz	18 3 (for 20 dB/6 dB)	60	Sonar systems, v.l.f. receivers
OVERTONE RESONATOR			
8 to 18 kHz at 455 and 500 kHz	5 (for 20 dB/6 dB)	20	Low-cost receivers, marine radios, CB equipment

and f_r of the shunt resonator. If resonators with the same Δf are used, the attenuation curve illustrated in Fig. 5 will result.

The C_0 of the individual resonator is determined by the electroded area, the dielectric constant, and the disk thickness. At frequencies above and below the high attenuation poles, both resonators act like a capacitance divider. The larger the ratio C_{shunt}/C_{series}, the larger the attenuation in the stopband. Since the resonator "Q", f_r, Δf, and C_0 are all variable in the manufacturing process, center frequency, the passband width, and the attenuation pole locations can be varied simply and inexpensively.

The nine-disk and seventeen-disk ladder filters are electrically connected *L*-sections with an extra series resonator at the end to make the input and output impedances equal. Since ceramic filters have their maximum attenuation just above and below the passband, they offer maximum rejection to adjacent signals. Most *LC* and quartz filters have their maximum attenuation points at frequencies of zero and infinity. Therefore, ceramic filters in the second i.f. of double-conversion receivers complement the attenuation pattern of the r.f. stage and the first i.f. and greatly improve the receiver's characteristics. Ceramic ladder filters have stopband attenuations from 50 dB to 90 dB, depending on the model. The stopbands are free of spurious responses from d.c. to 2.3 times the passband frequency.

Ladder filters are simple to use. They are especially designed to match resistive loads of 1000 to 2500 ohms, depending on the model; and are suitable for use with transistorized circuitry (see Fig. 6).

Specifying Parameters

When calling out ceramic filter parameters, the design engineer should specify minimum stopband attenuation, maximum insertion loss, and maximum passband ripple as with other filters types. He should, however, also call out the minimum 6-dB and the maximum 60-dB bandwidths.

Generally, filter impedance level is set by the manufacturer and is a function of center frequency and bandwidth and hence cannot be specified by the designer.

The designer should be aware that the filter's center frequency and bandwidth changes over the operating temperature range. For instance, center frequency of a 500-kHz filter will change a maximum of 1 kHz (0.2%) over the temperature range $-40°$ C and $+85°$ C. The 6-dB bandwidth is usually designed so that over this temperature range it stays larger than the minimum specification. In the frequency range 300 kHz to 700 kHz, the 6-dB bandwidth achievable

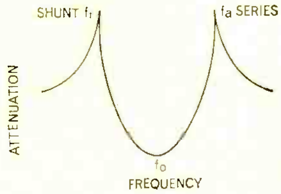


Fig. 5. Response curve of the two-resonator circuit shown in Fig. 4.

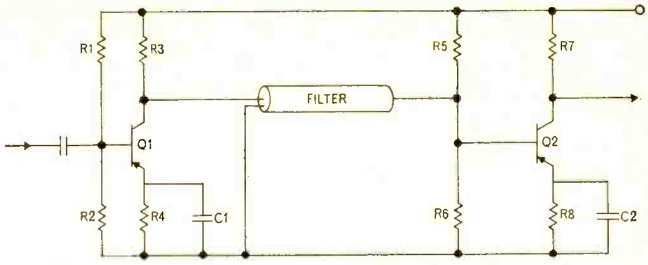


Fig. 6. Ladder filters are designed to match the resistive loads of 1000 to 2500 ohms found in transistorized circuits.

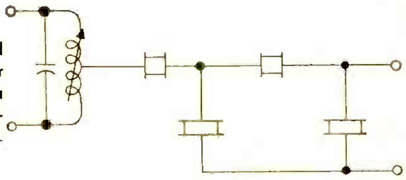


Fig. 7. 60-dB stopband in a narrow-band filter can be achieved when a tuned LC circuit is combined with four resonators.

with ceramic filters range from approximately 0.5% of center frequency to 20% of center frequency.

One of the lowest-cost filters designed by *Clevite* combines a tuned *LC* circuit with resonators having the maximum capacitance divider ratio. Thus, four resonators in a narrow-band filter design achieve 60-dB stopband attenuation; six resonators are required for wideband filters. The schematic of this low-cost unit is shown in Fig. 7 and Table 1 lists its specifications and applications as well as those of some other typical units.

Because ceramic filters are small in size, very rugged, fixed tuned, and extremely reliable, their future is bright.

Ceramic filters are competitively priced and are rapidly making inroads in low-cost entertainment equipment. They are especially attractive since they do not require the installation alignment of conventional tuned circuits.

Ceramic filters have already replaced larger, more expensive *LC* and mechanical filters in many mobile, portable, and Citizens Band receivers. They have also repeatedly proven themselves in military equipment as the most selective and rugged filters for their size and weight. ▲

BEADS BLOCK NOISE

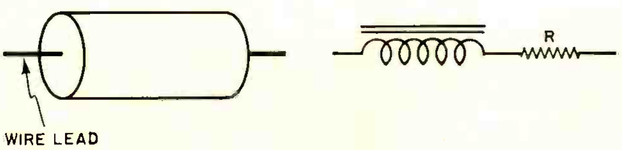
BLOCK spurious noise without d.c. losses? It can be done with a ferrite bead says the Electronic Components Division of Stackpole Carbon Co. They claim a ferrite bead is one of the simplest and least expensive methods of obtaining r.f. decoupling, shielding, and parasitic suppression without sacrificing low-frequency power or signal level.

Unlike conventional r.f. chokes, ferrite beads are compact; they do not couple to stray capacitance to introduce detuning or spurious oscillations. In addition, their impedance varies from quite low at low frequencies to quite high at noise frequencies. What else makes them different? Well, they need not be grounded, but grounding isn't detrimental to performance if they should touch the chassis.

Ferrite beads are available in a variety of sizes, from 0.038 inch o.d. and 0.150 inch long to 0.120 inch o.d. and 0.300 inches long. They come with either a single hole or multiple holes through their length, through which the current-carrying conductor passes. Some beads are being made with leads to which wires can be soldered.

Here's how they work. As noise current flows through a conductor (passing through a ferrite bead), it creates a magnetic field. As the field passes through the bead, the permeability of the bead at the noise frequency (r.f.) causes the impedance of the bead to rise rapidly, creating an effective r.f. choke. The higher the frequency, the higher the impedance and the greater the attenuation. Meanwhile, low-frequency current passes through the bead unimpeded. Several beads can be strung together for increased efficiency. ▲

Typical ferrite bead and its equivalent series circuit.



The author has experience in all phases of mechanical filter research and development. He joined Collins in 1961 after receiving his BSEE degree from Washington State University. His initial work was in the field of synthesis and fabrication of crystal filter networks. Since 1963 he has participated in studies of higher order vibration modes for extension of the mechanical filter operating frequency range, and in the development of filter design by computer programs. He was project engineer of the mechanical Minifilter and is currently involved in the design and fabrication of mechanical filter networks.

Mechanical Filters

By DONOVAN A. SOUTHWORTH/Collins Radio Company

Mechanical filters are not new, but new manufacturing techniques and new filter configurations have made them "tops" in sophisticated transceivers.

MECHANICAL filters were conceived and designed to provide a unique combination of high selectivity and stability in a compact package at a low cost. Many of these filters use a disk-wire construction (Fig. 1.) which has become popular in our industry.

The disk-wire filter is a mechanically resonant device which receives an electrical signal, converts this signal into mechanical vibrations, rejects unwanted frequencies within the mechanical structure, and then converts the mechanical vibrations back into electrical energy. The filter consists of three basic elements: input and output transducers which convert electrical signals into mechanical vibrations and *vice versa*; high-"Q" mechanically resonant metal disks; and coupling wires which acoustically transmit energy between the disk resonators.

In Fig. 3, if an electrical signal is applied to the input coil, it produces an alternating magnetic field that passes through the magnetostrictive transducer attached to the end disk. The transducer, when magnetically biased and tuned to vibrate at the impressed signal frequency, drives the first disk. The short coupling wires connecting the disks drive the next disk, and so on until the signal reaches the output transducer. The output transducer converts the mechanical vibrations into an induced voltage across the output coil and creates an electrical output.

Engineers are busy in Europe and Japan, as well as in the United States, designing mechanical filters and resonators. One popular i.f. filter design utilizes a wire-coupled torsional rod. But much of the engineering activity involves units operating below 50 kHz, where physical configurations other than the disk-wire or rod-wire arrangements are more suitable for production. In this frequency range, filters/resonators utilize a tuning fork or flexure mode bar. The devices commercially available in this range are often single resonator types rather than multiple-coupled resonators.

Disk-wire type filters are manufactured in the 60- to 600-kHz frequency range with pass bandwidths ranging from 0.06% to 10% (see Fig. 2). The shape factor (60 dB to 3 dB bandwidth ratio) is typically from 2:1 to 1.5:1 although in certain critical applications where even better selectivity is required, shape factors as low as 1.2:1 are being built. Frequency stability with temperature change can be made equal to the stability of a DT-cut crystal. This is one of the most widely used crystal cuts in the 200- to 500-kHz frequency range. Modern network design techniques have resulted in passband response variation of less than 0.5 dB; and insertion loss values as low as 2 dB can be realized, but a more typical value is 6 dB. Prices start around $7.00 and are related to performance requirements.

Some Uses

Mechanical filters were originally designed in the U.S. for use in single-sideband radios. They contributed to the success of such radios in the early 1950's and are still being used extensively in single-sideband equipment. The small size and weight of a mechanical filter make it very desirable for use in equipment such as manpack radios. These characteristics, in addition to high reliability, excellent frequency stability with temperature, and good cut-off characteristics, combine to satisfy the stringent requirements of military or commercial aircraft communications and navigation equipment. Generally, mechanical filters should be considered for use anywhere that high performance, small size, and reasonable cost are required.

Mechanical filters made in the U.S. employ two basic transducer types: a nickel-iron alloy wire and a nickel-ferrite rod. The filters which use the nickel-iron wire transducers are essentially self-terminated and have a relatively high insertion loss. They may be driven from any source impedance greater than 50k ohms by parallel tuning the transducer coil, or they may be driven from any impedance lower than 200 ohms by series-tuning the transducer coil. The same conditions apply for the filter output. If the circuit designer finds it to his advantage, a combination of series- and parallel-tuning capacitors may be used.

Filters using ferrite transducers have low insertion loss and are designed to work with a specific terminating resistance. For standard filters (either wire or ferrite transducer types), the terminating resistance can be modified using a transformer or capacitor dividing network to match some *other* value of termination. For special filter designs, the

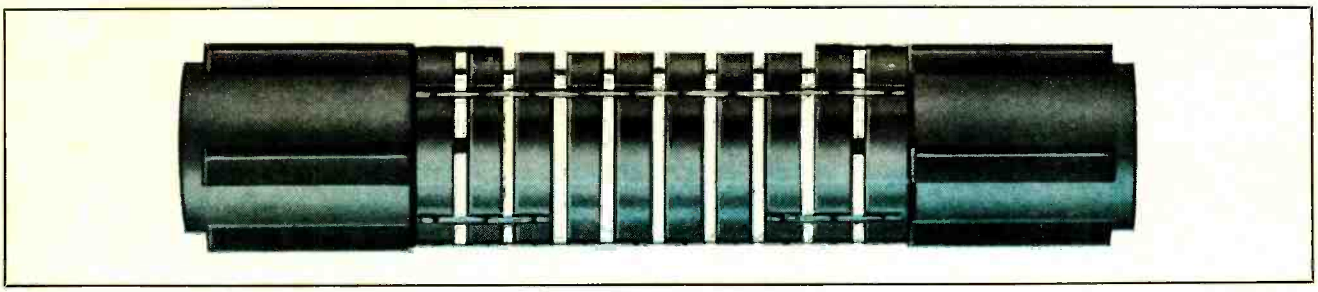


Fig. 1. Varying the coupling of a multi-element mechanical filter changes its bandwidth. Bandwidths range from 350 Hz-50 kHz.

terminating resistance may be specified in the range from 50 to 100,000 ohms. Essentially, the value of resistance determines whether the filter is parallel- or series-tuned. For low-impedance applications, such as conventional transistor circuits, the filter is tuned to series resonance. For high-impedance requirements—FET's, vacuum tubes, etc., parallel tuning is used.

All standard mechanical filters are designed with both input and output terminals isolated from ground. This eliminates the need for isolation transformers in applications using balanced loads. However, it is necessary to ground the filter case (either a terminal or mounting studs are provided for the ground connection). In any case, optimum selectivity is achieved when the coupling or "feed-through" between input and output terminals is minimized. If proper care is exercised, 120-dB discrimination is attainable.

Picking the Right Filter

Some of the characteristics to be considered when specifying a filter are: 1. center frequency or carrier frequency; 2. required passband width; 3. selectivity or skirt cut-off; 4. maximum passband ripple or response variation; 5. maximum insertion loss; 6. source and load impedances; 7. operating temperature range; 8. other environmental requirements, *e.g.*, shock and vibration; 9. package configuration; 10. special requirements, if any, such as particular phase shift or envelope delay requirements.

Confusion frequently exists when talking about "passband ripple." Passband ripple is sometimes interpreted to mean the ratio, in dB, between the maximum and minimum amplitude of immediately adjacent peaks and valleys, and does not define amplitudes relative to other peaks and valleys in the passband. A more meaningful interpretation is to use the term "response variation" since it always describes the worst-case condition. This term means the ratio in dB between the maximum amplitude and the minimum amplitude occurring anywhere across the entire passband whether these points are adjacent or not. It is important that the equipment designer realize how a particular manufacturer defines this characteristic since it may affect the performance of his equipment.

When specifying a filter, the circuit designer should remember that the more stringent his requirements, the higher the cost of the filter. It is usually worthwhile to analyze circuit performance so that the filter will not be "over-specified." Conservative design is always good engineering practice, as long as the designer recognizes that this might increase his costs.

The general outlook for the future of mechanical filters is excellent. New filter configurations are being investigated which will result in further advances in the state-of-the-art. For example, lattice configurations, which give the filter designer another degree of freedom, are being utilized. Filters with built-in delay equalization are being realized, resulting in characteristics that heretofore could be achieved only with an expensive filter and a separate expensive equalizer. Piezoelectric ceramic transducers are being used to give another design approach for filters with requirements that were previously unobtainable. Techniques for achieving better selectivity by means of bridged coupling wires have been developed and metallurgical techniques are being expanded to give even better operating temperature characteristics. In addition, advances in manufacturing processes have made it possible to miniaturize and build highly selective filters in less than a 0.07-cubic-inch package.

Mechanical filters have far exceeded the original requirements for which they were conceived. Future developments in mechanical filter technology will continue to place emphasis on high quality and sophisticated filter requirements in minimum size and at lowest cost. ▲

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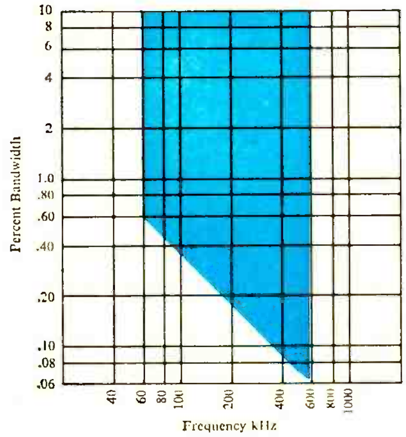
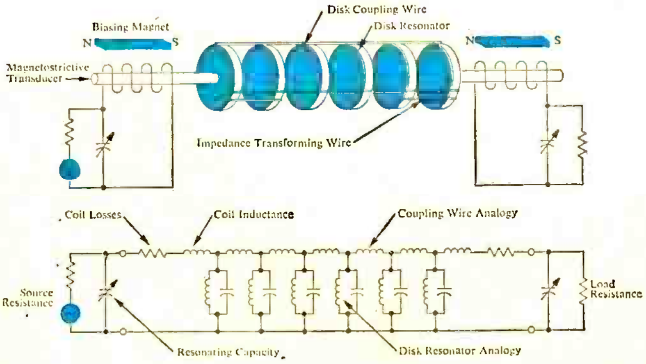


Fig. 2. Available percent bandwidth versus center frequency for a typical filter unit.

