

THE FUN WAY TO UNDERSTAND ELECTRONICS

# Electronics Theory Handbook

02E16

1975 EDITION \$1.35

By the Editors of ELEMENTARY ELECTRONICS

## BASIC THEORY FOR EVERYONE

- Electricity • Magnetism
- Resistance • Capacitance
- Ohm's Law • Inductance
- Batteries • Resistive Pads
- Fuses • Breakers • Bridges
- Prefixes • Exponents
- Power Supplies • Filters
- AVC • Squelch • Crystals
- AM Radio • Single Sideband
- Gain • Op Amps • Frequency
- Oscillators • Microwaves •

Bonus Section on

## HOW CB RADIO WORKS

All about receivers, transmitters, AM and SSB, frequency synthesis, noise eliminators, antenna systems, clippers, compressors, installation tips, and much more!



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go relaxing . . . go adventure . . . but

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Almost half of successful TV servicemen have home study training and among them, it's NRI 2 to 1! A national survey\*, performed by an Independent research organization, also showed that the pros named NRI most often as a recommended school and as the first choice by far among those who had taken home study courses from *any* school.

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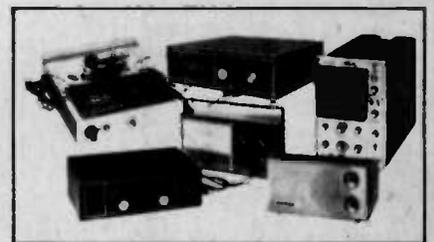
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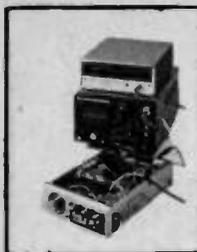


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# 1975 EDITION Electronics Theory Handbook

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You will learn how to build radios, using regular schematics; how to wire and solder punched metal chassis as well as the latest development of Printed Circuit chassis.

You will learn the basic principles of radio. You will construct, study and work with RF and AF amplifiers and oscillators, detectors, rectifiers, test equipment. You will learn and practice code, using the Progressive Code Oscillator. You will learn and practice trouble-shooting, using the Progressive Signal Tracer, Progressive Signal Injector, Progressive Dynamic Radio & Electronics Tester, Square Wave Generator and the accompanying instructional material.

You will receive training for the Novice, Technician and General Classes of F.C.C. Radio Amateur Licenses. You will build Receiver, Transmitter, Square Wave Generator, Code Oscillator, Signal Tracer and Signal Injector circuits, and learn how to operate them. You will receive an excellent background for television, Hi-Fi and Electronics.

Absolutely no previous knowledge of radio or science is required. The "Edu-Kit" is the product of many years of teaching and engineering experience. The "Edu-Kit" will provide you with a basic education in Electronics and Radio, worth many times the low price you pay. The Signal Tracer alone is worth more than the price of the kit.

### THE KIT FOR EVERYONE

You do not need the slightest background in radio or science. Whether you are interested in Radio & Electronics because you want an interesting hobby, a well paying business or a job with a future, you will find the "Edu-Kit" a worth-while investment. Many thousands of individuals of all

ages and backgrounds have successfully used the "Edu-Kit" in more than 79 countries of the world. The "Edu-Kit" has been carefully designed, step by step, so that you cannot make a mistake. The "Edu-Kit" allows you to teach yourself at your own rate. No Instructor is necessary.

### PROGRESSIVE TEACHING METHOD

The Progressive Radio "Edu-Kit" is the foremost educational radio kit in the world, and is universally accepted as the standard in the field of electronics training. The "Edu-Kit" uses the modern educational principle of "Learn by Doing." Therefore you construct, learn schematics, study theory, practice trouble shooting—all in a closely integrated program designed to provide an easily-learned, thorough and interesting background in radio.

You begin by examining the various radio parts of the "Edu-Kit." You then learn the function, theory and wiring of these parts. Then you build a simple radio. With this first set you will enjoy listening to regular broadcast stations, learn theory, practice testing, and trouble-shooting. Then you build a more advanced radio, learn more advanced theory and techniques. Gradually, in a progressive manner, and at your own rate, you will find yourself constructing more advanced multi-tube radio circuits, and doing work like a professional Radio Technician.

Included in the "Edu-Kit" course are Receiver, Transmitter, Code Oscillator, Signal Tracer, Square Wave Generator and Signal Injector Circuits. These are not unprofessional "breadboard" experiments, but genuine radio circuits, constructed by means of professional wiring and soldering on metal chassis, plus the new method of radio construction known as "Printed Circuitry." These circuits operate on your regular AC or DC house current.

### THE "EDU-KIT" IS COMPLETE

You will receive all parts and instructions necessary to build twenty different radio and electronics circuits, each guaranteed to operate. Our Kits contain tubes, tube sockets, variable, electrolytic, mica, ceramic and paper dielectric condensers, resistors, tie strips, hardware, wire, punched metal chassis, Instruction Manuals, hook-up wire, solder, selenium rectifiers, coils, volume controls and switches, etc.

In addition, you receive Printed Circuit materials, including Printed Circuit chassis, special tube sockets, hardware and instructions. You also receive a useful set of tools, a professional electric soldering iron, and a self-powered Dynamic Radio and Electronics Tester. The "Edu-Kit" also includes Code Instructions and the Progressive Code Oscillator, in addition to F.C.C. Radio Amateur License Instructions and the Progressive Code Oscillator, servicing wire, the Progressive Signal Tracer and the Progressive Signal Injector, a High Fidelity Guide and a Quiz Book. You receive Membership in Radio-TV Club, Free Consultation Service, Certificate of Merit and Discount Privileges. You receive all parts, tools, instructions, etc. Everything is yours to keep.

### FREE EXTRAS

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- SOLDERING IRON
- ELECTRONICS TESTER
- PLIERS-CUTTERS
- VALUABLE DISCOUNT CARD
- CERTIFICATE OF MERIT
- TESTER INSTRUCTION MANUAL
- HIGH FIDELITY GUIDE • QUIZZES
- TELEVISION BOOK • RADIO TROUBLE-SHOOTING BOOK
- MEMBERSHIP IN RADIO-TV CLUB: CONSULTATION SERVICE • FCC AMATEUR LICENSE TRAINING
- PRINTED CIRCUITRY

### SERVICING LESSONS

You will learn trouble-shooting and servicing in a progressive manner. You will practice repairs on the sets that you construct. You will learn symptoms and causes of trouble in home, portable and car radios. You will learn how to use the professional Signal Tracer, the unique Signal Injector and the dynamic Radio & Electronics Tester. While you are learning in this practical way, you will be able to do many a repair job for your friends and neighbors, and charge fees which will far exceed the price of the "Edu-Kit." Our Consultation Service will help you with any technical problems you may have.

### FROM OUR MAIL BAG

J. Stataitis, of 25 Poplar Pl., Waterbury, Conn., writes: "I have repaired several sets for my friends, and made money. The "Edu-Kit" paid for itself. I was ready to spend \$240 for a course, but I found your ad and sent for your kit."

Ben Valerio, P. O. Box 21, Magna, Utah: "The Edu-Kits are wonderful. Here I am sending you the questions and also the answers for them. I have been in Radio for the last seven years, but like to work with Radio Kits, and like to build Radio Testing Equipment. I enjoyed every minute I worked with the different kits; the Signal Tracer works fine. Also like to let you know that I feel proud of becoming a member of your Radio-TV Club."

Robert L. Shuff, 1534 Monroe Ave., Huntington, W. Va.: "Thought I would drop you a few lines to say that I received my Edu-Kit, and was really amazed that such a bargain can be had at such a low price. I have already started repairing radios and phonographs. My friends were really surprised to see me get into the swing of it so quickly. The Trouble-shooting Tester that comes with the Kit is really swell, and finds the trouble, if there is any to be found."

Progressive "Edu-Kits" Inc., 1189 Broadway, Dept. 503GM, Hewlett, N.Y. 11557

### PRINTED CIRCUITRY

At no increase in price, the "Edu-Kit" now includes Printed Circuitry. You build a Printed Circuit Signal Injector, a unique servicing instrument that can detect many Radio and TV troubles. This revolutionary new technique of radio construction is now becoming popular in commercial radio and TV sets.

A Printed Circuit is a special insulated chassis on which has been deposited a conducting material which takes the place of wiring. The various parts are merely plugged in and soldered to terminals.

Printed Circuitry is the basis of modern Automation Electronics. A knowledge of this subject is a necessity today for anyone interested in Electronics.

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CIRCLE 10 ON READER SERVICE COUPON

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### LED Digital Clock

Micronta's Digital Electronic Alarm Clock features a large, easy-to-see light emitting diode (LED) digital display, 24-hour

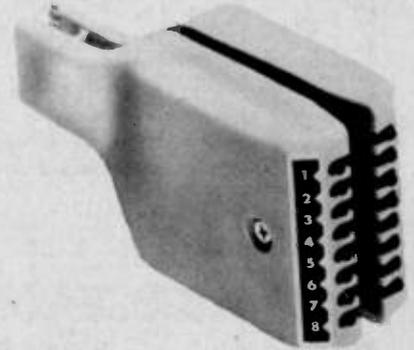


CIRCLE 11 ON READER SERVICE COUPON

alarm, and slim, modern styling for wall-mount or desk-top use. The large digital display shows the hour and minute, while a smaller digital display, which may be switched off if desired, reads seconds. The clock's accuracy is determined by the AC power line frequency which is automatically corrected over a period of days for precise time-keeping. The 24-hour alarm function eliminates the need for waiting 12 hours before resetting; immediately after the unique-sounding "beep" tone alarm goes off it can be reset to go off again 24 hours later, or the snooze button can be pressed for extra 10-minute naps. The Micronta Digital Electronic Alarm Clock is priced at \$39.95 and sold exclusively at more than 3,000 Radio Shack stores and Authorized Sales Centers in all 50 states, Canada and abroad.

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ELECTRONICS THEORY HANDBOOK 1975

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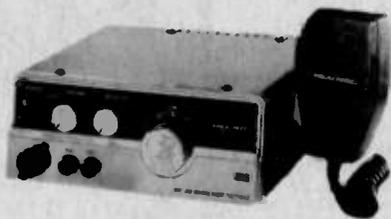
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## Hey, Look Me Over

powered, self-contained, pocket-size unit requires no calibrations or adjustments as it simultaneously displays static and dynamic logic states of DTL, TTL, HTL or CMOS DIP ICs. Now it is possible to watch signals work their way through counters, shift registers, timers, adders, flip flops, decoders, and even entire systems. Excellent for trouble-shooting and signal tracing, the Logic Monitor is considered faster than a scope and safer than a voltmeter. Simple to operate, the Continental Specialties Logic Monitor clips to any DIP IC up to 16 pins. Precision plastic guides and a flexible plastic web insure positive connections between non-corrosive nickel/silver contacts and the IC leads. Logic levels appear instantly on 16 large (.125" diameter) high intensity LEDs. Logic "1" (high voltage): LED ON. Logic "0" (low voltage or open circuit): LED OFF. Selling for \$84.95 each, the Continental Specialties Logic Monitor is available off-the-shelf from local distributors or from the manufacturer. Complete details are available by contacting Continental Specialties Corp., 44 Kendall Street, Box 1942, New Haven, CT 06509.

### Popeye Hailer

Just launched by Radio Shack is the new Realistic TRM-12 VHF/FM Marine Radiotelephone for dependable ship-to-shore and ship-to-ship communications on pleasure boats or small commercial vessels. The 12-channel two-way radio features switchable power output, 25 watts or 1 watt for efficient communications on the high seas or in the harbor. Comes equipped with crystals for channels 6, 16, and 26, plus two National Weather Service crystals for instant push-button weather information. A built-in automatic noise limiter reduces ignition interference and an adjustable squelch control silences receiver between calls.



CIRCLE 13 ON READER SERVICE COUPON

Receiver section is dual-conversion with ceramic filters. Sensitivity is given as 0.5  $\mu$ V for 20 dB quieting; selectivity, -60 dB at  $\pm 15$  kHz. FCC type accepted, Part 83. Includes microphone and built-in speaker plus rear panel jacks for second mike and external speaker. Mounting bracket is designed to hold securely in rough weather, yet releases quickly for "anti-theft" removal. The Realistic TRM-12 VHF/FM Marine Radiotelephone is priced at \$299.95. Additional crystals

are available for \$15.95 a pair. Realistic communications equipment, receivers, citizens band radios, antennas and accessories are available from more than 3,000 Radio Shack stores and Authorized Sales Centers in all 50 states and Canada.

### Digital Alarm Clock Radio Kit

The Heathkit GR-1075 AM/FM Digital Electronic Alarm Clock Radio features an all-electronic digital clock that reads out the time in bright orange digits that dim automatically in darkened rooms. A 24-hour alarm cycle feature means you can go to bed at 9 and set the alarm for 10 without being awakened in an hour.

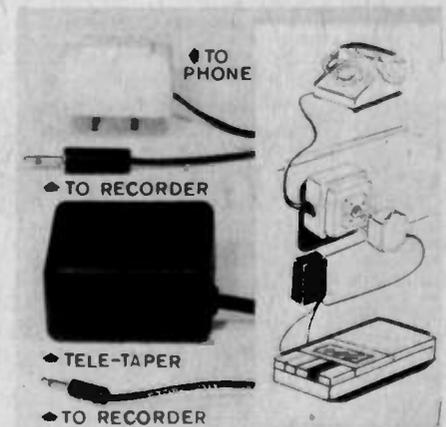


CIRCLE 1 ON READER SERVICE COUPON

Alarm can be set to go off with a controlled-volume electronic "beep," or with music from your favorite FM or AM radio station. A 7-minute snooze cycle is repeatable up to an hour. Another unique feature is an internal stand-by battery supply (batteries not supplied) that takes over in the event of a power failure. Traditional Heathkit quality has been incorporated into the sophisticated solid-state circuitry—the entire unit (including clock) contains four ICs, 41 transistors, and 35 diodes. The GR-1075 kit sells for \$129.95 mail order, F.O.B. factory. For more information, write Heath Company, Benton Harbor, MI 49022.

### Automatic Telephone Recordings

Used with any telephone and tape recorder, the TELE-TAPER starts taping when the receiver is lifted off the hook, steps when the receiver is replaced. Just set your recorder on "record" and the TELE-TAPER makes your taped record of



# LITERATURE LIBRARY

101. Kit builder? Like weird products? *EICO's* 1975 catalog takes care of both breeds of buyers at prices you will like.
102. *International Crystal* has a free catalog for experimenters (crystals, PC boards, transistor RF mixers & amps, and other comm. products).
103. See brochures on *Regency's* 1975 line-up of CB transceivers & scanner receivers (for police, fire, weather, & other public service emergency broadcasts).
104. *Dynascan's* new B & K catalog features test equipment for industrial labs, schools, and TV servicing.
105. Before you build from scratch, check the *Fair Radio Sales* latest catalog for surplus gear.
106. Get *Antenna Specialists'* cat. of latest CB and VHF/UHF innovations: base & mobile antennas, test equipment (wattmeters, etc.), accessories.
107. Want a deluxe CB base station? Then get the specs on *Tram's* super CB rigs.
108. Compact is the word for *Xcelite's* 9 different sets of midjet screwdrivers and nut-drivers with "piggyback" handle to increase length and torque. A handy show case serves as a bench stand also.
115. *Trigger Electronics* has a complete catalog of equipment for those in electronics. Included are kits, parts, ham gear, CB, hi fi and recording equipment.
111. *Midland's* line of base & mobile CB equipment, marine transceivers & accessories, and scanner receivers are illustrated in a new full-color 16-page brochure.
112. The *EDI (Electronic Distributors, Inc.)* catalog is updated 5 times a year. It has an index of manufacturers literally from A to X (ADC to Xcelite). Whether you want to spend 29 cents for a pilot-light socket or \$699.95 for a stereo AM/FM receiver, you'll find it here.
113. Get all the facts on *Progressive Edu-Kits* Home Radio Course. Build 20 radios and electronic circuits; parts, tools, and instructions included.
116. Get the *HUSTLER* brochure illustrating their complete line of CB and monitor radio antennas.
117. *Teaberry's* new 6-page folder presents their 6 models of CB transceivers (base and mobile): 1 transceiver for marine-use, and 2 scanner models (the innovative "Crime Fighter" receiver and a pocket-size scanner).
118. CBers, *GC Electronic's* 8-page catalog offers the latest in CB accessories. There are base and mobile mikes; phone plugs; adaptors and connectors; antenna switchers and matchers; TV1 filters; automotive noise suppressor kits; SWR Power and FS meters, etc.
152. Send for the new, free descriptive bulletin from *Finney Co.* It features the Finco line of VOM multi-testers (and accessories) for electronics hobbyists and service technicians.
128. A new free catalog is available from *McGee Radio*. It contains electronic product bargains.

119. *Browning's* mobiles and its famous Golden Eagle base station, are illustrated in detail in the new 1975 catalog. It has full-color photos and specification data on Golden Eagle, LTD and SST models, and on "Brownie," a dramatic new mini-mobile.
120. *Edmund Scientific's* new catalog contains over 4500 products that embrace many sciences and fields.
121. *Cornell Electronics'* "Imperial Thrift Tag Sale" Catalog features TV and radio tubes. You can also find almost anything in electronics.
122. *Radio Shack's* 1975 catalog colorfully illustrates their complete range of kit and wired products for electronics enthusiasts—CB, ham, SWL, hi-fi, experimenter kits, batteries, tools, tubes, wire, cable, etc.
123. Get *Lafayette Radio's* "new look" 1975 catalog with 260 pages of complete electronics equipment. It has larger pictures and easy-to-read type. Over 18,000 items cover hi-fi, CB, ham rigs, accessories, test equipment and tools.
124. *Mosley Electronics* reports that by popular demand the Model A-311 3-element CB beam antenna is being reintroduced. Send for the brochure.
125. *RCA Experimenter's Kits* for hobbyists, hams, technicians and students are the answer for successful and enjoyable projects.
127. There are *Avanti* antennas (mobile & base) for CB and scanner receivers, fully described and illustrated in a new 16-page full-color catalog.
129. *Semiconductor Supermart* is a new 1975 catalog listing project builders' parts, popular CB gear, and test equipment. It features semi-conductors—all from *Circuit Specialists*.
130. There are over 350 kits described in *Heath's* new catalog. Virtually every do-it-yourself interest is included—TV, radios, stereo & 4-channel, hi-fi, etc.
131. *E. F. Johnson's* new full-color catalog for CB transceivers and accessories is now available. Send for a free copy. They also have a free brochure on their line of scanner receivers.

150. Send for the free *NRI/McGraw Hill* 100-page color catalog detailing over 15 electronics courses. Courses cover TV-audio servicing, industrial and digital computer electronics, CB communications servicing, among others. G.I. Bill approved, courses are sold by mail.
132. If you want courses in assembling your own TV kits, *National Schools* has 10 from which to choose. There is a plan for GIs.
133. Get the new free catalog from *Howard W. Sams*. It describes 100's of books for hobbyists and technicians—books on projects, basic electronics and related subjects.
134. *Sprague Products* has L.E.D. readouts for those who want to build electronic clocks, calculators, etc. Parts lists and helpful schematics are included.
135. The latest edition of *Tab Books'* catalog has an extensive listing of TV, radio and general servicing manuals.
137. *Pace* communications equipment covers 2-way radios for business, industrial and CB operations. Marine radiotelephones and scanning receivers are also in this 18-p. book.
138. *Shakespeare's* new pocket-size catalog lists and describes their full line of fiberglass CB antennas, mounts and accessories offered in 1975.
144. For a packetful of material, send for *SBE's* material on UHF and VHF scanners, CB mobile transceivers, walkie-talkies, slow-scan TV systems, marine-radios, two-way radios, and accessories.
145. For CBers from *Hy-Gain Electronics Corp.* there is a 50-page, 4-color catalog (base, mobile and marine transceivers, antennas, and accessories). Colorful literature illustrating two models of monitor-scanners is also available.
147. *Telex's* 4-page, 2-color folder illustrates their new line of boom microphone head-sets for CBers and hams, as well as their line of communications headphones.
142. *Royce Electronics'* new full-color catalog updates information on their CB transceivers (base, mobile, handheld). It also describes new product lines—CB antennas and a VHF marine radiotelephone.

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### New "Big Momma"

A new mirror-mount CB antenna, model M-419 "Big Momma," with all the power, reach, and rugged construction of her famous twin sisters has been introduced by Antenna Specialists. The new antenna, especially designed for the high vibration environment of heavy vehicles such as long-haul trucks and motor homes, features the popular "Big Momma" heavy duty loading coil and 17-7 PH stainless steel whip securely affixed to a solid aluminum mast with a cast aluminum, vise-like mounting bracket. The bracket may be pivoted for fastening to either the vertical or horizontal hollywood mirror frame, and holds securely at highway speeds. The manufacturer's suggested list price is \$29.95. Antenna Specialists is also making available the mirror mount hardware only, model M-418, adaptable to any existing antenna with  $\frac{3}{8}$ -in., 24 thread base. It has an SO-239 connector for standard coax cable fittings. For further specifications contact The Antenna Specialists Company, 12435 Euclid Avenue, Cleveland, OH 44106.

CIRCLE 14 ON READER SERVICE COUPON

### Logic Memory Probe

A must for every field serviceman for fast, accurate testing of logic levels in any DTL or TTL integrated circuit system such as calculators, numerical control systems computers, or telephone systems. EICO has just released the Model



CIRCLE 15 ON READER SERVICE COUPON

DLP-6 Digital Logic Memory Probe which provides detection capabilities for pulse durations as short as 50 nano-seconds indicating the logic state of any DTL or TTL IC circuit. Indicator system consists of three light emitting diodes (LEDs). Bottom LED lights green for logic 1, center LED lights red for logic 0, top LED lights yellow to indicate positive- or negative-going transition. Remains in "ON" state for 200 ns regardless of pulse duration. Memory switch causes stretch LED to remain on permanently after positive or negative pulse occurs. Available in both easy-to-build kit form (\$19.95) or factory assembled (\$29.95). Write to EICO Electronics Instrument Co., Inc., 283 Malta Street, Brooklyn, NY 11207.

### Foam Speaker Grille Kits

Do-it-Yourself kits featuring sculptured-foam speaker grilles for replacement of conventional grille cloth on stereo and hi-fi speakers have been developed by Republic Systems Corp., 9160 S. Green Street, Chicago, IL 60620. In addition to providing a modern "sculptured" look to speakers, the new foam grilles also make stereo and hi-fi systems sound better.

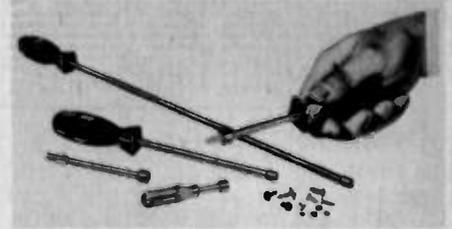


Unlike grille cloth, sculptured-foam does not distort sound, even in higher frequency ranges. The flexible urethane foam is "acoustically transparent," permitting sound to pass through as though there were no grille at all, for purest reproduction. Each kit contains sculptured foam grille self-sticking attachment material and instructions for fast, easy installation. Available in 15 x 8-in. and 14 x 24-in. sizes, the foam grille can be easily cut with household shears to fit smaller speakers. The foam grilles are a rich black color which blends with any style speaker. Grilles can also be sprayed with latex paint for any color desired. Prices range from \$7 to \$14.50.

### Magnetic Nutdrivers

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able from Xcelite. The magnetic line also includes two sizes of interchangeable shanks which fit all their Series 99 handles, both regular and ratchet types. The permanent alnico magnet in the insulated socket holds fasteners firmly for easy, one-hand driving or retrieving upon removal—cuts lost time, motion or fumbling in close quarters. Styles range



CIRCLE 17 ON READER SERVICE COUPON

from a  $3\frac{1}{2}$ -in. overall midget pocket clip to a super long 20 $\frac{3}{4}$ -in. driver, all in  $\frac{1}{4}$ -in. and  $\frac{5}{16}$ -in. hex openings. Intermediate lengths are 7-in. and 10-in. The comfort-contoured plastic handles, color-coded red or amber for easy hex opening identification, are designed for maximum torque with minimum pressure. Write to Xcelite for their catalog. They're at Apex, NC 27502.

### Technician's VOM

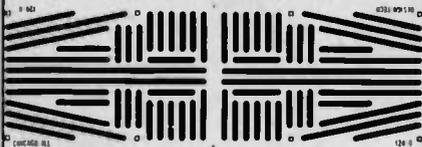
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CIRCLE 16 ON READER SERVICE COUPON

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Got a question or a problem with a project—ask Hank! Please remember that Hank's column is limited to answering specific electronic project questions that you send to him. Personal replies cannot be made. Sorry, he isn't offering a circuit design service. Write to:

**Hank Scott, Workshop Editor  
ELECTRONICS THEORY HANDBOOK  
229 Park Avenue South  
New York, NY 10003**

### Wants to Know

I was wondering if there's any way to increase the transmitting range of a 100 milliwatt walkie-talkie without adding a power amplifier.

—W. M., Clinton, NJ

Not much. A few tricks I use are: speak clearly into the mike at an angle of about 45°; be sure the antenna is fully extended and vertical; transmit from open spaces; keep away from buildings and trees; get high up in hilly country; use the top of a car as a ground plane; and be sure the batteries are fresh.

### Go Somewhere Else (Please)

Where in Canada can I purchase the Malory Sonalert? None of the shops in my area have ever heard of this audible warning device.

—R. D., Long Sault, Ont.

Write to the Editor of *Electron* magazine and maybe he can help you. *Electron* is sold on newsstands throughout Canada. It's a good magazine—read it.

### It Takes Some Effort

Hank, I've decided I would like to go into hobby radio. Since the FCC does not permit the use of CB radio as a hobby, what type of radio would you suggest I get? I thought about ham radio for awhile, but I just can't learn the Morse Code. Any ideas?

—T. T., Putney, KY

I had the same trouble. In fact, I couldn't get past 5 WPM until I really pushed myself. I have helped youngsters get up to 13 WPM and never met one who couldn't do it when he tried real hard. Pick up a taped Morse Code course from your local ham dealer. They come in cassette form now.

### Start Today at No Cost

Right now I am into CB and have tried my best to follow FCC rules, but I am really disgusted with the whole mess. I want to get into SWL but don't know much about it. My question is what type of rig should I start with and what type of investment would this mean?

—M. C., Fayetteville, AR

Keep it cheap and sweet. Spend a few evenings listening to the broadcast band radio especially after the locals go off the air. A whole new world appears! The clear channel stations bull right through from all over the map. Low power stations

squeak in, but delicate tuning and patient listening are required. You will get more facts and info when you pick up a copy of *COMMUNICATIONS WORLD* at the newsstand or write direct to this magazine for CW and enclose \$1.35 in check form.

### DXing the BCB

Lately I have gotten into medium-wave DXing. I logged 31 stations in the last week. I am wondering if AM stations give QSLs? If they do, how do I get them?

—K. A., Columbus, OH

Practically the same way you get them from shortwave stations. Send your listening report to the station in question. Keep it brief, but describe in detail what you heard during a 15-minute period. Give the announcer's name during a newscast or guest names on a talk show. Ask for a verification. If you get it, good. If not, ho-hum.

### What's Black Magic

How can I convert an AM table radio into a 13-30 MHz receiver?

—B. K., Howick, Que.

The table AM radio is a masterpiece of economic engineering that produces reasonable reception performance from a minimum of parts, hence it's cheap. No tuned RF stage is used. The antenna system is usually a ferrite rod with a tuned coil at one end designed for the AM broadcast band. Monkey with the radio and this engineering masterpiece is not worth the parts put in it. 30 MHz, even 13 MHz, requires special circuitry—tuned RF, possibly double conversion, narrow band IFs, antenna tuning, and lots more. Do yourself a favor, pick up a second-hand Hallicrafter receiver and you'll be better off for it.

### Beep Beep

I was wondering if you could design an amplifier that could be used to boost the output of my walkie-talkie to the legal limit of 5 watts? I'd be willing to pay you \$5 for the service. It should be fairly easy to build, and use easily obtainable parts.

—K. H., Carroll, NE

I can't believe it! Each issue we tell our readers we cannot provide a design service and each issue a host of readers ask the same impossible questions. Also, don't enclose a return envelope or postage—I can't answer the mail. Come on, fellows, give me a break.

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### Echo Nut . . . Echo Nut

I just bought an AM/FM 8-track car stereo and installed two speakers up front. I plan to install two speakers flush in the rear. To make it sound more "echoey," I want to add a simple reverberation system for the rear speakers. Would a spring delay unit work good for this and what extra do I need to power and drive the reverb unit? Where can I find all of these parts? What is your opinion of this "echoey" sound system idea?

—E. S. V., Grosse Pte. Wds., MI

I think you flipped your carburetor. Why go to the expense of adding quality audio reception and playback, then go ahead and destroy it. If you like the "echoey" sound, ride through a tunnel with the windows open!

### Has an Antenna Farm

I have an antenna for all my radios (CB, PB, Air, VHF, SW) except my AM BCB. My radio does not have a jack for an external antenna, so I was wondering if I still could put one on. Is it possible?

—M. L., Auburn, NY

I put one on last night, but let's talk about your AM radio's antenna troubles. There are many gimmicks you can employ to attach or couple an antenna to the receiver in question, but face it—it is a cheap rig designed to be played in the kitchen. Why

go through a lot of fuss over a unit that wouldn't perform any better with a good antenna.

### Some Friend!

A friend of mine was telling me that the police now have a receiver that can pick up conversations in the car ahead of them if the radio in that car is turned on. Have you heard of such a receiver as this? If so, how does it work?

—M. T., Calgary, Canada

Don't believe everything you hear from your friends. The police can hear what you say only if they plant a bug in your car. Now, why would the police do that to a nice kid like you?

### His Cycles Hertz

I'm doing some loudspeaker testing. Amateur stuff, you know, and I find that my signal generator does some strange things at low frequencies. I put about 50 cycles (Hertz to you) in and raise the level. Well, as the sound gets louder, the frequency jumps to 100 cycles above a certain sound level input. My oscilloscope says nothing is wrong with the generator, but my hearing says yes. What am I to believe—my eyes or my ears?

—I.N., Los Angeles, CA

Your ears, because the loudspeaker is doubling the frequency after the level gets too high for the cone to faithfully follow

the 50 Hertz (cycles to you) sweep. This is loudspeaker distortion. You'll find this distortion decreases as the frequency increases. Hey, fellah, you're beginning to get into what's wrong with cheap audio systems. Now you'll appreciate the better loudspeakers.

### He Wants to Practice

Enclosed you will find a schematic of an electrical stimulator used in acupuncture which I took to a radio parts store for the parts listed. They supplied all the parts listed except the wire coils, and they said the coils would have to be hand wound. What am I to do?

—M.G., Jacksonville, FL

I'm not publishing the schematic because I don't want to lose any readers. As for your patients, Doc, don't build the gadget and you won't lose any, either.

### Needs Lots of Work

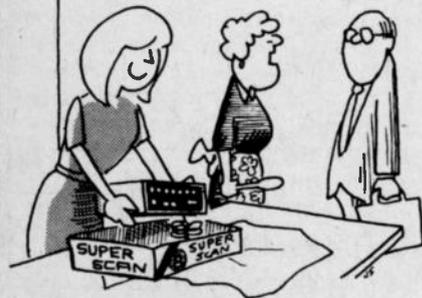
Hank, what is the best kind of home study course to take? I know very little about electronics and want to go all the way.

—T.T., Newton Falls, OH

The best course to take is the one you will complete. Too many youngsters begin home study courses and quit after a few lessons when they discover self-education takes work, dedication to their goal, continuous effort, and drive. Get started and stick to it. You'll thank me in 15 years—you said all the way!

## MONITOR MADNESS

by Jack Schmidt



"Her boyfriend is in the fire company. Now she will know exactly where he is at night . . ."



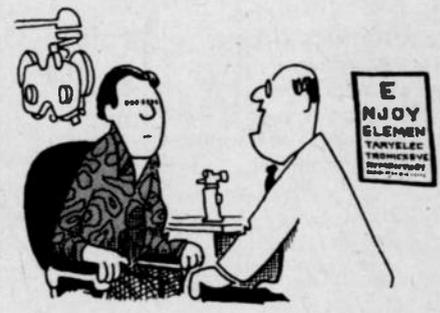
"Oh, is Dad furious. His police monitor locked onto Mom's hair dryer."



"If it's out there, Herbert can hear it!"

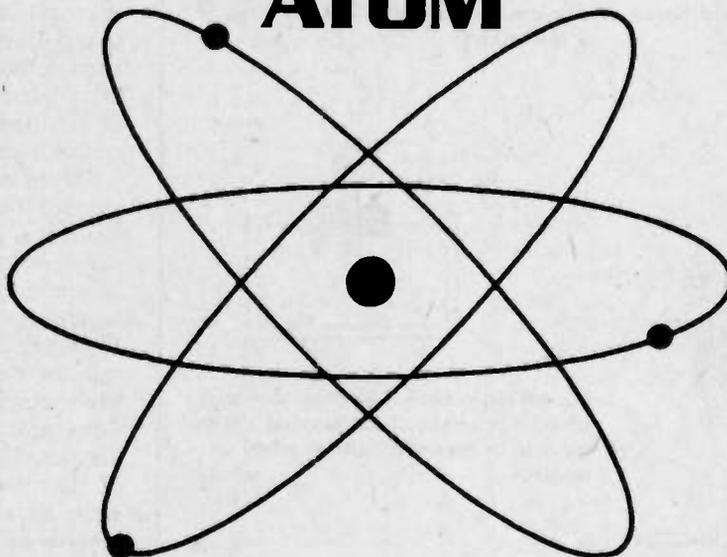


"Notice that no matter where we park, you can hear clearly every police and fire call in the county."



"I suggest you try listening to your scanner—not watch it!"

# ELECTRICITY, MAGNETISM, AND THE ATOM



□ ONE OF THE MOST thought-provoking discoveries of modern physics is the fact that matter and energy are interchangeable. Centuries of scientific headscratching about the nature of matter, the mystery of fire, and the once-terrifying crack of lightning have all come to focus on the smallest particle that is the building block of any given substance: the atom. An atom is necessarily matter and yet this atom of matter can undergo nuclear fission and release quantities of energy that are beyond the imagination. In the atom lies the secret of all phenomena. One theory of the universe, hypothesized by Georges Lemaitre, even regards the present universe as resulting from the radioactive disintegration of one primeval atom!

By the beginning of the 19th century, the atomic theory of matter—which actually originated in 5th century Greece when the atom was named—was firmly established. It was due primarily to the efforts of 17th century scientists who—actually working in the tradition of medieval alchemy—sought the prime constituent of all matter. Mainly through the work of John Dalton, whose investigations as to how various elements combine to form chemical compounds, it came to be regarded that an

atom was the indivisible and indestructible unit of matter.

This viable and working view of the indestructible atom served science until 1897 when the atom itself was found to be destructible! To anyone concerned with electricity or electronics, the year 1897 is a memorable one: it was the year J. J. Thomson, the English physicist, identified and experimentally revealed the existence of the first subatomic particle—the *electron*!

#### **The First "Electronic" Experiment.**

We blithely speak of electricity as the flow of electrons yet, often, we are little aware of the great body of research that went into elucidating this fundamental of basic electricity. In fact, before the discovery of the electron, convention held that the flow of electric current was in the direction that a positive charge moved. This convention of *positive current*, being the flow of positive charges and opposite to the direction of electron flow, is still found to be useful in circuit analysis and is used even today.

Thomson's experiment established that a particle much lighter than the lightest atom did indeed exist. The electron, as it was named, was the first subatomic particle to be defined.

The experiment was conducted utiliz-

ing a rudimentary version of a cathode ray tube—the modern version of which is in almost every home today in the form of the television picture tube. Before Thomson's experiment, it was discovered that when electric current was passed through a gas in a discharge tube, a beam of unknown nature traveled through the tube from the negative to positive terminal (opposite to the direction conventionally held as the direction of the flow of current).

This "cathode ray" beam also traveled in a straight line and was deflected by electric or magnetic forces applied perpendicular to the beam. What Thompson did was to use these facts to determine for one of the mysterious particles comprising the beam of cathode rays the relationship of its mass,  $m$ , to its electric charge,  $e$ . By deflecting the beam with a known electric force (Fig. 1) and then measuring what magnetic force applied in the opposite direction would bring the beam back to its original undeflected position, he could determine the relationship of  $e$  to  $m$ . He established a definite value for  $e/m$  and thereby "discovered" the electron which, as we now know, is 1,837 times smaller in mass than the lightest atom, the hydrogen atom. It also carries the smallest

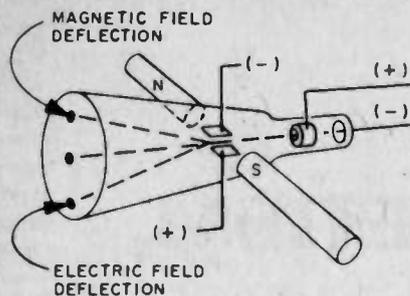


Fig. 1. Electron beam, like that in a TV picture tube (CRT), can be deflected magnetically or by an electric field. Force needed "measured" the electron.

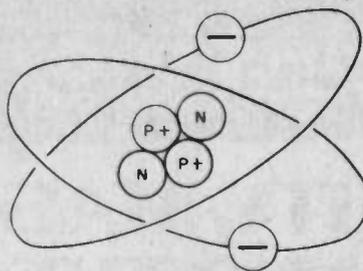


Fig. 2. Charge of each electron balances that of a proton. Other particles affect atomic mass but can be ignored in study of electronics.

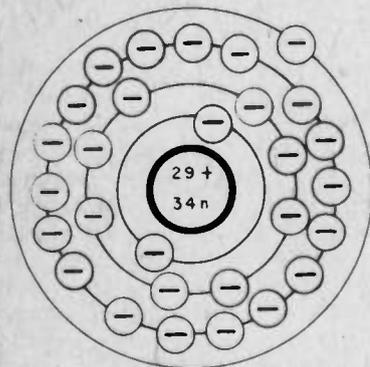


Fig. 3. The number of electrons to each ring are limited—2 in first; 8 in second; 18 for the third; and a total of 32 in fourth orbital ring.

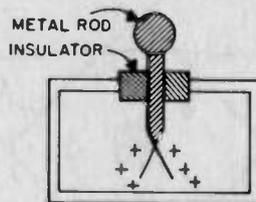


Fig. 4. Electroscope is a simple device to indicate electrical charges that are too weak to be measured with standard meters.

charge that occurs in nature; every electric charge is actually an integral multiple of the charge of the electron.

**From Minus to Plus.** With the discovery of the electron, it was still over a dozen years into the 20th century before a graphic conception of the atom evolved. Since the atom is electrically neutral and electrons are negatively charged, the existence of positively charged particles was a necessity, and the existence of a *proton* was postulated. Eventually the nuclear model of the atom was evolved. Each atom was conceived to resemble a solar system in miniature. The nucleus—positively charged—is surrounded by a number of electrons revolving around it; the charges balance and the atom is electrically neutral (Fig. 2). Further research in the 20th century has gone on to reveal more elementary particles than you can shake a stick at: neutrons, positrons, neutrinos, mesons, and more. The number continues to grow and yet the ultimate nature of matter remains a riddle. But, in a discussion of basic electricity, only the electron and proton need concern us.

**Electrons in Orbit.** An atom of matter has a number of electrons orbiting around its nucleus. A hydrogen atom, for example, has a single electron; carbon on the other hand has 6. These electrons are arranged in rings or shells around the central nucleus—each ring having a definite maximum capacity of electrons which it can retain. For example, in the copper atom shown in Fig. 3 the maximum number of electrons that can exist in the first ring (the ring nearest the nucleus) is two. The next ring can have a maximum of eight, the third ring a maximum of 18, and the fourth ring a maximum of 32. However, the outer ring or shell of electrons for any atom cannot exceed eight electrons. However, heavier atoms may have more than four rings.

**The Outer Orbit.** The ring of electrons furthest from the atom's nucleus is known as the *valence ring* and the electrons orbiting in this rings are known as *valence electrons*. These valence electrons, being further from the nucleus, are not held as tightly in their orbits as electrons in the inner rings and can therefore be fairly easily dislodged by

an external force such as heat, light, friction, and electrical potential. The fewer electrons in the valence ring of an atom, the less these electrons are bound to the central nucleus. As an example, the copper atom has only one electron in its valence ring. Consequently, it can be easily removed by the application of only the slightest amount of external energy. Ordinary room temperature is sufficient to dislodge large numbers of electrons from copper atoms; these electrons circulate about as free electrons. It is because of these large numbers of free electrons that copper is such a good electrical conductor. There could be no electrical or electronics industry as we know it today if it were not for the fact that electrons can fairly easily escape, or be stripped from the valence ring of certain elements.

**Electronic Charges.** If an electron is stripped from an atom, the atom will assume a positive charge because the number of positively charged protons in its nucleus now exceeds the number of negatively charged orbiting electrons. If, on the other hand, the atom should gain an electron, it will become negatively charged as the number of electrons now exceeds the protons in its nucleus. The atom with the deficiency of electrons is known as a *positive ion*, while an atom with a surplus of electrons is known as a *negative ion*.

Presence of an electrical charge on a body can be illustrated by use of an electroscope (Fig. 4). Two leaves of aluminum or gold foil hang from a metal rod inside a glass case so they're free from air disturbances. When the metal rod is touched by a charged body, the leaves acquire static electricity of the same polarity and, since like charges repel, they stand apart. The greater the charge, the further apart the leaves

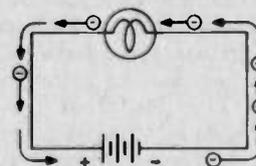


Fig. 5. Electron flow in any circuit is from negative to positive.

spread.

**Electron Flow.** When an electrical conductor is placed between these two oppositely charged bodies, free electrons are attracted by the positive body—free electrons will move through the wire. This movement of free electrons will continue only until the excess of electrons is equally divided between the two bodies. Under these conditions, the charges on both bodies will be equal and the electron flow will end.

In Fig. 5 are a battery, lamp, and

connecting leads between the battery and lamp. In this instance, the battery serves as an electric charge pump—free electrons continually developed at its negative terminal by chemical action flow through the connecting leads and lamp back to the positive terminal of the battery by the attraction of oppositely charged bodies. The battery, connecting leads, and lamp form an electrical circuit which must be complete before the free electrons can flow from the battery's negative terminal to its positive terminal via the lamp. Thus, the battery serves as a source of potential difference or voltage by continually supplying a surplus of electrons at its negative terminal. Summing up, we can say a flow of electric current consists of the movement of electrons between two oppositely charged bodies.

We cannot progress very far into the study of electricity without first becoming familiar with the basic properties of electrical circuits. Just as we define distance in feet and inches, so do we define electrical properties in specific terms and units.

**Potential.** Earlier, we saw that an electric charge difference has to exist between the ends of an electrical conductor in order to cause a flow of free electrons through the conductor. This flow of electrons constitutes the electric current. The electric charge difference, or potential difference, exerts a force on the flow of free electrons, forcing them through the conductor. This electric force or pressure is referred to as electromotive force, abbreviated EMF.

The greater the charge or potential difference, the greater will be the movement of free electrons (current) through the conductor as there will be more "push and pull" on the free electrons. The symbol used to designate electrical potential is the letter *E* which stands for electromotive force. The quantity of EMF is measured by a unit called the volt. Hence, the common name most often used in place of EMF is *voltage*.

**Current Intensity.** We have learned that an electric current consists of a flow of charge carriers (generally free electrons) between two points of different electrical potential. The rate of flow of these charges determines the intensity or strength of this current flow. Current strength is expressed in units known as *amperes*. One ampere of current flows in a circuit when 6,240,000,000,000,000 electrons flow out of a negative terminal, through a conductor, and back into a positive terminal in one second. The symbol for the ampere is the letter *I* which stands for intensity.

**Resistance.** The flow of electric cur-

rent through a conductor is caused by the movement of free electrons present in the atoms of the conductor. A bit of thought then indicates that the greater the number of free electrons present in the atoms of a particular conductor, the greater will be its electrical conductivity. Gold, silver, and copper rank as excellent electrical conductors, as their atoms readily release free electrons. On the other hand, the atoms of such elements as sulphur have almost no free electrons available and they are thus very poor electrical conductors. Such materials are known as electrical insulators. Between these extremes lie elements such as carbon whose atoms have a moderate number of free electrons available and thus are moderately good electrical conductors.

Even the best electrical conductors offer some opposition to the passage of free electrons. This opposition is called resistance. You might consider electrical resistance similar to mechanical friction. As in the case of mechanical friction, electrical resistance generates heat. When current flows through a resistance, heat is generated; the greater the current flow, the greater the heat. Also, for a given current flow, the greater the resistance, the greater the heat produced.

Electrical resistance can be both beneficial and undesirable. Toasters, electric irons, etc. all make use of the heat generated by current flowing through wire coils. Resistance is also often intentionally added to an electrical circuit to limit the flow of current. This type of resistance is generally lumped together in a single unit known as a resistor.

There are also instances where resistance is undesirable. Excessive resistance in the connecting leads of an electrical circuit can cause both heating and electrical loss. The heating, if sufficient, can cause a fire hazard, particularly in house wiring, and the circuit losses are a waste of electrical power.

Electrical resistance is expressed by a unit known as the *ohm*, indicated by the letter *R*. An electrical conductor has a resistance of one ohm when an applied EMF of one volt causes a current of one ampere to flow through it.

**Resistance Factors.** There are other factors beside the composition of the material that determine its resistance. For example, temperature has an effect on the resistance of a conductor. As the temperature of copper increases, for example, its resistance increases. The increase in temperature causes the electrons in the outer ring of the atom to resist release to the free electron state. This increase in resistance is known as a

*positive temperature coefficient*. Not all conductors show this increase in resistance with an increase in temperature; their resistance decreases with an increase in temperature. Such materials are said to have a *negative temperature coefficient*. Certain metallic alloys have been developed which exhibit a *zero temperature coefficient*: their resistance does not change with changes in temperature.

As you might suspect, the length of a conductor has an effect upon its resistance. Doubling the length of a conductor will double its resistance. By the same token, halving the length of a conductor will cut its resistance in half. Just remember that the resistance of a conductor is *directly proportional to its length*.

The cross-sectional area of a conductor also determines its resistance. As you double the cross-section of a conductor, you halve its resistance; halving its cross-section doubles its resistance. Here again, the "why" of this is pretty easy to see: there are more current carrying electrons available in a large cross-section conductor than in a small cross-section conductor of the same length. Therefore, the resistance of a conductor is *inversely proportional to its cross-sectional area*.

**Circuit Relationship.** Now that we have a basic understanding of voltage, current, and resistance, let's take a look at just how they interact under circuit conditions.

Fig. 6A shows a battery, ammeter (a device to indicate current strength), and resistor connected in series. Notice that the ammeter indicates that 4 amperes are flowing in the circuit.

Fig. 6B shows the identical setup with the exception that the battery voltage has now been doubled. The ammeter now shows that twice the original current, or 8 amperes, is now flowing in the circuit. Therefore, we can see that doubling the voltage applied to the circuit will double the current flowing in the circuit.

In Fig. 6C the same circuit appears again; this time, however, the battery voltage is one half its original value. The ammeter shows that one half of the original current, or 2 amperes, is now flowing in the circuit. This shows us that halving the voltage applied to the circuit will halve the current flowing through the circuit.

All this boils down to the fact that, assuming the same circuit resistance in all cases, *the current flowing in a circuit will be directly proportional to the applied voltage*—increasing as the voltage is increased, and decreasing as the applied voltage is decreased.

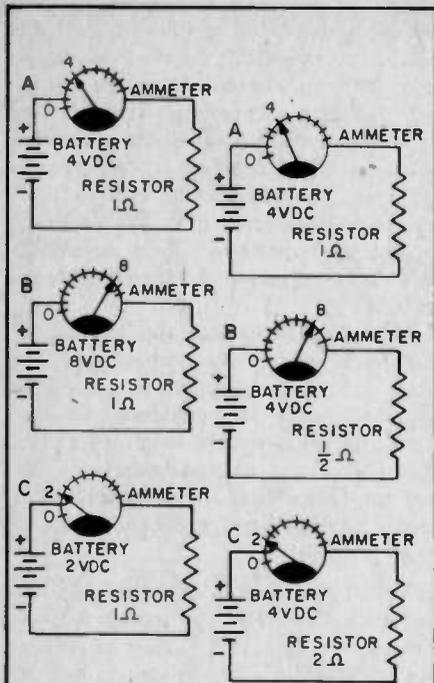


Fig. 6. In A, B, and C, the value of the resistor remains constant while the supply voltage is altered with a resulting current change.

Fig. 7. Battery voltage A, B, and C is held constant while resistor is halved and doubled in value. Resulting current changes are basis for Ohm's law.

In Fig. 7A we again see the circuit consisting of the battery, ammeter, and resistance. Notice that the ammeter indicates that 4 amperes are flowing through the circuit.

In Fig. 7B we see that the value of resistance has been cut in half and as a result, the ammeter indicates that twice the original current, or 8 amperes, is now flowing in the circuit. This leads us to the correct assumption that for a given supply voltage, halving the circuit resistance will double the current flowing in the circuit.

Fig. 7C again shows our basic circuit, but with the resistance now doubled from its original value. The ammeter indicates that the current in the circuit is now one half of its original value.

Summing things up: for a given supply voltage, the current flowing in a circuit will be inversely proportional to the resistance in the circuit.

**Ohm's Law.** From what you have seen so far, you are probably getting the idea that you can determine the current flowing in a circuit if you know the voltage and resistance present in the circuit, and the voltage if you know the current and resistance, or the resistance if the volt-

age and current are known.

All this is quite correct, and is formally stated by Ohm's law as follows:

$$I = \frac{E}{R}$$

Where: E = voltage  
I = current  
R = resistance

Now, let's take a look at how this formula is used:

To find voltage:

$$E \text{ (voltage)} = I \text{ (current)} \times R \text{ (resistance)}$$

To find current:

$$I \text{ (current)} = \frac{E \text{ (voltage)}}{R \text{ (resistance)}}$$

To find resistance:

$$R \text{ (resistance)} = \frac{E \text{ (voltage)}}{I \text{ (current)}}$$

A handy way to remember Ohm's law is by means of the triangle shown in Fig. 8. Simply cover the quantity (voltage, current, or resistance) that you want to determine, and read the correct relationship of the remaining two quantities. For example, if you want to know the correct current (I),

put your finger over I and read  $\frac{E}{R}$ .

Covering E or R will yield  $I \times R$  or  $\frac{E}{I}$ , respectively.

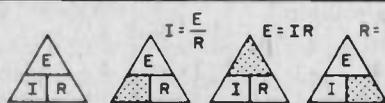


Fig. 8. Shaded portion of triangle indicates unknown quantity in the formula. Visible factors appear in their proper mathematical relation. Just fill in the known values and go on with multiplication or division.

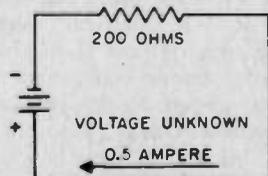


Fig. 9. Unknown quantity, voltage, found easily by applying Ohm's law.

**Ohm's Law to Determine Voltage.** Let's delve a bit more deeply into Ohm's law by applying it to a few cases where we want to determine the unknown volt-

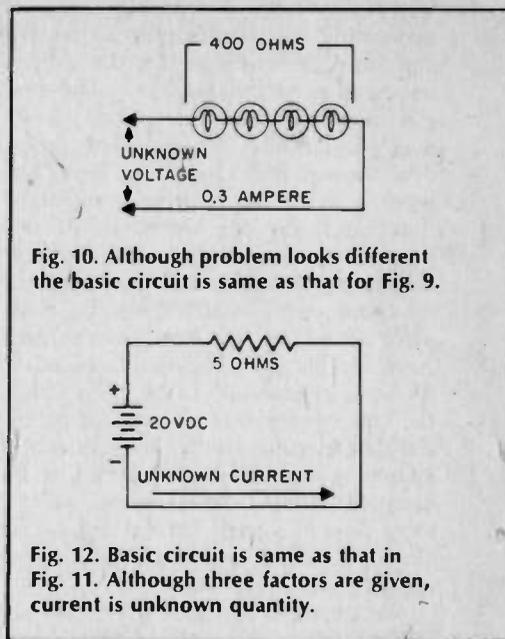


Fig. 10. Although problem looks different the basic circuit is same as that for Fig. 9.

Fig. 12. Basic circuit is same as that in Fig. 11. Although three factors are given, current is unknown quantity.

age in an electrical circuit. Take a look at Fig. 9, which shows a simple series circuit consisting of a battery and resistor. The value of this resistor is given as 200 ohms, and 0.5 ampere of current is flowing through the circuit. We want to find the value of battery voltage. This is easily done by applying Ohm's law for voltage as follows:

$$E = I \times R$$

Let's go through this again, this time using a practical illustration. Fig. 10 shows a string of light bulbs, the total resistance of which is 400 ohms. You find that the bulbs draw 0.3 amperes when lighted. Let's say you would like to operate this string of bulbs from the standard 120-volt house current, but you don't know the voltage rating of the individual bulbs. By using Ohm's law for voltage, you can easily determine the voltage to light the bulbs as follows: (unknown voltage) = 0.3 (amperes) x 400 (bulb resistance) = 120 volts.

**Ohm's Law to Determine Current.** Now, let's take a look at a few examples of how to determine the value of unknown current in a circuit in which both the voltage and resistance are known.

Fig. 11 shows a series circuit with a battery and resistor. The battery voltage is 20 volts DC and the value of resistance is 5 ohms. How much current is flowing through the circuit?

$$\text{Ohm's law for current: } I = \frac{E}{R}$$

$$I \text{ (unknown current)} = \frac{20 \text{ (battery voltage)}}{5 \text{ (resistance in ohms)}}$$

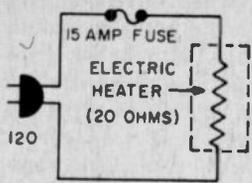


Fig. 11. Formula needed here is different since current is unknown. Just look for triangle in Fig. 8 that has I shaded.

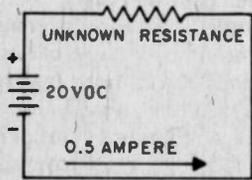


Fig. 13. Most Ohm's law problems are simple series circuits or can be reduced to simple series circuits.

$$I = 4 \text{ amperes}$$

Again to get a bit more practical, let's take a look at Fig. 12. Here we see an electric heater element connected to the 120-volt house line. We know that this particular heater element has a resistance of 20 ohms. The house current is fused with a 15-ampere fuse. We want to know whether the heater will draw sufficient current to blow the fuse. Here's how to find this out by use of Ohm's law for current.

$$I \text{ (unknown current)} = \frac{120 \text{ (line voltage)}}{20 \text{ (Heater resistance in ohms)}}$$

$$I = 6 \text{ amperes}$$

We find from the above use of Ohm's law for current that the heater draws 6 amperes, so it can be safely used on the line fused with the 15-ampere fuse. In fact, a 10-ampere fused line can also do the job.

**Ohm's Law to Determine Resistance.** Ohm's law for resistance enables us to determine the unknown value of resistance in a circuit. Fig. 13 again shows a simple series circuit with the battery voltage given as 20 volts and the current flowing through the circuit as 0.5 ampere. The unknown resistance value in this circuit is found as follows:

$$\text{Ohm's law for resistance: } R = \frac{E}{I}$$

$$R \text{ (unknown resistance)} = \frac{20 \text{ (battery voltage)}}{0.5 \text{ (current in amperes)}}$$

$$R = 40 \text{ ohms}$$

Fig. 14 is a practical example of how to determine unknown resistance. Here, we want to operate a 6-volt light bulb from the 120-volt house line. What value of series dropping resistor do we need to drop the 120-volt house current down to 6 volts? The bulb draws 0.2 ampere.

We must first determine the voltage which must be dropped across the series dropping resistor. This is done by subtracting the line voltage (120) from the bulb's voltage (€). This gives us a value of 114 volts which we use in conjunction with Ohm's law for resistance as follows:

$$R \text{ (unknown resistance)} = \frac{114 \text{ (voltage dropped by resistor)}}{0.2 \text{ (bulb current in amperes)}}$$

$$R = 570 \text{ ohms}$$

**Resistance in Series.** Many practical

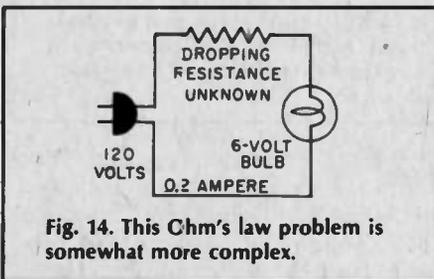


Fig. 14. This Ohm's law problem is somewhat more complex.

electrical and electronic circuits use two or more resistances connected in series. The point to remember in this case is that the total resistance is the sum of the individual resistances. This is expressed by the formula:

$$R \text{ (total resistance)} = R_1 + R_2 + R_3 + \text{etc.}$$

where R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, etc. are the individual resistances. Thus, in Fig. 15 the total of the individual resistances is R (total) = 40 + 6 + 10 + 5 = 61 ohms.

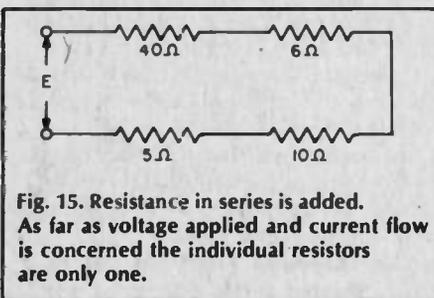


Fig. 15. Resistance in series is added. As far as voltage applied and current flow is concerned the individual resistors are only one.

Resistances may also be connected in parallel in a circuit as in Fig. 16. In this case the current flowing in the cir-

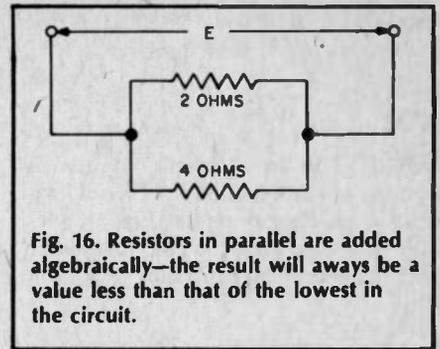


Fig. 16. Resistors in parallel are added algebraically—the result will always be a value less than that of the lowest in the circuit.

cuit will divide between the resistances, the greater current flowing through the lowest resistance. Also, the total resistance in the circuit will always be less than the smallest resistance since the total current is greater than the current in any of the individual resistors. The formula for determining the combined resistance of the two resistors is:

$$R \text{ (total)} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Thus, in Fig. 16 the effective resistance of R<sub>1</sub> and R<sub>2</sub> is:

$$R \text{ (total)} = \frac{2 \times 4}{2 + 4} = \frac{8}{6} \text{ or } 1.33 \text{ ohms.}$$

In a circuit containing more than two parallel resistors as in Fig. 17 the easiest way to determine the total circuit resistance is as follows: first, assume that a 6-volt battery is connected across the resistor network. Pick a value that will make your computations simple. Then determine the current flowing through each of the resistors using Ohm's law:

$$I = \frac{E}{R_1} = \frac{6}{2} = 3 \text{ amperes}$$

$$I = \frac{E}{R_2} = \frac{6}{3} = 2 \text{ amperes}$$

$$I = \frac{E}{R_3} = \frac{6}{6} = 1 \text{ ampere}$$

Next, add the individual currents flowing through the circuit:

$$2 \text{ amperes} + 3 \text{ amperes} + 1 \text{ ampere}$$

$$I = 6 \text{ amperes}$$

Inserting this 6 amperes in Ohm's law, the total circuit resistance is found to be:

$$R = \frac{6}{6} = 1 \text{ ohm}$$

The combined equation for determining the total resistance of *n* number of

resistances would be:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

Quite often an electronic circuit will contain a combination of series and parallel resistances as in Fig. 18. To solve this type of problem, first determine the combined resistance of R2 and R3:

$$R \text{ (total)} = \frac{6 \times 12}{6 + 12} + \frac{72}{18} = 4 \text{ ohms}$$

This total value of R2 and R3 may be considered a single resistance which is in series with R1, and forms a simple series circuit. This simple series circuit

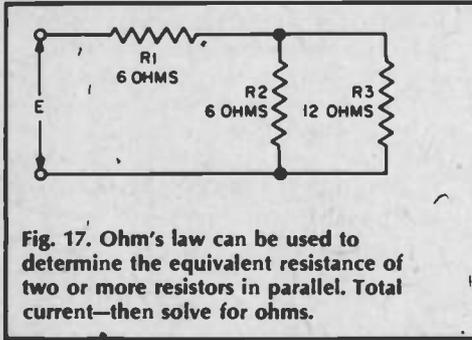


Fig. 17. Ohm's law can be used to determine the equivalent resistance of two or more resistors in parallel. Total current—then solve for ohms.

quantum and wave theories of light, is not so much a literal interpretation of a phenomenon as a useful concept that holds water when applied to the phenomenon of magnetism.

When the electron spins, the charge that is in motion produces a magnetic field. And, to briefly state the electronic explanation of magnetism, it seems that the magnetic properties of matter can be attributed to the orbital and spinning motion of the electrons comprising the atoms of the matter.

**Millennia of Magnetism.** Some of the basic principles and effects of magnetism have been known for centuries. The Greeks are credited as the ones

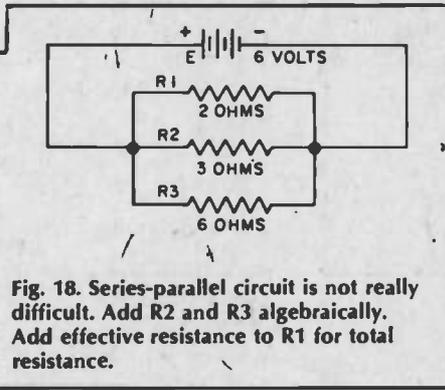


Fig. 18. Series-parallel circuit is not really difficult. Add R2 and R3 algebraically. Add effective resistance to R1 for total resistance.

is solved as follows:

$$R \text{ (total)} = 6 + 4 \text{ or a total of } 10 \text{ ohms.}$$

**Power.** The amount of work done by electricity is termed the *watt* and one watt is equal to one volt multiplied by one ampere. This may be expressed as:  $P = E \times I$  where E = voltage in volts, I = the current in amperes. Also:

$$P = \frac{E^2}{R} \text{ and } P = I^2 R$$

As an example, assume that a toaster draws 5 amperes at an applied voltage of 115 volts. Its wattage would then be:

$$P = 115 \times 5 \text{ or } 575 \text{ watts.}$$

**Magnetism and the Electron.** The atom and a concept of its structure were a necessary preface to our discussion of basic electricity. By the same token, both are necessary to understanding basic magnetism.

As we've mentioned, electrons are in continual motion about the nucleus. The orbit is, in fact, a small loop of current and has a magnetic field that's associated with a current loop. In addition, experimental and theoretical investigation seems to indicate that the electron itself has a spin. Each electron, having its own axis, is a spinning sphere of electric charge. *Electron spin*, like the

who first discovered magnetism. They noted that a certain type of rock had the ability of attracting iron. Later, the Chinese noted that an elongated piece of this rock had the useful property of always pointing in a north-south direction when suspended by a string. This was the beginning of our compass.

This strange stone which intrigued people over the centuries is actually a form of iron ore known as magnetite. Not all magnetite shows magnetic properties. Another name for the magnetic variety of magnetite is lodestone—the term lodestone being derived from two separate words, lode and stone. The term "lode" stands for guide, hence lodestone means "guide stone."

All magnets, whether natural or man-made, possess magnetic poles, which are commonly known as the magnet's north and south poles. As is the case of the electrical charges (which we studied earlier) between unlike magnetic poles and repulsion between like poles, it has been found that this magnetic attraction and repulsion force varies inversely as the square of the distance from the magnetic poles.

**The Magnetic Field.** We all know how a magnet exerts a force of attraction on a piece of magnetic material such as iron or steel. Also, when the north poles of two magnets are brought close together, they will try to repel

each other, while there will be attraction between the north and south poles of two magnets. Although it is not clearly understood just what this force of magnetic attraction and repulsion is, it is convenient to visualize magnetic lines of force which extend outward from one magnetic pole to the other as illustrated in Fig. 19.

**Permeability.** Magnetic lines of force can pass through various materials with varying ease. Iron and steel, for example, offer little resistance to magnetic lines of force. It is because of this that these materials are so readily attracted by magnets. On the other hand, materials such as wood, aluminum and brass do not concentrate or encourage the passage of magnetic lines of force, and as a consequence are not attracted by magnets.

The amount of attraction a material offers to magnetic lines of force is known as its permeability. Iron and steel, for example, possess high permeability since they offer little resistance to magnetic lines of force. Nonmagnetic materials have low permeability. For practical purposes, we can say that reluctance is to magnetic lines of

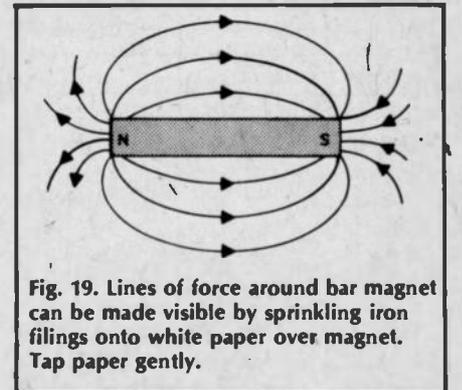


Fig. 19. Lines of force around bar magnet can be made visible by sprinkling iron filings onto white paper over magnet. Tap paper gently.

force what resistance is to an electrical current.

**Electromagnetism.** Any electrical conductor through which flows an electrical current will generate a magnetic field about it which is perpendicular to its axis as shown in Fig. 20. The direction of this field is dependent upon the direction of current flow, and the magnetic field strength proportional to the current strength. If this current-carrying conductor is wound into a coil, forming a solenoid, the magnetic field will be increased by each individual turn that is added. If an iron core is inserted in this current-carrying coil, the generated field will be increased still further. This is because the lines of force are concentrated within the iron core which has considerably less reluctance than the surrounding air.

The magnetic power of a multi-turn current-carrying coil through which a

core is inserted is proportional to the current flowing through the coil as well as the number of turns in the coil. The current through the coil is termed *ampere turns*. As an example, if a coil consisting of 200 turns is carrying 2 amperes, its ampere turns equal:

$$\text{Ampere turns} = 200 \text{ turns} \times 2 \text{ amperes} \text{ or } 400 \text{ ampere turns}$$

Similarly a coil of 100 turns through which a current of four amperes flows also has 400 ampere turns.