Fig. 3. An electrical analogy of a typical multi-element mechanical filter. The mechanical vibration of the input transducer is coupled by successive disks to the output magnetostrictive transducer where the vibration is converted into electrical energy. The equivalent circuit is also shown.



The author received his BSEE from San Jose College in 1957, his MS from Stanford in 1959, and his PhD from Montana State in 1966. He was formerly associated with Farinon Electric and Douglas Aircraft where he conducted research in the areas of network analysis and synthesis. He presently teaches part-time in the Electrical Engineering Department of Montana State University and has been president of Linear Networks since founding it in 1963.

Active Filters

By JAMES L. HOGIN/President, Linear Networks Company

Filters of this type are able to duplicate frequency responses of passive LC networks. But, as an added bonus, they provide gain.

ACTIVE filters differ from passive filters in that their operation depends, just as a transistor or any other active device, on an external power source. The most common type of active filter, and the one to be considered here, is the active *RC* network made up of resistors, capacitors, and active devices. The principal advantage of this filter is that it duplicates the frequency characteristics of an *LC* filter without the use of inductors. And, in reality, a special external power source is usually not required since the filter is often a part of a system for which power is already supplied. An additional advantage is that the active filter provides signal power gain which a passive filter, by its very nature, is incapable of giving.

Although active filters perform satisfactorily at the higher frequencies, they find their greatest use at very low frequencies; frequencies so low that inductive devices are either prohibitively large or are so lossy that they have no practical value. Some areas in which low-frequency active filters are used include medical technology, oceanography, seismology, and others where low-frequency phenomena, such as the beat of a heart or a movement of the earth, are encountered.

Operation and Characteristics

In active resistance-capacitance networks, the signal to be filtered is applied to the input terminals and the resultant filtered signal extracted from the output terminals. Internally the active filter is considered made up of two portions: an active portion composed of active devices and their associated passive components such as biasing resistors, coupling capacitors, etc., and a passive portion consisting of precision resistors and capacitors which determine the frequency characteristics of the filter.

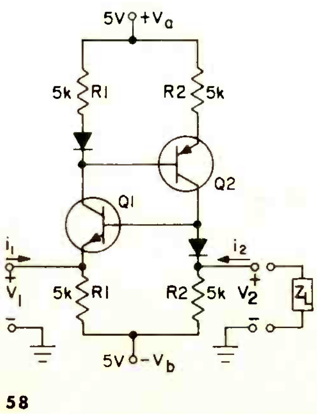
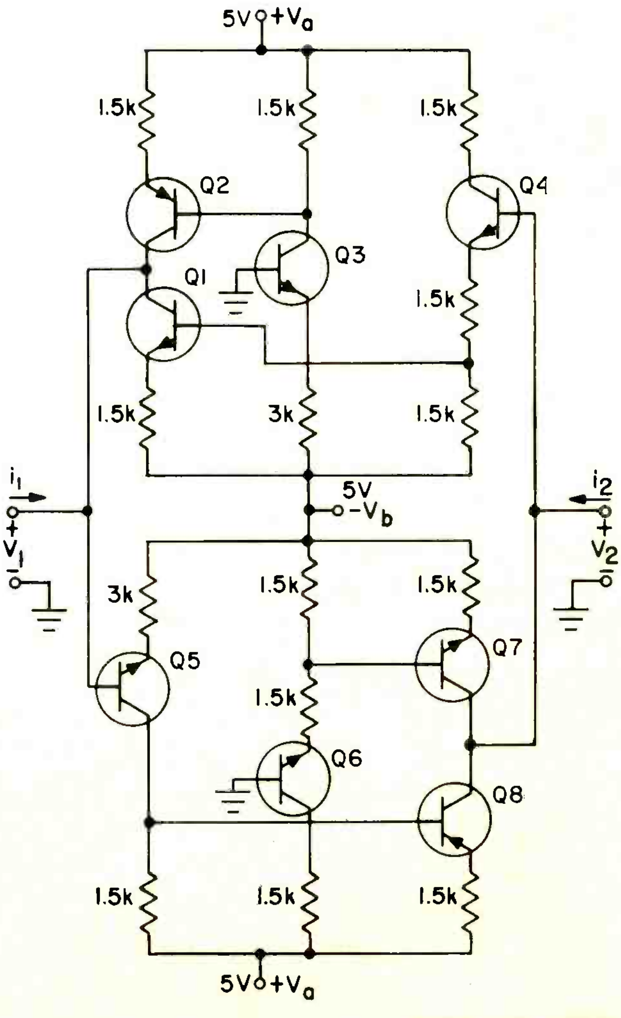


Fig. 1. In the negative-impedance converter, the input impedance, Z_{in}, is the negative of load impedance, Z_L. In this case, V_1 equals V_2 and i_1 is same as i_2.

Various active device configurations are used as the active portion of the filter. A sampling of the many types is given in the following paragraphs.

1. The negative-impedance converter, Fig. 1, (commonly known as the NIC) is a device configuration which, when loaded with an impedance at its output terminals, produces

Fig. 2. A gyrator consists of two voltage-to-current converters whose output current is proportional to its input voltage.



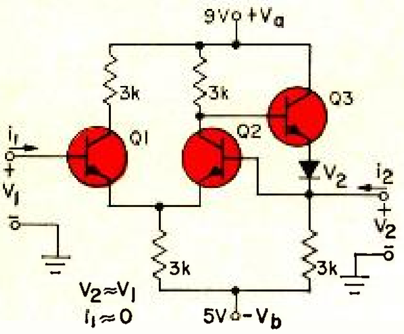


Fig. 3. In a unity-gain amplifier, $V_2 = V_1$ and $i_1 = 0$. In this example, the voltage across the load, V_2, is equal to 6.5 volts.

the negative of this impedance at its input terminals. Although the NIC has probably received the greatest amount of theoretical attention, it is considered by many to have little practical value.

There are two basic types of negative-impedance converters, the current conversion (INIC) type shown in Fig. 1 is where $V_2 = V_1$ and $i_2 = ki_1$ (k = 1 in example), and the voltage conversion (VNIC) type is where $V_1 = -kV_2$ and $i_1 = -i_2$. For either type the input impedance Z_{in} is the negative of the load impedance Z_L. The circuit in Fig. 1 can be analyzed as follows. The base-emitter voltage drop of $Q1$ as well as the voltage drop of the forward-biased diode is small, thus the condition that $V_2 = V_1$ is met. When no signal is applied, all resistor currents are equal by symmetry. The input current i_1 splits into $V_1/R1$ down through the lower left resistor, $[i_1 - (V_1/R1)]$ flows through the emitter of $Q1$. Since the collector and emitter currents of a transistor are approximately the same, the current $[i_1 - (V_1/R1)]$ flows through the upper left resistor; the voltage across the collector resistor of $Q1$ is then $(R1i_1 - V_1)$, positive at the bottom, which is also the voltage across the emitter resistor of $Q2$ since the base-emitter drop of $Q2$ is small. The upward emitter, and hence collector, current of $Q2$ is then $[i_1 (R1/R2) - (V_1/R2)]$. But the voltage $V_2 = V_1$ causes current $V_1/R2$ to flow in a downward direction in the lower right resistor. Hence, $i_2 = [(V_1/R2) + i_1 (R1/R2) - (V_1/R2)] = i_1 (R1/R2)$. If $R1$ is chosen equal to $R2$, then the condition that $i_2 = i_1$ is also fulfilled. The diodes are for base-emitter voltage drop compensation.

2. The gyrator is an active device configuration which produces an output current proportional to its input voltage. In addition, an input current, which is proportional to the output voltage of the device, flows. In other words, the gyrator possesses a significant reverse transconductance as well as a forward transconductance. Essentially, the gyrator circuit consists of two voltage-to-current converters (Fig. 2.).

3. The operational amplifier, in addition to its role as a building block in constructing other active device configurations, is useful when connected in the standard inverting or non-inverting configuration. It appears that the majority of modular active filters being manufactured today are the type which utilize the operational amplifier connected in the non-inverting configuration.

The unity-gain amplifier (Fig. 3) is probably the simplest active device to construct. Since the base-emitter drops of $Q1$ and $Q2$ are small, V_1 is transmitted directly to the output causing $V_2 = V_1$. Actually, there is a small difference voltage between V_2 and V_1 which is applied across the bases of the differential transistor pair which is made up of $Q1$ and $Q2$. This difference voltage is amplified and coupled to the output through emitter-follower $Q3$. Since the differential voltage drop is small, it follows that the input current i_1 is small. Thus the circuit of Fig. 3 approximately fulfills the standard conditions $V_2 = V_1$ and $i_1 = 0$. The zener diode is for biasing purposes only.

The 2-pole Butterworth low-pass frequency response function (Fig. 4A), V_{out}/V_{in} (s) $= 1/ (s^2 + \sqrt{2}s + 1)$, is one of the simplest transfer functions requiring both inductance and capacitance for its passive realization. This response is characterized by a magnitude plot which is maximally flat up to 3-dB cut-off frequency (10 Hz in the example) and attenuates rapidly for frequencies above the cut-off frequency. The passive network shown in Fig. 4B realizes the indicated transfer function. Active network realizations not requiring inductors are shown in Fig. 5.

The three active filters shown in Fig. 5 have exactly the same frequency response characteristic as the passive configuration shown in Fig. 4B. Although the passive realization, at first glance, appears the simplest, the active configurations will be smaller and perform better because of the difficulty in obtaining an inductor which performs satisfactorily at the 10-Hz cut-off frequency.

At this point, let us examine some of the active filter characteristics with emphasis on the operational-amplifier type of active network.

D. C. Offset Voltage. Since a filter's output is usually taken at the output of an operational amplifier, a d. c. offset voltage is present. For low-pass filters or others required to pass d. c., this offset voltage is essentially an error or noise component which is due not only to the offset voltage of the operational amplifier itself, but to the IR voltage drop due to the op-amp bias current flowing through the resistance associated with the passive portion of the filter. This latter component of offset voltage is most noticeable in the lower frequency filters where large RC products are required. Where low offset voltage and low frequency are specified, FET input operational amplifiers are specified because they have very low bias current requirements. Even in cases where the filter is not required to pass d. c., offset voltage

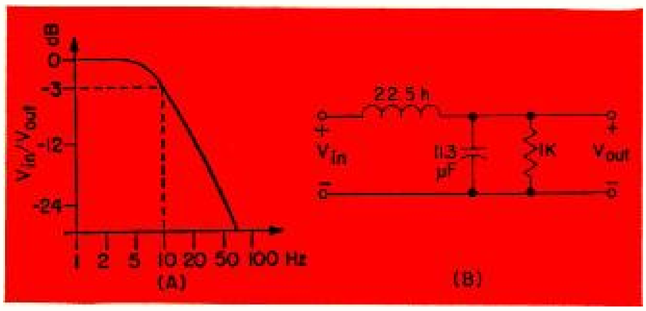
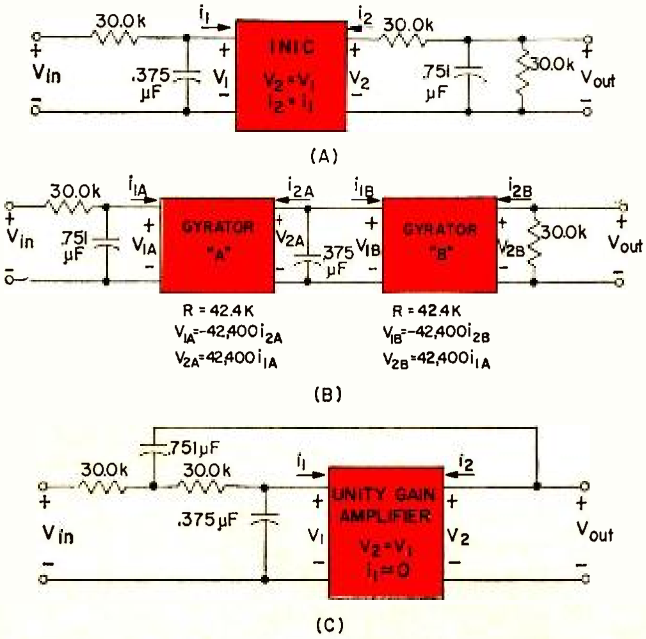


Fig. 4. Response curve of a 2-pole Butterworth low-pass filter. The passive circuit configuration is shown in (B).

Fig. 5. Typical active filter configurations. The INIC realization is shown in (A). Although constructed from active devices, the gyrator (B) is a passive device as far as its terminal behavior is concerned. The output voltage is one-half that of other circuits. Unity-gain realization is at (C).



can be a problem when operating frequencies are so low as to make the size of a d. c. blocking capacitor (at the output) prohibitively large.

Stability. Changes in filter characteristics due to temperature, aging, humidity, etc. are, of course, extremely important. Stability of the active filter depends not only on the stability of the individual components in the filter but on its required frequency behavior.

In comparing the stability of active and passive filters, several factors must be taken into consideration.

1. The time constants associated with an active filter are proportional to resistance-capacitance products while the time constants associated with a passive *LC* filter are proportional to the square root of inductance-capacitance products. Thus the sensitivity of the filter to frequency variations due to changes in component value are approximately twice as great for active filters as for passive filters.

2. While the stability of a passive filter is dependent only on the stability of its passive components, the stability of the active device or devices must be taken into account for active filters.

3. The greatest disadvantage (in terms of stability) of an active filter compared to its passive counterpart is that while the frequency characteristics of the passive device may be considered a direct function of the network's component values, the frequency behavior of the active filter must, in all cases, be realized by a subtractive or difference taking process. This means that small variations in the quantities whose differences are to be computed result in large variations in the difference quantity itself.

Despite previously mentioned obstacles, stable active networks may be produced without resorting to sophisticated compensation techniques. Reasonably stable resistors, capacitors, active devices, and active device configurations together with proper design of the passive portion of the network results in active filters which, from the standpoint of temperature and frequency stability, compare quite favorably with passive filters.

Useful Range (Frequency) of Operation. Another characteristic of active filters which should be considered is their operating frequency range. Although filters with cut-off or center frequencies below 0.1 Hz to above 10 MHz can be produced, it appears that the most useful frequency range is from 1 Hz to 20,000 Hz. *Linear Networks Company* has found that 95% of the demand for active *RC* filters lies in the frequency range from 1 to 200 Hz. However, in the case of the active low-pass filter, the region of interest extends down to and includes d. c.

Bandwidth. In the case of bandpass filters, bandwidth is an important characteristic to consider. Bandwidths corresponding to "*Q's*" up to 100 are quite practical. With a "*Q*"-multiplier circuit, much higher "*Q's*" are possible. However, bandpass filters in modular form (where external tuning controls are not provided) have their "*Q's*" limited to about 100. Multiple-pole bandpass filters are also available in active *RC* form, but they are normally restricted to octave, half-octave, and third-octave bandwidths. Two-pole units where the ratio of 24-dB bandwidth to 3-dB bandwidth is four are commercially available as well as three-pole units where the ratio of 36-dB to 3-dB bandwidth is also four. Octave bandwidth filters whose 3 dB-bandwidth spans a 2 to 1 frequency range as well as the fractional-octave bandwidth active filters find wide use in low-frequency spectrum analysis applications.

Dynamic Range. The dynamic range of active filters is restricted by the maximum signal level which the active device used in the filter can handle without distortion, and by the noise level of the active device. 80-dB dynamic range, a 20-volt peak-to-peak maximum signal level, and a 100-microvolt noise level are typical values for the modular active filter. As a general rule, it's preferable to perform filtering operations at high signal levels; and if amplification is required, it should be done before the filtering operation.

Termination. One distinct advantage which active filters have over passive filters is that termination problems can be practically eliminated. That is, the isolation properties of active devices may be used to isolate the load impedance from the filter elements which determine the frequency behavior. For a typical active filter, it makes little difference whether it has a 2-megohm or 2-kilohm load.

Specifying an Active Filter

Because the frequency transfer characteristics of an active filter may be made identical to its passive counterpart, specification of this parameter is simplified. All of the standard transfer functions such as the low-pass, bandpass, and high-pass Butterworth maximally flat amplitude response are very readily realized in the embodiment of an active *RC* network.

In like manner, the non-standard transfer functions associated with such things as magnitude, phase, or envelope-delay equalization are readily realized. Here the desired magnitude, phase, or delay characteristics are specified as a function of frequency. The filter manufacturer, usually with the aid of a digital computer, then determines a realizable transfer function whose frequency characteristics approximate the given specifications.

Usually, the realization of the transfer function is simpler for an active configuration than for a passive configuration. This is because the over-all transfer function may be separated into the product of less complicated subfunctions. Each of these subfunctions may then be realized independently.

In general, active *RC* filters are specified over passive or other type filters in the following situations: 1. When the frequency range of interest is so low that the active *RC* filter clearly has no satisfactory alternative; 2. In the audio range of frequencies where small size and low weight are important; 3. Where complicated equalization characteristics must be synthesized; and 4. When compatibility is desirable. For instance, where a series of bandpass filters covering the frequency spectrum from sub-audio to ultrasonic is required, it might be desirable to specify all filters as active filters even though the higher frequency units (if they were to be specified individually) would be specified as passive units.

The user, in deciding whether to design and fabricate his own active filters or to purchase them from a filter manufacturer, should consider the following points: 1. Is design help readily available? While the design data for a large number of passive *LC* networks is available in handbook form, information to such a wide extent is simply not available for active networks. Unless the transfer function is one of the more standard types with the required number of poles not exceeding two or three, the time, money, and effort spent in attempting to design and fabricate an active filter can quickly offset any possible advantages; 2. Are precision components readily available? The filter manufacturer has had experience with precision component specification and selection and is required to carry a sizeable inventory of such components. The gathering together of such parts for the fabrication of a small quantity of filters is expensive and time consuming; 3. If a large quantity of filters is called for, does the user have the facilities for their fabrication? If so, is it economically feasible to use them? Setting up and organizing an assembly line which is to run for only a month or two simply does not make sense from the viewpoint of economics.

In the future, it is expected that active filters will find more and more use. Not only should they find extensive application as replacements for their passive counterparts but, in addition, as the industries which deal with low-frequency phenomena continue to grow, the demand for active filters should keep pace. ▲

UJT MONOCYCLE MULTIVIBRATOR

A monocycle multivibrator may be defined as a multivibrator which is normally in a state where both of its transistors are off or non-actuated. Upon receipt of a pulse of proper polarity (in this case, positive) and sufficient amplitude, the circuit cycles once and turns off again. This is in contrast to a monostable multivibrator which, in its normal state, has one transistor conducting heavily, and upon receipt of a pulse, switches this transistor off and then on again. Current consumption of the monocycle multivibrator circuit given in Fig. 1 is less than 2 mA with a 9-volt power supply.

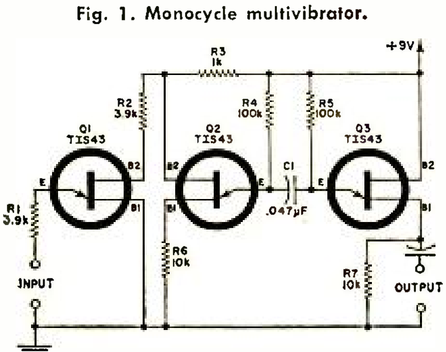
In the circuit of Fig. 1, unijunction transistors Q2 and Q3 and associated components, make up the multivibrator proper. It will be noted that this part of the circuit is similar to that of the author's dual-UJT multivibrator (February 1969 issue), which is free-running, except that the 10,000-ohm load resistors have been transferred from the base-2 circuits to the base-1 circuits of the UJT's. This transfer keeps the circuit from firing of its own accord, but permits it to cycle once for each pulse received from UJT Q1. The signal from Q1 is introduced into Q2's base-2 circuit in a direction which causes Q2's base-2 potential to be pulsed downward. This allows Q2 to fire, and when its portion of the cycle is completed, Q3 fires, and the circuit returns to rest.

UJT Q1 performs three functions: (1) It fires the monocycle circuit only when the amplitude of the input signal reaches a sufficiently high level; thus (2) it assures noise immunity; and (3) it provides a rectangular pulse to fire the multivibrator, even though the input signal may be of a sine or some other waveform.

The circuit of Fig. 1 has been designed to handle repetition rates up to 120 pps. It fires dependably when a 3-volt r.m.s. sine-wave signal or a 4.5-volt positive-going pulse is applied to the input terminals. A more sensitive circuit can be obtained by increasing the value of resistor *R2* and decreasing the values of resistors *R6* and *R7*. However, to do so reduces noise immunity. If *R6* and *R7* are made too low in value, the multivibrator may fire on power-supply noise pulses or break into oscillation as a free-running multivibrator.

In the author's application of the circuit, a sharp positive-going spike was needed to actuate the following circuit. This was obtained by differentiating the output signal of the monocycle multivibrator and selecting the positive-going spike with a diode. The circuit isn't especially critical in respect to input-signal waveform. ▲

Fig. 1. Monocycle multivibrator.



JOHN FRYE

Today's technician must learn to cope with the flood of information coming from R&D labs or be swamped.

KEEPING ABREAST OF YOUR FIELD

It was only April, but the coming summer had issued an unexpected sample. The sun blazed down on the greening lawns; fallen red buds carpeted the sidewalks beneath the maples; the thermometer stood at an astonishing eighty degrees; and an ever-so-gentle breeze, redolent with the exciting smell of warmed and awakening earth, wafted through the open rear door of the shop where Barney stood watching a spirited tug of war between a determined robin and a huge and rubbery night crawler.

"Hey, Mac," the youth called over his shoulder to his employer working at the service bench, "do you ever feel you're running on a treadmill that's being continually speeded up? I mean doesn't it sometimes seem humanly impossible to keep up with all the new things in electronics that are continuously popping up like spring mushrooms? Sometimes I feel just like that robin. While he's working hard to get that one worm out of the ground, a half-dozen others are getting away."

"I know the feeling well," Mac confessed, smiling sympathetically. "I almost hate to see new models of TV sets come out because I know they will include new circuitry I must study—even before I've completely caught up with last year's new circuits. And if you think it's bad for you, just remember I started in this game when all I had to understand was how a battery-operated radio receiver worked.

"Since then I've had to try to master a.c. radios, a.c.-d.c. sets, all-wave receivers, FM receivers, hi-fi receivers, stereo receivers, auto radios, and CB transceivers. Next it was black-and-white TV, u.h.f. TV, and color-TV. Then I had to learn the cotton-picking circuits all over again in terms of solid-state diodes and transistors instead of tubes. At the same time I had to be boning up on scopes, sweep generators, marker generators, square-wave generators, dot generators, color-bar generators, and—"

"Stop!" Barney interrupted. "You've made your point. Don't beat it to death. But I think you'll agree new things in electronics are coming faster and faster with each passing year. I remember you told me just a few days ago that man's store of technical knowledge was doubling every ten to fifteen years."

"That's true," Mac said with a nod. "Several factors contribute to this tremendous acceleration in technical learning. Improved communications is probably one of the most important. A new scientific discovery in any part of the world spreads rapidly over the entire globe so that other scientists can start experimenting with it and putting it to work almost immediately. The many uses quickly found for the laser are a good example of this.

"Another factor is the steadily shrinking time between the birth of a new device in the laboratory and its practical application. For example, only three years elapsed between the discovery of the transistor and the mass production of these units. Also, our widespread and diversified technology provides many areas into which almost any new discovery can be plugged to produce whole families of new products. A good example is the silicon controlled rectifier. You find it used in photography, in the chemistry laboratory, in medical equipment, in electric power tools, in household appliances, in smoke detectors and burglar alarms, in lamp dimmers, and in all sorts of industrial equipment.

"Finally, knowledge begets knowledge. Modern astronomy couldn't get going until Galileo figured out how to build a telescope. Da Vinci understood the theory of flight, but it was not until we knew how to make a gasoline engine that the airplane became possible. The village blacksmith, no matter how well he understood the theory of 'current carriers,' could never have built a delicate junction transistor. That had to wait until men knew how to grow and to precisely dope crystals of germanium and silicon. The more we know and the more techniques we have at hand, the easier it is for us to make new discoveries and to come up with new answers to old problems."

"Well," Barney said, "you've done a pretty good job of explaining why we are beset by this worsening blizzard of new discoveries, but you haven't told me how to cope with it. Do you have the answer to that one?"

"Only a partial answer based on my own efforts," Mac admitted, "but you're welcome to that. First, I try to mark off a major field of intense interest—electronic servicing, in my case, because that's my bread and butter—and to keep it separated from what I consider peripheral fields, such as electronic applications to medicine, computers, CATV, industrial design and fabrication, communications, oceanography, air and water pollution, and space. And I may as well confess I'm always interested in electronic gadgets.

"Then I try to put first things first by concentrating most of my reading and study on servicing. I feel I should, as nearly as possible, know *all* about this field. At the same time I want to have a general knowledge of the whole spectrum of electonics. Primarily this is because I simply want to know about it, but at the same time I'm never sure but that a discovery which seems to be away out in left field is going to move into my area of intense interest. I saw it happen with transistors."

"That sounds like a reasonable beginning," Barney said, "but how do you actually go about keeping up—even with just servicing? Do you concentrate on books, magazines, service data, or what?"

"I use all of them. I rely on books mostly for basic knowledge because the field of electronics is moving too fast for book publishers to keep up with the leading edge of it. By the time a book is written and in print, it is already obsolescent as far as current practice is concerned. Happily, though, basic theory does not change. A resistor still limits the flow of electric current and a capacitor still passes a.c. and blocks d.c., no matter in what circuit they are found."

"You have quite a library of electronics books, both here and at home. Do you need all those? Can't you use just one good book on theory?"

"No, because even basic electronic theory—embracing as it does the theory of electricity—is so vast and varied. D.c. circuits, a.c. circuits, vacuum-tube theory, solid-state theory, high-frequency propagation, radio circuitry, black-and-white TV circuits, color-TV theory and practice, servicing tools and techniques—each of these is a tremendous field in itself. At the same time, I like to have theory books written on two different levels: one at a popular, easily grasped level, and the other at a more precise mathematically correct level."

"Is this because you find it easier to grasp difficult theory by taking it in two steps?"

"Partially. It is sort of like using a microscope. If you start with a lower-power objective and examine a subject and its background to locate the important features and then switch to a higher-power objective to see the fine detail in areas of particular interest, you have a much better understanding of what you're seeing. The same thing applies in trying to absorb hairy electronic theory."

"Okay, now how about that 'leading edge' you were mentioning? How do you keep informed on the flood of new developments in electronics pouring out of the research and development laboratories every day?"

"I rely on my technical magazines, on the house organs of electronic concerns, and on the technical sections of popular magazines and newspapers for that. The information I get from these sources is, above all, timely; but it also provides me, again, with information presented at different levels of complexity."

"You surely don't try to remember everything you read. How do you find a particular bit of information later when you need it?"

"You're so right! I can't begin to remember everything I read, nor would I want to. All I try to remember is that I've read something somewhere on the subject, but I do try to make locating as easy and painless as possible.

"One way I do that is to cut the annual indexes from each of the many technical magazines we take and file them. Since these are usually pretty well cross-indexed, they ordinarily enable me to find an article vaguely remembered even though I don't recall the title of the article, how long ago I read it, or even in which magazine I read it. Experience has taught me I need keep magazines on file here in the shop for only five years. In that span of time, almost every one of the magazines will cover every major facet of servicing at least once; and any servicing article over five years old is likely to be pretty much out of date and it becomes expendable."

"How about the articles you read in newspapers and in other magazines that pertain to electronics?"

"I clip them out and file them according to subject matter. I place them in large manilla envelopes and write the titles of the articles on the outside of the envelope. One envelope, for example, will be labelled *Medical Electronics*; another, *Pollution*; another, *Space*; still another, *Computers*, etc. You'd be surprised at how rapidly those envelopes fatten up and how often I find occasion to dip into them. Time and again I find I want to supplement something I'm reading today with something I've read previously so I treat myself to a 'lucky dip'."

"Every now and then I see a program on TV about some phase of electronics —say computers or space travel—that contains facts and information I'd like to keep. Do you do anything about these?"

"On occasion I've taped one of these programs, but I don't try to preserve the whole tape. Locating what you want on such a recording is too time-consuming. I play the tape back while the program is still fresh in my mind and take notes on the parts that interest me and file these notes in the proper manilla envelope."

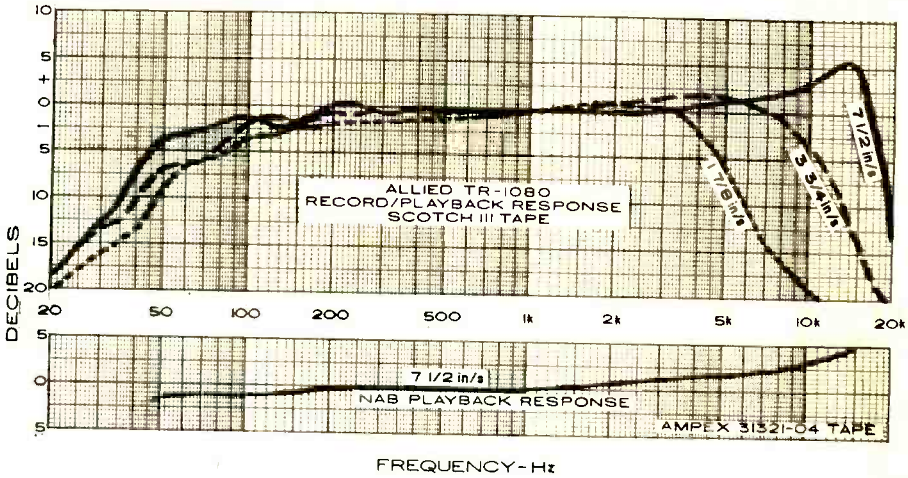
"With all this, do you honestly feel you're staying on top of the subject of electronics? And do you think all these little memory joggers are really worth the time and effort you expend on them?"

"Only to a degree. But I most certainly feel I'm more nearly abreast of what is going on in my own and neighboring fields than I would be if I made no organized effort to keep up and depended solely on my own experience and my memory. Even a young man's memory, as Mark Twain knew, can play him a dirty trick. Remember he said that when he was a young man he could remember anything—whether it happened or not! But don't you really think you've suckered me into letting you and your spring fever off work about long enough? That robin you were watching has finished his job and flown away a long time ago. Let's see you fly over here to the bench and start slinging some solder!" ▲

"Homework. . . .? Fourth Grade. . .?"

EW Lab Tested

(*Continued from page* 25)



3¾ in/s. Signal-to-noise ratio, referred to 0-vu recording level, was 46.5 dB at 7½ in/s, 49 dB at 3¾ in/s, and 48 dB at 1⅞ in/s (rated 45 dB or better). When referred to the standard distortion level of 3% (approximately 10 dB over maximum recording level), the signal-to-noise ratios at the three speeds were, respectively, 53 dB, 55 dB, and 55 dB. An input of 74 millivolts (Aux) or 0.4 millivolt (Mic) was required for a 0-vu recording, which resulted in a line output of 0.65 volt.

The "fast speeds" of the TR-1080 are rated at a rather slow 3 minutes, 30 seconds for 1200 feet of tape. They proved to be somewhat faster than rated, but were still quite slow, requiring about 2 minutes, 36 seconds to handle 1200 feet of tape. The normal operating speeds were quite exact, according to a stroboscopic disc that we employed.

Although the lack of separate recording and playback amplifiers and heads prevented our making a true A-B comparison of input and output signals from the recorder, we judged that at 7½ in/s there was virtually no change in signal quality other than a slight added brightness. At 3¾ in/s, the minute loss of highs could not be detected on most tapes made from FM broadcasts. The slowest speed had good quality, much better than "AM broadcast quality," and more than adequate for speech or non-critical music recording.