**Electromagnetic Induction.** We saw earlier how a current-carrying conductor will generate a magnetic field which is perpendicular to the conductor's axis. Conversely, a current will be induced in a conductor when the conductor is pass-

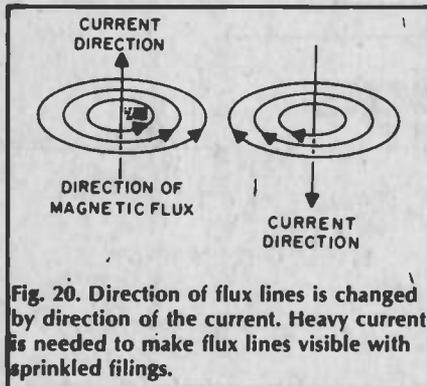


Fig. 20. Direction of flux lines is changed by direction of the current. Heavy current is needed to make flux lines visible with sprinkled filings.

ed through a magnetic field. The strength of this induced current is proportional to both the speed at which it passes through the field and the strength of the field. One of the basic laws pertaining to electromagnetic induction is Lenz's law which states: "The magnetic action of an induced current is of such a direction as to resist the motion by which it is produced."

Fig. 21 illustrates two coils, A and B, which are placed in close proximity to each other. Coil A is connected in series with a switch and battery so that a current may be sent through it when the switch is closed, and coil B is connected with a current-indicating DC meter. When the switch is closed, current will flow through coil A, causing a magnetic field to be built up around it. In the brief instant that the field is building up to maximum, it will "cut" the turns of coil B, inducing a current in it, as indicated by a momentary flick of the indicating meter. When the switch is opened, breaking the current flow through coil A, the field around coil A will collapse, and in so doing will again induce a current in coil B. This time, however, the flow of current will be in the opposite direction. The meter will now flick in the direction opposite to when the switch was closed. The important thing to remember is that the

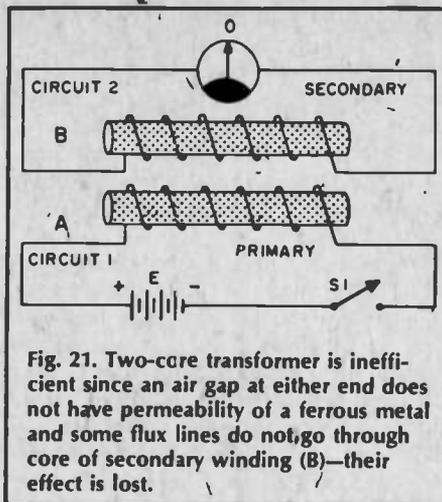


Fig. 21. Two-core transformer is inefficient since an air gap at either end does not have permeability of a ferrous metal and some flux lines do not go through core of secondary winding (B)—their effect is lost.

conductor must be in motion with respect to the magnetic field or vice versa in order to induce a current flow. You can perform this simple experiment using two coils made of bell wire wrapped around large nails, a few dry cells in series, and a DC zero-center scale meter.

**Self Induction.** As mentioned a short while ago, a magnetic field is built up around a coil at the application of current through the coil. As this field is building up, its moving lines of flux will cut the turns of the coil inducing a counter-electromotive force or counter-EMF which opposes the current flowing into the coil.

The amount of counter-EMF generated depends upon the rate of change in amplitude of the applied current as well as the inductance of the coil. This value of inductance is dependent upon the number of turns in the coil; a coil with many turns will have greater inductance than a coil with few turns. Also, if an iron core is inserted into the coil, the inductance of the coil will increase sharply. The unit of inductance is known as the *henry*.

**The Transformer.** One of the most important and widely used applications of magnetic induction is the transformer. Transformers find the major application in stepping up or down voltage and current in countless applications.

Fig. 22 shows the basic construction of a typical transformer. While two separate windings are shown here, some transformers can have as many as five or six windings.

A transformer consists of two or more separate windings, electrically insulated from each other. One winding, known as the primary winding, is fed from a source of alternating current.

The alternating currents flowing through the primary induce a current in the secondary winding by virtue of magnetic induction. The transformer core is

constructed from a relatively high permeability material such as iron which readily conducts magnetic flux between the primary winding and secondary winding.

The alternating current flowing in the primary of the transformer produces a variation in the magnetic flux circulation in the transformer core which tends to oppose the current flowing in the primary winding by virtue of self-induction. The counter-EMF is just about equal to the voltage applied to the primary winding when no load is connected to the transformer's secondary winding. This accounts for the fact that very little current flows through the primary winding when no load is connected to the secondary. The negligible current that does flow under this no-load condition is known as the transformer magnetizing current. As the current drawn from the secondary winding increases, the primary current will increase proportionately due to the reduction in the counter-EMF developed in the primary winding of the transformer.

In any transformer the ratio of the primary to secondary voltage is equal to the ratio of the number of turns in the primary and secondary windings. This is expressed mathematically as follows:

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

where  $E_p$  = primary supply voltage

$E_s$  = voltage developed across secondary

$N_p$  = number of primary turns

$N_s$  = number of secondary turns

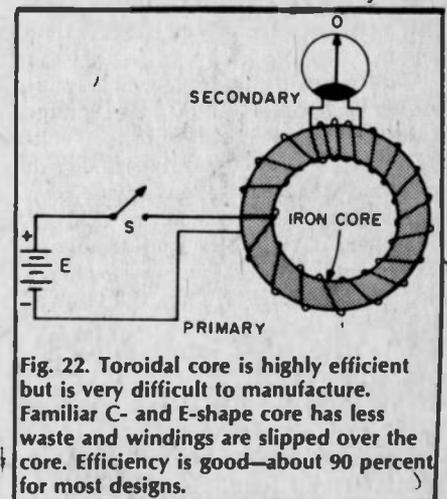


Fig. 22. Toroidal core is highly efficient but is very difficult to manufacture. Familiar C- and E-shape core has less waste and windings are slipped over the core. Efficiency is good—about 90 percent for most designs.

The above formula assumes that there are no losses in the transformer. Actually, all transformers possess some losses which must be taken into account.

**Transformer Losses.** No transformer can be 100 percent efficient due to

losses in the magnetic flux coupling the primary and secondary windings, eddy current losses in the transformer core, and copper losses due to the resistance of the windings.

Loss of magnetic flux leakage occurs when *not all* the flux generated by current flowing in the primary reaches the secondary winding. The proper choice of core material and physical core design can reduce flux leakage to a negligible value.

Practical transformers have a certain amount of power loss which is due to power being absorbed in the resistance of the primary and secondary windings. This power loss, known as the copper loss, appears as heating of the primary and secondary windings.

There are several forms of core loss—

hysteresis and eddy current losses. Hysteresis losses are the result of the energy required to continually realign the magnetic domain of the core material. Eddy current loss results from circulating currents induced in the transformer core by current flowing in the primary winding. These eddy currents cause heating of the core.

Eddy current loss can be greatly reduced by forming the core from a stack of individual sheets, known as laminations, rather than from a single solid piece of steel. Since eddy current losses are proportional to the square of core thickness, it is easy to see that the individual thin laminations will have much less eddy current loss as compared with a single thick core.

Another factor which effects eddy

current loss is the operating frequency for which the transformer is designed to operate. As the operating frequency is increased, the eddy current losses increase. It is for this reason that transformers designed to operate at radio frequencies often have air cores and are void of ferrous metals.

**Theory and Practice.** We've come a long way from our initial discussion of the atom and its importance for an understanding of electricity and magnetism. And there's still a long way to travel to understand all about the subatomic nucleus and its satellites and how they are being harnessed in an ever-expanding electronics technology. But, we move ahead by mixing theory with practice—so, put your new knowledge to work in a project or two! ■

## Wheatstone Bridge

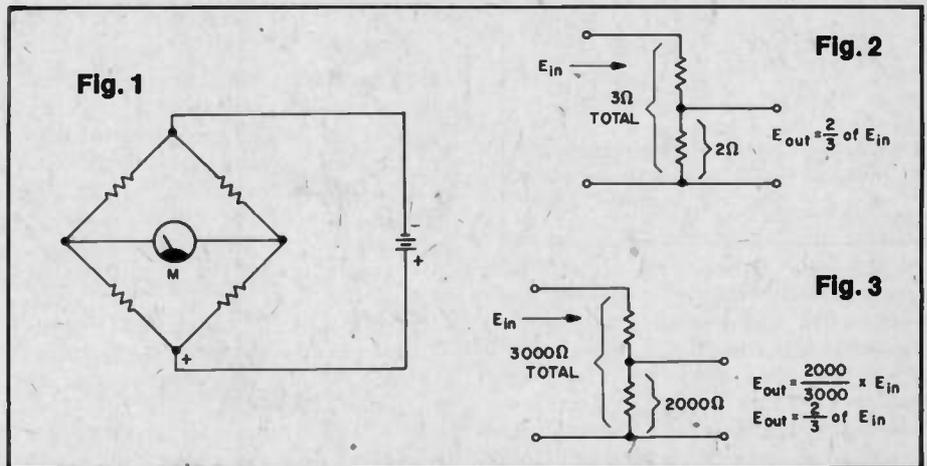
□ BACK IN 1843, Charles Wheatstone had a need for a convenient way to measure unknown resistances. He solved his problem by using and publicizing a circuit devised by S. H. Christie some ten years earlier. This same circuit is still widely used today, and, despite Wheatstone's earnest attempts to ascribe the invention to its proper inventor, it is best known as the Wheatstone bridge.

The circuit Mr. Christie invented in 1833 is usually shown as a diamond-shaped cluster of resistors with a battery across two of the opposite points of the diamond, and a meter or other detector across the two remaining points. See Fig. 1. With this circuit, it is possible to determine accurately the value of one of the four resistors, provided value of other three is accurately known.

To understand this bridge, first let us consider a familiar circuit, the voltage divider. As you probably know, a voltage divider is a two-resistor circuit which can convert a given voltage to a lower voltage. For example, in this circuit shown in Fig. 2 the output voltage will be two-thirds of the input voltage. And, if you don't like such low resistor values, then look at Fig. 3. This circuit will also have an output which is two-thirds of the input.

If we apply 9 volts to the input of either circuit shown in Figs. 2 and 3, the output will be 6 volts. For a 90-volt input, a 60-volt output results.

Since the outputs of the two above circuits are identical, connecting a meter between the two outputs should give no reading at all, because the two leads of the meter are connected to identical voltages. Take a look at Fig. 4. For



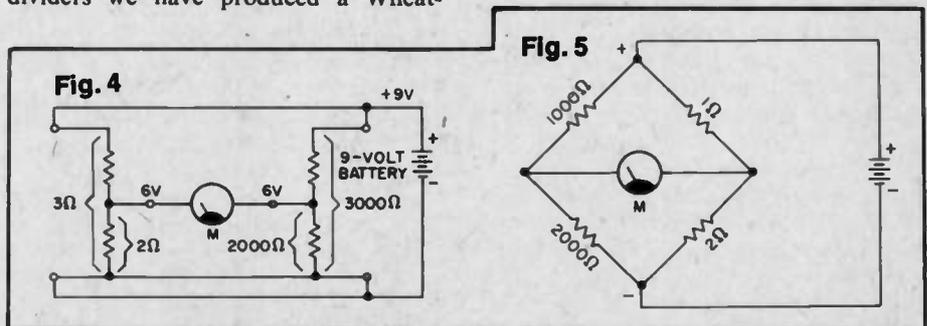
that matter, changing the 9-volt input to 10, 50, or 100 volts will still give no (zero) meter reading, because each voltage divider is providing two-thirds of the same number, be it 9 volts, 10 volts, or whatever. Therefore, both meter leads are kept at the same matched voltages, regardless of the input voltage, so the meter continues to register zero.

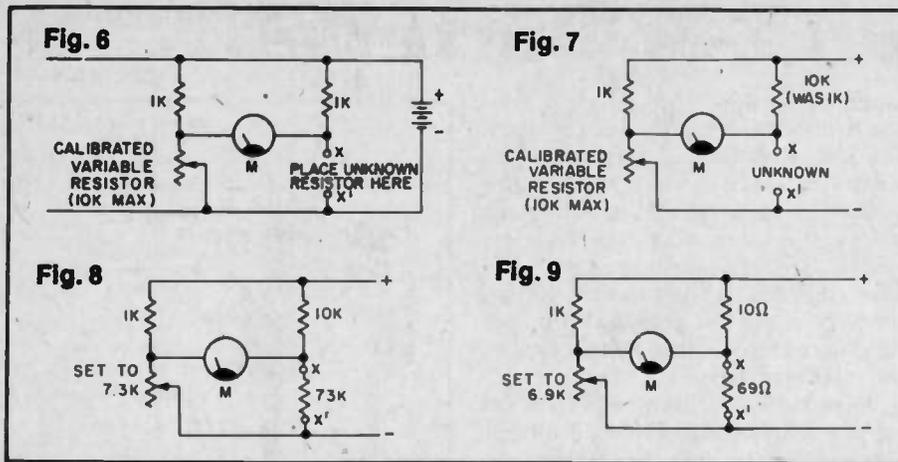
As you have probably already deduced, by combining these two voltage dividers we have produced a Wheat-

stone bridge. This may be more obvious if we draw the circuit as shown in Fig. 5.

When the resistor values are such that the meter reads zero, the bridge is said to be *balanced*. The reverse is also true: if the bridge is balanced, we know that the left side of the bridge and the right side of the bridge are matched voltage dividers.

**Using the Bridge.** To determine an unknown resistance, we could arrange





the circuit as shown in Fig. 6.

Since the two uppermost resistors are identical (1,000 ohms each), the bridge will be balanced only if the two lower resistors are also identical to each other. Therefore, we can connect an unknown resistor to the terminals X and X', and adjust the calibrated variable resistor until the meter reads zero. At this condition, the calibrated variable resistor is identical to the unknown, so the value on the calibration dial is the value of the unknown resistor.

Of course, if the unknown turns out to be larger than 10,000 ohms (the largest value of the calibrated variable resistor), no adjustment of the calibrated variable resistor will make the two lower resistors identical. Hence, the bridge cannot be balanced. How, then, can the bridge be used to determine the value of an unknown resistor greater than 10,000 ohms?

One way to measure a larger resistor with this bridge is to change one of the upper resistors from 1,000 ohms to 10,000 ohms as done in Fig. 7. Compare Fig. 7 with Fig. 6.

Since the right-hand uppermost resistor is now ten times the left-hand uppermost resistor, the bridge will be balanced only if the lower right-hand resistor (the unknown) is ten times the lower left-hand resistor (the variable one). For example, one condition of bridge balance would be as shown in Fig. 8.

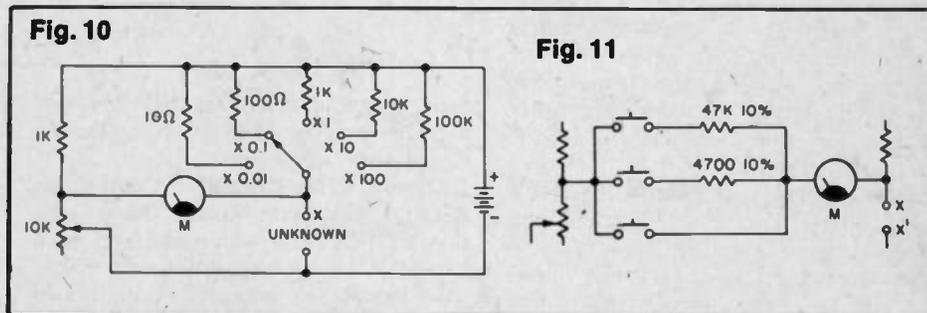
On the other hand, a very low value of unknown resistor (for example, 69 ohms) could not be read accurately on the above bridge, because it would require that the 10,000-ohm calibrated variable resistor be set to one-tenth of 69 ohms, or 6.9 ohms. Although such a setting is physically possible, it does not result in a very accurate reading.

To measure such low-value resistors, we change the upper right-hand resistor again; this time to 10 ohms. See Fig. 9 for the balanced condition.

This immediately suggests a very ver-

satellite bridge, which uses a multi-position selector switch to select a variety of values for the upper right-hand resistor. In addition to 1,000 ohms, 10,000 ohms, and 10 ohms, which were used in the above examples, we can choose 100 ohms and 100,000 ohms. Fig. 10 illustrates such a bridge.

To use this versatile bridge to measure low-value resistors, select the 10-ohm resistor by placing the selector switch in the "X 0.01" position, connect the unknown resistor the terminals X and X', and adjust the calibrated



resistor until the bridge is balanced, as indicated by a reading of zero on the meter. The reading on the calibrated resistor's dial is then multiplied by 0.01 to give the value of the unknown resistor. For example, if the reading is 3,700, the unknown is 37 ohms.

Similarly, setting the selector switch to "X 100" allows you to measure large resistors. If a certain unknown resistor results in a reading of 3,700 at balance, the unknown is 370,000 ohms.

**Practical Considerations.** Although this bridge can be built using ordinary 5 percent resistors, the errors in measurement will be as large as  $\pm 10\%$ . It's better to use 1% resistors everywhere.

The variable resistor, similarly, could be an ordinary potentiometer with a hand-calibrated dial. However, this also limits accuracy; it would be much better to use a resistance decade of the type sold by some of the leading electronic kit manufacturers. Calibrated

multi-turn pots are also available.

The meter should be a zero-center microammeter (such as the 25-0-25 microamp type) for the best accuracy. However, even an ordinary 0-1 meter will suffice if you are willing to trade some accuracy to keep the cost down.

Remember, however, the more sensitive the meter, the more accurately you can balance the bridge, especially on the high resistance ranges. Also, the more easily you can burn out the meter when the bridge is not balanced! To forestall this catastrophe, connect your meter to the bridge through a group of normally-open pushbuttons and resistors (10% type), as shown in Fig. 11.

Pressing the top button will give a reading on the meter if the bridge is far from balance, but the large value of resistance in series with the pushbutton will keep the meter from being damaged by the large unbalance. Holding this button, balance the best you are able, and then press the next pushbutton, which will further increase the sensitivity of the meter and permit you to obtain a better balance. Finally, pushing the last pushbutton connects the meter directly across the bridge without any

protective resistors in series, giving maximum sensitivity and accuracy.

The voltage of the battery used to power the bridge is not critical. However, the lower the voltage used, the less sensitive the bridge becomes, especially on the high-resistance ranges. On the other hand, high voltages force excessive currents through the resistors in the bridge, especially on the low-resistance ranges. These currents can damage the unknown or the calibrated variable resistor. A good compromise for the values shown is provided by a voltage of around 3 volts. At this voltage, the 10-ohm resistor should have a one-watt rating. It's important that current periods be kept short.

Well over a century separates Wheatstone and Christie from the present day, but you can bridge those years, electronically, as you find that their concise and clever circuit still does an excellent job in the integrated circuit era. ■

# All About C-Zn Batteries

□ THERE ARE SEVERAL SOURCES of electricity available for experimenters now as opposed to very limited sources at the beginning of the electronic age. Initially, early experimenters had only static electricity, produced essentially by rubbing an insulating material such as a hard rubber or glass rod with cloth or fur, or as Ben Franklin demonstrated, by flying a kite during an electrical storm.

In this modern age of widespread power distribution nearly every home and building is wired to a power company's generating station. In addition, there are various kinds and shapes of batteries readily available that are more useful than static electricity. The main reason that static electricity is of no practical use is because modern electrical machinery, appliances, and electronic equipment require a continuous flow of current for their operation.

Since the subject of this discussion is the zinc-carbon battery, we'll confine our words to this one source of reliable electrical power. Today's very efficient dry cells evolved from the original zinc-carbon battery, called the Leclanché cell, named after its inventor, Georges Leclanché. Before the advent of electronics they were used extensively for door bells, alarms, telephones, and other applications where current is needed only intermittently.

**How Batteries Are Made.** There's a great deal of similarity between the original Leclanché cell and modern zinc-carbon batteries. Everyone's familiar with the conventional round single cells, such as AA, C, D, and #6 sizes, which are packaged and wired together to make up higher voltage batteries. In addition, there are flat rectangular cells, that stack one on top the other, which have been developed for higher voltage batteries. These flat cells produce a longer-lived battery since there is less wasted space, making it possible to produce a higher capacity cell in a given cubic space. Though available in many different shapes and sizes, the zinc-carbon battery, more commonly called dry-cell, is comprised basically of the same materials originally used by Leclanché.

His cell was made up of a positive carbon element, a zinc negative element formed to serve as a container, and an electrolyte. The electrolyte is a solution of sal ammoniac (ammonium chloride) that doesn't actively attack the zinc when no current is drawn from the cell, or when it's being stored.

A thin separator of either porous

paper, or a thin layer of wheat flour and cornstarch, lines the zinc container. The separator, which is saturated with electrolyte, separates the metal from the mix and prevents the cell from discharging itself in short order. The separator permits chemical action to take place when the cell is furnishing electrical energy to a load and prevents the chemical action when the load is disconnected and no current flows.

When current is drawn from the cell for reasonably long periods, hydrogen gas accumulates on the carbon element. This accumulation of hydrogen gas bubbles polarizes the cell, which, in

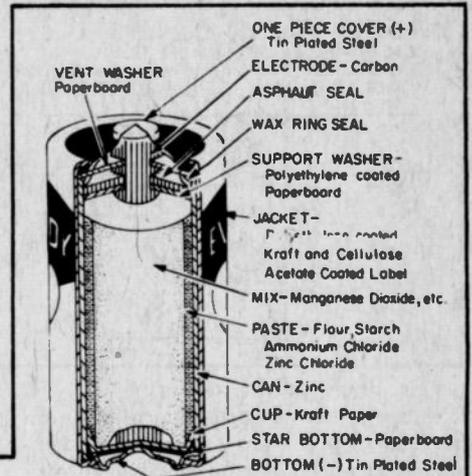
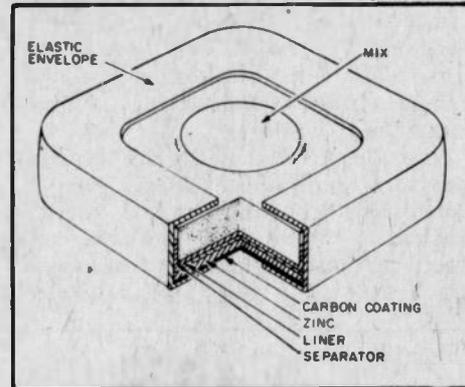


Fig. 1. Cutaway view of a flashlight cell, either AA, C, or D size. This view shows various components making up cell. Study of this and reference to text helps to understand general makeup of carbon-zinc battery.

Fig. 2. Cutaway view of square "mini-max" zinc-carbon cell. It develops 1.5V—the same as round cells; chief advantage is that for the same volume of space it has a greater capacity.

turn, appreciably reduces the current it will deliver. The cell, however, doesn't revive after a rest period.

**Depolarizing Agent.** Continuous heavy current drain initiates the generation of hydrogen within the cell that causes it to become polarized, which soon results in low cell output. Leclanché added a chemical depolarizing agent, manganese dioxide, which is really an oxidizing agent. By definition, an oxidizing agent is a chemical that releases its oxygen readily. Since oxygen and hydrogen have a strong affinity for one another, the hydrogen that accumulates on the carbon element unites chemically with the oxygen from the manganese dioxide and forms water. In essence, the depolarizer ( $MnO_2$ ) reacts with and removes the hydrogen to avoid polarization.

The term "dry cell" is a misnomer, since the electrolyte, though not a liquid, is a wet paste that also contains the depolarizing agent and fine particles of carbon to reduce internal cell resistance. Cell design, customized for specific applications, is based primarily on the percentage of carbon particles in the mixture. The cell won't spill, evaporate, or run over because, on commercially manufactured cells, the top is sealed. When the battery no longer produces

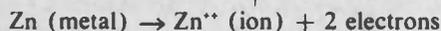
electrical energy it isn't because the wet paste has dried up or because any one particular chemical has been used up. Instead, it's because all of the active ingredients are chemically united to form new compounds that are not active, thus for all intents and purposes creating a worn-out cell.

A dry cell remains inactive until a load is connected, at which time elec-

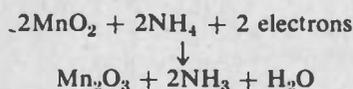


Fig. 3. "Old Faithful" #6 dry cell shown here in cross section has been used where long life is a must. Though larger than AA, C, and D cells, its output voltage is still only 1.5V.

tricity is produced by chemical reaction. Each zinc atom gives up two electrons to the load circuit and forms a positive zinc ion ( $Zn^{++}$ ) that goes into the electrolyte. The chemical equation is:



The electrons return to the cell through the positive electrode and enter into another reaction with ammonium ions ( $NH_4^+$ ) and the manganese oxide ( $MnO_2$ ). These electrons are absorbed in the reaction and produce manganic oxide ( $Mn_2O_3$ ), ammonia ( $NH_3$ ), and water ( $H_2O$ ). The equation for this reaction is:



In addition, the ammonia ( $NH_3$ ) combines with the zinc ion to form a complex zinc ion.

Some cells may contain zinc chloride ( $ZnCl_2$ ) which create other reactions. Regardless of the chemicals used, the electrons that make up the current flow come from the zinc metal, which is consumed in the process.

**Shelf Life.** Open circuit voltage of a dry cell, regardless of its size, is 1.5 volts. As the active ingredients become depleted, the internal impedance or cell resistance increases until the cell becomes useless. The resistance of new AA, C, D, and #6 cells normally is less than  $\frac{1}{2}$  ohm. Shelf deterioration results from two major factors: (a) loss of moisture through evaporation because of poor seals, or (b) low-level chemical reactions that occur within the cell independent of those created by current drain. Internal current leakage causes the cell to discharge itself at a slow rate. This accounts for the gradual de-

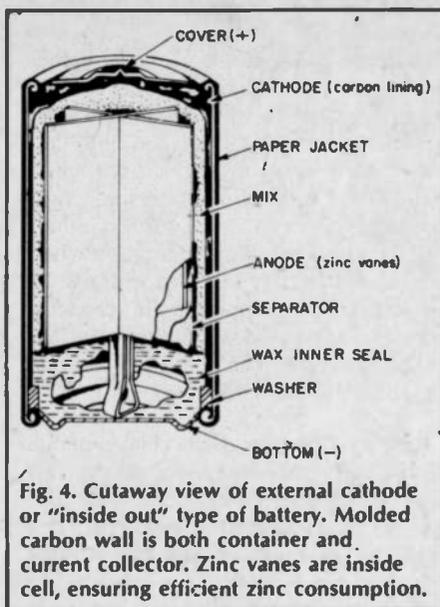


Fig. 4. Cutaway view of external cathode or "inside out" type of battery. Molded carbon wall is both container and current collector. Zinc vanes are inside cell, ensuring efficient zinc consumption.

pletion of battery output even though the cells are not connected in a circuit to supply power. This gradual depletion of battery life is commonly referred to as shelf life.

Since raising the temperature of chemical mixtures speeds up most chemical reactions, the storage of dry cells in abnormally high ambient temperature environments will hasten wasteful zinc corrosion and other side chemical reactions within the cell to reduce its shelf life. Storage in lower than normal, but not freezing temperatures, will appreciably reduce shelf life deterioration. Temperatures above  $125^\circ$  will effect rapid deterioration and possible leakage. Ideal storage temperature is from  $40^\circ$  to  $50^\circ F$ . The average shelf life for dry cells not in use under ideal temperature conditions is two to three years.

**Capacity.** Ordinarily, dry-cell batteries are tested on circuits of constant

resistance and the capacity is expressed as the time of discharge rather than in ampere-hours. It's relatively easy to calculate ampere hours by determining the average value of current drain. To calculate the average drain you must first determine the average voltage by plotting voltage readings taken at regular intervals from full voltage to cutoff voltage. From this and the known fixed resistance used as a fixed load, the average current is computed, which, in turn, is multiplied by the total time of actual discharge to arrive at ampere hour capacity. Since voltage characteristics of different brands of batteries differ, the average current delivered by a particular size cell will be only an approximation of the capacity of other cells and batteries under comparable conditions.

Other factors affecting battery capacity are: (a) temperature—discussed previously, (b) cutoff voltage—capacity is greater as cutoff voltage is lowered, (c) relative time of discharge and recuperation—performance normally is better when discharge is intermittent, and (d) rate of discharge—capacity is greater as discharge current is less, down to a certain level, at which point efficiency decreases because of spontaneous reactions within the cells.

No definite statement can be made, but, as an example, maximum service efficiency for continuous discharge of a #6 cell is obtained on a 60- to 100-ohm circuit, or at a current of 10 to 20 mA. For smaller cells this current will be proportionately smaller. From this it can be seen that other factors such as size, weight, convenience, and initial cost must be taken into account to determine the ultimate service efficiency that can be obtained.

**Selecting Batteries.** From the variety of different sizes and types of batteries available one might get the impression that battery selection is a difficult task. You can reduce the problem considerably by first outlining basic operational requirements and then matching up a battery that most nearly fulfills them.

To obtain factual information on the many types of batteries available, we suggest you get a copy of a publication titled *Battery Applications Engineering Data*, published by Union Carbide, the makers of Eveready brand batteries (Burgess also publishes a similar handbook). In addition to being loaded with battery characteristics, standard test procedures, etc., it contains a most comprehensive listing of a wide variety of Eveready batteries being manufactured as well as cross-referencing to batteries of other manufacturers.

There is a certain minimum amount

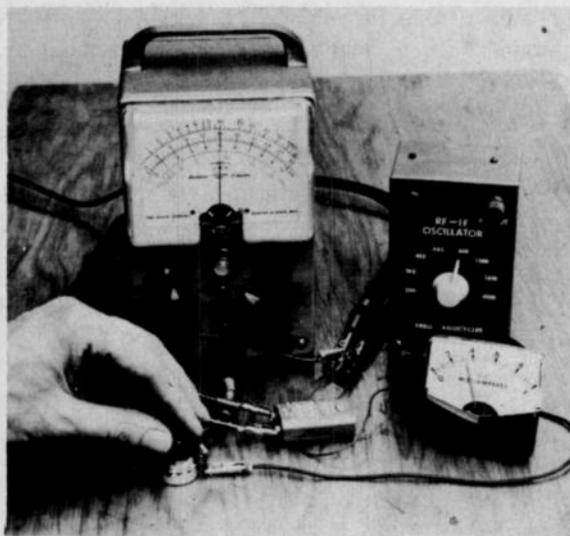


Fig. 5. Checking cutoff voltage and current consumption to plot capacity of battery for most economical operation of signal generator.



terminals, cost, etc.

If there is a limit in voltage below which the equipment will no longer function properly (called cutoff voltage) this must also be taken into account when selecting a battery. Some circuits have a high initial current drain and then operate at a more nominal drain once started—a consideration when arriving at the circuit's current drain. In arriving at the ampere-hour capacity necessary, current drain along with discharge schedule and required service life are determining factors.

**Battery Charging.** Dry cells generate electricity by chemical action which eats away the negative electrode. Once this has been completely destroyed, and since the structure of the cell is such that they are sealed, it's impossible to replace the negative electrode. To truly restore the charge in a dry battery you must replace this electrode. However, the operating life of the dry cell can be extended in some cases. This would be more like a rejuvenation process rather than a recharging one. As pointed out previously, the chemicals added to the electrolyte deter the formation of gas around the positive electrode, which reduces the polarization and increases the

life. The longer a battery is used the more these chemicals are used up and polarization sets in, weakening the battery.

By applying a reverse polarity with current flowing in an opposite direction, electrolysis takes place in the electrolyte. This ionizes the gas atoms around the positive electrode, clearing it for more efficient chemical action, which will determine how well the life of the cell can be extended. Recharging is economically feasible only when the cells are used under controlled conditions using a system of exchange of used cells for new ones.

Though dry cells are nominally considered to be primary cells, they may be restored for a limited number of times if the following conditions are used: (1) the operating voltage or discharge of the cell is not below 1 volt per cell when the battery is removed from service and charged. (2) battery is placed on charge immediately after it's removed from service. (3) ampere-hours of charging should be 120% to 180% of the discharge. (4) the charging rate must be low enough so that the recharge takes 12-16 hours. (5) the battery must be put into service soon after charging. ■

of information that must be tabulated before a suitable battery can be selected. You must know such things as nominal operating requirements of the circuit, its current drain, its operating cycle, its desired service life, temperatures in which equipment will be used, size and weight limitations, type of

## 5V/3A For Digital Projects

□ The 5-volt power supply is almost the universal power source for digital projects. Only problem is the 5 volts must be highly regulated, for a power line transient riding through the supply can zap a board full of ICs. This supply gives you full protection against transients, as well as providing tight regulation. The entire regulator is contained in IC1; no other components other than the filter capacitor and rectifier are needed. For full 5 ampere output IC1 requires a

heat sink of 30 square inches; but if you use a metal cabinet 3 x 4 x 5 inches or larger the cabinet itself serves as the heat sink. Since pin 3 on IC1 is grounded (to the cabinet), all you need is some silicon heat sink grease between the IC and the cabinet—no insulator.