The microphones had pleasing quality, and were about as good as any microphones we have seen supplied with home tape recorders. The speakers, although small, delivered acceptable sound for casual listening, especially when full bass-boost was used. When played through a good external amplifier and speakers, the quality was excellent.

The TD-1080 is housed in a portable, vinyl-covered case and the entire package measures a compact 12¼ inches x 19⅛ inches x 12¼ inches. The weight of the tape recorder is under 40 pounds.

The *Allied* TR-1080 is certainly one of the more versatile and easy-to-use home tape recorders in its price class. We appreciated the convenience of automatic reversal during recording. The recorder sells for $349.95, complete with microphones, cables, and speakers. The same deck, less microphones, power amplifiers, and speakers, is also available as the Model TD-1070 for $299.95. ▲

NATURAL INTERFACES

WHEN engineers discuss interface problems, they're usually concerned with making the input requirements of one system compatible with the output characteristics of another. However, the most important interface of all, nature, is often overlooked or discounted as being of little significance in the scheme of things.

A few of these natural interfaces are highlighted by Rexford Daniels, President of *Interference Consultants*, a Boston firm, in his paper commenting on a report by the IEEE's Joint Technical Advisory Committee on use of the electromagnetic spectrum.

The first interface is listed as the "principle of resonance absorption." A partial description of this phenomenon is as follows: "The interaction of electromagnetic radiation with matter is basically similar although different materials are affected at different wavelengths. . . ." Essentially, the principle states that everything in nature can be activated at one or more electromagnetic frequencies with constructive or destructive results. For example, microwaves are used for diathermy—constructive; but they also produce cataracts on the eyes—destructive.

The second interface concerns the magnetic forces in nature which have an effect on animate and inanimate matter. Some are cyclical, like those affected by the sun and moon, while others are variable and react to magnetic storms and the magnetic field of the earth.

The next interface concerns electrostatic charges built up in nature as a result of friction and low humidity. These can cause explosions, deterioration of electronic components, and pollution of photographic negatives.

In summary, nature in its interface with electronics brings with it a host of variables. Nature changes constantly and it provides the means for change in all living matter. These changes involve length, distance, humidity, light and darkness, noise, age, movement, polarity, and cyclic rhythms, to name just a few. Length, for example, is closely tied to resonance; and age (growth) often means a baby can be susceptible to certain frequencies where a grown man will not. Moisture evaporating from a box sometimes causes a change in frequency, but the negative ions generated by splashing water often make a man sing in the shower. Thus, nature's interface with electronics is not one of set formulas, but one that must often be approached empirically. ▲

HIGH-SPEED TELEMETRY MOVES TO U. H. F.

HIGH-SPEED, large-capacity telemetry equipment, operating in u.h.f. bands, has been perfected—according to the Naval Weapons Center Corona (Calif.) Laboratories which developed the miniature telemetry modules that are to be employed in the near future.

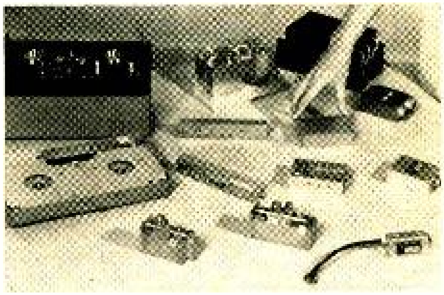
With this development, all telemetry for the Department of Defense will be shifted from v.h.f. to u.h.f. on January 1, 1970. The DOD changeover directive is based on national frequency allocation planning which made provision for air/space telemetry service at u.h.f.

Current efforts at the labs have resulted in the development of a series of modular units in tiny packages. They consist of general-purpose u.h.f. transmitters, miniature u.h.f. transmitters for special applications, power amplifiers, and miniature receivers. Development of solid-state devices has made it possible to build the equipment to operate at u.h.f. in the severely restricted space and weight limitation of missiles.

Telemetry is used with satellites and all types of missiles to evaluate their flights during the developmental phase as well as during training exercises, and sometimes in actual tactical firings. The quantities transmitted include such continuous information as temperature, acceleration, attitude, altitude, speed, and the many voltages and currents that monitor the performance of motors, controls, and guidance systems. Normally an average of 40 distinct and separate sets of data are monitored and recorded during one flight, but several hundred are needed in some cases.

A feature of the new system is a PAM/FM (pulse amplitude modulation of an FM carrier) data transmission format developed at Corona. It has a greatly increased data capacity, permitting all quantities measured in a flight test to be sent with one transmitter instead of the two or three required with FM/FM systems. ▲

Miniaturized u.h.f. telemetry modules for use with missiles and satellites have been perfected by Corona Labs and are ready to go into industrial production.



Propagation Predictions

(*Continued from page* 29)

A linear relationship between the F_2-layer and the sunspot number was first established in the early 1930's. Observations made during the succeeding 11-year solar cycle continued to correlate well with the sunspot number. This led to the conclusion that, from a practical point of view, it seemed advisable to use this phenomenon as a basic reference point. Generally speaking, as the sunspot number increases during the given 11-year solar cycle, the F_2 layer increases in density and altitude, permitting the higher frequencies to "open up" to various parts of the world. Fig. 1 shows a group of well-formed sunspots observed in 1956.

Three other sunspot variations must be taken into account when predicting solar activity: (1) solar rotation (which lasts about 27 days; this causes the longer-lived sunspots to reappear several times on the earth-side of the sun's surface); (2) seasonal changes brought about by the difference in solar bombardment reaching the two hemispheres during the winter and summer months; (3) detectable waxing and waning of sunspot numbers over long periods of time (one hundred years or more).

Occasionally, during times of maximum 11-year cycles, tremendous bursts of solar energy, called "flares", eject highly charged electrofied particles millions of miles into space around the sun. Energy bursts such as these often cause the F_2 layer to temporarily disappear, bringing about a complete radio circuit breakdown above about 4 MHz.

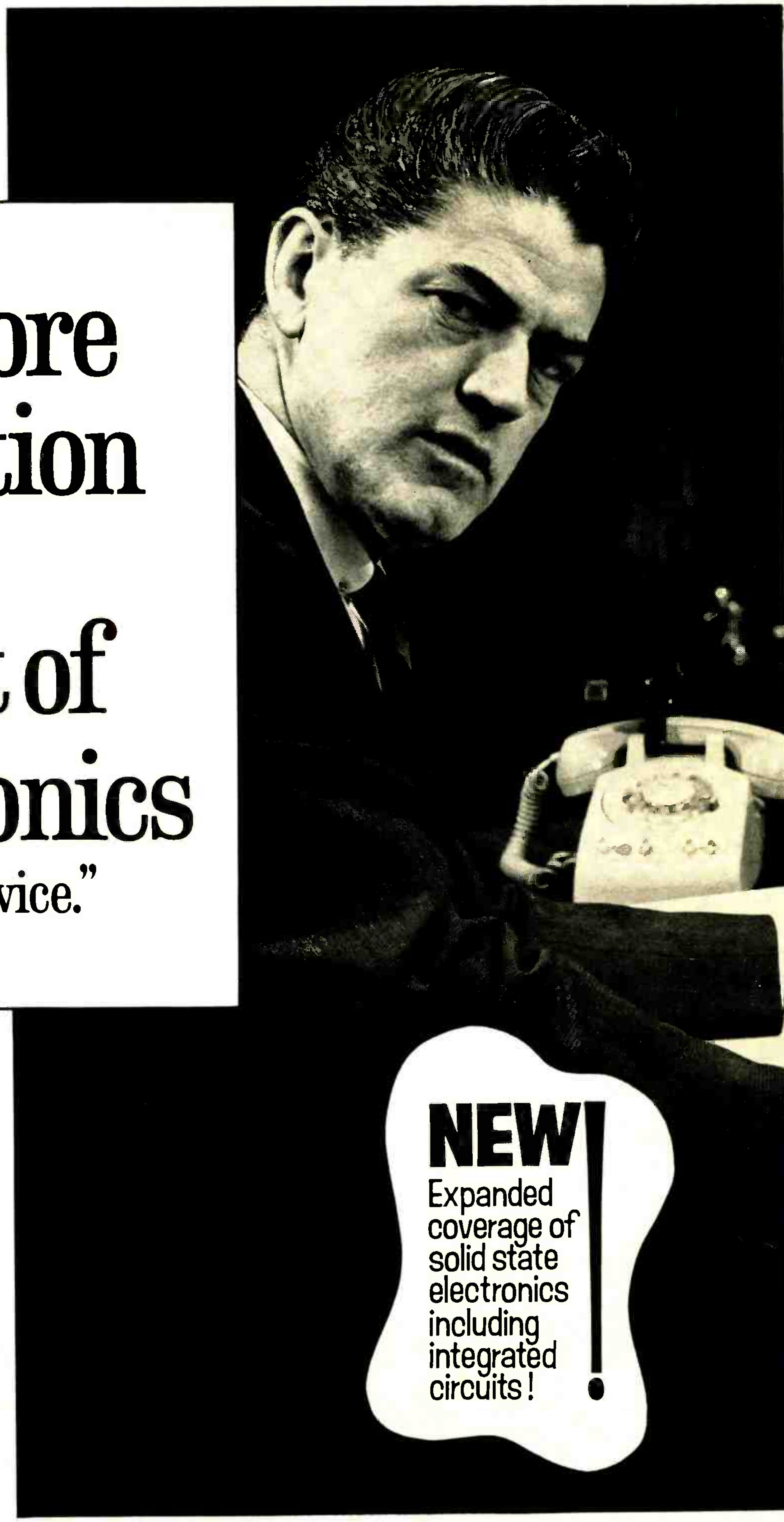
Ionospheric Soundings

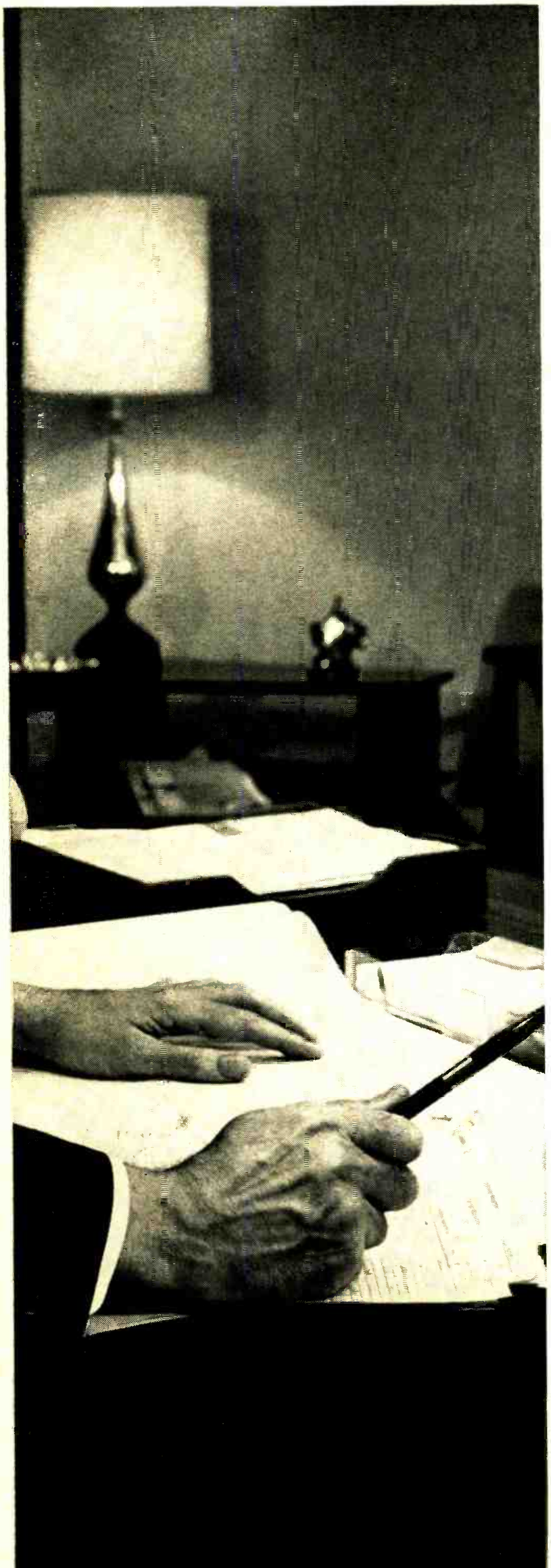
It is apparent that for purposes of radio communications, it is necessary to have as much information as possible about ionospheric characteristics. Therefore, sounding stations have been installed in more than 150 locations around the world to provide a steady flow of solar data to a central location where it is analyzed, computed, and relayed to users.

Height and density of the F_2 layers are obtained at the sounding stations by the use of an *ionosonde*, a pulse radar device in which the exploring frequency can be varied over a wide range of frequencies from about 1 MHz to 25 MHz. The ionosonde is equipped with an antenna system to direct radio energy at a 90-degree angle and is designed to measure the elapsed time for a pulse to travel to the F_2 layer and return. As the frequency of the ionosonde is increased, the point at which the radio signal is no longer returned is recorded. This is the Critical Frequency. Fig. 2 is a diagram of a typical ionosonde. ▲

"Get more education or get out of electronics

...that's my advice."





Ask any man who really knows the electronics industry.

Opportunities are few for men without advanced technical education. If you stay on that level, you'll never make much money. And you'll be among the first to go in a layoff.

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APPROVED FOR TRAINING UNDER NEW G.I. BILL

Biomedical Engineers Stress Need For Rapport With MD's

ENGINEERING in medicine was the subject of a colloquium held late last year between the engineering and medical communities.

Sponsored by the National Academy of Engineering, the symposium outlined the advances in health care that could take place if the two communities did more "communicating." More than 500 members of industry, government, and the academic community heard 40 speakers discuss biomedical engineering as it relates to education, instrumentation, patient monitoring, health care of developing nations, and industry.

In his opening remarks, Eric A. Walker, President of NAE, stressed the importance of the partnership of engineering and medicine and emphasized the growing need for interaction with the social, behavioral, and life sciences.

One of the points covered in depth by Ivan L. Bennett, Jr., Deputy Director of the Office of Science and Technology, is the difficulty involved in bringing about engineer-physician cooperation. He noted that "Specialization in medicine has evolved in the form of an ever-narrowing focus of responsibility and an ever-increasing depth of knowledge in the field of clinical care. This specialization, with rare exceptions, has not been forced by or undertaken for technological innovations and, within the medical profession, there is a persistent image or perception of medical care as the domain solely of the physician." This attitude, according to Bennett, poses great difficulties in working with "non-medical" specialists on medical problems on any large scale. It means, for example, that engineers who work with physicians are likely to have little opportunity to participate in the selection of objectives, to formulate questions, to structure and restructure problems, and to devise alternatives for their solution.

In noting the prospects for biomedical engineering in the future, Dr. John F. Davis, Director of the International Institute for Medical Electronics and Biomedical Engineering, said that the existing state of its application is "a perfect example of failure to apply overall systems principles to the resolution of a major problem."

One bright spot, engineering and surgery are working together harmoniously in developing new tools, such as automated service and diagnostic systems, for the relief of human suffering. ▲

"STANDARDS" INDEX SET UP AT NBS

Master listing data on 16,000 engineering standards available to engineers and manufacturers.

ARE there any existing standards for my product? Have test methods been set up for determining various characteristics of materials or products? Has nomenclature for my field been defined? Have specs been established on the materials I am considering for use in my product?

The answers to these and other questions about published engineering standards and specifications are now available from the Information Section of the National Bureau of Standards' Office of Engineering Standards Services.

Over the past several years, the Section has collected 16,000 engineering and related standards and specifications published by more than 350 U.S. trade, professional, and technical societies. These standards have been catalogued and indexed and are maintained in a technical library. In addition, a Key-Word-In-Context (KWIC) Index of all standards in the collection has been compiled by the Information Section.

This Section will function both as a technical library and as a referral activity in providing answers to questions on engineering standards and standards activities, and in directing inquirers to the appropriate standards-issuing organization for copies of such published standards.

For many years, NBS has worked closely with national and international organizations that develop and promulgate engineering standards. The Bureau's function is to provide the measurement standards and techniques upon which these standards are based. In addition, the Bureau has, through its Office of Engineering Standards Services, worked cooperatively with industry groups in developing voluntary standards for specific products. These standards are now identified as Product Standards and are included in the Information Section's collection of published standards.

Written inquiries concerning published standards should be directed to: Information Section, Office of Engineering Standards Services, National Bureau of Standards, Washington, D. C. 20234. ▲

BOOK REVIEWS

"OUTLINE FOR DC CIRCUIT ANALYSIS" by Phillip Cutler. Published by *McGraw-Hill Book Company*, New York. 198 pages. Price $3.95. Soft cover.

This is a workbook which is the first in a projected series of outline-type problems books for electrical-electronics engineering technology. Since d.c. circuit theory is usually the first topic which confronts the student engineer, the author has selected and discusses the essential principles of this important subject.

The text is divided into sixteen chapters covering units, definitions and notation, current-voltage-power relationships, resistance, resistance of electrical conductors, series circuits, parallel circuits, series-parallel circuits, superposition theorem, Thevenin's theorem, Norton's theorem and Millman's theorem, compensation, maximum-power-transfer, and reciprocity theorems, Kirchhoff's voltage law, equivalent circuits, and graphic methods of circuit analysis.

Simple arithmetic and algebra are used throughout the text. Each chapter has ten problems for the student to work and turn in to the instructor. The worksheets are perforated. Mr. Cutler, who is with the *Autonetics Division* of *North American Rockwell*, has presented his material in concise, no-nonsense form. Although designed for formal classes, it is detailed enough so that a student could use this "outline" as a self-instruction text.

* * *

"ANGLO-AMERICAN MICROELECTRONICS DATA 1968-69" edited by G. W. A. Dummer and J. Mackenzie Robertson. Published by *Pergamon Press, Inc.*, 44-01 21st Street, Long Island City, New York 11101. Price is $46.00 for each of the two volumes.

These two volumes cover IC's made by companies in the U.S. and Britain. Basically, these volumes are a compilation of technical data. Each type is listed separately with a brief description of the circuit function, quick-reference data, an outline of the device with numbered leads, logic function, design data, truth tables, performance, characteristics, ratings, outlines and dimensions, design and characteristic curves, circuit diagrams, and the corporate name and address of the manufacturer.

Volume one covers companies whose names start with A through P while the second volume covers the rest of the alphabet. American and British firms are about equally divided in this listing.

By providing technical data from all firms within a single volume, the publishers have expedited the job of selecting IC's for specific design applications.

* * *

"SEMICONDUCTOR POWER CIRCUITS HANDBOOK" compiled and published by *Motorola Semiconductor Products Inc.* 264 pages. Price $2.00. Soft cover. Available from *Motorola Inc.*, Box 20924, Phoenix, Arizona 85036.

This handy volume has been compiled especially for users of power transistors, thyristors, rectifiers, and zener diodes. It contains many designs which are being published for the first time. Some 150 new circuits have been designed, constructed, and tested in the company's applications test laboratories before being presented.

The handbook is divided into six chapters which cover the major application areas of interest: motor-speed controls, inverters and converters, regulators, static switches, audio and servo amplifiers, and miscellaneous thyristor and transistor switch applications. There are nearly 270 illustrations including waveforms and circuit diagrams. A complete bibliography is appended to each chapter for further perusal if desired.

* * *

"TV SERVICING GUIDEBOOK: PROBLEMS & SOLUTIONS" by Art Margolis. Published by *Tab Books,* Blue Ridge Summit, Pa. 17214. 167 pages. Price $6.95. Soft cover edition $3.95.

In the largely "anonymous" world of TV servicing, there is one name that many technicians will recognize—Art Margolis. He has written copiously over the years on servicing problems based on his own experiences as a benchman and as a service-shop owner. The hallmark of all his writing has been its practicality. This new volume is presented in the same vein.

He outlines 30 separate troubleshooting approaches, each predicated on specific symptoms, to help nail down any TV problem quickly, without waste motion, and cut troubleshooting time. The author has divided all TV troubles—both black-and-white and color—into 62 classic symptoms. He then describes the servicing procedures which have proven most successful in actual practice.

The book is well illustrated, the writing is straightforward and no-nonsense, and the material is well organized. For the practicing service technician, this guidebook should be a useful aid.

* * *

"MANUFACTURING POLICY IN THE ELECTRONICS INDUSTRY" by Wickham Skinner & David C. D. Rogers. Published by *Richard D. Irwin, Inc.,* 1818 Ridge Road, Homewood, Illinois. 287 pages. Price $6.00. Soft cover.

This volume, subtitled "A Casebook of Major Production Problems", follows the standard Harvard Business School "casebook" format. Originally prepared as a textbook for graduate courses, the material has been released to the public for wider dissemination of the information.

To enable the reader to understand the functions of the vice-president of manufacturing and his staff, this volume analyzes the operations of eight firms: *Lansing, National Video, American Printed Circuit, Prince Company, RCA, Honeywell, Zenith,* and *Instrumentation Laboratory.* The bulk of the book is taken up with industry statistics of various types—ranging from output to the markets and processes used to produce electronic items. Unfortunately, all the statistics cover the period only through 1965, but if the reader keeps this in mind, the over-all picture can still be valid as an indication of current trends in the electronics industry.

* * *

"99 WAYS TO USE YOUR OSCILLOSCOPE" by A. C. W. Saunders. Published by *Tab Books,* Blue Ridge Summit, Pa. 17214. 192 pages. Price $6.95. Soft cover edition is priced at $4.95.

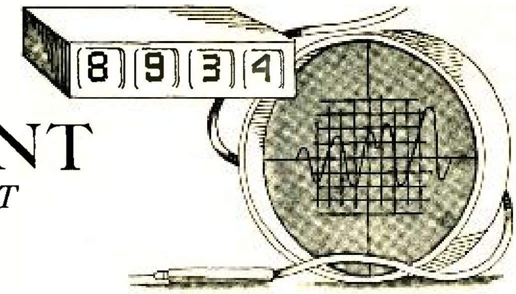
As noted, this volume contains information on 99 applications of the scope to uses ranging from checking the frequency response with a square wave to determining the distribution of burst and chrominance signals.

Each application is listed separately and information is provided on the equipment needed to run the test, how to set up the scope, and the types of patterns which will be obtained under conditions of correct and incorrect circuit operation.

The author has assumed that the user of this text is familiar with the basic operation of his scope and makes no attempt to instruct him on the operation of the various scope controls.

It is only fair to point out, however, that this volume is full of typographical errors. Whether or not this detracts from the usefulness of the book will depend on how sensitive the reader is to such bloopers. ▲

TEST EQUIPMENT
PRODUCT REPORT



Sencore TF-151 Transistor Tester

For copy of manufacturer's brochure, circle No. 20 on Reader Service Card.

THERE is certainly no shortage of transistor testers on the market today. The technician has a large number to choose from, ranging from the inexpensive "go/no-go" tester to the fairly elaborate laboratory-type transistor analyzer. What is rare, however, is a transistor tester that will check the increasing number of field-effect transistors (FET's) that are finding their way into home-entertainment electronic equipment. The new *Sencore* TF-151 is just such an instrument.

The tester has the appearance of two instruments in one. When the large function knob on the front panel is rotated to one of the six left-hand positions, the instrument is set up to check regular transistors either in or out of their circuit. The *beta* gain of both low- and high-power transistors is checked and there is a special checking position for low-current r.f. transistors. In addition, collector-to-base leakage current is measured directly on the six-inch meter.

When the function knob is rotated to one of the six right-hand positions, the tester is set up to check field-effect transistors, either in- or out-of-circuit. These transistors are tested for transconductance (G_m) as well as for leakage current between gate and source electrode. The instrument can even test FET's that have two separate gate leads. Although these are not widely used, it is comforting to know that the tester can handle these types as well. Transconductance of FET's is measured directly in micromhos, which are read on the large meter. There is also a test for zero bias drain current (I_{DSS}), which is useful for matching FET's or for selecting a group with certain characteristics out of a large quantity.

In addition to transistors, the new tester can also check just about all the common and special semiconductor diodes, including power rectifiers, signal diodes, zeners, and variable-capacitance types that are used in electronic equipment.

A new transistor and FET manual, showing all the test setups and results to expect on over 14,000 transistors and FET's, is included with the instrument. The book can also be used with other transistor testers since it gives type. basing information. gain, and leakage of the various semiconductors listed. Hence, it is expected to be made available separately at about $10.

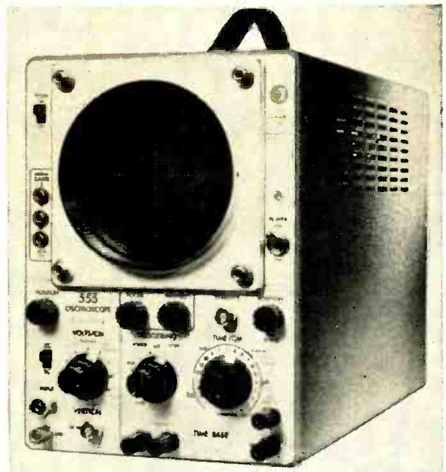
The new *Sencore* Model TF-151 is housed in a vinyl case with a chrome panel. It is priced at $129.50. ▲

Data Instruments Model 555 Oscilloscope

For copy of manufacturer's brochure, circle No. 21 on Reader Service Card.

A GOOD many test-equipment manufacturers have looked with envy at the very lucrative laboratory-oscilloscope market. It seems that no matter where you go in the electronics industry, whether on a production line or in a laboratory, you'll see the ubiquitous *Tektronix* lab scopes in frequent use. These scopes are certainly top-quality products and for those companies which can afford them, they do an excellent job. Recognizing that there is a considerable market for a somewhat lower priced triggered-sweep scope, this leading scope manufacturer some time ago took over a line of British scopes that have many of the features of the lab scope but at considerably lower price. With this line of scopes, called *Telequipment* (a subsidiary of *Tektronix, Inc.*) it is possible to obtain a solid-state triggered-sweep instrument at around $350 rather than at figures perhaps two or three times higher for the more elaborate *Tektronix* version.

Several U.S. companies are now importing Japanese triggered-sweep scopes for this very same market. A recent one of these that has come to our attention is the Model 555, imported and distributed by *Data Instruments*. This company has an entire line of scopes ranging in price from $93 to $566. The Model 555 (right) at $284, is just at the middle of the line in features, performance, and price.



This scope is a 5-in instrument with a bandwidth from d.c. to 7 MHz. Just about all the circuitry, including the high-voltage rectifier, is solid-state. Transistors are used for everything except for a 12AU7 high-impedance vertical-input stage, and a couple of 6DJ8's as vertical- and horizontal-output stages.

The vertical input attenuator has nine steps and is calibrated from 20 mV/cm to 10 V/cm, at an input impedance of 1 megohm. The sweep circuit is either free-running or it may be triggered at any selected point on the waveform to be observed and measured. There are nineteen calibrated sweep ranges from 1 microsecond/cm down to 1 second/cm. A built-in vertical calibrator delivers a 1-kHz square wave with a peak-to-peak amplitude of 5, 0.5, and 0.05 volt to three terminals at the left of the scope face. A well-regulated power supply, delivering plus and minus 50 volts to the transistor circuits, keeps the pattern stable in spite of variations in line voltage.

The Model 555 is fairly compact for a 5-in scope, thanks to the use of a number of solid-state subassemblies. The unit measures 8 by 10½ by 16 in deep and it weighs 22 lbs. A detailed operating and maintenance manual accompanies each instrument. ▲

EMC Model 215 Tube and Transistor Tester

For copy of manufacturer's brochure, circle No. 22 on Reader Service Card.

In spite of the fact that so much of the new electronic equipment is solid-state, there are still plenty of vacuum tubes in use. Most new TV sets, for example, employ tubes so that when these have to be checked or when you want to test the tubes in an older TV model, you should have a simple-to-operate tube tester. One such unit that was brought to our attention is the *EMC* Model 215.

This inexpensive tube tester made by *Electronic Measurements Corp.* is really two pieces of test equipment in one case. Not only does it check a wide variety of commonly used vacuum tubes, but it is also a simple transistor tester as well.

The tube checker is a conventional a.c.-operated emission and leakage tester that can handle compactrons, magnavols, nuvistors, and novars as well as the more conventional miniature and standard tube types. Readout is on a three-color meter scale on the front panel of the instrument.

When a slide switch is moved from "Tubes" to "Transistors", the unit is converted to a battery-operated transistor tester. The transistor being tested is inserted in the instrument's oscillator circuit, the output of which is monitored on the 5-mA meter. A pair of "C"-cells operates this circuit, which checks both high- and low-power *n-p-n* and *p-n-p* transistors.

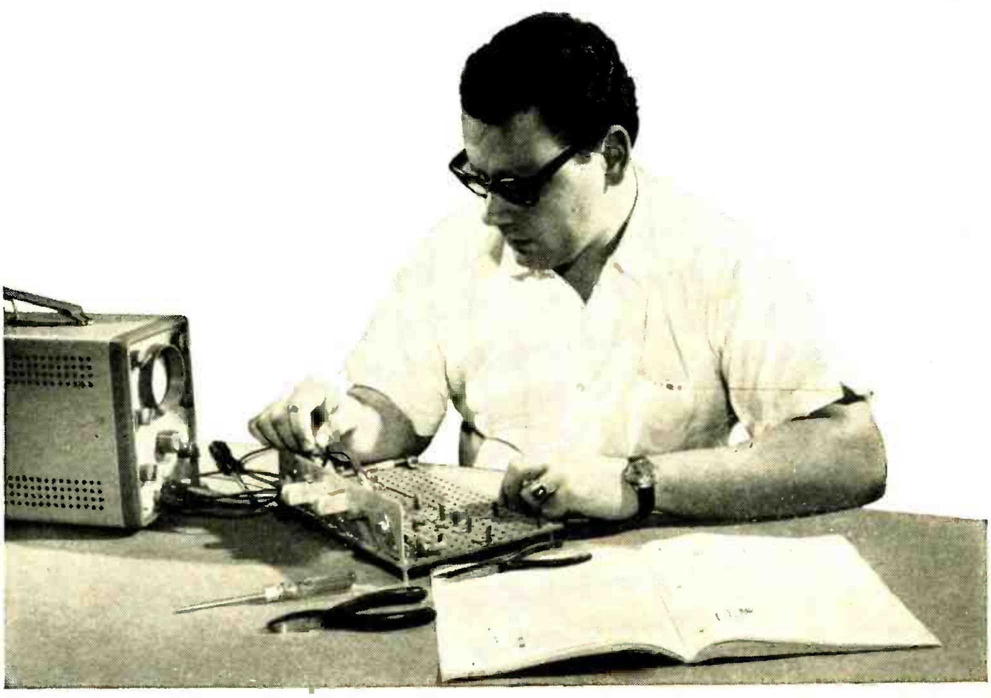
A ring-bound tube-chart manual is supplied with the tester to show the settings to be used when checking tubes.

The Model 215 is housed in a Bakelite case with carrying strap. It measures only 8½-in high by 7¼-in wide by 4-in deep. It is available either in kit form at $27.95 or factory-assembled at $42.95. ▲

CIRCLE NO. 80 ON READER SERVICE CARD→

10 Reasons why RCA Home Training is

your best investment for a rewarding career in electronics:



Performing transistor experiments on programmed breadboard — using oscilloscope.

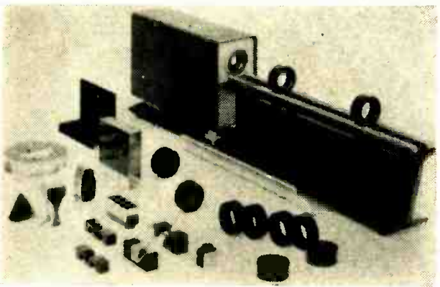
NEW PRODUCTS & LITERATURE

Additional information on the items covered in this section is available from the manufacturers. Each item is identified by a code number. To obtain further details, fill in coupon on the Reader Service Card.