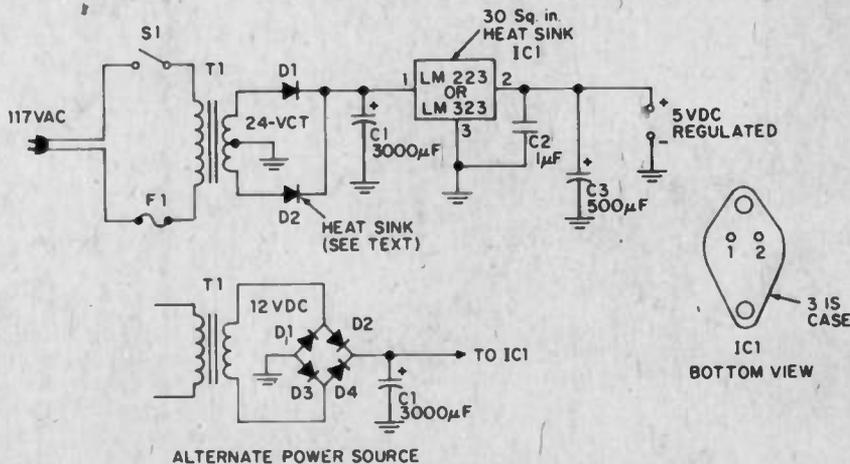
Power transformer T1 must be rated for the maximum current you will use or need. If you want the full 5 amperes T1 must be rated 5 amperes. But if you will need less cur-

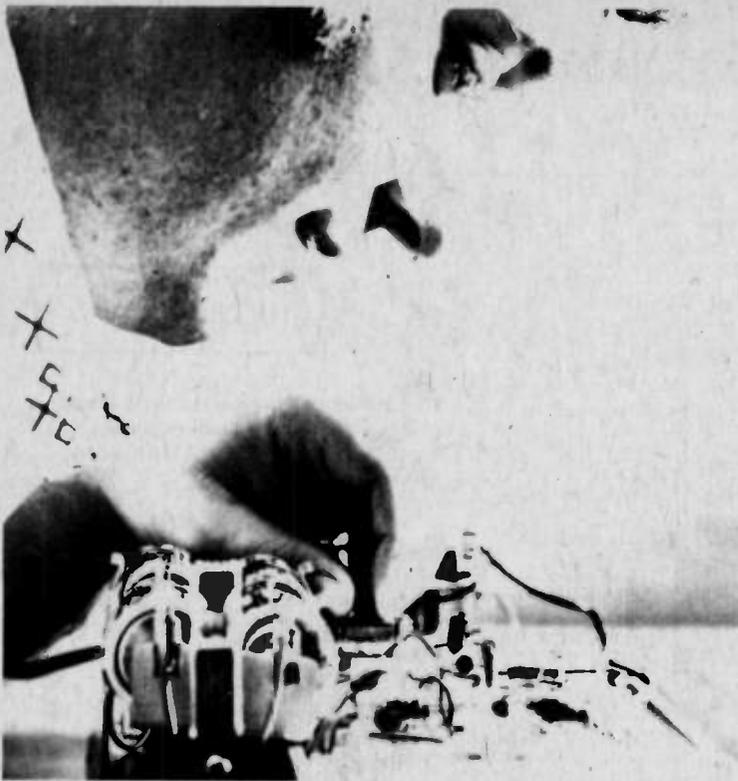
rent, say 2 amperes, T1 can be rated 2 amperes.

Rectifiers O1 through O2 are available with ratings up to 3 amperes in the standard coaxial mounting. For greater current capacity the rectifiers must be heat-sinked (electrically isolated) to the cabinet, or other sink. A 10-ampere bridge rectifier such as sold by Calectro and Radio Shack can be substituted, but make certain it is heat sunked to the chassis.

### PARTS LIST FOR 5V/3A FOR DIGITAL PROJECTS

- C1—3000- $\mu$ F, 25 VDC electrolytic capacitor
- C2—0.1- $\mu$ F Mylar capacitor
- C3—500- $\mu$ F, 10 VDC electrolytic capacitor
- O1-D4—See text
- F1— $\frac{1}{4}$  ampere, 3AG
- IC1—5-volt regulator, LM223 or LM323
- S1—Spst slide or toggle switch
- T1— see text





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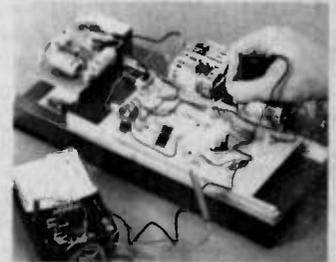
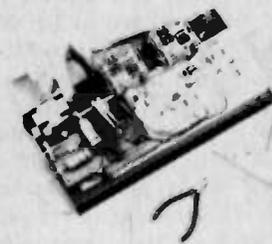
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# Extra Life from Dry Cells

□ AS YOU THROW that worn-out battery from your transistor radio into the nearest trash can, have you ever wondered if there might be some method of getting a bit more life out of a standard battery? An automobile battery gets recharged every time you run the car's engine. How would it be if the useful life of a battery for your radio could be extended in some way?

Now if you go along to your friendly neighborhood radio dealer and ask him about it he'll probably tell you that it can't be done. Well, after all, he is in business to sell you a new battery. Don't give up in despair because you'll be pleased to learn that dry cell batteries, like the one in your radio, can be recharged—up to a point.

It's not too difficult to get several times the normal life out of a standard battery before it becomes useless. If you or the kids use a radio, battery powered model, or other battery driven appliance fairly regularly, the cost of replacing batteries may be starting to hit your pocket. So why not scout around the junk box and make yourself a battery charger! This article will give you plenty of handy information about inside a battery, too.

**Inside the Cell.** Many of the batteries commonly used today are of the Leclanché dry-cell type. Let us take a look at the inside of a typical dry-cell and see what makes it work.

As a typical example of construction let us take a standard size D flashlight cell and saw it in half from top to bottom. The inside will look like Fig. 1.

Under the paper or plastic labels on the outside of the cell is an outer metal case which acts as the cathode, or negative electrode, of the cell. This case is made from zinc.

The anode, or positive electrode, consists of a black mixture which fills most of the inside of the cell. This mixture is made up from manganese dioxide and powdered carbon. The active element in the mix is the manganese dioxide but this is a relatively poor conductor of electric current. Carbon, which is a good conductor, is added so that current can flow more easily through the cell.

At the center and running from top to bottom of the cell is a carbon rod. This rod acts as the anode connection out of the cell and is usually capped by a cap or plate which serves as the positive terminal of the cell.

Between the anode and cathode is a thin layer of corn starch impregnated

Find all the parts you need for a simple charger like this in a well-equipped junk box. Table below shows R1/R2 values to use.

Battery	Volts	R1 ohms*	R2 ohms*	I mA
Transistor-type	9	470	10000	10
6 AA cells	9	120	2700	40
4 AA cells	6	220	2200	40
2 D cells	3	68	470	125

\*All resistors are 1/2 watt except the 68-ohm resistor which is 1 watt.

with sal ammoniac (ammonium chloride) which forms the electrolyte of the cell. This is the fluid that messes up your radio if you leave "dead" batteries in it for a long time. Normally the electrolyte is prevented from leaking out of the cell by a bitumen or plastic seal at the top of the cell.

To prevent the cell from being short-circuited, the anode and cathode are insulated from one another by fiber disks at the top and bottom of the cell. Thus the only connection internally between the anode and the cathode is through the electrolyte.

Some batteries are built in a different way, but the materials used and the method of operation are similar. Transistor radio batteries are often built in layer form. Each layer forms one cell and since they are effectively connected in series there would be six layers in a normal 9-volt transistor radio battery.

**How it Works.** Electricity is generated in the dry cell by chemical reactions, which occur between the anode, cathode, and the electrolyte. If the anode and cathode are brought into contact through the electrolyte, an electrical potential will be developed between them. This potential ionizes the electrolyte. The ions in the electrolyte are atoms on which there is a positive or negative charge because they have either lost or gained an electron. These ionized atoms can then migrate through the electrolyte to either the anode or cathode. When an external circuit is wired across the cell, current flows between anode and cathode and the ions flow through the

electrolyte to maintain it.

The actual chemical reactions which go on inside the cell as it discharges are quite complex. In the process the zinc in the case dissolves into the electrolyte and becomes converted into zinc chloride and zinc oxide. In time, this case gets eaten away and the electrolyte becomes ineffective or leaks out (that's why some cells are clad in steel). When this happens, the internal resistance of the cell increases so that it can no longer deliver its normal load current. For a new cell the output voltage will be about 1.5 volts. As the cell discharges the voltage falls until it gets below 1 volt when the cell is considered dead and needs to be replaced.

**Recharging?** Ever since dry cells were first made there have been various attempts made to recharge them. If a direct voltage is applied across the cell so that current is driven back into it, the chemical reactions that occur in the cell tend to work in reverse (the zinc compounds in the electrolyte are converted back into pure zinc which forms on the case, and the electrolyte returns to its original state).

Unfortunately, not all of the chemical reactions operate in reverse so the cell cannot be restored completely to its original "as new" condition by recharging it. In fact, direct current (DC) charging makes the zinc "plate-out" unevenly, so holes will still appear in the case after a time and the cell will eventually die. Nevertheless, this type of charging can increase the effective life of a cell which saves you a few pennies

each time.

In the early 1950s it was found that an asymmetric method of charging gave better results. In this system the cell is charged during the positive half cycles of the AC supply and allowed to discharge slightly during the negative half cycles. It seems that this makes the zinc plate-out more evenly on the cell walls, so holes do not form so quickly. The cell also charges more efficiently.

**Charger Circuit.** The basic circuit for a charger suitable for use with dry cells is shown in this schematic. A small transformer is used to provide an AC supply of 24 volts at about 250 mA. Diode D1 is a small silicon rectifier such as the 1N4001; it half-wave rectifies the supply to produce a pulsating DC voltage across the cell. Resistor R1 limits the charging current fed into the cell. The second resistor (R2) provides the path for the discharge current which will flow when the diode stops conducting during the negative half cycle. The value of R2 is adjusted so that the reverse (discharge) current is about one tenth the forward (charge) current.

The amount of charging current depends upon the size of the battery and

varies from about 10 mA for a small 9-volt transistor battery up to about 125 mA for a size D flashlight cell. Values for R1 and R2 for some typical battery arrangements are given.

For other batteries or combinations of cells resistors R1 and R2 can be made variable and adjusted by experiment. With R2 out of circuit, adjust R1 so that the current into the cell is about the same as the current you intend to draw from it in use. Reconnect R2 and set it so that the reverse current through R2 is about 10% of the current of R1.

When using size AA or D flashlight cells, it is usually convenient to mount them into a plastic battery holder. These holders take four or six cells which are simply clipped into the holder and automatically connected in series to the holder terminals. Of course you could make your own cell holder and save money.

**Charging Technique.** Batteries are usually rated to deliver their normal discharge current continuously for about 10 hours. When they are used intermittently, say for 3 or 4 hours a day, the cells recover between periods of use and the life will be extended to a total

of about 20 to 25 hours.

When you recharge dry-cells it is best to recharge them regularly after every three or four hours use. This way the cell doesn't deteriorate too much before being recharged. It is best not to let the cell voltage fall below about 1.25 volts before recharging the cell. The length of charge is not critical and can be between 6 and 12 hours.

At the end of a charging session the voltage across each cell may be as high as 2 volts, but this will fall to the normal 1.4 to 1.5 volts quite quickly. If the cell gets hot while it is being charged, the current flowing into it is too high and *should be reduced!* If a cell starts to leak electrolyte, throw it away. You may be able to charge it, but the mess it will make is just not worth the trouble.

How much life can you expect to get from a typical dry cell? It depends a little on how long the cell was on the dealer's shelf before you got it. For a standard size AA penlight cell a life of better than 100 hours of intermittent service can probably be obtained by recharging the cell regularly. That's worth a few extra cents for sure! ■

## Resistive Pads

□ STOP TO THINK about the various meanings the word *pad* has! A dog has several on each paw; a hippy sleeps in one; this article was first drafted on one; and it's just another name for *attenuator*. Webster tells us that when something is attenuated, it is lessened or weakened—it is reduced in strength. However, attenuation is not a pad's primary function. It just happens to be a byproduct in most cases. Primarily, a pad is used to maintain impedance matching. Yet virtually all the pads that are used in audio work started out as attenuators and owe their design principles to attenuator theory. So it's the old "Which came first, the attenuator or the pad?" paradox, and to resolve it we have to start with attenuation.

**Resistance Networks.** The simplest attenuator is a series resistor in a circuit. It causes a voltage drop and dissipates a certain amount of electrical energy in the form of heat. The DC resistance of an ordinary carbon or wirewound resistor is measured in ohms.

A coil of wire has a certain resistance to the flow of direct current. But it has a different sort of resistance to alternating current, and this is called *impedance*. While impedance is also measured in ohms, it is measured at a specific frequency, since it varies with

changes in the frequency of the attenuating current. When the voice coil of a loudspeaker is said to have an impedance of 8 ohms, it is measured at 1,000 cycles. At 100 cycles and at 10,000 cycles, the voice coil's impedance will be different.

In virtually all audio amplifiers, the impedance of the speaker voice coil should "see" an equivalent impedance on the secondary of the output transformer. This equality is called an impedance match, and is very important for maximum efficiency and minimum distortion. The output transformers on high-fidelity and stereo amplifiers have several taps at different impedances for correct matching with the speaker voice coil.

**Attenuators.** When an attenuator is added to the circuit, naturally it is going to cause a change in circuit impedance, amount of power transfer, and general operating characteristics. A simple attenuator such as potentiometer R1 in Fig. 1 can be used as a local volume control. It will vary the volume level of the speaker, but at the cost of causing an impedance *mismatch*. If the secondary winding of the transformer has an impedance of 8 ohms and the total resistance across R1 is 8 ohms, then the transformer side of the circuit is perfectly matched with the wiper of R1

located at point A. But as the wiper is moved toward point B, the effective resistance connected across the speaker voice coil decreases, causing a serious mismatch.

This is where the pad network comes in. An ideal attenuator will cause variations in speaker volume without changing the impedance (resistance in this case) across the transformer of the voice coil. A fixed attenuator called a "T-pad" is shown in Fig. 2. In this type

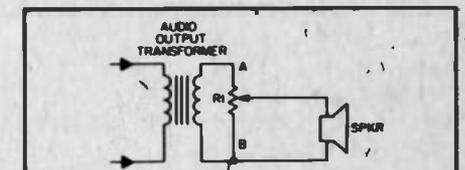


Fig. 1. Fader-type volume control for loudspeaker uses only one pot—but it's not practical in most cases.

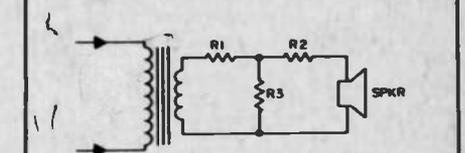


Fig. 2. A fixed T-pad gives equal impedance on both circuit ends—winding and loudspeaker see equal Z.

of pad, R1 will equal R2, while R3 is some other value selected to match the impedance on both sides of the circuit.

A variable version of the T-pad is shown in Fig. 3. This type of attenuator is commonly used as a local volume control for loudspeakers in high-fidelity installations. Generally, its function is to balance a system for differences in speaker efficiency, room acoustics, and, in the case of extension speakers, act as a volume control at the speaker location. These pads are generally mounted on the speaker cabinet.

Connected a different way, the T-pad is frequently used as a "brilliance" or a "presence" control. Such pads, usually factory-wired into a loudspeaker cabinet, vary the amount of signal that is fed to the high-frequency speaker.

The three resistors in Fig. 3—R1, R2, and R3—are "ganged." They are all mounted on the same shaft so that as the knob is rotated all three are varied by the same amount. The arrows in the drawing indicate the direction the wipers (center connections) move when the shaft of the pad is rotated clockwise to turn up the speaker volume. When the knob is turned to the full clockwise position for maximum volume, R1 and R2 are effectively shorted, providing a direct connection between points A and B with no loss. R3 will offer maximum resistance, permitting very little current to flow from one side of the circuit to the other. In this position, the speaker voice coil sees only the impedance of the output transformer secondary coil—just as if there were no pad in the circuit at all.

In the opposite position, fully counter-clockwise, R1 and R2 are at their maximum resistance and R3 is at minimum resistance. In this position, very little current can flow through the upper leg of the pad because of the high series

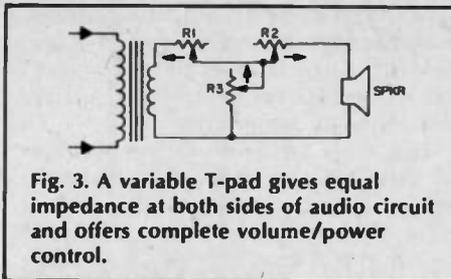


Fig. 3. A variable T-pad gives equal impedance at both sides of audio circuit and offers complete volume/power control.

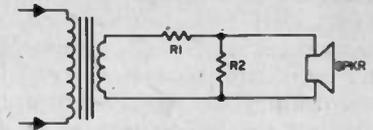


Fig. 4. The fixed L-pad has a very low energy or insertion loss. It's widely used to match two different impedances.

resistance. Any current flowing in the lower half is shorted to the upper branch through R3 which has become zero ohms—a direct short. The resistances have been selected so that the total resistance of the pad in this position, or any intermediate one, is always the same on both sides. This way, impedance matching is maintained.

#### Matching Different Impedances.

A pad is a versatile device and can be used for matching two very different impedances. A frequently used configuration is the L-pad, which is simply a T-pad with one resistor removed (see Fig. 4). An application for this pad would be matching an output transformer with a 500-ohm secondary to a 16-ohm speaker.

Another way of looking at an L-pad is shown in Fig. 5. Viewed this way, the pad looks like nothing more than a voltage divider, and that's exactly what it is! The total resistance of R1 and R2 should equal the nominal impedance of the transformer secondary coil. The resistance of R2 alone will equal the impedance of the voice coil. In the case of matching a 500-ohm secondary with a 16-ohm speaker, R1 would equal 492 ohms and R2 would be 16 ohms.

Naturally, whenever any pad (or attenuator, if you will) is placed in a speaker circuit, there will be a certain amount of power loss—the attenuation that gives its name to these devices.

Even in the case of a pad with low-value resistors, there will be some loss of energy and this is known as "insertion loss."

**Isolating with Pads.** Another application for the pad is isolating one part of a circuit from another. The need for isolation arises when a circuit has wide variations in impedances (usually due to frequency changes) and the associated circuit must be kept at a constant impedance. A typical circuit that must frequently be isolated is the equalizing network in a high-fidelity preamplifier. Another instance is the output signal from a program source such as a tape recorder that is coupled to an amplifier circuit that requires constant impedance.

Effective isolation is possible with an H-pad shown in Fig. 6. The network resistance is the same at both the input and the output, providing good impedance matching. But the resistance of the network is high enough to prevent any impedance variations from being transferred from one side to the other.

The amount of actual attenuation in any pad depends on the resistance values of the total networks. There will always be a certain amount of insertion loss, even with the so-called "low-loss" types, such as the L-pad.

**Signal Dividing.** A commonly used pad is the two-set coupler for simultaneously operating two TV sets from the same antenna. The H-pad is usually used. Fig. 6 shows how the connections are made. The input from the antenna is across resistor R1, and the two TV sets (or one TV set and FM tuner) are connected to the two opposite sides of the "H." Even with careful impedance matching, the insertion loss is so high that couplers of this type are practical only in strong signal areas.

Some manufacturers make "powered-couplers"—signal dividers with a tube or transistor amplifier in the circuit. They overcome the insertion loss of the resistor network, and in some cases can provide enough gain to drive three or more TV sets.

**Audio Mixers.** A simple resistance network is often used for mixing two

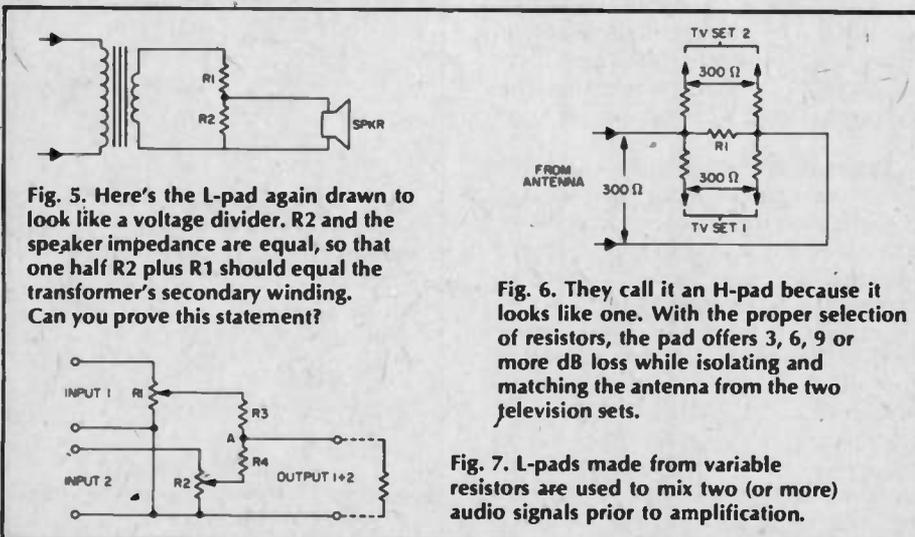


Fig. 5. Here's the L-pad again drawn to look like a voltage divider. R2 and the speaker impedance are equal, so that one half R2 plus R1 should equal the transformer's secondary winding. Can you prove this statement?

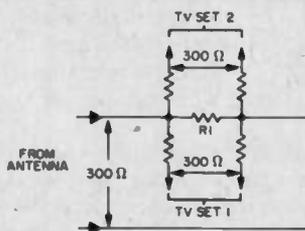


Fig. 6. They call it an H-pad because it looks like one. With the proper selection of resistors, the pad offers 3, 6, 9 or more dB loss while isolating and matching the antenna from the two television sets.

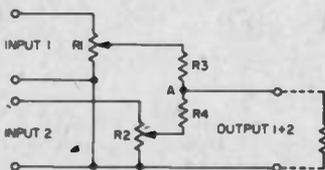


Fig. 7. L-pads made from variable resistors are used to mix two (or more) audio signals prior to amplification.

different signals—such as from two microphones or from a microphone and a record player—for making home tape recordings. Fig. 7 shows a circuit of this kind. Resistors R1 and R2 are, in effect, variable L-pad controls, and can vary the amount of attenuation of the input signal. R3 and R4 form the other loss of the L-pad or voltage divider. Since

they are of equal resistance, the signal voltage at their common point, A, will be a mixture of the signals from the center taps of both R1 and R2.

While this simple mixer will do its intended job effectively, like the H-pad TV set coupler, there will be some insertion loss. This loss will be minimal if the amplifiers used with the mixers

have enough gain. Many mixers are of the powered type—that is, they have a tube or transistor at the output. This will provide enough gain to overcome the insertion loss of the attenuator. A transistor in the output has the additional advantage of constant impedance and will provide better matching over a wide frequency range. ■

## Prefixes and Exponents

□ ANYONE WHO'S DIPPED his little toe into electronics is certain to have run across such terms as *microFarad*, *milli-Henry*, and *milliAmpere*—not to mention *megaHertz*, *megOhm*, and *kilo-Hertz*. The prefixes here, *micro-*, *milli-*, *mega-*, and *kilo-*, are an important part of the electronic vocabulary. It follows, then, that anyone who wants to be proficient in electronics will have to develop skill in understanding and using them.

These prefixes are used to change the value of an electronic unit of measure. For example, if you see a resistor with the familiar brown/black/green color code, you *could* call it a 1,000,000-ohm resistor. The thing is, it's usually less awkward to call it a 1-megohm resistor. Putting the prefix *meg-* or *mega-* before the Ohm inflates the value of the unit, Ohm, by 1,000,000 times.

Similarly, one kiloVolt is recognizable as 1,000 Volts, and one kiloHertz as 1,000 Hertz, and so on. These prefixes are usually so automatic with electronics aficionados that they will invariably refer to a millionaire as a guy who has one megabuck!

**The Debit Side.** At the other end of the scale, the *milli-* and *micro-* prefixes are useful for shrinking units. A Farad, for example, is too big a unit to use in everyday electronics. In dealing with the real-life capacitors (the kind you solder into circuits), we normally use a basic unit of *one-millionth* of a Farad—a *microFarad*. The prefix *micro-* cuts up a unit into a million tiny slices, enabling us to use one such slice as a convenient-sized unit. A microAmpere, similarly, is a millionth of an Ampere; a microVolt, one millionth of a Volt.

If you need larger slices, the *milli-* prefix is available, which provides a unit only one-thousandth the size of the basic unit. A milliAmpere, for example, is a thousandth of an Ampere; that is, it takes 1000 mA (milliAmperes) to equal 1 Ampere.

To handle these tiny slices of units, it's wise to spend a few minutes learning *scientific notation*, which is designed to make it easy to handle very large and

very small numbers. Once you've mastered this technique, you can manipulate all the various-sized units of electronics as easily as you can add two and two!

Take, for example, the familiar *kilo-Hertz* (known at one time as the *kilocycle*). A broadcasting station operating at 840 kHz (kiloHertz) in the broadcasting band is radiating 840,000 cycles of RF energy every second. To change from 840 kHz to 840,000 Hz, you can think of the "kilo-" as being replaced by "x 1000", thus:

840            kilo        Hertz  
 840            × 1000     Hertz  
 840,000       Hertz

But you can also write "1000" as "10 x 10 x 10". And you can write "10 x 10 x 10" as "10<sup>3</sup>". (Ten to the third power, or ten cubed.) As we develop these ideas further, you will see how you can greatly simplify your future work in electronics by thinking of the prefix "kilo-" as being replaceable by "x 10<sup>3</sup>", thus:

$$840 \text{ kiloHertz} = 840 \times 10^3 \text{ Hertz}$$

### ELECTRONIC PREFIXES AND THEIR MEANINGS

Prefix	Pronunciation	Symbol	Exponent	Example
tera-	TEHR-uh	T	10 <sup>12</sup>	Frequency of infrared light is approx. 1 teraHertz
giga-	GIG-uh	G	10 <sup>9</sup>	Frequency of TV channel 82 is approx. 1 gigaHertz
mega-	MEG-uh	M	10 <sup>6</sup>	Frequency of typical shortwave broadcast station is approx. 1 megaHertz
kilo-	KILL-oh	k	10 <sup>3</sup>	Top note on a piano is approx. 4 kiloHertz
hecto-	HEK-toh	h	10 <sup>2</sup>	(not often used in electronics)
deka-	DEK-uh	da	10 <sup>1</sup>	(not often used in electronics)
deci-	DESS-ih	d	10 <sup>-1</sup>	A decibel is 1/10th bel
centi-	SENT-ih	c	10 <sup>-2</sup>	Wavelength of TV channel 82 is approx. 30 centimeters
milli-	MILL-ee	m	10 <sup>-3</sup>	Collector current of a typical small transistor is approx. 1 milliAmpere
micro-	MY-kroh	μ	10 <sup>-6</sup>	Base current of a typical small transistor is approx. 20 micro-Amperes
nano-	NAN-oh	n	10 <sup>-9</sup>	Time for a radio wave to travel 1 foot is approx. 1 nanosecond
pico-	PY-koh	p	10 <sup>-12</sup>	Collector-to-base capacity of a good high-frequency transistor is approx. 1 picoFarad
femto-	FEM-toh	f	10 <sup>-15</sup>	Resistance of 6 microinches of 0000 gauge wire is approx. 1 femtoOhm
atto-	AT-toh	a	10 <sup>-18</sup>	6 electrons per second is 1 atto-Ampere

Similarly, a 6.8 megohm resistor, measured on an ohmmeter, will indicate 6,800,000 ohms. In this case, the prefix "meg-" can be replaced by "x 1,000,000":

6.8	meg	Ohms
6.8	x 1,000,000	Ohms
6,800,000		Ohms

But you can write "1,000,000" as "10 x 10 x 10 x 10 x 10 x 10" (six of 'em; count 'em), which is 10<sup>6</sup>. Thus, you should learn to mentally replace "meg-" with x 10<sup>6</sup>, so that 6.8 megOhms becomes a 6.8 x 10<sup>6</sup> Ohms. The 6 is called an *exponent*, and shows how many 10s are multiplied together.

**The Minus Crowd.** What about the "milli-" and "micro-" prefixes? "Milli-", we've said, is one-thousandth; in a way, it is the opposite of the "kilo-" prefix. Make a mental note, then, that millican be replaced with "10<sup>-3</sup>" (read as "ten to the minus three power"), which is 1/10 x 1/10 x 1/10 = 1/1000. Similarly, the "micro-" prefix can be considered as the opposite of "meg-", and replaced by 10<sup>-6</sup>.

The beauty of this approach appears when you are faced with a practical problem, such as, "if 1.2 milliAmperes flows through 3.3 megOhms, what voltage appears across the resistor?" From our knowledge of Ohm's law, we know that E = IR; that is, to get Volts (E) we multiply current (I) times resistance (R). Without the aid of scientific notation, the problem is to multiply 0.0012 Amperes by 3,300,000 Ohms, which is rather awkward to carry out. The same problem, however, is very easy in scientific notation, as can be seen below:

$$\begin{array}{r} 1.2 \times 10^3 \\ 3.3 \times 10^6 \\ \hline 3.96 \times 10^9 \end{array}$$

The answer is 3.96 x 10<sup>3</sup> Volts, or 3.96 kiloVolts. We obtained the answer by multiplying 1.2 x 3.3 to get 3.96, and adding the -3 exponent to the 6 exponent to get 3 for the exponent of the answer. The advantage of scientific notation is that the largeness and smallness of the numbers involved is indicated by numbers like 10<sup>6</sup> and 10<sup>-3</sup>, and the largeness or smallness of the answer is found by *adding* the 6 and the -3.

What about a division problem? For the sake of a good illustrative example, consider the unlikely problem of finding the current when 4.8 megaVolts is applied across 2 kilOhms. The problem is written as:

$$I = \frac{E}{R}$$

$$= \frac{4.8 \text{ megaVolts}}{2 \text{ kilOhms}} = \frac{4.8 \times 10^6 \text{ Volts}}{2.0 \times 10^3 \text{ Ohms}}$$

$$4.8 \div 2 = 2.4$$

$$2.4 \times 10^3 \text{ Amperes} = 2.4 \text{ kiloAmperes}$$

In division, then finding the size of the answer becomes a *subtraction* problem, in which the exponent representing the size of the divisor ("bottom" number) is subtracted from the exponent representing the size of the dividend ("top" number).

A more practical division problem answers the question, "What current flows when 5 Volts is applied across 2.5 kilOhms?"

$$I = \frac{E}{R} = \frac{5 \text{ Volts}}{2.5 \text{ kilOhms}}$$

$$= \frac{5.0 \times 10^0}{2.5 \times 10^3} = \frac{5.0 \times 10^{(0-3)}}{2.5}$$

$$= 2.0 \times 10^{-3} \text{ Amperes}$$

$$= 2.0 \text{ milliAmperes}$$

Note that it's perfectly legal to use 10<sup>0</sup> (ten to the zero power) to indicate a unit that has no prefix—in other words, one of anything.

**For the Solving.** Here are a few more problems:

1. The inductive reactance of a coil is given by

$$X_L = 2\pi fL$$

What is the reactance of a coil whose inductance L = 22 milliHenries, when an alternating current of frequency f = 1.5 megaHertz is applied to it?

$$X_L = 2 \times \pi \times (1.5 \times 10^6) \times (22 \times 10^{-3})$$

$$= 207.24 \times 10^3 \text{ Ohms}$$

$$= 207.24 \text{ kilOhms}$$

2. An oscillator is connected to a wavelength-measuring apparatus, and the wavelength of its oscillations is determined to be 2.1 meters. What is the frequency of the oscillator?

$$F = \frac{\text{speed of light}}{\text{wavelength}}$$

$$= \frac{3.0 \times 10^8 \text{ meters per second}}{2.1 \text{ meters}}$$

$$= \frac{3.0 \times 10^8}{2.1 \times 10^0} = 1.4286 \times 10^8 \text{ Hertz}$$

We wish this answer had come out with a "10<sup>8</sup>", instead of a "10<sup>8</sup>", because we can convert 10<sup>8</sup> Hertz directly to megaHertz. However, we can change the answer to 10<sup>6</sup>, by shifting the decimal point of the 1.4286. Remember this rule: To *lower* the exponent, shift

the decimal point to the *right*. (Of course, the opposite rule is also true.) Since we wish to lower the exponent by 2, we must shift the decimal point to the right by two places:

$$142.86 \times 10^6 \text{ Hertz} = 142.86 \text{ megaHertz}$$

3. A 3.3 microfarad capacitor is being charged from a 20-volt battery through a 6.8-kilOhm resistor. It charges to half the battery voltage in a time given by

$$T = 0.69RC$$

For the particular values given in the problem, what is the time taken to charge to half the battery voltage?

$$T = 0.69 \times (6.8 \times 10^3) \times (3.3 \times 10^{-6})$$

$$= 15.4 \text{ milliseconds}$$

**Tera to Atto.** Since scientific notation is so potent, you'll probably be interested in the meaning of *all* the prefixes used in the scientific community, not just the four (micro-, milli-, kilo-, and mega-)-that we've discussed so far. Very common in electronics is the *micro-microFarad*, which is 10<sup>-6</sup> x 10<sup>-6</sup> Farad, or 10<sup>-12</sup> Farad. This is more commonly known as the *picoFarad*. Similarly, a thousandth of a microAmpere is 10<sup>-3</sup> x 10<sup>-6</sup> Ampere, or 10<sup>-9</sup> Ampere. This is known as a nanoAmpere. At the other extreme, 1000 megaHertz is called a gigaHertz. See the table of all these prefixes for a rundown of their meanings and pronunciations.