COMPONENTS • TOOLS • TEST EQUIPMENT • HI-FI • AUDIO • CB • HAM • COMMUNICATIONS

LASER TEACHING KIT

Forty-four experiments in geometrical and physical optics are detailed in a new laser experimenter's kit designed for classroom use. Included in the kit are complete accessories, designed for



use with the firm's educational He-Ne laser, LAS-2002, and an illustrated 80-page manual for the instructor's use.

Convenient and vivid display of the most intricate properties of light are provided by twenty-four individual elements including a beam divider, the self-centering optical bench, convex and concave lenses, and beam display elements. The components are made from a nonbreakable plastic which permits direct viewing of the light rays. Eight complete course programs, from junior high school to college level are described in the manual, enabling the instructor to pick a program which meets the needs of his class. Electro Optics

Circle No. 126 on Reader Service Card

LC FILTERS

The Series FL and FH LC filters are a group of nine-pole Chebyshev low- and high-pass filters which are available as off-the-shelf items.

The units are compact and incorporate components that meet the latest applicable MIL-Spec requirements. A useful application is the series connection of a low-pass and high-pass unit to produce an effective bandpass filter.

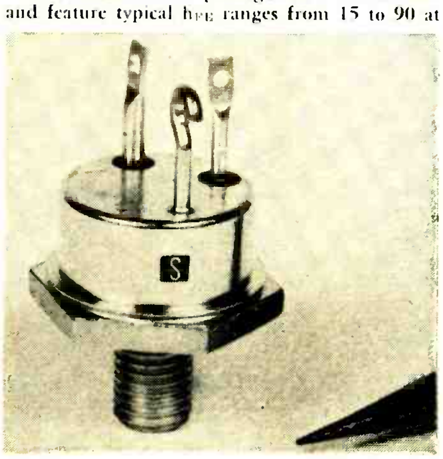
Full details on the two series are available on request. Allen Avionics

Circle No. 127 on Reader Service Card

20-A POWER TRANSISTORS

A new series of 20-amp "n-p-n" diffused silicon power transistors with voltages from 100 to 200 volts has been introduced as SDT 8751 through SDT 8758.

The transistors are packaged in a TO-63 case and feature typical h_{FE} ranges from 15 to 90 at



a collector current of 10 A and collector saturation voltages lower than 0.5 V. The f_t of these transistors is typically 30 MHz.

Primary uses for these devices are in high-voltage, fast-switching applications including radar systems, telemetry, servo amplifiers, switching regulators, and sweep circuits. Solitron

Circle No. 128 on Reader Service Card

CRYSTAL FILTERS

A new line of monolithic Gaussian crystal filters which the company claims are smaller, more reliable, and less costly than conventional Gaussian filters has been introduced.

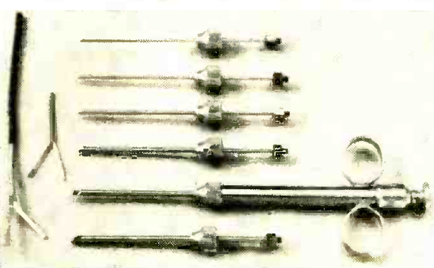
The new filters are designed for minimum delay distortion in FM, nonovershooting pulse response in radar and other pulse-modulated systems, and for reduced ringing in swept-frequency applications such as spectrum analysis and doppler acquisition.

The Model 6354 MA, for example, is a four-pole design housed in a cold-welded TO-8 enclosure. Center frequency (f_o) is 10.7 MHz, the 3-dB bandwidth is 2.5 kHz, while the 40-dB bandwidth is 17.5 max kHz. Source impedance is 500 ohms resistive. Damon

Circle No. 129 on Reader Service Card

LEAD EJECTOR

The G-6 lead ejector is a syringe-like tool for use on shielded cables. It parts the braiding from the inside without breaking wires and then ejects the inner lead through the hole, producing a neatly finished pigtail in one operation. No fur-



ther trimming is needed so that the danger of loose "wire whiskers" in electronic equipment is eliminated.

The unit is easy to use and cuts production time and improves appearance of wiring. A simple adjustment programs the tool to make identical pigtails of any desired length.

The device is supplied with a kit of six interchangeable plungers to fit cable inner lead diameters from 0.039" to 0.175". Other sizes can be supplied on special order. Bailey Company

Circle No. 130 on Reader Service Card

TREASURE-LOCATOR KIT

A new metal-mineral detector is now being offered in kit form as the Model TRL-1 treasure locator.

Three FET's and two silicon transistors are used in the circuit to provide operating stability. Kit assembly is simplified with etched-circuit board constructon and easy-to-follow instructions. A six-inch etched-circuit "search" coil is furnished with the kit. There are no coils to wind and no test equipment is needed for alignment. Rugged glass-epoxy material is used for both etched-circuit boards. It is estimated that construction time will be under three hours.

The unit weighs only 24 ounces. The handle folds in the middle for convenient storage. The search coil is adjustable to any angle. Power is provided by a 9-volt battery. The kit comes with all parts, wire, solder, headphone, and complete instructions. Caringella Electronics

Circle No. 1 on Reader Service Card

REGULATED D.C. SUPPLY

A d.c. lab-type power supply, which features automatic protection against overloads and shorts, is now available as the No. 99-5077. Useful in servicing portable transistor and car transistor radios, recharging small batteries, and where a

stable, low-ripple d.c. voltage is required, the new supply provides a continuously variable d.c. voltage of 5-13 or 12-20 volts at up to 2 amperes. Ripple is less than 5 mV r.m.s. at full load; regulation is ±1%.

The output voltage and current are monitored by two d'Arsonval meters. Both input and output are fused for full protection. Input is 115 or 230 volts a.c. ±10%, 50-60 Hz. The supply is housed in a rugged steel case with rubber feet and measures 6½" high x 4½" wide x 8¾" deep. Lafayette

Circle No. 2 on Reader Service Card

BROADBAND FILTER

The new "L" network broadband filter has been designed for EMI protection. This 50-V d.c. filter has a guaranteed minimum attenuation over the entire temperature range from −55° C to +125° C with full load applied. There is no derating in working voltage and exceptionally low d.c. resistance, according to the company.

These temperature-stable filters meet or exceed the applicable parameter of MIL-F-15733. Gulton

Circle No. 131 on Reader Service Card

MATCHING TRANSFORMER

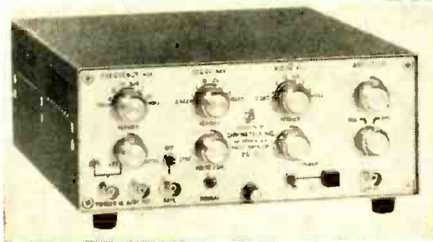
A new indoor 82-channel matching transformer has just been introduced as the Model MT60. The unit is used to match 75-ohm coaxial cables to the 300-ohm inputs of TV and FM sets. It passes all u.h.f. and v.h.f. television channels, plus all FM frequencies.

An outdoor version of this matching transformer is also available. Completely weatherproofed, it is supplied with a snap-on insulator to hold it to the antenna cross arm, plus a weatherboot. It is designated Model MT61. JFD

Circle No. 3 on Reader Service Card

PULSE GENERATOR

A new low-cost pulse generator has just been introduced as the Model PG-11. The instrument provides single or double pulses, pulse pairs, pulse bursts, or one-shot output. It will operate over a repetition rate range of from 10 Hz to



20 MHz in the double-pulse mode and to 10 MHz in the single-pulse mode. Rise and fall times are 5 ns maximum at full ±15-volt output amplitude.

The PG-11 may be triggered from d.c. to 20 MHz and/or may be synchronously or asynchronously gated. Output amplitude is switch-selected "+" or "−" and is without a measurable d.c. component. Repetition rate, output width (25 ns to 10 ms), delay (20 ns to 10 ms), and amplitude are continuously variable over wide dynamic ranges.

The new generator is suitable for bench or rack mounting. In rack mounting form it measures 3½" high x 8½" wide x 9½" deep. Chronetics

Circle No. 132 on Reader Service Card

EMI SUPPRESSION FILTER

The new "M" series filter is a miniature hermetically sealed EMI suppression filter designed for critical applications where small size, weight, environmental conditions, and reliability are factors.

The uniquely designed toroidal coils provide maximum inductance with high d.c. saturation. The case mounts quickly to the equipment by

means of lock washers and hex nut. They are available in "L" section, "pi" section, and "T" section filter types and in working voltages of 100 and 150 V d.c. and 115 V a.c. for operation at 10 kHz to 10 GHz.

All "M" series filters have a 0.375-inch diameter and over-all length of 1.028 to 1.630, depending on type. All units meet or exceed MIL-F-15733. Components Corp.

Circle No. 133 on Reader Service Card

TEMPERATURE LABELS

The new line of "Tempilabels" contains four heat-sensitive indicators rated at 70, 80, 90, and 100 degrees F. This special low-temperature monitor was conceived and developed primarily for checking maximum temperatures to which heat-sensitive photographic films had been subjected. However, it is anticipated that the new low range will find many applications in the fields of biologicals, foods, synthetic textiles, pharmaceuticals, and in many other industries in which materials are heat-sensitive.

The labels are manufactured under cold-room conditions and are shipped in specially prepared thermally insulated packages.

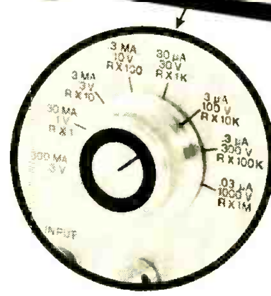
Further details on the labels and information on suggested applications will be supplied on request. Tempil Corp.

Circle No. 134 on Reader Service Card

TUNED BANDPASS FILTERS

Two new series of fixed tuned bandpass filters have just been introduced as the BC and BE series.

The BC series permits any center frequency to be specified from 50 MHz to 4 GHz with attenuation characteristics available for 3 through 16 sections. Its modular design construction enables it to be designed, built, tuned, stabilized, and shipped in less than 48 hours. The percent bandwidth ranges from 1% through 70%.



The BE series can be specified with any center frequency from 15 MHz through 1 GHz, with attenuation characteristics from 3 through 16 sections. This series offers the lowest center frequency, lowest insertion loss, and highest power rating available, according to the company. Its aluminum case makes it lightweight and suitable for many general and laboratory requirements. Texscan

Circle No. 135 on Reader Service Card

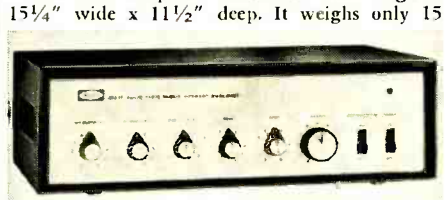
HI-FI — AUDIO PRODUCTS

80-WATT P.A. AMPLIFIER

The Model 3281T 80-watt amplifier has been designed to handle any major public address sound function including coverage of large auditoriums, factories, outdoor assemblies, and athletic fields.

The solid-state circuit uses all-silicon transistors for cool, long-lived operation at minimum current drain. Features include a large master gain control, separate mixer controls, and inputs for two microphones, plus a fader for two auxiliary inputs. An anti-feedback switch helps to prevent "squeal" and protects trumpet speakers. There are separate bass and treble controls, a high- or low-impedance mike switch, a mike precedence feature for paging use, and a pilot light.

The new amplifier measures 5 3/16" high x 15¼" wide x 11½" deep. It weighs only 15



pounds. It may be used with appropriate speakers, sound columns, or weatherproof trumpets for either indoor or outdoor applications. Allied Radio

Circle No. 4 on Reader Service Card

STEREO CASSETTE SYSTEM

A mini-compact stereo cassette system has just been introduced as the Model SHC-44. Consisting of four units—a recorder deck, matching AM-FM stereo tuner, and two matching speaker sys-

tems—the system is housed in teak wood cabinets. The deck features piano-key function controls, cassette ejection button, digital tape counter, record level/battery condition indicator, plus volume, tone, and selector controls. The circuit uses 14 transistors. Operation is from 117 V a.c. or six "D" cells. Frequency response is 100 to 10,000 Hz.

The tuner features vertical slide-rule tuning, FM stereo lamp, and a selector switch. It uses 13 transistors. The speaker systems each house a four-inch full-range PM dynamic speaker with power handling capacity of five watts. Crown

Circle No. 5 on Reader Service Card

100-WATT STEREO RECEIVER

The Model S-7600a AM-FM stereo receiver features 100 watts of power at 4 ohms. It uses integrated circuits for the FM i.f. and limiters and FET's for r.f. and mixer stages.

Front-panel controls include rocker switches for loudness compensation, main and/or remote speaker switching, and tape monitor. Other controls are loudness and AM-FM tuning as well as bass, treble, balance, and variable FM interchannel hush. A three-position switch on the rear panel adjusts the phono-input level to equalize the magnetic phono cartridge level to the tuner signal level.

Over-all size is 16½" x 4½" x 12" deep. It is available in either a walnut-grained leatherette metal case or an oiled walnut-wood cabinet, both at extra cost. Sherwood

Circle No. 6 on Reader Service Card

TRANSCRIPTION TURNTABLE

A new and advanced transcription turntable has just been introduced as the Thorens TD-125. It incorporates a transistorized drive system which reduces the speed of rotation of the motor to an

extremely slow value with the resultant complete lack of audible rumble. Other features include an electronic speed selector and pitch control, three speeds—16, 33, 45 r/min, dynamically balanced 12" diecast turntable, and a replaceable tonearm for mounting a choice of tonearm. Elpa Marketing

Circle No. 7 on Reader Service Card

TEACHING TAPES

The Wollensak Teaching Tapes library is now available in cassette form and is being expanded by 150 titles.

The prerecorded tapes, which were designed for supplemental, enrichment, and individualized instruction in language arts, science, mathematics, and social studies were introduced a year ago.

Availability of the tapes in cassette form coincides with the availability of a heavy-duty cassette recorder for classroom applications, the Model 2520AV. Each package, which is a booklike box and fits on standard library shelves, contains the prerecorded tape, a set of 72 worksheets, and a teacher's guide. 3M

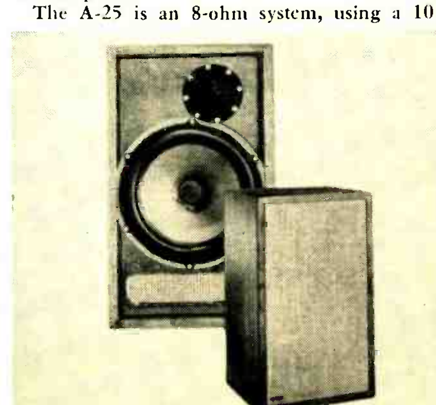
Circle No. 8 on Reader Service Card

BOOKSHELF SPEAKER SYSTEM

The A-25 bookshelf speaker system is the first in a new line and a departure from the company's usual output of hi-fi components.

Of aperiodic design, the speaker uses a novel acoustic impedance system to provide the effect of variable cabinet volume. According to the company, this design improves speaker damping and contributes to improved low-frequency transient response.

The A-25 is an 8-ohm system, using a 10"



extended-excursion woofer and a new non-rigid hemispherical tweeter with a 1500-Hz non-inductive crossover network. With a constant 25-watt input, total harmonic distortion stays below 3% above 50 Hz and is far lower above 1000 Hz, according to the company. It is suitable for use with power amplifiers having continuous power ratings between 15 and 60 watts.

The compact 20" x 11½" x 10" deep cabinet is available in oiled walnut with a natural linen grille cloth. Recessed binding posts and hangers for flush wall mounting, and a 5-position tweeter level control are included. Dynaco

Circle No. 9 on Reader Service Card

CB-HAM-COMMUNICATIONS

BATTERY-BOOST REGULATOR

A new battery-boost regulator for CB and Business mobile transceivers is now available. The solid-state direct-current regulator boosts available supply voltage—which can be as low as 11 volts—to the required value. It delivers a fixed output to the communications equipment, from no-load up to its rated 2 A maximum. Factory preset to deliver 15.5 volts, the regulator can be adjusted for output voltage from 12 to 16 volts. Mark Products

Circle No. 10 on Reader Service Card

CB RADIO/MONITOR RECEIVER

The "Telsat 150" is a two-way CB radio plus a police and fire monitor receiver, packaged as a single unit. The all-solid-state unit is designed to provide reliable mobile two-way communications on all 23 crystal-controlled CB channels as well as reception on v.h.f. FM police and fire frequencies in the 150-174 MHz band.

Completely self-contained, the unit includes a built-in power supply for 12 V d.c., negative or positive ground, and will operate on 117 volts a.c. with an optional power supply. The circuit uses one IC, one FET, and 25 transistors, plus 9 diodes. Sensitivity is 0.7 μV on CB and less than 1 μV on v.h.f. FM. The CB unit also has a TVI trap and a socket for an optional private tone caller.

The unit comes complete with all crystals, except for the 150-174 MHz band, and a mobile mounting bracket. It measures 2½" high x 6½" wide x 8" long and weighs 7½ pounds. Lafayette

Circle No. 11 on Reader Service Card

TRANSFORMER-BALUN

The TRS-57 transformer-balun has been developed to permit any short-wave listening doublet to be adapted to receive standard broadcast bands below 4 MHz. On these bands, the transformer-balun automatically transforms the doublet into a long-wire antenna, thus eliminating the need for an additional antenna to receive local stations and distant cities.

On regular short-wave bands, the TRS-57 acts as a balun to provide balanced receiver input. It can be easily installed on the back of the SWL receiver with a screwdriver. Mosley

Circle No. 12 on Reader Service Card

23-CHANNEL CB UNIT

The Model A-2569 23-channel CB transceiver is all-solid-state and uses 31 active semiconductor devices including silicon and field-effect transistors, an IC, silicon diodes, and a zener diode.

The unit may be used as a base station or can be installed in a car or boat. It measures 1⅝" high x 6¼" wide x 7¼" deep. The full legal-limit 5-watt input and a speech compressor pro-

vide maximum talk power and transmitting range, according to the company.

The transceiver features a dual-conversion superhet receiver with a sensitivity of 0.2 μV, adjustable squelch control, a.g.c., and a.n.l. The transmitter section features 100% modulation capability, solid-state transmit/receive switching, and a stable frequency synthesizer that permits crystal-control transmit and receive operations on all 23 channels. Allied Radio

Circle No. 13 on Reader Service Card

MANUFACTURERS' LITERATURE

MOS/LSI BROCHURE

A 44-page brochure describing MOS/LSI integrated circuits and other recent MOS IC products is now available. The 8½" x 11" reference guide provides a section on MOS standard off-the-shelf products and a second section on custom MOS arrays, including the company's "Micromosaic" arrays. Illustrative charts and diagrams are included.

The standard products section features a series of one-page specifications on the firm's complete line of MOS circuits. These products include more than ten standard LSI circuits as well as a representative cross-section of static and dynamic type circuit designs to complement the LSI devices. Fairchild Semiconductor

Circle No. 136 on Reader Service Card

CALCULATORS/TECH BOOKS

A new 32-page catalogue containing full descriptions of a line of design slide .ies and data selectors, drafting templates, handbooks, manuals, technical books, curves, kits, and converters is now available.

Designed for electronic, mechanical, chemical, manufacturing, and structural designers, engineers, and draftsmen, all the products listed in the catalogue are available from stock. TAD Product

Circle No. 14 on Reader Service Card

IC SHORT-FORM CATALOGUE

A 24-page catalogue containing reference data on op amps, voltage regulators, communications circuits, TTL 54/74 series, TTL MSI types, MOS memories, analog switches, and logic elements has just been issued. National Semiconductor

Circle No. 137 on Reader Service Card

ELECTROLYTIC REPLACEMENTS

A new 68-page cross-reference guide has been compiled to offer the service technician a handy tool for locating single, dual, triple, and quadruple section replacement electrolytics quickly and easily.

The twist-prong electrolytics are listed in three different ways: by catalogue number, by capacity, and by voltage. There are also three cross-reference sections in the book designed to solve selection problems. The first is a complete "Color-Lytic" cross-reference between OEM numbers of 42 color set manufacturers and equivalent catalogue numbers; the second is between catalogue numbers of other manufacturers and the company, and the third is between OEM numbers of major black-and-white set makers and the company's numbers. Cornell-Dubilier

Circle No. 15 on Reader Service Card

SCHOOL DIRECTORY

A new up-to-date "Directory of Accredited Private Home Study Schools" has been issued by the Accrediting Commission of the National Home Study Council and is available for distribution.

The listing is designed to assist interested persons in selecting a home study school and to inform them of the hundreds of courses available. National Home Study Council

Circle No. 16 on Reader Service Card

POWER-SUPPLY CATALOGUE

A comprehensive 56-page catalogue of power supplies, instruments, and systems for laboratory, test equipment, and OEM applications is now available.

The catalogue gives detailed specifications and prices and complete ordering information for over 300 models of power supplies, gives details on a complete power-supply assembly systems using standard components and accessories supplied preassembled ready to plug into a customer's system, and provides a convenient selection guide which lists all models with specifications and features to facilitate selection. Lambda

Circle No. 138 on Reader Service Card

LOUDSPEAKER CATALOGUE

Catalogue 1090-C covers the firm's "Concert" and "Viking" series loudspeakers designed for custom installation and replacement applications. The publication also lists details on the "Concert-Vibranto" line of electronic musical instrument speakers and speaker systems. Jensen

Circle No. 17 on Reader Service Card

QUARTZ CRYSTALS

A new listing of low- and high-frequency crystals in a range from 90 kHz to 210 MHz is contained in a new four-page bulletin. Available in a range of sixteen sizes and types of holders, the crystals cover both standard and custom units for a wide variety of applications. Complete specifications and dimensional data are provided. Tedford

Circle No. 139 on Reader Service Card

ELECTROLYTIC DATA

A six-page "Color-Lytic" catalogue listing every electrolytic capacitor in the company's line is now available for distribution. The selection offers single, dual, triple, and quadruple section electrolytics. The 250 units are designed as replacements for over 2500 different capacitors.

The listing also has blank space for each rating that can be used for inventory taking, price notations, and product movement indication. Cornell-Dubilier

Circle No. 140 on Reader Service Card

TRANSDUCER DATA

A large summary chart listing the characteristics of the firm's line of standard surface-type temperature transducers is now available for distribution. The chart describes over a dozen models and gives operating characteristics, accuracy ranges, sizes, and general features. Trans-Sonics

Circle No. 141 on Reader Service Card

SWITCH CATALOGUE

A new 16-page catalogue giving complete technical specifications on six new series of miniature rotary switches has just been issued. Included for the first time are many modifications which can now be obtained on various switches. Such modifications include units designed for PC use, plus switches with specially coded outputs, including decimal-to-binary for digital work. RCL

Circle No. 142 on Reader Service Card

AIR TRIMMER CAPACITORS

Information and data useful to users of air dielectric trimmers is included in a new issue of "Trimmer Topics," a publication slanted to the design engineer.

The two-page publication provides a comparison of rotating vs non-rotating concentric ring air trimmers, features of the company's new "A" line trimmers, and a comparison of concentric ring air trimmers vs piston-type trimmers. Voltronics

Circle No. 143 on Reader Service Card

PC HEAT-RISE DATA

A chart showing how the thickness of conductors affects circuit temperature at various voltage

and current levels is now available. The chart has been prepared to aid the designer or specifier of die-stamped and etched printed circuits. GTI
Circle No. 144 on Reader Service Card

CAST MICA CAPACITORS

New data on cylindrical-body cast mica capacitors for operation up to 125° C is presented in Bulletin No. 1240A. Types 375M, 380M, 385M, and 390M capacitors use a so-called "solid impregnant." This impregnation method eliminates all air voids and makes it possible to obtain high insulation resistance, "Q", and voltage breakdown parameters.

The r.f. current ratings for each standard catalogue rating and complete performance characteristics are also included. Sprague
Circle No. 145 on Reader Service Card

INSTRUMENTATION CATALOGUE

The newly published Scientific Instrumentation Catalogue is now available for distribution. This 68-page catalogue lists instruments for research and development, in industry as well as for educational purposes. Included are full specifications, illustrations, and many schematics covering a spectroscopy system, instrumentation laboratory, chart recorders, recording pH electrometers, polarography system, physics lab. as well as scopes, power supplies, voltmeters, signal generators, testers, and bridges. Heath
Circle No. 146 on Reader Service Card

LINEAR IC's

A 28-page brochure which is designed to help electronics engineers solve complex design problems by means of second generation integrated circuits is now available.

The publication is divided into three parts. Section 1 describes seven off-the-shelf devices and provides all the information needed to incorporate them into circuits. Section 2 discusses applications for these units and Section 3 outlines electrical characteristics and parameters that will appear as tomorrow's standard products.

Ordering information is included in the brochure, along with a listing of the company's sales offices and stocking distributors. Fairchild Semiconductor
Circle No. 147 on Reader Service Card

ELECTROLYTIC BULLETINS

Axial-lead aluminum electrolytic capacitors are described in two new bulletins now available. Covered in a 12-page publication is the Type 056 capacitor which is available in capacitances from 2.4 to 15,000 μF and in cases with diameters ranging from 0.5 to 1 inch and lengths from 1.125 to 3.625 inches. Operating temperature ranges from −40 to +85° C.

The other bulletin, containing 16 pages, covers the Type 556 computer-grade capacitor. This unit has an operating temperature range of −40 to +105° C and is available in capacitances from 5 to 2000 μF. Diameters range from 0.375 to 0.500 inch and lengths from 0.687 to 2.125 inches. Sangamo
Circle No. 148 on Reader Service Card

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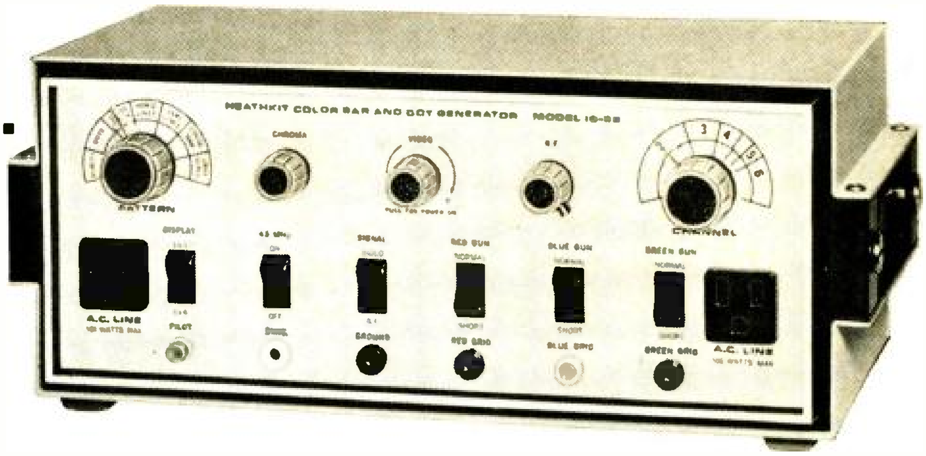
For Top Performance And Value In Electronics —

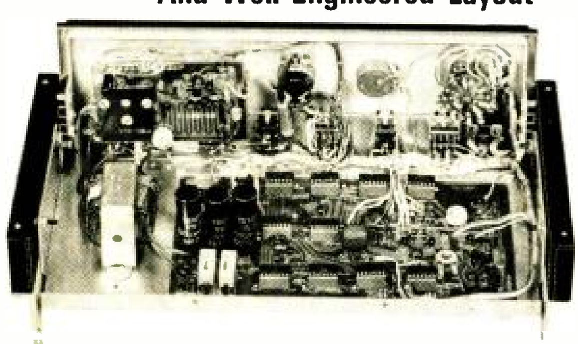
Introducing The NEW Heathkit® IG-28

Color Bar — Dot Generator...

Advanced IC Design Gives 12 Patterns Plus Clear Raster Display & Eliminates Divider Chain Instability Forever!

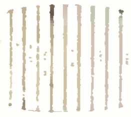


Stable Integrated Circuitry And Well-Engineered Layout



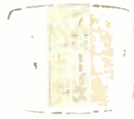
Circuit Board-Wiring Harness Construction. Note the extremely clean, open layout — another advantage of integrated circuitry. The Video board is upper left, the Divider board mounts on the chassis.

Fast Switch Selection Of Either Standard 9 x 9 Display OR Exclusive Heath "3 x 3" Display



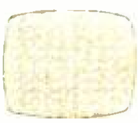
Color Bars

Shading Bars



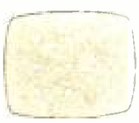
3x3 Color Bars

3x3 Shading

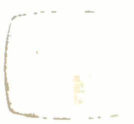


Dot Pattern

Cross Hatch



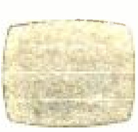
3x3 Dot



3x3 Cross Hatch

Horizontal Bars

Vertical Bars



3x3 Horizontal

3x3 Vertical

The Most Advanced Instrument In Color TV Service

• All solid-state construction using Integrated Circuitry • No divider chain adjustments • Stable pattern display — no flicker, bounce or jitter • Produces 12 patterns plus clear raster • Instant switch selection of all functions • Exclusive 3x3 display plus standard 9x9 display of all patterns • Horizontal lines only one raster thick for added accuracy • Variable front panel tuning for channels 2 through 6 • Variable front panel positive and negative video output • Front panel negative going sync output • Two handy AC outlets on front panel • Built-in gun shorting circuit with lead piercing connectors • Front panel switchable crystal controlled sound carrier • Copper-banded transformer to reduce stray fields • Safe three-wire line cord • Fast, easy construction with two circuit boards and two wiring harnesses

The new Heathkit IG-28 is the ultimate signal source for all Color and B&W TV servicing. No other instrument at any price will give you as much stable, versatile TV servicing capability. Here are the details:

All Solid-State Circuitry produces dots, cross-hatch, vertical and horizontal lines, color bars and shading bars in the familiar 9x9 display . . . plus the exclusive Heath 3x3 display of all these patterns so necessary for static convergence, linearity and color demodulator phase adjustments . . . plus a clear raster that lets you adjust purity without upsetting AGC adjustments. Fifteen J-K Flip-Flops and associated gates count down from a crystal controlled oscillator, eliminating divider chain instability and adjustments.

Time-Saving Versatility. While many generators only give you one or two channel capability, the new IG-28 has variable front panel tuning for channels 2 through 6. The RF tank coil is actually etched into the circuit board for extra stability. Plus and minus going video signals are available at the turn of a front panel control. And for sync, in-circuit video or chroma problems, there's a front panel sync output. Convenient AC outlets are provided for degaussing coil, test instruments, TV set etc. Built-in gun shorting circuits and grid jacks are also included. Add any service type scope (with horizontal input) to the IG-28 and you have vectorscope display capability too. Other features include a crystal controlled sound carrier oscillator, a well regulated full wave power supply with dual primary copper-banded transformer, safe three-wire line cord, and rugged, compact Heath instrument styling. Two circuit boards and two wiring harnesses provide easy construction in about ten hours. Start enjoying the versatility you couldn't get before . . . put the remarkable new Heathkit IG-28 on your service bench now.

Kit IG-28, 8 lbs..$79.95*

Look To The Leader

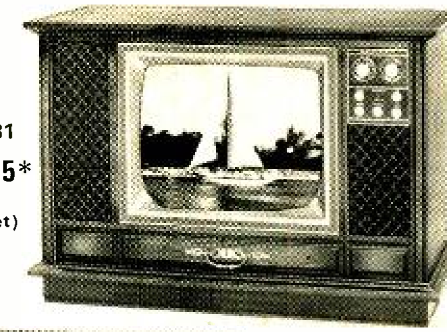
HEATHKIT®

Now There are 4 Heathkit Color TV's . . . All With 2-Year Picture Tube Warranty

NEW Deluxe "681" Color TV With Automatic Fine Tuning

The new Heathkit GR-681 is the most advanced color TV on the market. A strong claim, but easy to prove. Compare the "681" against every other TV — there isn't one available for any price that has all these features. Automatic Fine Tuning on all 83 channels . . . just push a button and the factory assembled solid-state circuit takes over to automatically tune the best color picture in the industry. Push another front-panel button and the VHF channel selector rotates until you reach the desired station, automatically. Built-in cable-type remote control that allows you to turn the "681" on and off and change VHF channels without moving from your chair. Or add the optional GRA-681-6 Wireless Remote Control described below. A bridge-type low voltage power supply for superior regulation; high & low AC taps are provided to insure that the picture transmitted exactly fits the "681" screen. Automatic degaussing, 2-speed transistor UHF tuner, hi-fi sound output, two VHF antenna inputs . . . plus the built-in self-servicing aids that are standard on all Heathkit color TV's but can't be bought on any other set for any price . . . plus all the features of the famous "295" below. Compare the "681" against the others . . . and be convinced.