The jargon of electronics which has grown up around their prefixes is just as important as the prefixes themselves. Here are some examples of "jargonized" prefixes as they might appear in speech:

**Puff**—a picoFarad (from the abbreviation, PF).

**Mickey-mike**—a micro-microFarad (which is the same as a puff).

**Meg**—a megohm. Also, less often, a megaHertz.

**Mill**—a milliAmpere.

**Megger**—a device for measuring megOhms.

**dB** (pronounced "dee-bee")—a decibel, which is one-tenth of a Bel.

**Mike**—a microFarad. Also, to measure with a micrometer.

So, if you understand the prefixes and know their corresponding exponents, you'll have command of another set of important tools to help you do practical work in electronics. In addition, you'll be ready for the inevitable wise guy who'll ask if you can tell him the reactance of a 100-puff capacitor at 200 gigaHertz. After calculating the answer in gigaseconds, reply in femto-Ohms!

# Fuses and Circuit Breakers

□ FOR TWO BITS or less you can protect \$500 when you consider that an inexpensive fuse protects a costly color TV set. Would you believe ten cents worth of electric protection saves \$35,000? Fuses also keep the house from burning down. The little zinc links can pop in picoseconds or broil hours before blowing. Hundreds of fuses and circuit breakers safeguard electronic equipment against shortcircuit damage, momentary surges, or slow overload. Pick the right one and you'll never put a penny in the fuse box, wrap cigarette foil around a glass fuse, or jump wire across cartridge clips—all dangerous dodges of those who refuse to re-fuse.

**Thar' She Blows.** Edison made the first fuse before 1900 by enclosing a thin wire in a lamp base. As an intentionally weakened part of the circuit, the wire acted as a safety valve which melted from excessive current. Trouble was, early fuses were nearly as dangerous as the condition they were designed to prevent. Fuse wire fashioned from copper had to reach a dangerous temperature before blowing. This is now cured by changing to metal alloys of lower melting point.

You can see another problem by observing how a fuse blows. See Fig. 1. The link begins to overheat in the slim center region. Overheating begins at this point since the wider ends of the link are better able to radiate heat. Soon the melted center drops away.

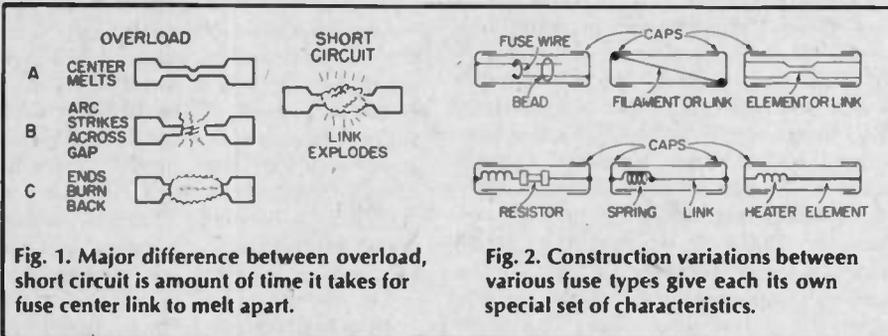


Fig. 1. Major difference between overload, short circuit is amount of time it takes for fuse center link to melt apart.

This supposedly ruptures the circuit, but a second effect takes over. Circuit voltage is still applied across the narrow gap in the link and it strikes an electrical arc. This burns back metal toward each end until increasing electrical resistance kills the arc. That happens during a simple overload. But everything's vastly speeded up for a dead short.

You can see in Fig. 1 that a total short circuit explodes the link. The whole center section, in fact, suddenly vaporizes. And the vapor itself becomes a good electrical conductor—so the arc

keeps snapping dangerously across the gap. Is that a safety valve?

Today's fuses are not lethal weapons because of certain refinements in construction. The larger, cartridge-type fuses contain a powdery filler material that quenches the arc through cooling and condensing the metal vapor. In smaller fuses, sturdy, insulated tubes of glass or porcelain provide necessary protection. See Fig. 2. One manufacturer states (with a Gothic turn of phrase) that today's fuse won't "belch fire."

**Vengeful Volts.** Most talk about fuses concerns amperage and how various types respond to current flow. Yet all fuses are rated by volts. This relates to the explosive fury of a fuse gone wrong. Although a fuse may have a well-insulated holder, certain conditions may cause voltage to soar dangerously as the fuse blows.

If it's protecting a circuit that contains a coil, for example, sudden interruption may cause an "inductive" kick to feed back to the fuse terminals. It could be sufficiently high to shatter the holder. Voltage ratings assigned to fuses, though, are quite conservative.

When a fuse is rated at 125 volts, for example, it refers to a standard test performed by the manufacturer. He assumes that the fuse will not shatter on this voltage when subjected to a short circuit with the colossal current of 10,000 amperes! Unless you're protecting a private power generating plant,

current (to charge big filter capacitors in the power supply, for example) might cause the fuse link to let go. And some devices, like an electric motor, draw starting currents far greater than normal running amperage.

At the other extreme, a delicate test instrument might be destroyed if the fuse didn't speedily break the circuit. These variations introduce time as an element that's just as important as the number of amperes. Some fuses have a built-in mechanism that decides whether to blow fast or slow, depending on circuit conditions.

But, first, what does a fuse rating actually mean? Simply saying that a fuse in a car radio is rated at 7½ amps doesn't tell the whole story. The 7½-amp figure means the fuse can carry that current indefinitely. Determining the current needed to melt the fuse must also reckon with overload time.

A typical automobile fuse might take fully four hours to blow when the fuse's rated current reaches 110 percent—which is amps times 1.1. This would happen as the radio drew 8¼ amps through the fuse (or 7.5 X 1.1). This is not a severe overload and the radio is still protected.

But if a short-circuit caused current to zoom to double the fuse rating—or 200 percent—the fuse promptly pops within 20 seconds. Higher percentages of overload would even speed up the process. Thus the radio continues to operate during minor surges. It won't blow the fuse unless overload current threatens irreversible damage to its components.

Not all devices need this brand of protection. To cope with a wide range of equipment, fuses are manufactured in three broad categories that relate to blowing times: *Medium Lag*, *Quick-Acting*, and *Time Delay*. A look at these types reveals that fuses might have the same ampere rating but behave in quite different fashions.

**Medium Lag.** This is the most common type you're apt to encounter. It also goes under the name "Normal Lag" or "Standard." This is the fuse for auto and other radios, amplifiers, TV sets, heaters, and lighting circuits. If you want an idea of how such a fuse behaves, check the curve marked "Medium" in Fig. 3. It reveals, for example, that at 200 percent of rated current (two times), the fuse typically blows in about 5 or 6 seconds. The greater the overload, the faster the action.

Common fuses in the medium category are the S.F.E. types (for automo-

your electronic equipment subjects the fuse to a piddling fraction of those ratings. Thus circuit voltages may usually be higher than fuse voltage rating without undue hazard.

**Twin Ratings.** The job of choosing a fuse would be simple if it merely meant measuring a circuit you wish to protect, then selecting a type to blow on slightly higher amperage. A hi-fi amplifier might operate with AC line current of 1.4 amps, but a 1.5-amp fuse would be a poor choice. It would cause much "nuisance" blowing. Whenever you turned on the amplifier, a sudden inrush of

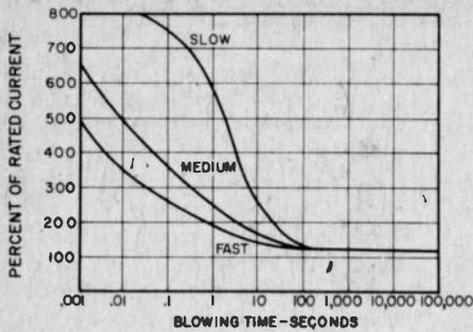


Fig. 3. Note how slow-blow fuse takes considerably longer time for a current surge to open the circuit the fuse protects.

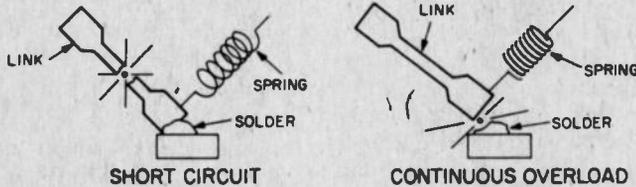


Fig. 4. The dual-purpose mechanism of a slow-blow fuse allows it to withstand momentary surges and overloads, typically up to 400% of rated circuit current.

biles) and 3AG by Littelfuse. There's also the AGC type made by Bussmann. The letters "AG", incidentally, originally meant "automotive glass."

As the "AG" number rose so did amperage rating and physical length. This was intended to foil any attempt to insert a fuse of excessive rating into a holder. So many new fuse types have appeared, however, that the system is all but abandoned. "AG" is no longer a reliable index of fuse size.

**Quick-Acting.** This fuse category is also known as "Instrument" or "Fast-Acting." As the name implies, this kind of fuse blows faster than the medium type. It's useful for delicate instruments, meters, and other devices that can't tolerate even small overload currents for any length of time. The fuse element is very fine and low mass, causes it to melt at rates marked "Fast Blow" in Fig. 3. Note that at 200 percent rated current, the fuse expires in less than a second.

**Slow-Blow.** Also known as the "slow-acting," "time-delay" or "time-lag" fuse, this type lets a strong surge through the circuit without blowing, but protects against shorts and overloads. It is especially useful for motors, switching circuits and TV receivers. Special dual construction enables the fuse to operate in two ways.

As shown in Fig. 4, the fuse contains the regular fusible link found in other types. It is designed to blow only during extreme short-circuit conditions. The second mode of operation occurs during a continuing overload condition, far longer than a temporary surge. This causes heat to build near the spring portion. If of sufficient duration, the heat

softens the low-melting solder and the spring pulls the link to break the circuit. The slow-blow fuse is often applied in circuits that can tolerate currents of about 400 percent normal for 1 to 10 seconds.

**Specials.** As you can see in Fig. 5, there are many variations in fuses to meet special applications. Some fuses signal when they've blown, others are tightly enclosed to prevent radio-frequency interference pickup (a problem in space vehicles). There are sub-miniature fuses, as well as high-reliability types with gold-plated caps that survive high-G forces.

One novel type found in many TV sets is the *fusible resistor*, a combination of fuse and resistor. It's often used where solid-state rectifiers occur in the TV power supply. When the set is first turned on, a heavy inrush of current must be limited by a small-value resistor (usually less than 10 ohms) to protect the rectifiers. By making a resistance element with fuse-like qualities a single component, the fusible resistor does the job of two parts. The component is often mounted with plug-in

pins for convenient replacement.

**Circuit Breakers.** A leading contender in the fuse field is the circuit breaker. See Fig. 6. It's found on many major appliances and the newer TV sets. The attraction is obvious: you just press a red button after an overload. No need to hunt for a fuse.

As you can see by the curve in Fig. 7, the breaker behaves like a fuse, permitting brief overload current to pass but tripping when the fault looks serious.

What happens, though, when a determined TV-viewer sees sound and picture fade just as the 5:40 comes roaring down on Millicent, tied to the track for not paying the you-know-what? Our viewer leaps behind the set, pushes the red panic button—and holds it down in an effort to restore the program. If the breaker had tripped on a severe short-circuit, not just a transient, our viewer might as well join Millicent. Yet the story has a happy ending since the breaker is viewerproof. The red button must be released before the circuit breaker closes.

The chart in Fig. 8 shows typical ratings for several Mallory breakers. Note in all units that breaking the current is somewhat higher than operating current, but allowable surge current is much higher than either rating. Tripping time is ten seconds or less after breaking current is reached.

The circuit breaker is also replacing certain fuses in the automotive field. It's chiefly used in high-current circuits such as headlights, convertible top motors, and window motors. The car breakers, however, automatically reset themselves when the overload no longer exists. Not only is it convenient, but a bi-metal element of the breaker won't suffer a common fault of fuses in these circuits—fatigue. Fuses tend to fail when cycled repeatedly at high (though normal) on-off currents. (Fatigue also explains mysterious fuse failure in radio and TV sets when no circuit fault exists.)

**How Many Amps?** The equipment designer has already done the job of figur-

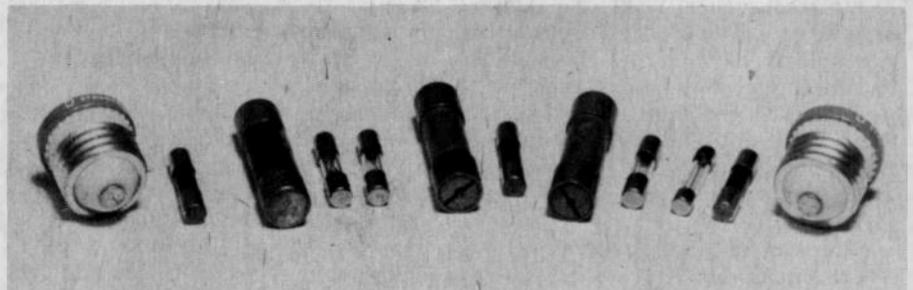


Fig. 5. Three different fuse styles are shown, but each has its own current rating. NEVER substitute like-styled fuse of higher amp rating for lower-amps-rated one.

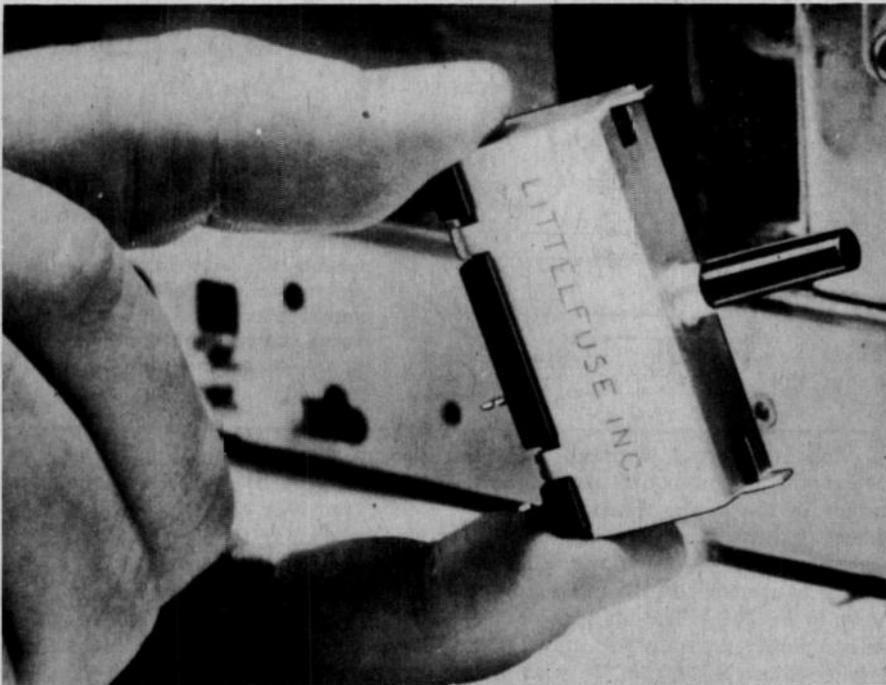


Fig. 6. Forget that box of spare fuses you keep at arms distance from your TV. Circuit breaker eliminates need for replaceable fuse, can be reset as often as needed. Press cylindrical-shaped button located on top of circuit breaker after you find fault; your TV is once again protected. Breakers come in many ratings.

ing the right fuse for his electronic gear. When the fuse blows—and the fault cured—the replacement fuse may merely duplicate the original. But if you home-brew equipment, you'll have to do some calculations to obtain the fuse rating. We've talked of fuse ratings but this is not the same as current consumed by the equipment being protected. To avoid nuisance blowing, the fuse almost always should be able to conduct more current than is drawn by the equipment.

It is considered good practice not to load a medium-blow fuse by more than 75 to 80 percent of its rating in amperes. To translate this into a practical value, you must know the number of amperes consumed by the equipment during normal operation.

Let's say it is 4 amps. This number, therefore, should be 75 percent of the fuse rating. To find the answer, divide 4 by .75. The result is 5.3 amps, the fuse rating. This is an odd value, so select the next *highest* standard fuse size, which is 6 amps.

You'll find suitable types in the catalogs to fit into clips, an extractor post or to be soldered directly into the circuit with pigtail leads. Most common physical size for electronic gear is the glass 3AG or AGC type (1/4" x 1 1/4").

If you check commercial circuits, chances are you'll find that the fuse is operated at 50 (not 75 or 80) percent of its rating. This is another way of saying the fuse rating is double the load

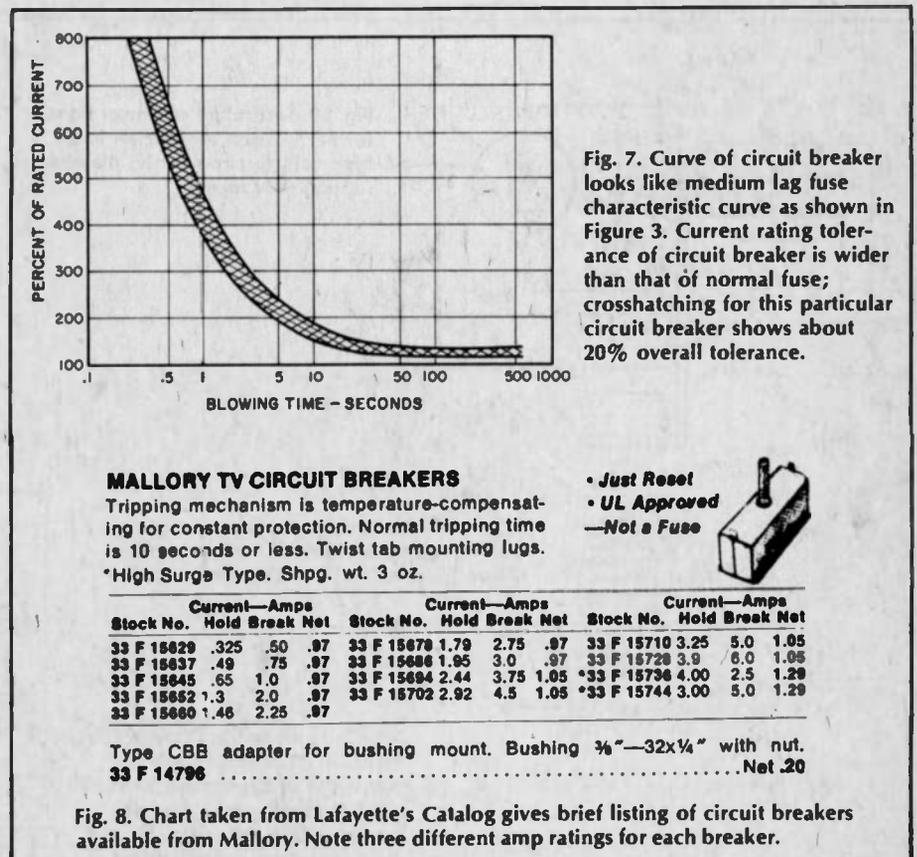
current. A car radio, for example, might draw 3 to 4 amperes, but the fuse is usually 7 1/2 or 9 amps.

You can also follow this practice, especially if your circuit is subject to

temporary surges. This may seem like overfusing the circuit but the fuse should melt before anything is damaged (and it is less subject to nuisance blowing).

When equipment will certainly cause temporary overloads several times normal circuit current, then choose a time-lag or slow-blow fuse. Recall that it has a dual element to cope with this condition. It withstands brief overloads of several times normal current. With this kind of surge protection, it is common practice to select the rating of a slow-blow at a somewhat higher figure than the medium type. It should be about 80 to 90 percent. To convert this into a slow-blow fuse rating, measure the circuit's normal current and divide it by .8 or .9 for the fuse amperage.

**Where to Fuse.** There's some compromise in where to locate a fuse for maximum circuit protection. Fig. 9, a typical full-wave power supply, shows why. The fuse is inserted in one leg of the incoming AC power line. Since the fuse is situated at the closest point to the power source, it provides overall protection. If a defect develops in some circuit, however, there's a chance the fuse will not blow for, say, a shorted bypass capacitor that doesn't create enough excess fuse current. It could burn out a few resistors in the process. The expensive power transformer, however, gets a reasonable



degree of protection with this system.

More sensitive fusing occurs in Fig. 10. With the fuse in the centertap of the transformer, it responds only to changes in the B+ current. Since this bypasses high currents consumed by tube filaments, the fuse can be much smaller and is responsive to partial shorts in the remaining circuits. A variation of this is in Fig. 11: a half-wave supply that might be found in an AC-DC table radio. Only here there's a fusible resistor of the type described earlier. Since you can obtain a fusible resistor locally or from electronic parts houses, why not modify your table radio today!

This leaves the problem of fusing filaments. Although a conventional fuse can be used to protect the filaments, you might borrow a trick used in some circuits.

Shown in Fig. 12 is the system used in some color TV sets, one of the more thoroughly protected home-entertainment devices. There are no less than three techniques to guard against overcurrent. In one leg of the primary lead is a thermistor. Although it is not a breaker-type device, it prolongs the life of the circuit by slowing the inrush of current when the set is first turned on. It might present 120 ohms when cold, thus limiting current, but electrically disappears when hot since it sinks to just

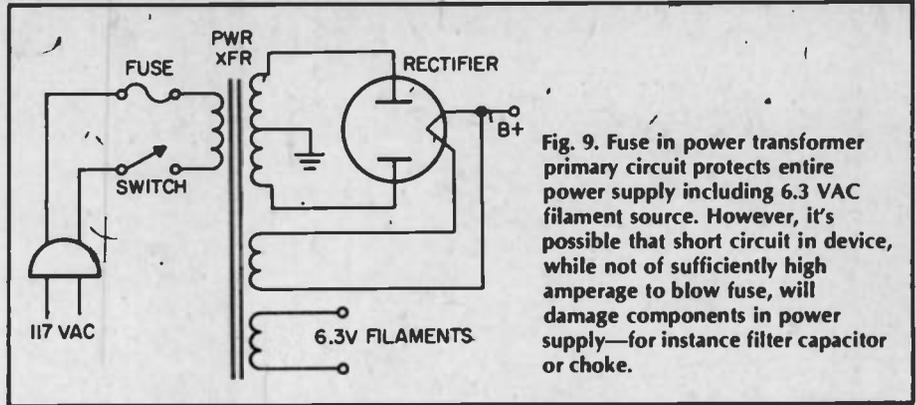


Fig. 9. Fuse in power transformer primary circuit protects entire power supply including 6.3 VAC filament source. However, it's possible that short circuit in device, while not of sufficiently high amperage to blow fuse, will damage components in power supply—for instance filter capacitor or choke.

1.5 ohms after circuit warmup.

Next site of protection is a circuit breaker in the power transformer secondary. It trips during overload anywhere along the B+ leg in the receiver. (This is equivalent to the centertap fuse shown in Fig. 10.) The filament circuit has completely separate protection. It is merely a short link of No. 26 wire that melts when a short exists along the filament supply. There's little hazard since voltage is only 6.3 VAC and serious arcing won't occur.

**Fusing Transistors.** There have been attempts to protect transistors by fusing, but fuses generally will not react fast enough. Techniques which use additional semiconductors (such as diodes) provide a better solution. There is,

though, some consideration in fusing the power supply of solid-state equipment. Since transistor circuit voltages are significantly lower than those encountered in tube circuits, the resistance of the fuse becomes increasingly important. It may be an ohm or less, but this introduces a new element that might affect the operation of a delicate circuit. Two solutions are possible: use the largest fuse size consistent with circuit protection (since this reduces resistance), or install the fuse in the primary side of the 117 volts of alternating current.

**Getting Clipped.** How a fuse mounts is more important than is generally believed. Much trouble with nuisance blowing has been traced to defective fuse clips or holders. Poor contact between clips and fuse produces hot spots that blow the fuse prematurely. It may also introduce electrical resistance that upsets the circuit being protected.

One manufacturer suggests the following: you should hear a resounding "snap" when inserting a fuse into clips—it signals good grip strength. And you should have to pry a defective fuse from its clips. Since dirty clips are a frequent cause of trouble, shine them with contact cleaner. Just be sure to remove the AC plug from the wall outlet before touching any contact with your fingers. It helps reduce the con-fuse-ion.

Always remember: fuses protect valu-

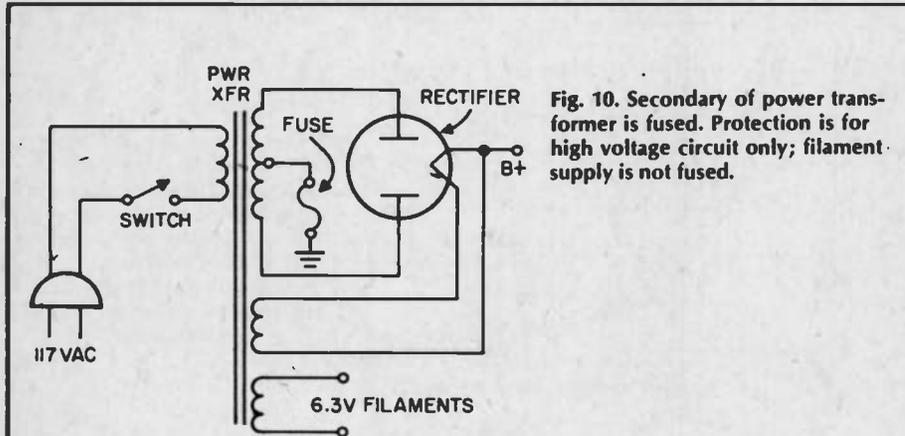


Fig. 10. Secondary of power transformer is fused. Protection is for high voltage circuit only; filament supply is not fused.

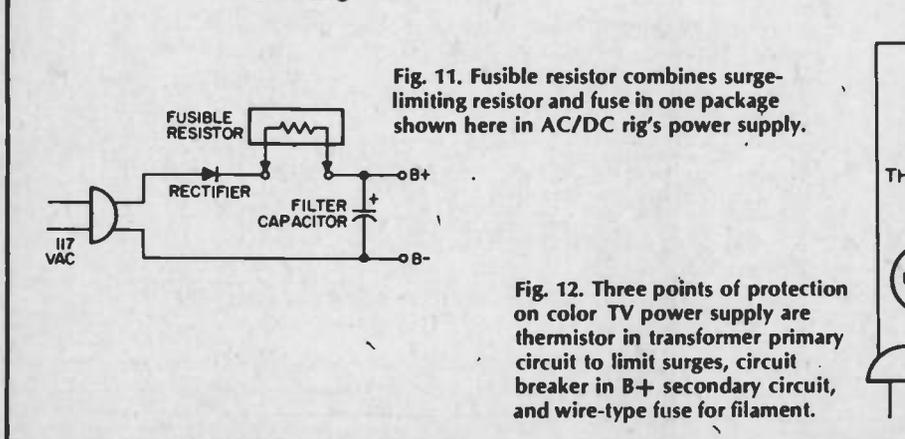
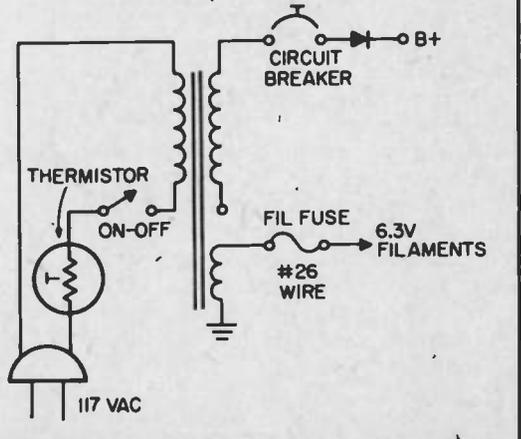


Fig. 11. Fusible resistor combines surge-limiting resistor and fuse in one package shown here in AC/DC rig's power supply.

Fig. 12. Three points of protection on color TV power supply are thermistor in transformer primary circuit to limit surges, circuit breaker in B+ secondary circuit, and wire-type fuse for filament.



able equipment from going up in smoke and eliminate dangers to human life.

By overriding an existing fuse circuit with a penny, jumper, or oversized fuse,

you may be putting a hole in your pocketbook—or one in the ground. ■

# Parallel Resistance Nomograph

□ WHETHER YOU'RE WORKING at home on the final stages of a pet project or on the job servicing an electronic system, nothing is quite as frustrating as discovering that the resistance value you need isn't available. And, your usual source of supply either is closed or doesn't stock the particular value. Or maybe you want a resistance within a tolerance of 1%, and just don't feel justified in paying the extra cost.

Whatever the problem, the experienced guy doesn't lose his cool, because he knows he can come up with any resistor value he needs by connecting available resistors in series and/or parallel. This combination can either be left in the circuit or replaced at some later time with a single resistor.

**Making Resistors.** Making resistors by *series-ing* several resistors to reach a desired value poses no problem as the resistances are additive; i.e., if you connect a 51-ohm resistor in series with a 68-ohm resistor the final resistance of the combination is 119 ohms.

However, when you parallel resistors, the resultant resistance is no longer so

easy to calculate. If you connect a 51-ohm resistor in parallel with a 68-ohm resistor the net resistance value is about 29 ohms. About the only thing you know is that the equivalent resistance of a parallel combination will be less than the value of the smallest resistor in the combination. You can't determine the equivalent resistance of a parallel combination with simple mathematics. The formula isn't complex, but it does take time to write down and solve. The easiest, fastest modern method for determining the values of parallel resistor combinations for the serviceman is by using an equivalent resistance nomograph.

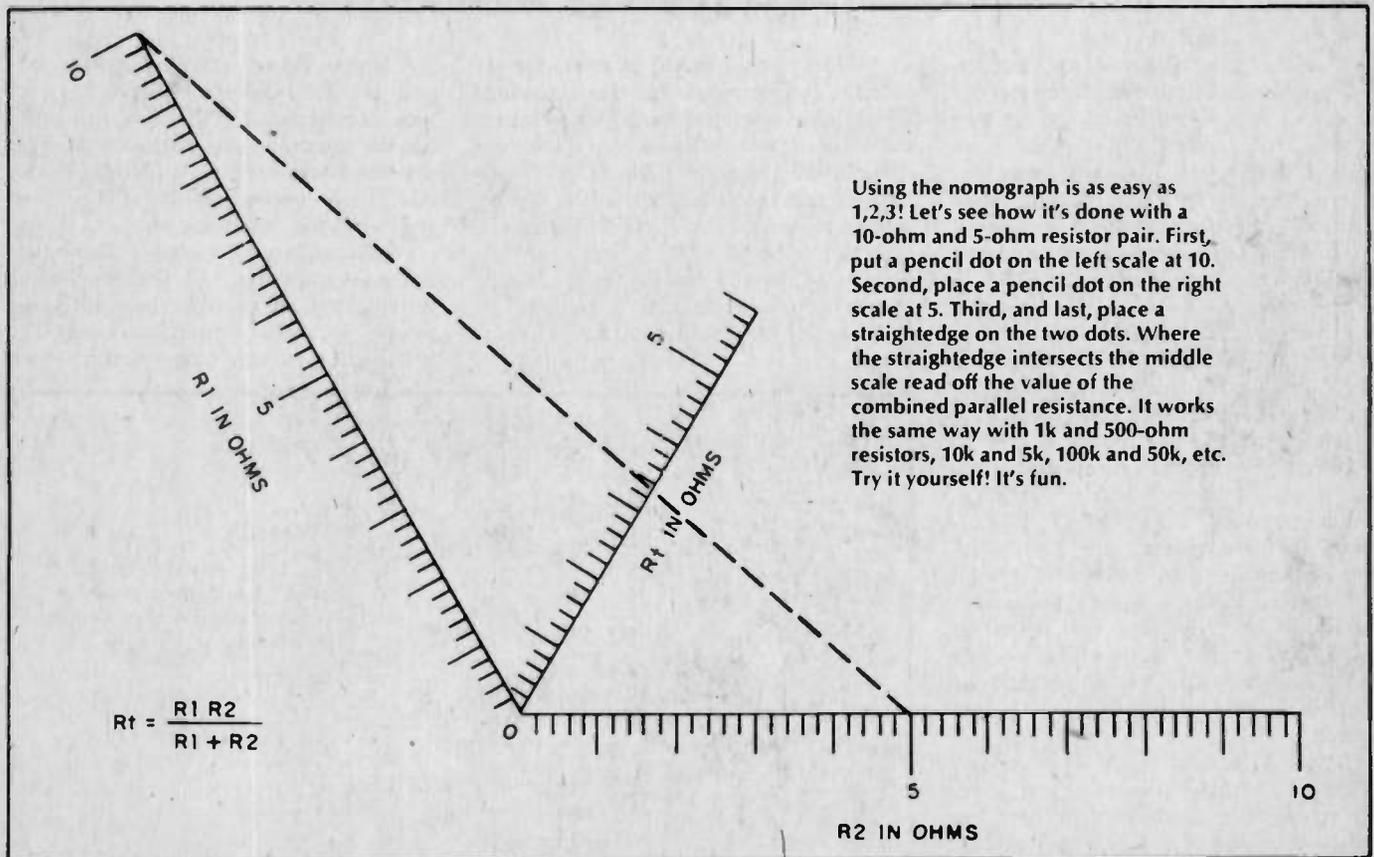
**What's A Nomograph?** Everyone's familiar with the old old Chinese proverb about one picture worth a thousand words. A nomograph is simply a graphic picture of a simple approach to solving a mathematical calculation. And technicians in all fields are using nomographs in ever-increasing numbers. A nomograph can be constructed to solve almost any problem, and though the actual construction may require a master's

degree in math, anyone can use the final end product to solve problems which might normally require a college degree and bushels of valuable time.

This is one of the most appealing features of most nomographs, i.e., that you don't need theoretical knowledge of the subject to use a nomograph to solve problems in that field. All that's necessary is to lay a straightedge, or draw a line, between two known values on given scales, and read the answer where the line intersects a third scale.

**Making A Nomograph.** The nomograph printed in these pages is an equivalent resistance nomograph that can be cut out for use in your work. With it you can determine the resistance of any two resistors connected in parallel in much less time than you could normally write down the mathematics required to solve the problem.

The R1 and R2 scales are equal in length, and positions at an angle of 120° with respect to one another. The Rt scale is a little more than one half the length of the other two scales, and bisects the angle between them. The



scale lengths and angular positioning are usually by courtesy of some slaving mathematician somewhere, but, if you have the time and patience, you can construct some nomographs by trial and error. The graduations on all scales of our nomograph are of the same length and can be assigned any value that you desire as long as the same size and values are used on all scales. For example, if one major division on the R1 scale is valued 100 ohms, then one major division on the R2 scale and one major division on the Rt scale must also be valued 100 ohms. With this in mind, let's find out how to use the equivalent resistance nomograph to solve parallel resistance problems.

**Using A Nomograph.** The equivalent resistance nomograph can be used in either of two ways. In one application you have two resistors connected in parallel and want to know what value single resistor will be needed to replace the parallel combination. This situation often arises in breadboarding new circuits. To solve this problem you simply locate one resistance value on the R1 scale, and the other resistance value on the R2 scale. Then lay a ruler, or draw a straight line between the points located on the R1 and R2 scales. The equiv-

alent resistance will be where the straightedge crosses the Rt scale.

In another application you know the value of one resistor and want to know what value of resistance must be connected in parallel with it to obtain a desired value. This problem may arise because your stock of resistors is depleted, or because the required resistor is not a standard value. Non-standard values of resistance cost more, of course, and at times two resistors in parallel will enable you to get the desired resistance at a much lower cost. To arrive at the value of the resistor that you need to parallel with one of known value to reach the odd-ball resistance you want, find the mark on either the R1 or the R2 scale for the known resistance value. Next locate the resistance of the desired resistor value on the Rt scale. Then lay a straightedge between the two points, and read the value of the required parallel resistor on the remaining scale.

**Typical Problems.** A typical problem will serve as an example that should bring everything into sharp focus now. Let's suppose that we have two resistors, 100,000 ohms and 47,000 ohms, connected in parallel in a project that's breadboarded and now ready for final-

izing. With this parallel combination in the circuit our little jewel works fine, but the combination is bulky, unsightly, and expensive for quantity production. So obviously it's desirable to replace the bulky parallel resistor combination with a single fixed resistor.

Using the Equivalent Resistance Nomograph, locate the 100,000-ohm value on either the R1 or R2 scale (we used the R1 scale). We could have chosen any point on the scale as 100,000 ohms, but for better resolution the maximum point is the best choice. Next locate 47,000 ohms on the R2 scale, remembering that each major division is equal to 10,000 ohms because of the location of our assignment of the 100,000-ohm point on R1.

Now lay a straightedge across the nomograph so that it intersects the 100,000 and 47,000-ohm points on R1 and R2. Where the straightedge crosses the Rt scale, a line can be drawn on the nomograph, or, if you prefer, you will read the resultant resistance value, 32,000 ohms, on the Rt scale. In comparison, the correct answer, using slide rule and/or pencil and paper, of 31,950 ohms certainly will take much longer to calculate than if you use the Equivalent Resistance Nomograph. ■

## Power Supply Basics

□ THE CATALOG of a leading electronics supplier contained this glowing description: A superhet shortwave receiver covering the standard broadcast band through 20 Meters. Its cabinet was luxurious walnut, its audio output push-pull into a high-quality speaker. The set boasted low current drain and the latest circuitry. The price?—a mere \$49.75.

The catalog was Allied Radio's and the date was 1932. The radio was a console meant for the living room, and it no doubt pulled in the A&P Gypsies with reasonable fidelity. The thing is, it required batteries for power.

Here's the battery complement for the handsome, but hungry, *Knight 8* vintage receiver: three 45-volt "B" batteries for tube plates; one 2-volt "A" cell for lighting filaments; one 22.5-volt "C" battery for biasing tube grids. This mountain of Evereadys cost \$9.00, a rather steep tab even in the good old days. And they could have pooped out right in the middle of a Herbert Hoover speech.

**Super Supplies.** That danger is gone, thanks to power supplies. Now a receiver takes raw electricity from the utility company and converts it to filament, plate, or bias voltages. It does the

same for transistorized circuits. Or it perhaps participates in the growing trend to 3-way operation, where you use the same device at home, in a car, or carry it as a portable. The supply not only powers the equipment in the home, it also recharges the portable batteries. Cost is low because AC power is priced about 3¢ per kilowatt hour—which means you can operate a plugged-in table radio for about 100 hours on a penny.

Though power supplies operate circuits of vastly different voltage and current requirements, the basic principles are the same. In most instances a supply accepts house current—usually 117 volts AC alternating at 60 Hz (cycles)—and performs the following steps.

● **Transforming Voltage.** The power company provides 117 volts for home outlets, but it's hardly the value that many electronic devices demand. The plates of receiving tubes require about

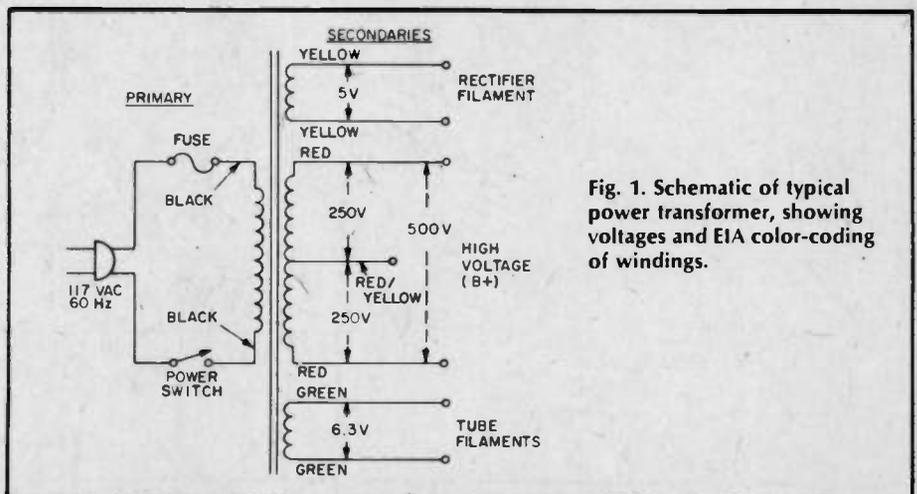


Fig. 1. Schematic of typical power transformer, showing voltages and EIA color-coding of windings.

100 to 250 volts for operation, while transmitting tubes may need a "B+" several hundred volts higher. Transistors, on the other hand, usually function at less than 30 volts. So the first task of the supply is to transform voltage to the desired value. In many CB sets, for example, there's plate-voltage requirement of 250 and filament-voltage requirement of 12.6 VAC. The power transformer delivers these levels.

● **Changing AC to DC.** Furnishing correct voltage is not enough. Those voltages must often be DC—and the power company provides alternating current. So the second function of a supply is to *rectify*, or convert AC to DC. If a rectifier malfunctions in your radio you'll soon learn its function. The symptom is annoying hum in the speaker (caused by 60-Hz alternations in the audio). In a TV set, suffering rectifiers can put a thick, dark, "hum" bar across the screen.

● **Filtering.** Though rectifiers change AC to DC the product is far from suitable because it contains objectionable ripple. This will be attacked by the filter, which smooths the pulsations to pure DC.

The final step of the supply depends on the designer. He can add a *bleeder*, choose a *regulator*, or insert a *divider* at the output. We'll look at these extras, but first consider how the supply's basic parts operate.

**The Transformer.** In Fig. 1 is a typical power transformer that's been produced by the millions with only slight variations. As we'll see, the transformer acts to create a voltage change between its primary and various secondary windings. The trick's based on the turns-ratio between the various windings. If turns in the secondary number twice those of the primary, then output voltage doubles; if turns in the secondary are a fraction of those in the primary, then a stepdown in voltage occurs.

Thus, in Fig. 1, the rectifier filament, which operates at 5 volts, has few turns compared to the primary; the high-voltage winding at 500 volts, however, has about five times as many turns as the primary. The colors shown for the windings, incidentally, are standard and observed by many transformer manufacturers.

The *centertap* connection of a winding splits the voltage in half. In our example, the high-voltage secondary is capable of 500 volts across the full winding (red to red), but only 250 volts between the centertap (red/yellow) and either end. The most important job for a centertap occurs in a *full-wave* supply, as we'll see in a moment. Note that a protective fuse and a power switch are

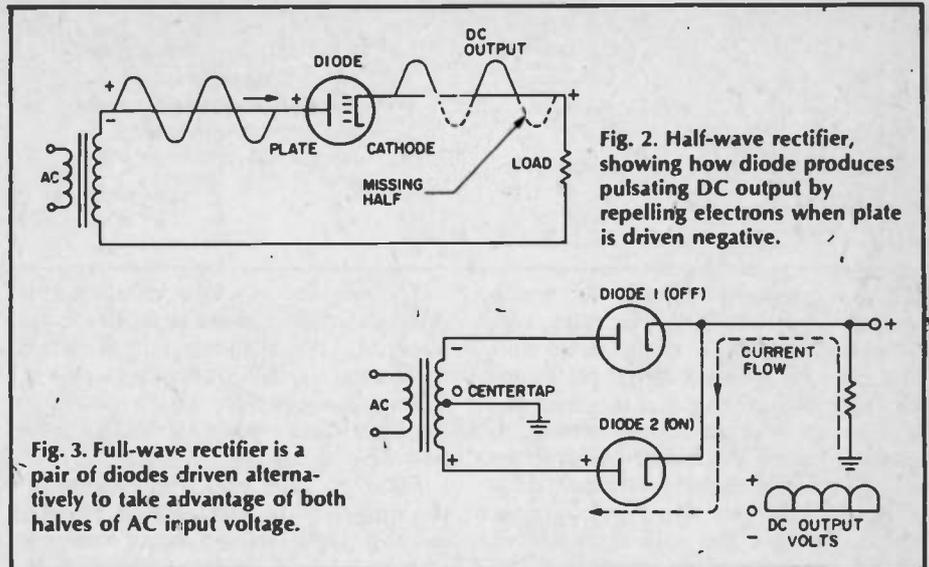


Fig. 2. Half-wave rectifier, showing how diode produces pulsating DC output by repelling electrons when plate is driven negative.



Fig. 3. Full-wave rectifier is a pair of diodes driven alternately to take advantage of both halves of AC input voltage.

located in one primary lead of the transformer.

**Rectification.** The two filament voltages from our transformer (5.0 for the rectifier and 6.3 for other tubes) will need no further processing. AC can be applied directly for filament heating (or for lighting pilot lamps on the front panel). High voltage, however, must be converted to DC before powering tube plates or transistor collectors and drains.

A circuit for changing AC and DC is a *half-wave* rectifier, shown in Fig. 2. It's based on a diode's ability to conduct current in only one direction. The rectifier cathode boils off electrons (negative) which are attracted to the plate when the plate is driven positive by incoming AC.

When the next half-cycle of the AC appears, the plate is driven negative, so electrons are repelled at this time. The net result is shown in the output: a series of positive voltage pulses appearing at the load. (The dotted line shows where the negative side occurred.)

In practical circuits the half-wave rectifier is usually reserved for light-duty power supplies. It's inefficient because it fails to make use of AC voltage half the time (during the negative pulses). Secondly, those wide spaces between pulses are difficult to filter because of low ripple frequency. In a half-wave rectifier, the pulsations occur at 60 Hz, the same frequency as the applied line voltage. But don't underrate

the half-wave supply because it's been used in just about every 4- or 5-tube table radio now playing. After all, its power requirements are low and the circuit is inexpensive to manufacture.

**Full-Wave Supplies.** Transmitters and higher-power equipment overcome the half-wave's shortcomings with the full-wave system. It's nothing more than a pair of diodes that are driven alternately so they consume every bit of AC input voltage. The key to full-wave operation is the centertap on the transformer's secondary winding. As applied AC appears across the complete winding, it makes the top end negative (as shown in Fig. 3) and the bottom end positive.

The centertap at this time establishes the zero voltage point because it's at the common, or grounded, side of the circuit. During the time the lower diode (No. 2) has a positive plate, it does the conducting. Next, the applied AC voltage reverses and makes the top diode plate (No. 1) positive so this tube now conducts.

This load-sharing combination of two diodes and a centertapped power transformer not only improves efficiency, but doubles the ripple frequency. An input of 60 Hz emerges as 120 Hz in a full-wave arrangement because every half-cycle appears in the output. This reduces the pulsating effect (cycles are closer together) and the DC becomes easier to filter.

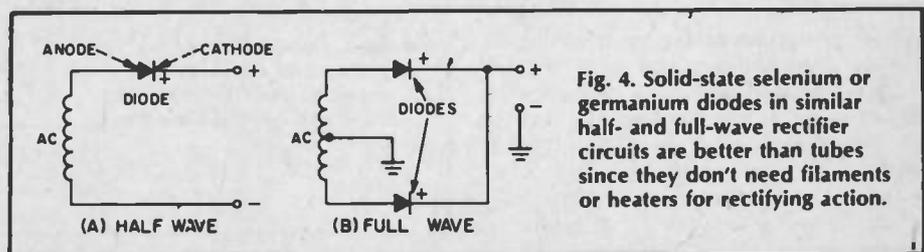


Fig. 4. Solid-state selenium or germanium diodes in similar half- and full-wave rectifier circuits are better than tubes since they don't need filaments or heaters for rectifying action.

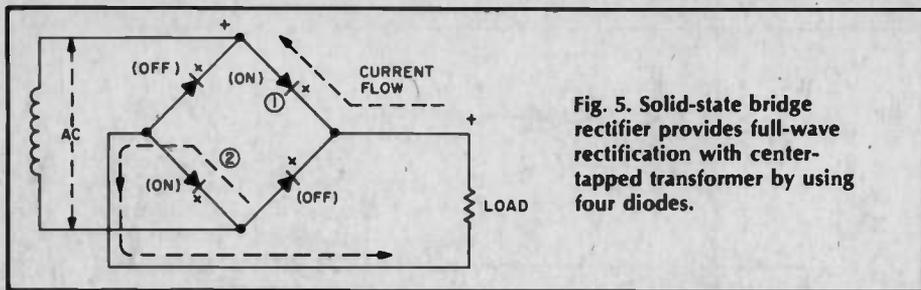


Fig. 5. Solid-state bridge rectifier provides full-wave rectification with center-tapped transformer by using four diodes.

If you purchase a transformer, watch out for one pitfall. It may be rated, say, "250 volts CT" and appear to be suitable for a rig with a 250-volt plate supply. In a full-wave supply, however, the transformer voltage output would be only 125, since a centertap reduces the voltage of a winding by one half. This can be avoided by specifying a transformer that has 250 volts *each* side of centertap or, stated another way, "500 volts CT."

**Solid-State Rectifiers.** Tube rectifiers are still widely found in electronic equipment, but they're destined for the Smithsonian Institution. Solid-state equivalents are superior because they don't need filaments or heaters to accomplish the same rectifying action. They're several hundred times smaller and much cooler in operation. Instead of a huge 5U4 vacuum-tube rectifier in your TV set you're now more apt to find a pair of tiny silicon diodes.

Circuits using these semiconductors, though, are similar to those of vacuum tubes. As shown in Fig. 4, diodes can be used in equivalent half- and full-wave arrangements.

Unlike tubes, though, solid-state diodes rectify AC and DC by a semiconductor effect at the diode junction (a region between the anode and cathode). The action, in simplified fashion, occurs when "current carriers" in the material flow toward and away from the junction under the influence of applied AC. When few carriers appear at the junction, little current gets through the diode; conversely, when many carriers are in the area, they reduce the junction's opposition to current flow. Depending on the way the diode is connected in the circuit, it can recover either the positive or negative half of the AC.

**Bridge Rectifiers.** Another common arrangement is the full-wave bridge (Fig. 5). Though it uses four diodes, it offsets this disadvantage by an ability to produce the same output as a regular full-wave supply without a center-tapped transformer. It accomplishes the feat by operating one pair of diodes during each half cycle. And as one diode pulls current out of the load, its partner pushes current into it.

The net effect is a total voltage across the load which is about equal to the applied AC. We've shown how it occurs for diodes 1 and 2 in the diagram (Fig. 5) but a comparable action occurs in the other diodes when the AC switches polarity.

**Filtering.** The next major section of the supply is the filter, which smooths out the ripple. Its two major components are often a capacitor and a choke which eliminate pulsations by dumping a small amount of current from the peak of each ripple into the "valleys" between them. The result, as shown in Fig. 6, is pure DC fit for a tube or transistor.

In operation, pulsating DC arrives at the filter choke, a coil of wire wound on a soft iron core. As the name implies, the choke attempts to oppose any change in current flow. The rippling part of the wave, therefore, encounters high reactance in the choke and fails to get through. This is aided by the filter capacitor which is charged by ripple voltage.

As the ripple falls (between pulses), the capacitor discharges part of its stored current into the "valley." Thus the combined effect of choke and capacitor results in smooth DC which can have ripple as low as a few percent of the total voltage.

You won't find the choke in some power supplies because it's an expensive item. Many designers eliminate it (especially in mass-produced equipment) by using a resistor instead, as shown in Fig. 7. The resistor does the job of filtering, but with one penalty: it reduces the amount of available voltage at the output. Yet, the loss can be tolerated in many circuits and filter resistors are common.

Another use for resistors in a supply

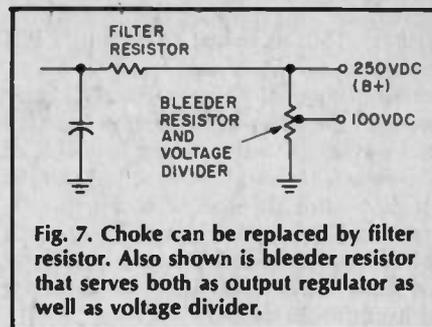


Fig. 7. Choke can be replaced by filter resistor. Also shown is bleeder resistor that serves both as output regulator as well as voltage divider.

is to serve as a *bleeder*, also shown in Fig. 7. In this function, it protects parts in the supply from possible damage due to sudden voltage surges when the supply is first turned *on*. Also, a bleeder helps stabilize voltage output when the load changes (as in a keyed ham transmitter) by always drawing some small degree of load current. Bleeders, too, are found in dangerous high-voltage circuits where they bleed-off the stored charge of filter capacitors that could deliver a lethal shock to a repairman (even after the equipment has been turned *off*.)

Note that a tap can be added to the bleeder to provide a second output voltage from the supply. Now the bleeder becomes a *voltage divider*. As such, it can supply the designer with multiple output voltages for operating various devices in a circuit.

**Voltage Regulation.** A ham who's received a "pink ticket" from the FCC for chirpy signals, a color TV that's gone fuzzy, a shortwave receiver that won't stay on frequency—all may suffer from a problem in voltage regulation. Line-voltage fluctuations or other electrical swings can cause poor, unstable operation. So the engineers have come up with methods for "stiffening" a power supply.

If, say, line voltage changes from 105 to 130, they design the circuit to operate at 100 volts. Whatever voltage arrives over the line is reduced to 100, and the surplus is dumped (usually in the form of heat). To perform this task, the regulator establishes a reference point, then regulates around it.

A common example is the zener diode found in the power supply of many CB transceivers. Since these rigs can

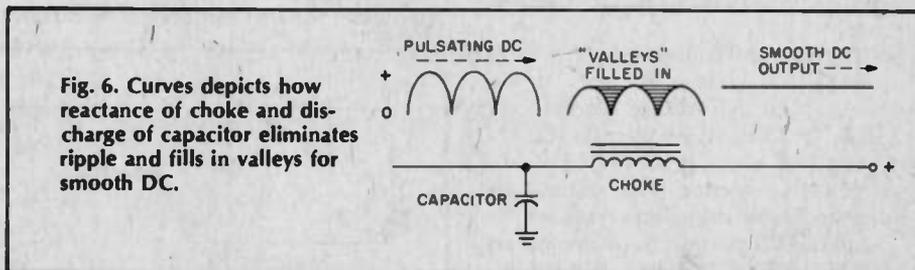
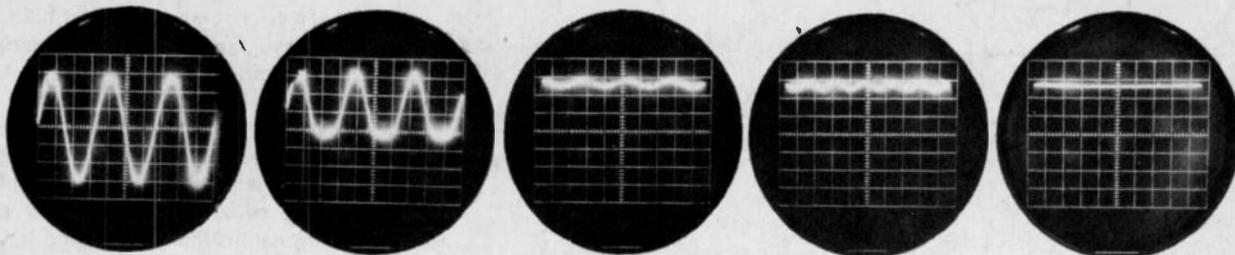


Fig. 6. Curves depicts how reactance of choke and discharge of capacitor eliminates ripple and fills in valleys for smooth DC.



Scope photos, from left to right, show (a) 60-Hz line voltage, (b) output from half-wave rectifier with negative portion eliminated, (c) ripple voltage from half-wave rectifier at same frequency as AC line voltage, (d) frequency of ripple voltage from full-wave rectifier double that of AC line voltage, (e) final DC output from power supply with no ripple voltage.

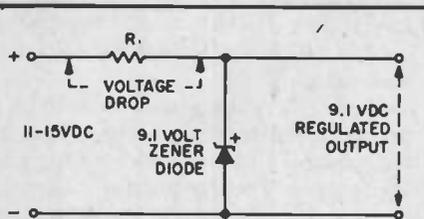


Fig. 8. For more efficient regulation than produced by bleeder resistor, zener diode shunted across DC output will hold voltage to specified limit.

operate from a car's battery or generator, supply voltage can swing from 11 to 15 volts. This could happen if you're standing for a traffic light, then pull away, causing a shift between car battery and generator. If the CB set is on at this time, receiver tuning could be thrown off because of large changes in local oscillator voltage.

A zener diode can compensate for the shift, as shown in Fig. 8. At first glance it appears as an ordinary diode connected backward. Since the cathode (upper) terminal is connected to the positive side of the supply, there's a "reverse bias" condition. A zener diode, however, "breaks down" (or "avalanches") whenever its rated (zener) voltage is exceeded. In our example, the zener is a 9.1-volt unit, so the diode conducts current as the supply voltage shifts from 11 to 15 VDC.

Yet we see 9.1 volts indicated at the output. Secret of the zener's ability to hold at 9.1 is that it detours part of the supply current as the voltage increases. Since a resistor is in series with that current flow, a voltage drop (as shown) appears across the resistor. Thus, any increase in supply voltage is dissipated across the resistor and effectively subtracted from the output. This automatic

and continuous action occurs for any voltage above 9.1—the zener's nominal rating—so the output is said to be regulated.

**More and Merrier.** This barely brushes the subject of power supplies, since the variations are nearly endless. More than 20,000 volts for the picture tube of a color TV are derived from a special "flyback" transformer. It captures voltage from rapidly moving magnetic fields in the set's horizontal scanning section. An oscilloscope power supply contains strings of adjustable voltage dividers to move the pattern of light on the screen in any direction.

There are also high-current supplies with massive rectifiers for battery charging and super-smooth lab supplies for circuit design. But behind most of them are the simple principles which transform, rectify, filter, and regulate a voltage so it can do the job at hand. ■

## Electromotive Force Multiplier

□ WHEN YOU NEED a power supply for a high voltage, low current application, your best bet is a voltage multiplying type power supply. They are simple. They are inexpensive. And you can develop almost any voltage you want by selecting the transformer used and cascading basic multiplier stages. The only limiting factor is the ratings of the components you can obtain.

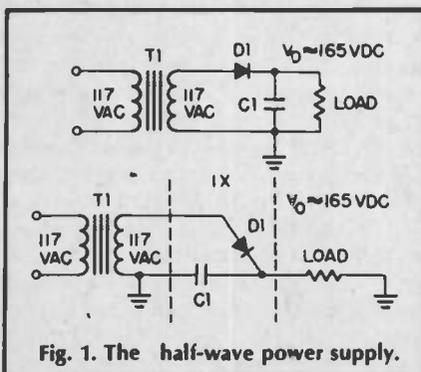


Fig. 1. The half-wave power supply.

Basically, a voltage multiplier circuit consists of simple, inexpensive diodes and capacitors connected in such a way as to develop a DC output voltage that is some multiple of the peak value of the input voltage. Only one diode and one capacitor are required for each time you want to multiply the voltage. As a safety factor, a transformer should be used to isolate the power supply from the line voltage. But part of the beauty of using voltage multipliers to obtain high voltage is that you don't have to begin with an expensive high voltage transformer.

**How It Works.** Voltage multiplier circuits will operate with any type of waveform as the input. The only factor that might be considered is the switching time of the diodes used. The rise time and fall time of the input signal must be slower than the time that the diodes require to reverse conduction—sort of like the frequency response of an amplifier.

However, since most power supplies operate from 60-Hz power, this factor will not affect most experimenters. The reason the frequency of the input is interesting is because the ripple content of the power supply output can be reduced by operating the circuit at a higher frequency.

Referring to Fig. 1, note that the basic voltage multiplier circuit is none other than our old friend the humble half-wave power supply. This simple circuit forms the basis for a complete family of voltage multiplying circuits, and is shown both in the standard schematic format and a simplified form that will facilitate the development of additional multiplier circuits.

With little or no current required from this power supply, the value of the DC output voltage will approach the peak value of the AC input voltage. For example, if T1 were simply an isolation transformer, with primary and second-

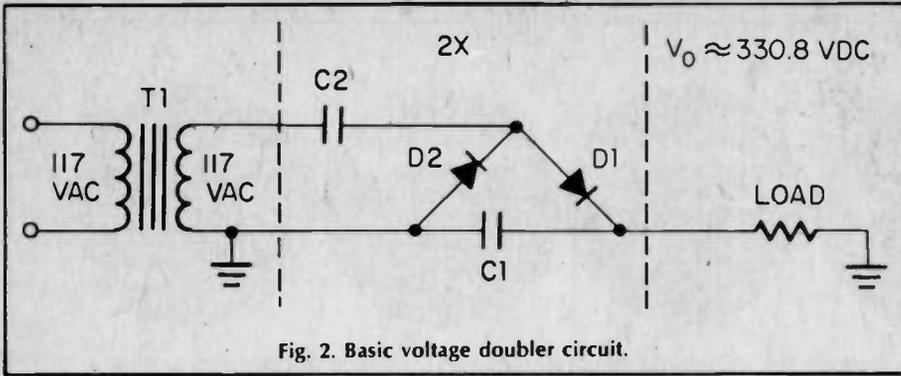


Fig. 2. Basic voltage doubler circuit.

ary voltages of 117 Vrms, the theoretical DC output from a half-wave power supply would be  $1.414 \times 117$ , or about 165.4 VDC.

In practice, because of circuit losses, the actual output voltage will decrease as more current is required from the circuit. We will discuss how to estimate the output voltage of a given circuit shortly.

**Double Up.** By adding a second diode and capacitor combination to the basic half-wave circuit, as shown in Fig. 2, it becomes a voltage doubler circuit—effectively multiplying the peak value of the input voltage by two. Notice that the new diode, D2, and capacitor, C2, are connected in series (cascade) with the original diode, D1, and capacitor, C1, and are between them and the transformer, T1.

The circuits shown in Figs. 1 and 2 are the basis of all voltage multiplication. The voltage tripler circuit shown in Fig. 3 is merely the doubler circuit shown in Fig. 2 connected in cascade with the half-wave circuit shown in Fig. 1. Likewise, the quadrupler circuit shown in Fig. 4 is simply two doublers connected in cascade. To multiply a voltage five times just cascade two doubler circuits with a half-wave circuit. To multiply a voltage six times just cascade three doubler circuits. And so on. As most things are, it is simple once you see the patterns involved.

**The Fog Lifts!** Notice the basic pattern that forms voltage multiplier circuitry. Beginning with the half-wave circuit shown in Fig. 1, and moving from the load toward the transformer,

each additional stage of multiplication is simply a diode and a capacitor connected as follows: The diode that is being added to the circuit has its cathode connected to the anode of the previous diode, and its anode connected to the “opposite” side of the circuit; the capacitor being added is connected to the anode of the previous diode on one end, and to the transformer at the other end, and to the transformer at the other end. Notice also that the capacitors being added alternate from one side of the circuit to the other.

This basic pattern can be continued

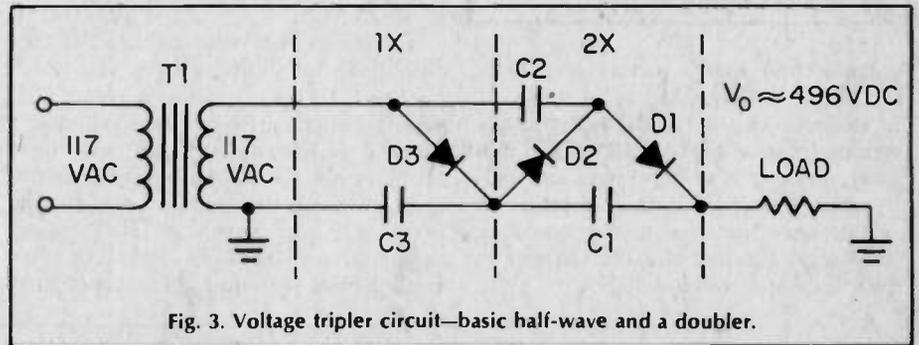


Fig. 3. Voltage tripler circuit—basic half-wave and a doubler.

until the input voltage has been multiplied as many times as desired. The ultimate value will, of course, depend upon the voltage ratings of available components.

**Component Ratings.** When building voltage multiplier circuits there is one basic rule to follow: *all* components should be rated for at least *two times* the peak value of the input voltage. For example, if the secondary voltage of T1 is 200 Vrms, the peak-inverse voltage (PIV) of all diodes and the

working voltage (WVDC) of all capacitors should be at least  $1.414 \times 200 \times 2$ , or 566 volts. Most transformers will satisfy your requirements as built, but it is always good practice to verify the voltage rating of the windings to preclude problems.

At voltage values of 1000 volts or more, special consideration should be given to wiring insulation and physical spacing of all components to prevent arcing within the power supply.

As load requirements increase, adequate ventilation must be considered. The diodes, and to some extent the capacitors, dissipate heat because of forward-drop, switching, and leakage losses. This heat must be removed to prevent the diodes from going into thermal runaway.

Capacitor values should be as large as practical, but some values may become too expensive to be considered for your application. Though filtering and regulation will be improved by using large values of capacitance, there is a point beyond which the improvement isn't worth the cost. The optimum value of

capacitance can be calculated using (for you math whizzes)

$$C = \frac{N^3 I_o}{720 (NV_p - V_o)} \quad (1)$$

For simplicity, all capacitors should have the same value and voltage rating. The value computed using formula number (1) is not absolute; the nearest value available at your parts house, or found in your junk box, will suffice.

**Determining Output Voltage.** The output voltage of any multiplier circuit with a load is a function of the input voltage, the source impedance, the capacitor values, the forward voltage drop of the diodes, and the frequency of the input voltage. By assuming that the diodes are ideal (no voltage drop across them in the forward direction) and if the values of all capacitors are made equal (generally the best way to go) the approximate output voltage from a given circuit can be calculated using

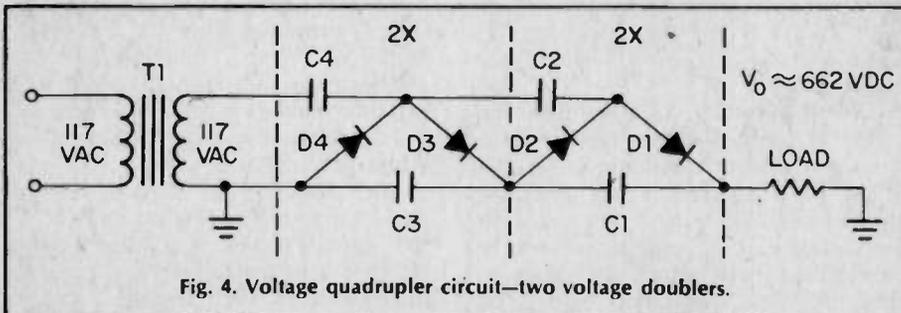


Fig. 4. Voltage quadrupler circuit—two voltage doublers.

$$V_0 = NV_P - \frac{N^3}{720(C)} I_0 \quad (2)$$

if the input frequency is 60 Hz—as will be the case in most instances.