GRA-295-4, Mediterranean cabinet shown **$119.50***
Other cabinets from $62.95*



kit GR-681
$499^95*
(less cabinet)

Deluxe "295" Color TV . . . Model GR-295

Big, Bold, Beautiful . . . and packed with features. Top quality American brand color tube with 295 sq. in. viewing area . . . new improved phosphors and low voltage supply with boosted B + for brighter, livelier color . . . automatic degaussing . . . exclusive Heath Magna-Shield . . . Automatic Color Control & Automatic Gain Control for color purity, and flutter-free pictures under all conditions . . . preassembled IF strip with 3 stages instead of the usual two . . . deluxe VHF tuner with "memory" fine tuning . . . three-way installation — wall, custom or any of the beautiful Heath factory assembled cabinets. Add to that the unique Heathkit self-servicing features like the built-in dot generator and full color photos in the comprehensive manual that let you set-up, converge and maintain the best color picture at all times, and can save you up to $200 over the life of your set in service calls. For the best color picture around, order your "295" now.

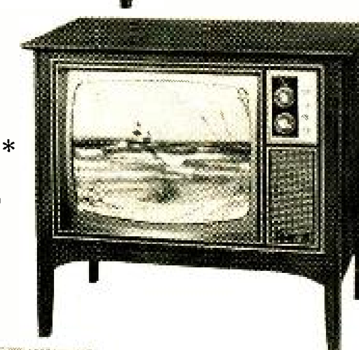
GRA-295-1, Walnut cabinet shown **$62.95***
Other cabinets from $99.95*

kit GR-295
now only
$449^95*
(less cabinet)

Deluxe "227" Color TV . . . Model GR-227

Has same high performance features and built-in servicing facilities as the GR-295, except for 227 sq. inch viewing area. The vertical swing-out chassis makes for fast, easy servicing and installation. The dynamic convergence control board can be placed so that it is easily accessible anytime you wish to "touch-up" the picture.

GRA-227-1, Walnut cabinet shown **$59.95***
Mediterranean style also available at $99.50*



kit GR-227
now only
$399^95*
(less cabinet)

Deluxe "180" Color TV . . . Model GR-180

Same high performance features and exclusive self-servicing facilities as the GR-295 except for 180 sq. inch viewing area. Feature for feature the Heathkit "180" is your best buy in deluxe color TV viewing . . . tubes alone list for over $245. For extra savings, extra beauty and convenience, add the table model cabinet and mobile cart.

GRS-180-5, table model cabinet and cart **$39.95***
Other cabinets from $24.95*

kit GR-180
now only
$349^95*
(less cabinet)

Now, Wireless Remote Control For Heathkit Color TV's

Control your Heathkit Color TV from your easy chair, turn it on and off, change VHF channels, volume, color and tint, all by sonic remote control. No cables cluttering the room . . . the handheld transmitter is all electronic, powered by a small 9 v. battery, housed in a small, smartly styled beige plastic case. The receiver contains an integrated circuit and a meter for adjustment ease. Installation is easy even in older Heathkit color TV's thanks to circuit board wiring harness construction. For greater TV enjoyment, order yours now.

kit GRA-681-6, 7 lbs., for Heathkit GR-681 Color TV's **$59.95***
kit GRA-295-6, 9 lbs., for Heathkit GR-295 & GR-25 TV's **$69.95***
kit GRA-227-6, 9 lbs., for Heathkit GR-227 & GR-180 TV's . . . **$69.95***

New Wireless
TV Remote Control
For GR-295, GR-227 & GR-180
$69^95*

New Wireless
TV Remote Control
For GR-681
$59^95*

NEW FREE 1969 CATALOG!

Now with more kits, more color. Fully describes these along with over 300 kits for stereo/hi-fi, color TV, electronic organs, electric guitar & amplifier, amateur radio, marine, educational, CB, home & hobby. Mail coupon or write Heath Company, Benton Harbor, Michigan 49022.

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Please send model (s)________________
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Address________________

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CIRCLE NO. 104 ON READER SERVICE CARD

SAVE WITH A SINGLE-TURN POT

By LOUIS CASO
Westinghouse Electric Corp.

A practical method of obtaining the fine adjustment that is usually associated with a 10-turn pot is to parallel a 1-turn linear pot with a common resistor (Fig. 1A).

The total resistance between A and B, R_T, is a function of the changing parallel resistance of R_P and R_L as the pot is rotated. This change will be rapid as the pot is rotated from fully clockwise (CW) position to about one-half way (0% to 50%). As the pot continues to move to the fully counterclockwise (CCW) position (50% to 100%) the change in R_T will then be relatively small.

To illustrate, if a 100,000-ohm single-turn pot and a 25,000-ohm resistor are available, wiring the two components as shown in Fig. 1B will give the characteristic described by the curve $R_P = 4R_L$ in Fig. 2.

In Fig. 1B the pot is in the fully CW position (0% rotation). R_T is 0. With the potentiometer half rotated (Fig. 1C) R_P is 50% of its rated value; thus

$$R_T = \frac{(0.50)\ (100k)\ (25k)}{(0.50)\ (100k) + 25k} = 16.7k \text{ ohms or } 67\%\ R_L.$$

In the fully CCW position (Fig. 1D),

$$R_T = \frac{(100k)\ (25k)}{100k + 25k} = 20k \text{ ohms or } 80\%\ R_L.$$

The change in R_T between half rotation and fully CW position is: $100 \times [(80/67)-1] = 20\%$.

This example is for a pot value four times the value of the resistor ($R_P = nR_L$). Without calculation, the characteristic over the entire range of rotation can be seen in Fig. 2. The values available in the parts box govern what curve should be used. If linearity is not a critical factor in a circuit, you can save a few dollars by using a single-turn rather than a multi-turn pot. ▲

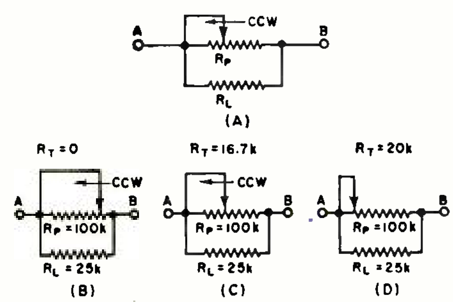

Fig. 1. Using a one-turn pot. Refer text for details on various positions.

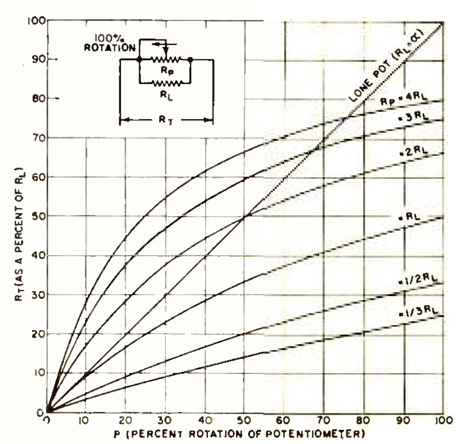

Fig. 2. Using the curve to determine values of R_T.

ELECTRONICS MARKET PLACE

COMMERCIAL RATE: For firms or individuals offering commercial products or services. 85¢ per word (including name and address). Minimum order $8.50. Payment must accompany copy except when ads are placed by accredited advertising agencies. Frequency discount: 5% for 6 months; 10% for 12 months paid in advance.

READER RATE: For individuals with a personal item to buy or sell. 50¢ per word (including name and address). No minimum! Payment must accompany copy.

GENERAL INFORMATION: First word in all ads set in bold caps at no extra charge. Additional words may be set in bold caps at 10¢ extra per word. All copy subject to publisher's approval. **Closing Date:** 1st of the 2nd preceding month (for example, March issue closes January 1st). **Send order and remittance to:** Hal Cymes, **ELECTRONICS WORLD,** One Park Avenue, New York, New York 10016.

FOR SALE

JUST starting in TV service? Write for free 32 page catalog of service order books, invoices, job tickets, phone message books, statements and file systems. Oelrich Publications, 6556 W. Higgins Rd., Chicago, Ill. 60656.

GOVERNMENT Surplus Receivers, Transmitters, Snooperscopes, Radios, Parts, Picture Catalog 25¢. Meshna, Nahant, Mass. 01908.

METERS Surplus, new, used, panel or portable. Send for list. Hanchett, Box 5577, Riverside, Calif. 92507.

CONVERT any television to sensitive big-screen oscilloscope. Only minor changes required. No electronic experience necessary. Illustrated plans, $2.00. Relco-A22, Box 10563, Houston, Texas 77018.

MUSIC LOVERS, CONTINUOUS, UNINTERRUPTED BACKGROUND MUSIC FROM YOUR FM RADIO, USING NEW INEXPENSIVE ADAPTER. FREE LITERATURE, ELECTRONICS, 11500-Z NW 7th AVE., MIAMI, FLORIDA 33168.

TREASURE HUNTERS! Prospectors! Relco's new instruments detect buried gold, silver, coins. Kits, assembled models, Transistorized. Weighs 3 pounds. $19.95 up. Free catalog. Relco-A22, Box 10839, Houston, Texas 77018.

A FEW COUNTERS FROM OUR LIST:

10 Hz to 510 MHz: USM-26 plus 525C	925.00
10 Hz to 510 MHz: H.P. 524B/525A/525C	995.00
10 Hz to 510 MHz: H.P. 524D/525A/525C	1095.00
2 MHz Preset & Eput Solid-state Inline	395.00
1 MHz Universal freq. & period, etc	295.00
WWV Receiver/Comparator	195.00

A FEW OSCILLOSCOPES FROM OUR LIST:

Tekt. #531 with plugin	415.00
Tekt. #535 with plugin	715.00
Tekt. #541 with plugin	730.00
Tekt. #545 with plugin	790.00
Tekt. #545A with plugin	915.00
Fairchild 2-trace Solid-State 5" scope	895.00
Dumont 2-Gun 100 microvolt sensitivity	295.00
Dumont 304A overhauled & calibrated	129.50
H.P. Sampling Scope plus Delay Line	425.00

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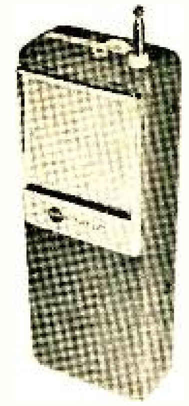

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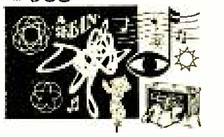

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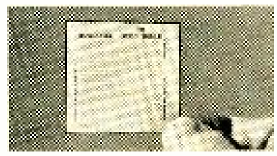

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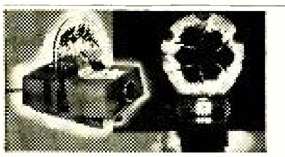

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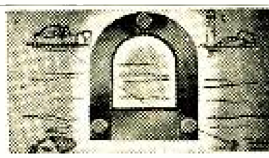

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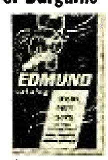

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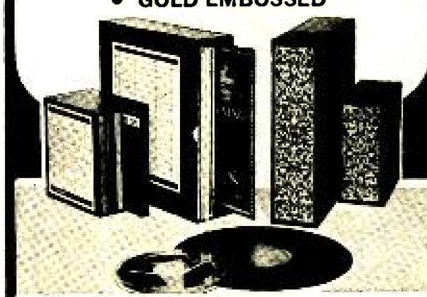

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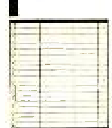

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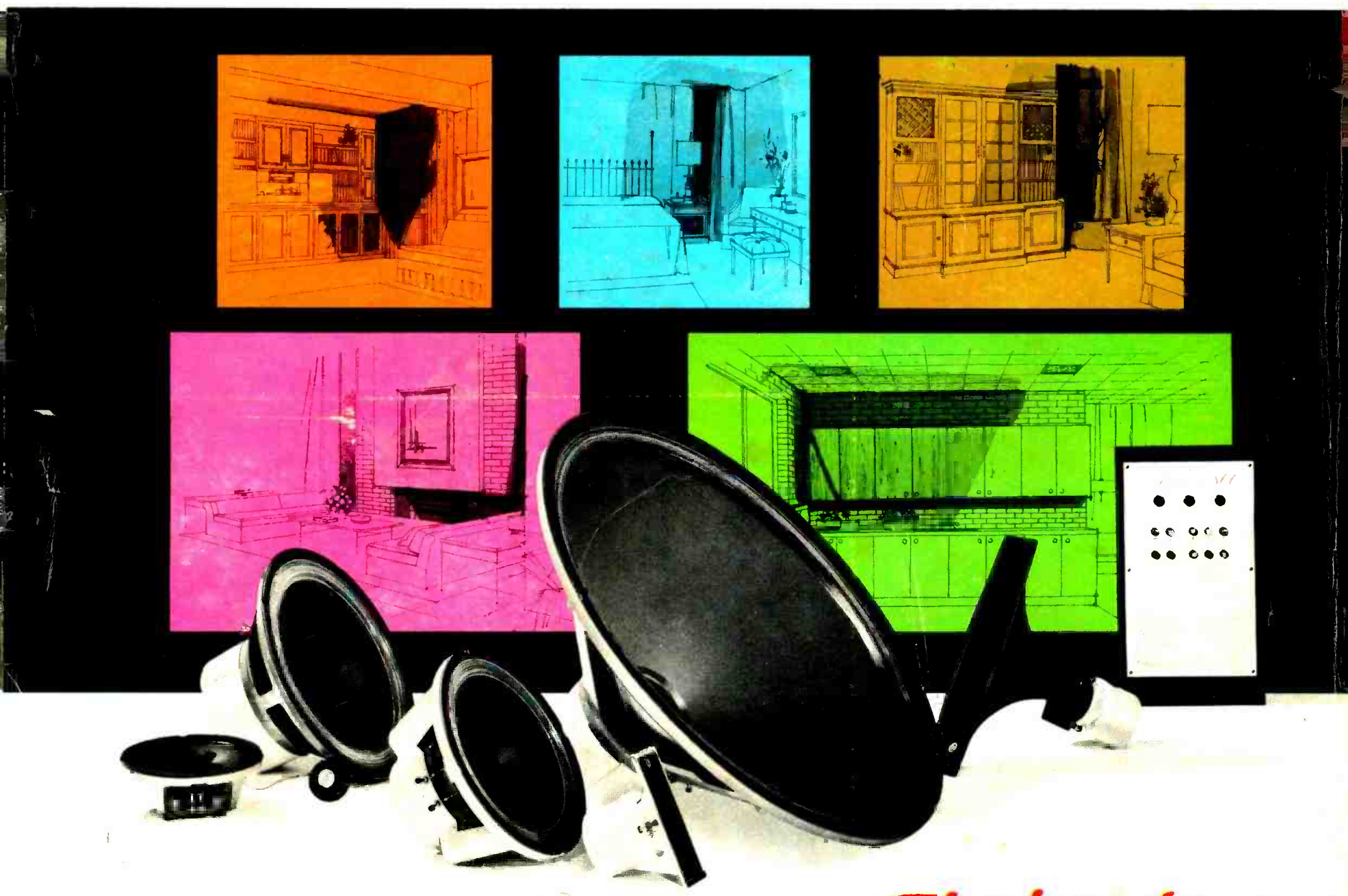

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