If you have decided to use a specific circuit configuration (say a tripler), know the output voltage that you want, and have selected the capacitors that you "must" use, you can calculate the required input voltage using

$$V_{IN} \text{ (PEAK)} = \frac{V_0 + \frac{N^3 I_0}{720(C)}}{N} \quad (3)$$

In formulas (1), (2), and (3):

$C$  = the value of the capacitors used in the voltage multiplier circuit. All capacitors should have the same value.

$I_0$  = the amount of current required from the power supply.

$N$  = the number of diodes used in the voltage multiplier circuit.

$V_0$  = the output voltage expected from the voltage multiplier circuit.

$V_P$  = the peak value of the transformer secondary voltage.

If a negative output voltage is desired merely reverse all the diodes in a voltage multiplier circuit. All other considerations remain the same.

If the math leaves you cold, you can still build voltage multiplier circuits by making some educated assumptions.

Use the largest values of capacitance that you can locate, say 10 to 20 microfarads, and assume that the voltage output will be approximately 70 percent of the theoretical value if the power supply were unloaded. This procedure will provide valid results, and the power supply output will be within normal tolerances for most applications.

One last word of caution. These supplies can add up to a lethal dose of the old EMF. Take care. ■

## The Superheterodyne Circuit

□ BORN OUT OF NECESSITY during World War I, the superheterodyne receiver circuit toppled all existing conventional receiver types on electronics' popularity chart. And, to this day, none of the "conventional" radios of that era have been able to recapture electronics' limelight. Stranger yet, every branch of electronics is still being swept along the path of Progress by a circuit that should have gone the way of the flivver and the flapper. From military and industrial to commercial and consumer—everybody who's ever seen a radio, and certainly a television set, has found himself staring face to face with a superheterodyne receiver. The fact is, you'd be hard-pressed to find any up-to-date radio—even the integrated-circuit-and-ceramic-transformer variety—that doesn't somehow utilize the superhet circuit.

After the First World War, the "All-American Five," as it was dubbed, took its place in living rooms and parlors from coast to coast. And it continues to be built today as its inventor generally conceived of it, way back when the circuit was made to track and help locate enemy aircraft spitting fire over French skies.

**Narrow Squeeze.** The superheterodyne found itself ruling the receiver roost largely because it had a redeeming quality no other receiver of that vintage era could boast. Called *selectivity*, this hitherto unheard-of quality endowed the superhet with the ability to select the particular station a listener wanted to hear (and later see), and reject all others. Indeed, it was a revolutionary step forward in receiver design. But selectivity was hardly a quality needed back in grandfather's day. Why?

First, grandpop used to listen to signals sent by spark-gap transmitters. The primitive spark signals generated by those common-as-apple-pie transmitters

were extraordinarily broad. It was like listening to the lightning crashes you can pick up as you tune across the dial of an AM radio during a thunderstorm. More important, though, there were fewer signals on the air. So selectivity wasn't too important.

The year 1922 saw the meteoric rise of radio for entertainment and communication. As hundreds of stations took to the air it became apparent that the primitive receiving gear capable only of broad-bandwidth reception couldn't even begin to handle the impending traffic jam beginning to build on the airwaves. And the problems of receiving only one station, without an electronic cacaphony drowning it out, takes us back even further into electronics' primeval time.

**Cat's Whiskers and TRF.** Digging through to the bottom of the twentieth century, we uncover two electronic fossils: the cat's whisker crystal receiver, and the tuned radio frequency (TRF) receiver. These were popular predecessors of the superhet circuit.

The crystal set had the least selectivity of either circuit, and what it did have was obtained mostly from one measly tuning circuit. Consisting of a coil and a homemade variable capacitor, these crude tuning devices could barely pick out a desired radio signal and, hopefully, reject all RF intruders trying to elbow their way into the listener's headphone on either side of the signal. The cat's whisker consisted of a strand of fine wire for gently probing, or tickling, the crystal's natural galena surface in order to locate its most sensitive point. Though the cat's whisker detector could extract audio signals from the amplitude-modulated radio frequency signal, the galena detector couldn't help but ruin the radio's selectivity. It loaded the tuning circuit, in-

creasing the listener's chances of picking up stations other than the desired one.

Matters improved with the TRF receiver. It aimed for, and hit, sharper reception dead center, by adding more tuned circuits. This feat wasn't practical with crystal sets, because this circuit's inherent losses ran too high to gain any benefit from any additional coils.

The invention of the triode vacuum tube gave engineers the perfect amplifying device. Circuit losses could now be overcome with ease; the TRF took over where the cat's whisker left off, dooming the crystal set to mantelpiece and museum.

Three or four amplified radio-frequency stages were customarily added prior to the TRF's detector, all the while adding to selectivity's cause. However, all wasn't perfect in TRFville.

The amount of noise introduced by the tubes limited the number of TRF stages. So the Silver-Masked Tenor's strains could still be heard with those of the Clicquot Club Eskimos—but not by his choice, or that of the listener.

**Pitching the Low Curve.** The public soon learned that these newfangled TRF receivers weren't exactly the living end. The TRFs, as a rule, failed to perform satisfactorily as frequencies inched higher into kilohertz land. Seems that as the frequency of the signal went up, the TRF's tuned circuit efficiency for that frequency dropped almost proportionately.

To demonstrate this, look at our example. The bell-shaped curve represents response of a tuned circuit selecting some low-frequency station. The circuit delivers good selectivity, and interference on a slightly higher frequency is rejected.

But examine what happens when a similar tuned circuit is operated on a

higher frequency. Although the curve's proportions remain the same, it's actually responding to a much greater span of frequencies. Now it's possible for two closely spaced stations to enter the response curve and ultimately be heard in the speaker.

Since tuned circuits grow more selective as frequency is lowered, wouldn't it be to our technical advantage to receive only low-frequency signals? This idea probably occurred to Major Edwin Armstrong, because his invention, the superheterodyne circuit, does just that.

**Supersensitivity.** By stepping signals down to a lower frequency than they were originally, the new circuit could deliver neat-as-a-pin selectivity on almost any band. The fact is, this development helped open the high-frequency bands, and by the 1930s virtually every receiver adopted the Major's superheterodyne idea.

The word "superheterodyne" is, by itself, revealing. It begins with *super*, for supersonic, referring to a new signal created within the radio. The generated signal is neither in the audio nor higher radio-frequency range, but in between. *Hetero* means combining, the *dyne* is force. The newly-created ten-dollar term, *superheterodyne*, neatly sums up this circuit's action.

**Major Blocks.** You can get a good picture of the superhet in its natural habitat if you look at our block diagram. Though our schematic shows a tubed receiver, all equivalent stages tend to do the same job regardless of whether the receiver is transistor or tube. Now that you know what the superhet does and how it looks, let's take a peek at how it works.

For sake of illustration, assume a signal of 1010 kHz in the standard BC band enters the antenna, and from there is sent down the line to the mixer. But what, you ask, is mixed?

Our frequency mish-mash consists of the different frequencies made up of the desired station on 1010 kHz, and a second signal generated internally by the local oscillator. This oscillator perks at a frequency of 1465 kHz, for reasons which you'll understand in a moment.

True to its name, our mixer combines both signals from antenna and oscillator. And from these two frequencies, it delivers yet another frequency that is the *difference* between them—namely 455 kilohertz. So far, our superhet circuit changed, or reduced the desired signal to a frequency having an intermediate value. Beating two frequencies together in order to produce a third signal is known by members of the Frequency Fraternity as mixing, heterodyning, or beating. And some engineers

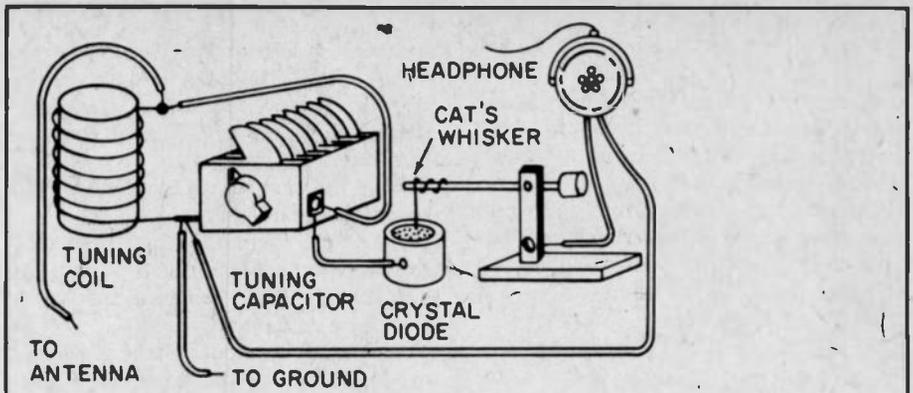
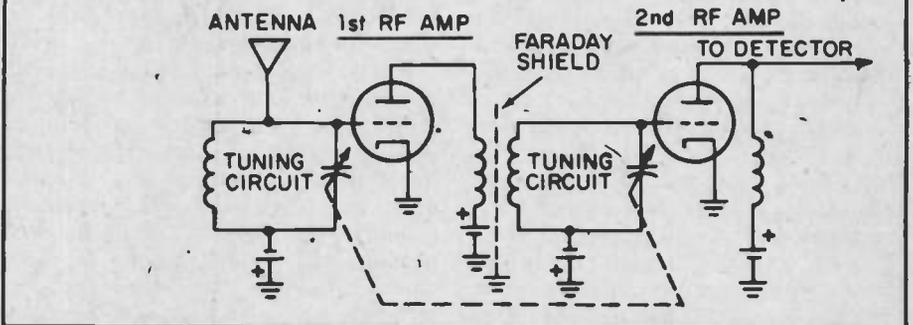


Fig. 1. Schematic representation of crystal radio shows how cat's whisker gently contacted crystal surface in order to achieve demodulation of RF signal. Earliest semiconductor diodes made were miniature crystal diode/cat's whisker affairs encased in glass package.

Fig. 2. Our schematic shows relatively advanced tuned radio frequency receiver. First TRFs had individually adjusted tuning capacitors; ganged units were still to be invented. By adjusting battery voltage twist ground, tuning circuit, radio gain's varied.



prefer to call the lowly mixer a converter; this term often appears in schematics. But whatever name you throw its way, the result is the intermediate frequency.

There's something else you should know about the intermediate, or IF, frequency. It always remains the same no matter what station you tune to. If you sweep the dial across the broadcast

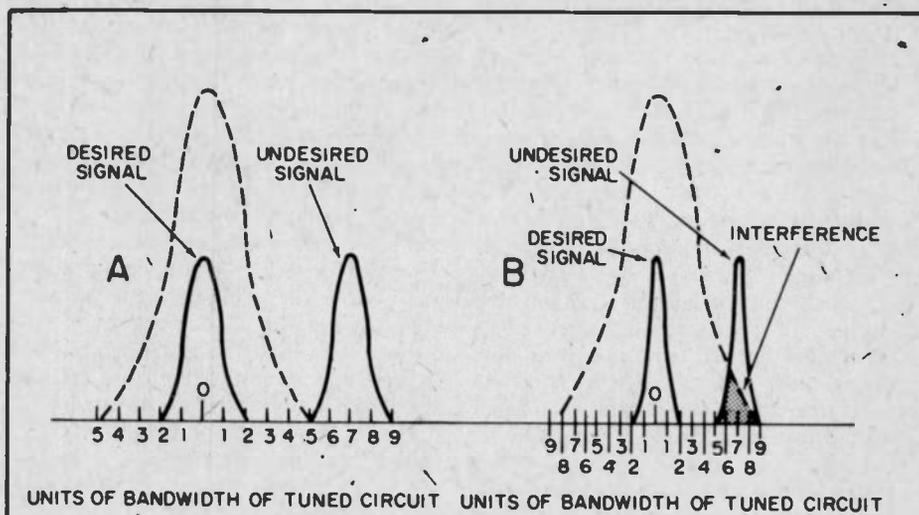


Fig. 3. Tuned-circuit bandwidth varies proportionally with frequency. Tuned circuit A, working at low frequency, rejects unwanted signal. Tuned circuit B, working at high frequency, can't completely reject undesired signal; interference results.

band in one continuous motion, the IF frequency remains constant. How's this accomplished?

It's done by tuning the incoming signal simultaneously with the local oscillator. That's something akin to the mechanical rabbit which paces greyhounds at a race track. In the superhet a ganged tuning capacitor performs this dynamic-duo feat.

Take a close look at the tuning capacitor, and you'll see physically smaller plates assigned to the local oscillator. Since these plates are smaller than the antenna stage capacitor plates, the effect is to lower the capacity, and raise the frequency of the oscillator stage. That's how the oscillator stage consistently produces a signal which is 455 kHz above the incoming frequency. But why bother, you ask?

**More Muscle, Too.** When we convert each incoming station's frequency to the same IF, we gain another advantage besides better selectivity. A fixed-tuned amplifier always operates at higher efficiency than one which needs to muscle a multitude of frequencies. There are fewer technical bugaboos in a one-frequency amplifier, so our tubes or transistors can operate more effectively at this lower frequency. And, last but not least, circuit layout and wiring are less critical. All of this is well and good, but how do we actually extract our Top-Forty tunes, news, and weather from our super-duper-het?

**Sound Sniffing.** The detector stage recovers original audio voltage from

the station's signal. Since we're cranking the RF voltages through a superhet circuit, the RF signal did a quick disappearing act, only to appear as an IF frequency of 455 kHz. Though the original carrier (1010 kHz) is converted downward in frequency to 455 kHz, any audio voltage variations impressed upon the carrier remain the same. So if a musical note of 1000 Hz was sounded back in the radio studio, the note still remains that value in both RF and IF circuits, despite the mixing process.

Like a ladle skimming heavy cream off the top of a jug of fresh milk, the detector rectifies either the positive- or negative-going portion of the carrier, skimming off the audio signals from the carrier. Though audio modulation appears during both positive and negative swings of an amplitude-modulated carrier, only one half of the available signal is used. If both positive and negative portions of the RF signal were detected simultaneously, the audio signals would cancel each other at the output!

Now let's look at the stages of an ordinary solid-state superhet circuit that might be found in a common table radio or transistor portable.

**Simplified Schematic.** Our diagram is pretty typical of transistorized superheterodyne circuits. Of course, there may be variations on this circuit's theme, like the addition of an RF amplifier ahead of the mixer to improve sensitivity. The number of IF stages also varies with receiver quality, and specialized items such as filters may appear

in ham and SWL rigs.

If you can follow our basic block diagram you'll have the key to virtually any solid-state superhet. In order to further simplify matters, many resistors and capacitors not essential to our tour through solid-state superhet country have been omitted.

Leading the pack on our superhet speedway is the antenna tuning circuit. Loopstick antenna L1 grabs the RF signal out of the ether, and also serves in partnership with the tuning capacitor in the tuning circuit. You sharpies will also notice that the antenna tuning capacitor is mechanically joined to the oscillator tuning capacitor. (This is represented schematically by a dotted line.) Remember now, we want to develop the IF frequency. This ganged antenna/oscillator capacitor ensures the necessary tracking of the local oscillator with the radio-frequency signal.

The oscillator frequency is developed by the oscillator portion of our variable capacitor, and coil L2. In our superhet's schematic, the oscillator signal is capacitively coupled from the oscillator transistor base and sent on its way to the mixer stage. The mixer, therefore, "sees" both oscillator and incoming station frequencies. The electrons from oscillator and antenna circuit get it all together in the mixer's base, producing our intermediate frequency.

If you could look at the mixer's output, you'd see more than just the IF signal. In fact, the mixer's load contains a jumble of frequency byproducts. As signals combine in this circuit, they add, subtract, and recombine in many ways. It's as if you had to separate the wheat from the chaff with a pair of tweezers!

Only the desired signal emerges from the mixer stage because intermediate-frequency transformer IF1 picks the proper signal to the exclusion of all the others. Now our freshly-created signal passes through a stage of IF amplification, and receiver selectivity is further whipped into shape by the second intermediate-frequency transformer, IF2.

As we've already described, the detection process takes place at the diode, regaining the radio station's original audio signal. This audio voltage is fed from the volume control to both audio stages where they're further amplified and sent to the loudspeaker.

The detector diode doesn't merely extract soul sounds from the ether; it also delivers a second voltage output. Called AGC (Automatic Gain Control), this voltage controls our mixer's amplification, preventing the speaker from blasting when you suddenly tune your radio to a strong station. In our simplified schematic, the AGC voltage is a posi-

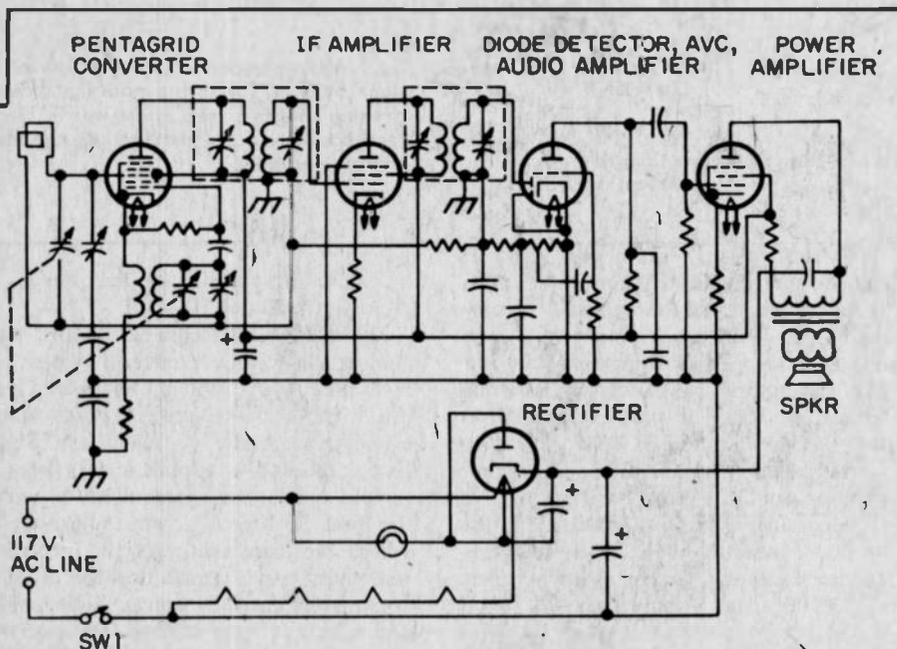


Fig. 4. Virtually all superhets sold commercially are five-tube rigs; most are also, in terms of design, electrically and mechanically equivalent.

tive-going voltage which increases proportionately with rising signal strength. But before AGC can control receiver gain, it's filtered for pure DC in a resistor and capacitor network.

The result is a DC signal which can be used to control the gain of the mixer transistor. Thus, if a strong RF signal tries to muscle its way through this stage, the mixer is subjected to a higher bias voltage on its base terminal, which tends to put the brakes on our mixer's gain.

**Pitfalls, Yet.** Let's not lionize the king of receivers, though, for sometimes its growl turns to a puny purr. The biggest problem, and the most annoying, is a form of interference peculiar to the superhet known as an *image*. Produced by a mathematical mixup, images are all

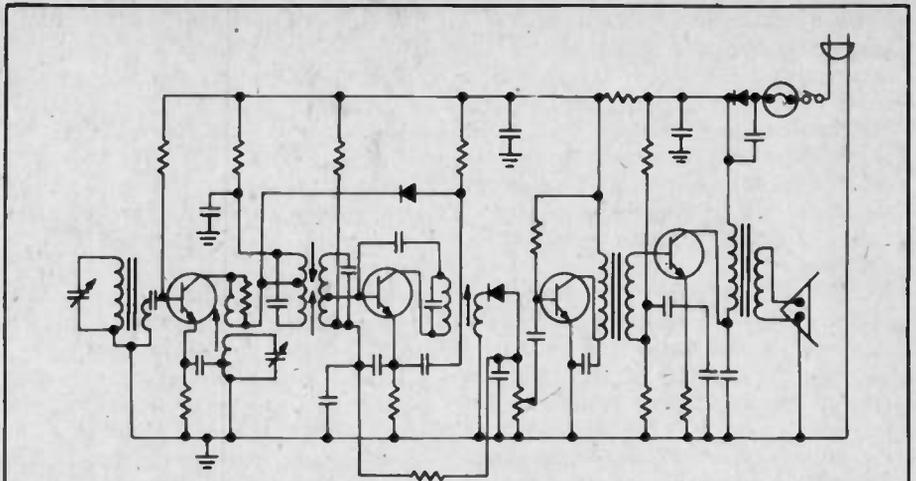


Fig. 5. Our schematic of a transistorized superheterodyne receiver is similar to the tubed superhet shown in Fig. 4. Biggest differences between the two are semiconductor diodes found in audio detector, AVC loop, and power rectifier stages.

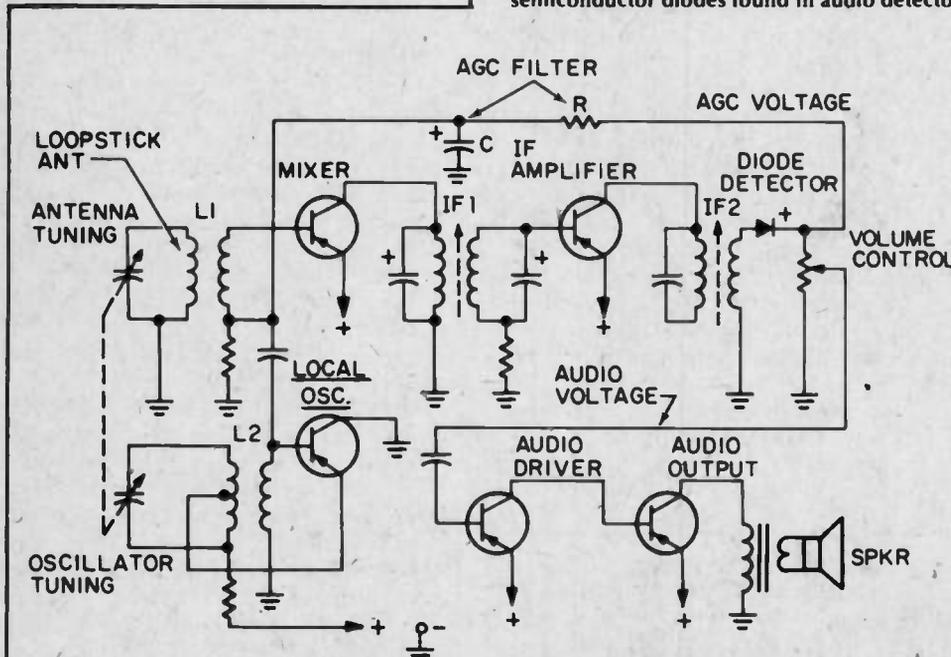


Fig. 6. Most superhets don't have separate local oscillator, mixer function; this schematic is more typical of BCB set. Communications-type receiver needs added usefulness of separate stages—it's easier to suppress images.

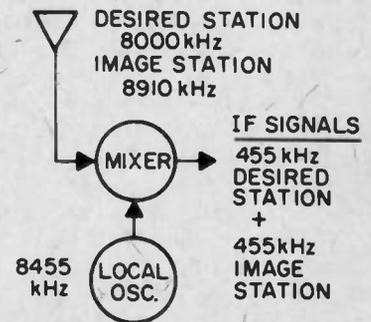


Fig. 7. Mixer is superhet's weakest link as signal handler. Too strong input signal can develop image frequency. Too much local oscillator signal pumped into mixer has same effect.

of those undesired signals finding easy routes to travel through your receiver. Take a look at our image explanation; you'll see the receiver is tuned to a desired signal of 8000 kHz.

The local oscillator generates a frequency of 8455 kHz, which places it exactly in our IF signal ball park. But note that a second station—a pop fly on 8910 kHz—also happens to be 455 kHz away from the local oscillator. For each oscillator frequency there are now two station frequencies giving identical IF frequencies. It's up to your receiver to strike out the image station. Otherwise, the RF ball game will turn into a rout!

You might expect the receiver's antenna tuning circuit to completely re-

ject the image signal. After all, it's supposed to be tuned to generate a very high IF frequency, positioning any images developed by the mixer well outside the tuning range of the antenna circuit. Looking at our example of a double superhet, you'll see one IF amplifier perking at 5000 kHz and another working on 455 kHz. Now if we receive an incoming signal on 8000 kHz, the local oscillator, now called a high-frequency oscillator, generates a frequency at 13,000 kHz, so the first IF signal works out to 5000 kHz. Your receiver would have to pick up a signal falling on 18,000 kHz to produce any image. Naturally, the image frequency in this instance is significantly removed from

the antenna circuit, so the image is greatly attenuated.

While high IF frequencies work well against image interference, they also revive Nagging Problem Number One: the higher the frequency of a tuned circuit, the poorer its selectivity. Since this situation also applies to IF stages, a second conversion is required, bringing the first IF signal down to 455 kHz, where we can sharpen our receiver's selectivity curve. That's how the double-conversion receiver solves both image and selectivity hassles. Any ham or SWL rig worthy of an on/off switch is sure to have this feature. But don't think of dual conversion as a receiver cure-all.

Dual conversion is *not* usually found

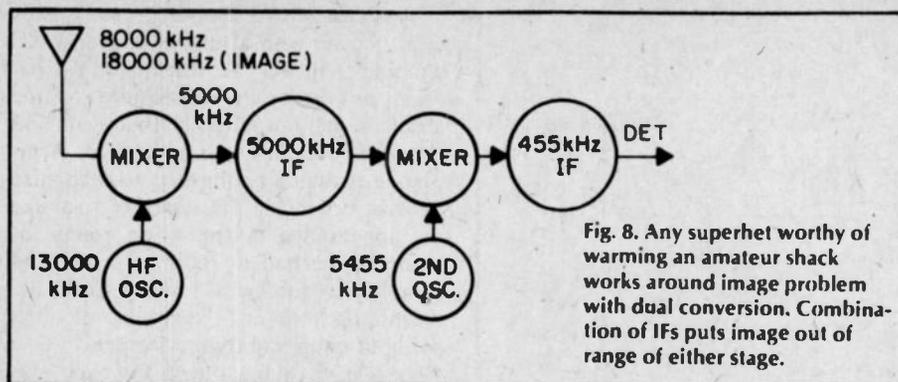


Fig. 8. Any superhet worthy of warming an amateur shack works around image problem with dual conversion. Combination of IFs puts image out of range of either stage.

## How Superhets Grew Up

□ MAJOR EDWIN ARMSTRONG was too busy to take time to contemplate the superior performance of his newly developed radio receiver which was spread out on the laboratory table before him. He and his assistants had been in France only a short time but they had already witnessed the war devastation wrought upon the countryside. But at this time they were probably too far from the front lines to feel the earth-shaking rumble of the German Army Big Bertha guns which gave evidence of the last desperate attempt by the enemy to stem the sweep of the American Expeditionary Forces across France. The year was 1918 and World War I would soon be drawing to a close.

Armstrong called his new radio a superheterodyne and his genius helped save the day for the Allies. When American troops jubilantly landed on French soil they were hopelessly unprepared with any type of electronics which would intercept those faint German communications signals. Armstrong, with a host of significant radio developments already to his credit, was commissioned to go to France and solve the problem.

Those first scenes in that French radio laboratory with its vast array of radio components and with those large electron tubes glowing like embers under a witches' cauldron, must have looked as impressive as a Saturn V launch. But the code signals that filled the room were a far cry from what was to come—for the days of radio broadcasting as we know them were a mere two years away. Little did Armstrong realize that he had created the most important radio circuit the world had ever seen. For every present-day TV set or radio bears his mark—they all use that same basic circuit concept born in the mind of this great radio genius.

**At the Beginning.** Let's take a look

at some of the things that led Armstrong down the path of the superhet. First of all, the early radio designers quickly found out that it wasn't easy to build an RF amplifier that would work at high frequency. By high frequency I mean 1500 kHz—the top of the broadcast band! This was mostly blamed on the tubes available at that time, triodes, which had so much interelectrode capacity that the plate energy would sneak back across to the grid and force the circuit break into oscillation. At the low end of the broadcast band, the RF amplifier was OK; but as the frequency increased, so did the whistles and screeches.

Armstrong reasoned that if the tubes worked well at low frequency, why not somehow convert the high frequency antenna currents to a low frequency within the radio receiver. He already knew that if two RF signals were mixed together their frequencies magically add and subtract to produce, among other things, a frequency which is the difference frequency between the two. Why not make some kind of an electronic *lash-up* which would mix the incoming antenna signal with one generated in the radio set to produce a low frequency difference? Then follow this up with a narrow band RF amplifier that would amplify this nice low fre-

quency without problems with oscillation.

But, for all its faults, the basic superhet circuit we've been talking about must be doing something right. Every year several million superhets are sold in the U.S. Not bad for a circuit that might have gone the way of the hip flask, eh? ■

quency without problems with oscillation.

Well, the Major did just that and let's take a look at one of Armstrong's first circuits. This is shown in simplified form in Fig. 1 and we see the oscillator tube V8 with its associated components. It is made to oscillate by feeding plate energy back to grid circuit and tuned by the L2-C2 combination. These oscillation currents are induced in the pick-up coil L1 which is connected in series with the loop antenna. This arrangement allows the incoming signal from the loop, tuned by C1, to be mixed with the oscillator frequency tuned by C2 and fed to the control grid of V1—the mixer stage. The voltage variations in the plate circuit of V1 are a mixture of the radio station's frequency plus those produced by the oscillator which combine to produce the difference of the two.

**How It's Done.** The mixing operation can go something like this. If C1 (see Fig. 1) is tuned to the station frequency of 1000 kHz and C2 to 1100 kHz, the difference frequency from the mixer is 100 kHz. Transformers T1, T2, and T3 are wound to resonate at 100 kHz and, together with V2, V3, and V4, constitute an amplifier adapted to amplify this 100 kHz difference signal. This section of the receiver was called



The 1925 battery-operated Remler superhet was made available to advanced experimenters in kit form only. It featured eight triodes and required a magic touch to make it work.

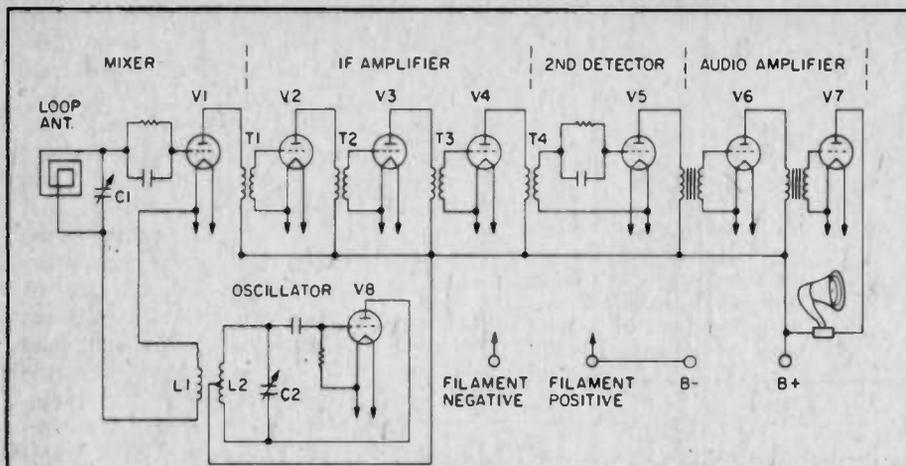


Fig. 1. An early superhet circuit varies very little from circuits used in modern receivers. The local oscillator stage, V8, pumps the mixing signal to the antenna: a great idea at the time, but the circuit radiated some of the signal into the ether. This would cause considerable noise and jamming with today's billions of receivers.

the intermediate frequency amplifier, or IF amp. After demodulation in V5 and after going through audio amplifiers V6 and V7, out comes the voice program. For every new setting of the mixer tuning, the oscillator is tuned exactly 100 kHz above it. So the purpose was accomplished—the mixer-oscillator combination converted every incoming signal to a nice comfortable low value that made the IF amplifier feel at home.

**Results.** The circuit's sensitivity and selectivity proved to be astounding. Coast to coast reception became a reality with the *superhet*. One proud owner of that period bragged that his set would amplify a weak signal so well that if a fly walked on the antenna wire it would come out of the speaker sounding like a jungle war dance.

**Problems.** With the coming of the radio broadcasting era in 1920, you would think that the superhet would naturally be the only way to build a radio receiver. But all was not rosy in superhet town. For one thing it was too expensive! A good triode cost about \$6.50 per copy and, considering an 8-tube lineup, that would take a small bundle for tubes alone, taking into account what the dollar was worth in 1920. In fact, there were only a few components that were available for less than a \$5 bill. Transformers, tuning coils, variable condensers, etc., all fell into this high-price bracket. Besides, the circuits were complex and difficulty arose from the fact that the oscillator was separately tuned because ganged tuning capacitors had not yet been invented. This allowed the operator to set the oscillator to a frequency on either side of the incoming signal which placed every station at two points on the oscillator dial. For example, the

mixer tuned to 1000 kHz and the oscillator to either 900 kHz or 1100 kHz would give a difference of the required 100 kHz, so the station would show at both points.

Another problem reared its ugly head. The mixer was very broad in its tuning and powerful off-frequency locals could come pounding in even with the mixer set at 1000 kHz. If the operator had chosen the 1100 kHz spot for the oscillator and a powerful local was also broadcasting on 1200 kHz, it too could make its way into the mixer and produce the required 100 kHz which would really make a cat fight in the speaker. This latter problem, where the difference frequency is produced by a station you don't want, is called an image, and plagues low cost superhets more or less to this day. You might be able to teach a little old lady to work all the levers on her Stanley Steamer, but there would be no chance to expect her to puzzle out the oscillator tuning. Because of this and other problems, the ultra-sensitive and selective superhet was temporarily left to the very experienced experimenter or radio amateur.

**The TRF Had Its Day.** With the skyrocketing popularity of radio broadcasting, the home entertainment center featured not the superhet but instead a tuned radio frequency receiver—TRF for short. Early radio magazine ads showed home life on a cold snowy night with a warm fireplace crackling and everyone seated comfortably around the TRF and listening attentively while Dad readjusted the three main tuning dials. Outside was a massive long wire antenna installation carefully rigged to hold up one or more strands of copper wire at a great height.

**Regeneration.** The radio usually was a 5-tube set with a tunable low cost RF amplifier. It was an instrument to behold by those just introduced to the electron art, but with all its squeals and whistles it left a lot to be desired. Armstrong was one of the first to recognize that in order for the superhet to make its appearance in the living rooms of America he had to reduce its cost and simplify its tuning. He began work, determining to reduce the number of tubes without chopping the performance. One way was to make the mixer tube also double as an oscillator. Consider the circuit shown in Fig. 2. Here the mixer stage is also made to oscillate by virtue of the plate signal fed back to the grid circuit through the inductive coupling of L1 and L2. If C1 is tuned to say 1100 kHz, then any 1000 kHz broadcasting signal that can struggle into broad tuning L1 will also be impressed on the grid and we have a resulting difference frequency of 100 kHz. It is then fed to the IF amplifier in the usual way. What's wrong with this scheme is that C1 is actually detuned from the desired 1000 kHz broadcast station so we lose sensitivity.

Next let's try the circuit shown in Fig. 3. Here the oscillator is set in motion by using the same general scheme of inductive plate to grid feed-back through T2. The radio station's modulated signal comes in on T1. Notice that L1 and L2 are connected in series. We can tune the L1-C1 combination to 1000 kHz and the L2-C2 combination to 1100 kHz. We then have in the plate circuit of V1 the 1000 kHz signal from the radio station plus the 1100 kHz feedback oscillator output which combine to give us our good friend the 100 kHz difference frequency. It sounds easy but it turns out that it was practically impossible to tune. In reality, the tuning of C1 and C2 are only 100 kHz apart and if you change the setting of C1 it interacts to alter the tuning of the L2 and C2 network and vice versa. So you would have to be an expert to keep up with that tuning marathon.

Armstrong's staff finally came up with the solution to the dilemma. They used the same circuit as in Fig. 3 except that C2 is tuned to produce an oscillator frequency exactly half of that used during the marathon bout. In other words, with C1 tuned to the usual 1000 kHz, C2 is tuned to 550 kHz instead of 1100 kHz. But why do that? Well, oscillator circuits in those days were rich in harmonics, so appearing at the IF transformer is not only the 1000 kHz component but also the second harmonic of the oscillator frequency, or 1100 kHz, which produces the nice 100 kHz need-

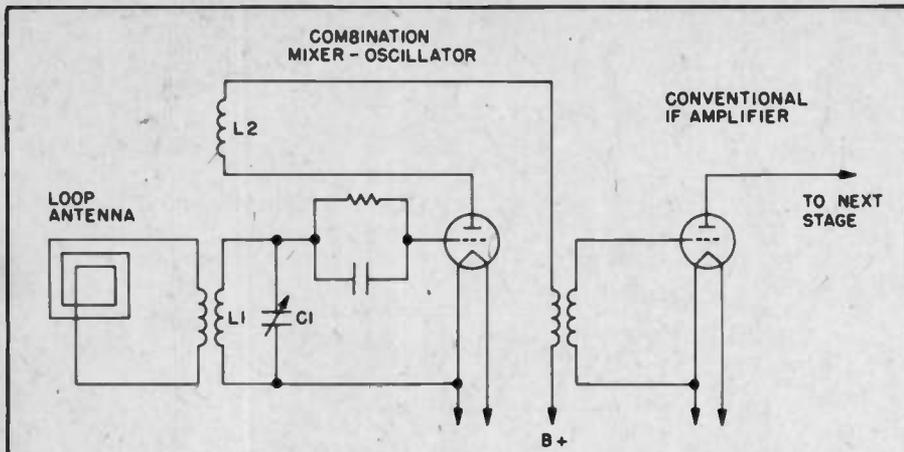


Fig. 2. Don't confuse this circuit with a regen receiver—actually, it is a superhet-type. Capacitor C1 is tuned to 100 kHz above the antenna signal and mixed in the first stage.

ed for the IF amplifier. This placed the mixer tuning and oscillator tuning far apart in frequency by a factor of 100% and therefore practically no interaction exists between the two. So now we have a satisfactory mixer and oscillator in the same tube! This was a major receiver circuit breakthrough.

**More Tricks.** Armstrong wasn't satisfied with this. He needed to sharpen up the tuning of the mixer to eliminate the image frequency problem mentioned earlier. An RF amplifier ahead of the mixer was in order, but how to get it without adding another tube? He solved this by going ahead and adding the RF tube ahead of the mixer but also let it double as an IF amplifier. Armstrong was getting tricky.

Refer to Fig. 4 and we will see how he did it. The modulated signal comes in on the loop which is tuned to our usual 1000 kHz station by C1. This is amplified by RF amplifier V1 and is fed through L3 to the input of the second IF transformer. (Note how V2 is bypassed.) Since the 2nd IF transformer is tuned to pass 100 kHz only, the 1000 kHz signal can't get through and stops there. Notice that while this was going on the RF energy is also passed inductively to L4 and mixes with the oscillator frequency by virtue of the same hookup shown in Fig. 3. C2 is tuned to 550 kHz and the components of the station signal and the 2nd harmonic of the oscillator show up in the plate circuit of V2. Obviously a 100 kHz difference is generated, which is routed back to the primary of the 1st IF transformer. It passes this frequency real well and impresses it back on the grid of V1. Now, V1 is looking at two signals, the modulated station frequency at 1000 kHz and the 100 kHz difference. Tube V1 amplifies both signals just fine and passes them on through L3 again and

to the 2nd IF transformer which passes the 100 kHz component real well. The IF amplifier gladly amplifies it before passing it on to the following vacuum-tube stages.

So Armstrong now had another breakthrough. He had succeeded in incorporating all the virtues of a well-designed superhet by using six battery-powered triode tubes. In conjunction with the packaging engineers of RCA, this circuit made its appearance in 1924 as the Radiola Superheterodyne. It sported a built-in loop antenna making the big long-wire antenna unnecessary. You might say this was the beginning of public acceptance of the superhet. It wasn't low cost (\$286 without batteries); but thousands were sold because affluence was becoming more common in the dawn of the great business boom of the mid 1920s. It was not too difficult to tune, although the separate oscillator tuning caused repeat points for every station. However, careful adherence to the instruction book reduced this. So now the little old lady with the

Stanley Steamer could easily tune in these distant stations and have no difficulty in separating the Merry Old Chief of the Kansas City Night Hawks from Harry Reser's Clicquot Club Eskimos.

**A New Dawn!** The introduction of the Radiola Superheterodyne in 1924 breathed new life into the radio fan fraternity. The radio magazines of the day now featured a vast array of superhet circuits encompassing all sorts of theoretical advantages. Gerald Best, McMurdo Silver, Robert LaCault, and Jackson Pressley were some of the popular figures who offered design innovations. The public's hunger for selective reception of distant stations spawned bigger and better sets. Competition among radio manufacturers was bringing down the price of tubes and parts, so one didn't have to be quite as economically minded when cooking up a *super circuit*. Our friend the radio experimenter now bragged that his set tuned so sharply that when *tuning in a duet*, it *came through as a solo!* Superhet kits began making their appearance with easy step-by-step instructions for the not-so-learned radio fan.

With the advancing state of the art, the operating frequency of the IF amplifier started to increase. Instead of the popular 50 kHz and 100 kHz, in the early days, values of 175, 262, and 370 kHz made their appearance to help reduce image frequency. It is a well-known fact that 455 kHz is the popular one today. How did we ever settle on that value? This is kind of a mystery, but one reason already mentioned is to help reduce image frequency. For example, go back to the case of tuning the mixer to a 100 kHz station, the oscillator would be tuned to 1455 kHz to produce a difference of 455 kHz. Now, if the mixer also allowed a 1910 kHz signal through, it would produce a 455 kHz difference and would come through

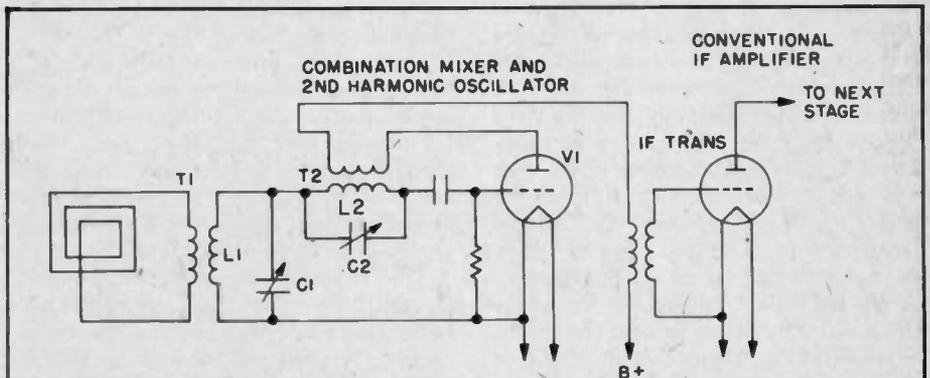


Fig. 3. Once you read the text explanation on how this circuit works, it will be difficult to understand that it works at all! Tuned circuits L1-C1 and L2-C2 interact, making it practically impossible to tune the receiver. Armstrong had to tune L2-C2 to half the desired mixing frequency to obtain the second harmonic for signal mixing.

on top of the 1000 kHz station. But it would be a pretty lousy mixer that would be so broad as to allow this to happen.

But there is a bit of folklore that had more to do with pegging 455, and it had something to do with harmonics. Notice that the second harmonic of 455 KHZ is 910 kHz. In the late 1920s there were no U.S. stations broadcasting on 910 KHZ. It was reserved for the Canadians. Legend has it that 455 was selected to protect the IF amplifier against interference. An improperly shielded 455 kHz IF amplifier would easily let a 910 kHz (2nd harmonic) station get through if you had a powerful one nearby. So, unless you lived on the border, this arrangement would help protect against that problem in your early superhet.

**Bye-Bye TRF.** With the further loosening of the economy, the general public began finding out about the superhet and the TRF began losing favor. In the late '20s the superheterodyne circuit flourished, with the appearance of the big \$400 consoles which featured a single tuning dial and tremendously improved audio quality.

Since necessity is the mother of invention, when the bottom dropped out in 1929 the radio designer had to come up with something that could be had for a few bucks. Next came the entrance of the cathedral-shaped table radio.

Radio designers now had to resort to all kinds of tricks in order to drastically reduce cost but still maintain good selectivity and tone quality.

One of the marvelous examples of such a play is the 1931 vintage Philco Model 80. All the superhet action is done with two tetrode tubes! Add a pentode audio stage and a power supply rectifier (4 tubes total) and you have a very fine set to sell for about \$19.95. The circuit is shown in Fig. 5 and it operates something like this: connected to the plate of the 236 mixer-oscillator, V1, is an oscillator coil with its tank circuit tuned 455 kHz higher than the incoming signal. This energy is transferred by pickup coil L2 in series with the cathode bias resistor R1, so the plate current in V1 will vary at the oscillator rate. Also, the plate is varied by the incoming signal on the grid so we end up with the difference frequency of 455 kHz which is passed on to the IF transformer. They couldn't afford an IF amplifier tube, so they made up for it by introducing a little positive feedback in the 2nd detector by virtue of coupling coil L3. Believe it or not, even though the actual circuit contains 8

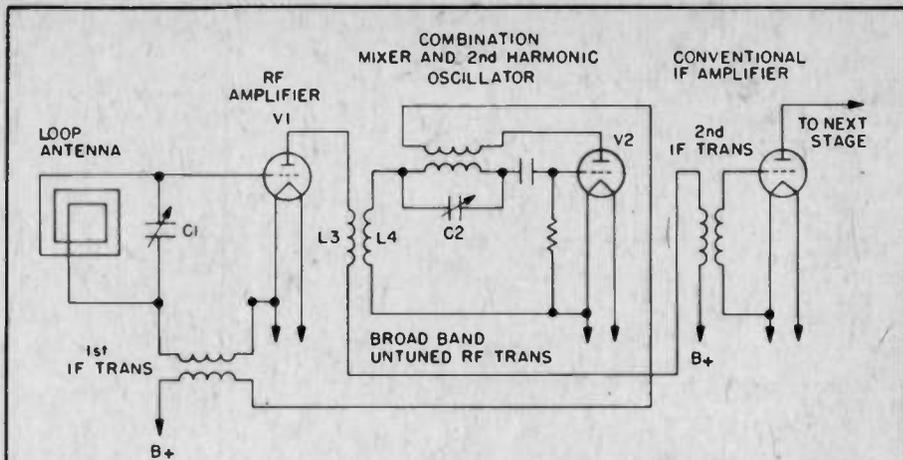


Fig. 4. Here is a circuit that defies analysis at first glance. The combination mixer and 2nd harmonic oscillator circuit operates like the circuit in Fig. 3. This receiver circuit was first used in 1924.

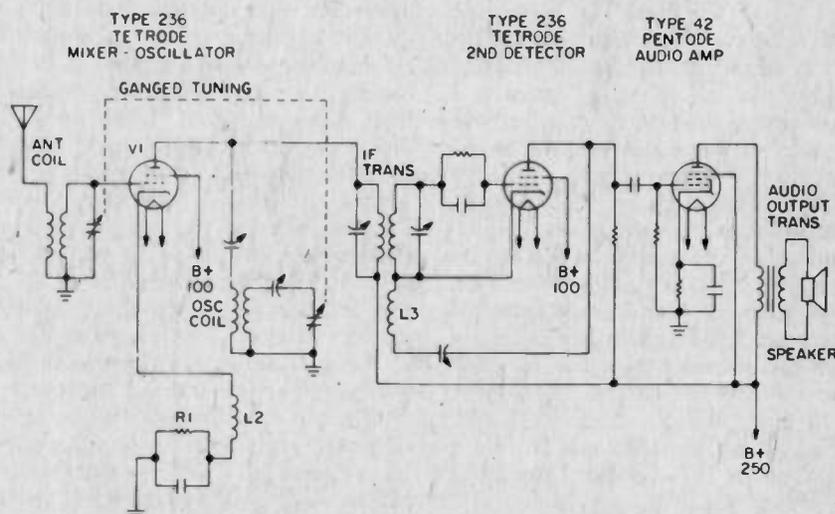


Fig. 5. Now the superheterodyne circuit is shaping up to resemble the circuit used today. One-knob tuning was now a reality with the invention of the ganged tuning capacitor. This circuit was used in the 1931 Philco Model 80. The tetrode and pentode vacuum tubes were relatively new. A rectifier tube, not shown, provided DC voltage, eliminating the need for expensive wet-cell batteries.

trimmer capacitors which needed peaking up, the Philco Model 80 home receiver really performed with the one-dial tuning at that.

By now the little old lady with the Stanley had lost all her money in the stock market crash. She may be forced to drive a used Model T Ford, but she's fortunate in one way—she only needs a \$20 bill to get a first class table model superhet that would eat alive her old Radiola Superheterodyne.

The radio development that finally sounded the death-knell to the TRF radio and made the superhet the front runner for good and all was the advent of the pentagrid converter tube. One of the first was the type 2A7 and was basically two tubes in one and allowed the mixing and oscillator action to happen in one envelope. All previous at-

tempts described so far using conventional tubes depended upon the signal frequency and oscillator frequency being impressed on the same control grid. This arrangement loses efficiency as the oscillator frequency goes up because the signal and oscillator voltages get out of balance. The pentagrid tubes provided electronic shielding between the two functions and eliminated all the loading and detuning problems. The type 2A7 was the grandfather to the 6K8, 6SA7, 6BE6, etc., which were so popular in the twilight hours of tube-type superheterodyne radio.

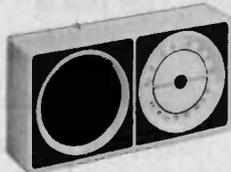
History will certainly call Edwin Armstrong "Mr. Superheterodyne." His contributions were a major factor in leading the way to awaken the giant that we have come to recognize as the fabulous electronics industry. ■

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# INSIDE CB RADIO

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□ THE CB TRANSCEIVER is truly an amazing device. Dollar for dollar it is the best value in consumer-type electronic equipment. Organized around two basic design systems—amplitude modulation and single sideband—the modern CB transceiver can be specifically tailored to a given level of performance or operating convenience by adding a dollar or so of parts here, fifty cents worth of hardware there. No other consumer device can be so easily expanded to meet the needs of the user. Whether you are a hobbyist or a business-only CBer, that black box called a transceiver can do exactly what you want it to do when you want it to.

The CB transceiver can provide general, or blanket, communications over a general area, provide pinpoint line-of-sight communications, keep you informed of emergency situations, record messages while unattended, substitute for a telephone across impenetrable mountains, function as a pocket-phone, and . . . well, anything you can think of in the way of personal communications can probably be handled by the modern CB transceiver. In short, the CB transceiver is a sort of universal “communicator” in that it can be made to meet any operating needs.

The exact facilities delivered by your present CB transceivers, or models you might be considering adding to your CB station, depends on the performance and features of small, individual “modules” which the manufacturer has

plugged together at the factory. Using more or less basic circuits he can build upward from a three-control black box (channel selector, volume, and squelch) to one of those gold-plated specials with everything except running water.

In this article we're going to look into those “modules,” for by having an understanding of how CB transceivers work you'll be able to purchase a CB transceiver having *all the features and performance needed for all your applications*. As a side benefit, by knowing the in and outs of your CB transceiver, you'll be able to handle operating and minor repair problems which might come your way.

**Two CB Systems.** There are presently two distinct and separate types of transmission systems in use: AM, or amplitude modulation, and SSB, or single-sideband. They are incompatible with each other, meaning an AM station cannot “work” a sideband station and vice versa. Only if the individual transceivers have *both* AM and SSB can they work all CB stations.

In the amplitude modulation system the voice energy, termed modulation, is impressed on the radio frequency carrier generated by the transmitter. In the process of combining the audio modulation and RF carrier, new frequencies called *sidebands* are generated. These sidebands are equal in frequency to: the RF carrier *plus* the modulating frequencies, and the RF carrier frequency *minus* the modulation frequencies.

The maximum amount of *undistorted* modulation that can be impressed on the RF carrier is one half of the carrier power input, which, of course, also means one half the carrier power output. If the CB transmitter takes 5 watts input, the maximum amount of modulation is 2.5 watts. If the transmitter has 80% efficiency—actual output power divided by input power—there will be 4 watts carrier output power and 2 watts of modulation divided between two sidebands, so that each sideband has only 1 watt of modulation power.

**One Does The Job.** The AM receiver responds only to the energy in one sideband; it requires the carrier and other sideband for restoration of the signal back to audio, but only one sideband conveys intelligence. (The other sideband can be eliminated at the transmitter with very little audio loss at the receiver.) Therefore, of the entire 7.5 watts of energy put into the transmitter, 1 watt of RF output power, at most, is converted back to an audio signal at the receiver.

The advantage of the AM system lies primarily in the fact that circuits are relatively simple, and it is quite easy to build a good communications system at a rather low price—as evidenced by some rather noteworthy CB transceivers in the \$100 price range. It is the easiest system to use, requires no adjustments other than selecting the desired channel, and will generally give years of trouble-free operation even under the most se-

vere handling.

Disadvantages to the AM system are excessive channel bandwidth and susceptibility to interference. Though only one sideband is needed to transmit intelligence, the AM signal has two sidebands, one sideband taking up space that could be used by another station. Though this is really of no concern to the average user, the citizens band is fast becoming saturated with stations fighting for the available channels; if the second, unneeded, sideband were eliminated, the citizens band could accommodate twice the number of interference-free signals. As far as interference is concerned, an AM receiver is particularly susceptible to heterodyne interference, the whistle caused when two stations try to use the same frequency simultaneously. The interfering station's signal strength need be only 1/100 that of the desired station to cause objectionable interference.

**A Solution?**—Single Sideband, or SSB as it is termed, utilizes the principle that only one sideband is required for transmitting intelligence. By eliminating the carrier and second sideband at the transmitter, all the intelligence-carrying energy goes into the entire signal transmitted by the station. This means that the transmitter input power allowed by the FCC, 5 watts average DC power, goes into the modulation energy. This is four times greater than the 1.25 watts of power input for one sideband of an AM signal.

To digress for a moment, you'll often find SSB transceivers rated at 10 watts P.E.P., or 15 watts P.E.P. This does not mean 10 or 15 watts power input. The P.E.P. stands for Peak Envelope Power, which when integrated over the complete cycle comes out as 5 watts average power input, which is the same thing the FCC means when they specify 5 watts DC power input.

All the RF energy radiated from the SSB transmitter is sideband energy, and since the power input of the sideband energy is four times that of the AM sideband input, the signal at the receiving station is four times stronger than that of an AM transmitter. The only problem is that the receiver hears the sideband signal as monkey chatter or Donald Duck: completely, but completely unintelligible.

As we've said, a carrier is necessary at the receiver for converting the signal back to audio. With a sideband receiver, the carrier is reinserted at the receiver by a separate oscillator which is part of the receiver's detector. (The detector doesn't care where the carrier comes

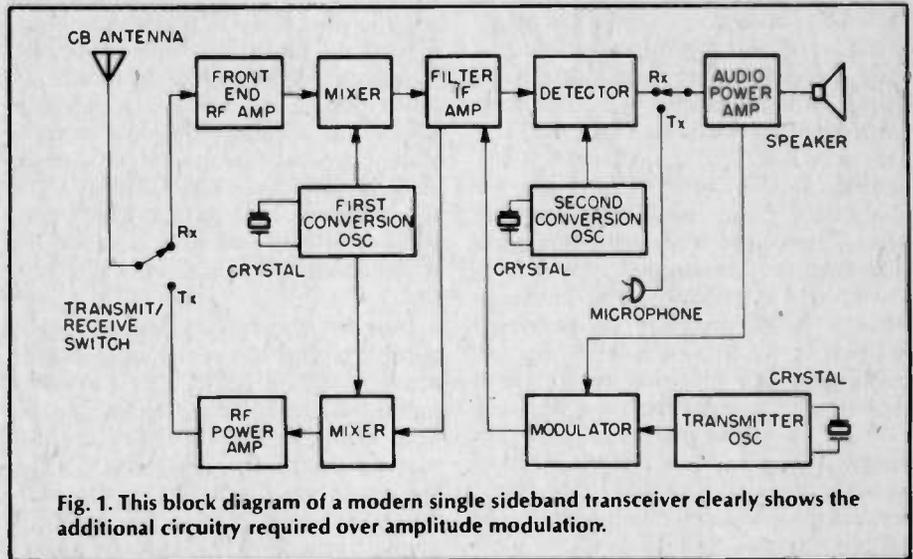


Fig. 1. This block diagram of a modern single sideband transceiver clearly shows the additional circuitry required over amplitude modulation.

from as long as one is there.)

**23 Times SSB=46.** If we backtrack, we see that the SSB signal uses only the radio frequencies that are needed for one AM sideband—it could be the upper or lower sideband frequencies. This frees the frequencies needed by the unused AM sideband for another SSB station; and, in fact, two SSB stations can share the same channel without interference, one using the upper sideband frequencies, the other the lower sideband frequencies. If all CB stations were SSB the present 23 channels could provide 46 communication channels.

Single Sideband offers several advantages over AM. First, there's the matter of *working range*. The intelligence-carrying part of the signal is four times stronger than AM; added to signal enhancement by the process of SSB detection in the receiver, an SSB signal is the equivalent of 8 to 10 dB more effective than an AM signal. The effect at the

receiver is as if an AM station were running almost 50 watts input power. Also, there is no carrier, so there is no heterodyne "whistle" interference if all stations using a channel are SSB. The interference between SSB signals sounds like chatter, which is not as annoying as a constant background whistle.

Since highly selective filter circuits are required for the generation of an SSB signal, these same filter circuits are sitting there, available for receiving, so you'll find that SSB transceivers feature high selectivity (adjacent channel interference rejection).

Since SSB requires considerable precision circuitry, as you'd expect, SSB rigs are not cheap. Unlike AM transceivers, which can be stripped of circuits to the bare bone and still deliver excellent overall performance, SSB requires sophisticated circuits for both budget and higher priced models—the differences in price generally reflecting

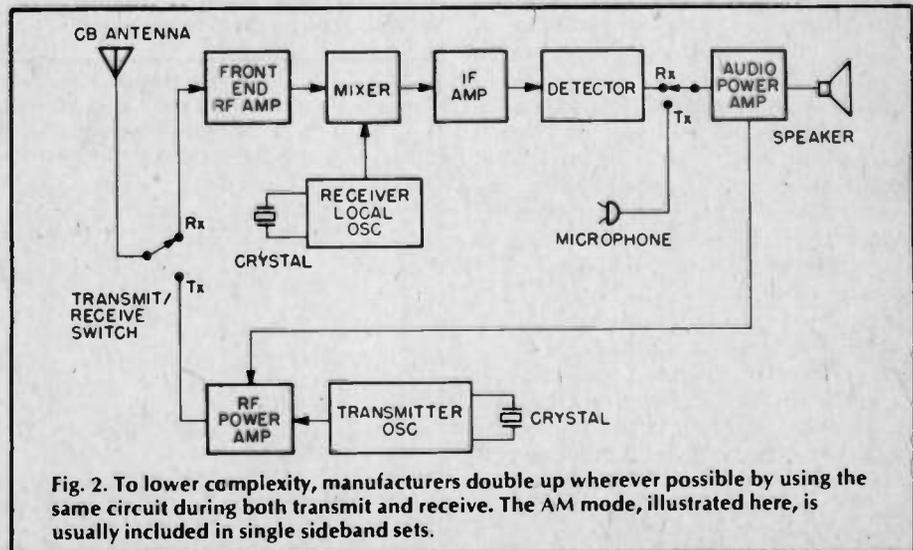


Fig. 2. To lower complexity, manufacturers double up wherever possible by using the same circuit during both transmit and receive. The AM mode, illustrated here, is usually included in single sideband sets.

# CB special section

operating convenience features rather than performance.

Figures 1 and 2 give a good illustration of the difference: Fig. 1 is a basic AM mobile transceiver; Fig. 2 is a basic mobile SSB transceiver. If we consider that each individual circuit function is a *module* or *building block*, you can see that many more modules or building blocks are required for SSB. While the simplified AM transceiver can be produced as a reliable, low cost unit suitable for mobile operation, the basic SSB transceiver requires considerable circuit refinement and precision for fuss-free operation. The extra circuitry required for SSB is reflected in its substantially higher price compared to AM CB transceivers; however, because SSB transceivers must be built with a high degree of precision, all SSB models are inherently "gold-plated specials" offering the highest level of performance.

Of all the circuits that go into a CB transceiver—whether AM or SSB—it is those which make up the receiver section that most directly determine the final communications performance, for it is the receiver which determines if you can hear the other station—and if you can't hear 'em you can't work 'em.

The receiver must perform two basic functions. First, it must receive the weakest signals possible, for the better the weak signal reception the greater the overall communications range; second, the receiver must be responsive only to the desired signal, rejecting all signals—such as atmospheric noise or radio transmissions—other than those appearing on the tuned channel.

Receiving the signal is primarily the job of those circuits we group as the *front end*, which consists of an RF pre-amplifier broadly-tuned for maximum gain at the CB frequencies, a mixer, and a crystal controlled oscillator. A typical front end block is shown in Fig. 3.

**Just What Happens?** The RF amplifier amplifies the weak received signal to a usable level, discriminating against those signals which lie outside the citizens band. Unfortunately, an amplifier tuned to 27 MHz isn't too effective at discriminating between CB signals and signals close to the citizens band; in fact, it has no discrimination at all against adjacent or alternate CB channels. If an RF amplifier were used to provide all the receiver gain, the user would hear every signal on the band—all at the same time. So, it becomes necessary to convert the 27 MHz CB signal to a *lower* frequency signal, for the lower the frequency of a radio ampli-

fier, the greater is its inherent discrimination against adjacent and alternate signals. If the tuned frequency of a radio frequency amplifier is made sufficiently low (or with the use of special filter devices) it is actually possible to completely separate two *adjacent* signals, such as from channels 9 and 10. The lower frequency amplifier which provides selectivity and gain is called the intermediate frequency, or IF, amplifier.

**How It's Done.** The front end components termed the *mixer* and *oscillator* convert the 27 MHz RF amplifier's output to the IF frequency. Assume the desired signal is 27.065 MHz (channel 9), and the IF frequency is 455 kHz. We would select a crystal for the oscillator that would produce an oscillator output frequency 455 kHz above 27.065 MHz (27.520 MHz). We could also use an oscillator frequency 455 kHz below channel 9; it wouldn't make any difference for this simple illustration. Now, both the RF amplifier output of 27.065 MHz and the 27.520 MHz oscillator are fed into the mixer where they beat together to produce new frequencies equal to the sum and difference of the two input frequencies. The output of the mixer will consist primarily of four signals: the original 27.065 and 27.520 MHz, the sum of the two which is 54.585 MHz, and the difference of the two which is 455 kHz. (Aha!) The mixer's output is then fed to a circuit *tuned* to 455 kHz. Of the four mixer output signals, only 455 kHz is passed by the tuned circuit; this is the signal which is fed to the IF amplifier.

**The IF Amplifier** provides most of the receiver's gain and all selectivity. IF amplifier systems used in CB equipment are either single or double conversion, though there have been a few

models in the past which went so far as triple conversion. The important point to bear in mind about single vs. double conversion is that it really bears no relationship to receiver performance other than *image rejection*.

A simplified single conversion IF consists of an amplifier and a tuned circuit, as shown in Fig. 4. The input tuned circuit is really the same tuned circuit as used for the output of the front end. The IF amplifier's output tuned circuit feeds the detector, which separates the modulation from the radio frequency signal, passing the modulation on to audio amplifiers and, finally, to the loudspeaker.

The selectivity of the IF amplifier is determined by the tuned circuits; greater selectivity is attained by using more tuned circuits. Additional tuned circuits are generally added in conjunction with more amplification, and a typical IF section from a moderate cost CB transceiver would more likely resemble Fig. 5—two IF amplifiers with three tuned circuits. This arrangement is commonly used, and provides some 20 to 25 dB adjacent channel rejection.

To attain even greater selectivity requires more tuned circuits, of a type which are relatively expensive. Recent developments in mechanical and crystal filters (and ceramic tuned circuits) allow extra selectivity to be built into a receiver at substantially reduced cost and complexity compared to specially coupled tuned circuits. The most common super-selective device is the mechanical filter—which is found in everything from budget priced walkie-talkies to high performance base stations. As shown in Fig. 6, the mechanical filter can be "dropped" into an existing IF amplifier design, and though easily added to the design, the filter increases adjacent channel rejection from some-

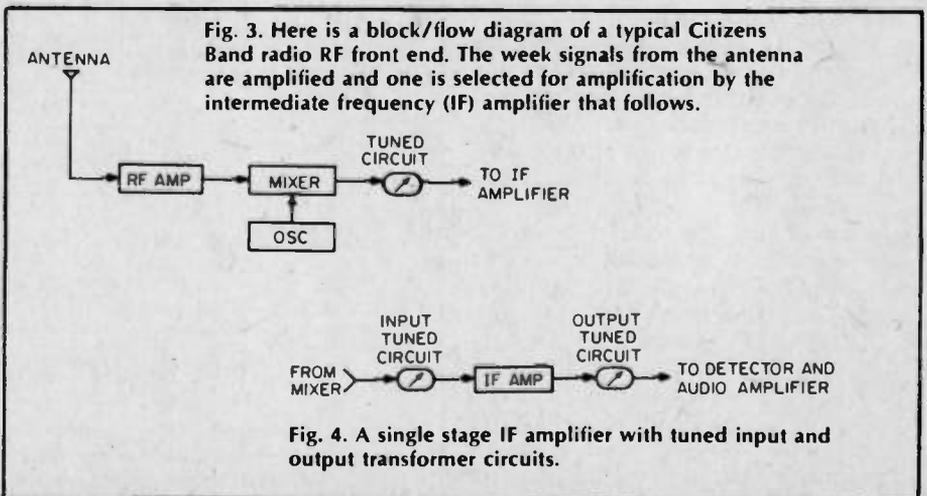


Fig. 3. Here is a block/flow diagram of a typical Citizens Band radio RF front end. The weak signals from the antenna are amplified and one is selected for amplification by the intermediate frequency (IF) amplifier that follows.

Fig. 4. A single stage IF amplifier with tuned input and output transformer circuits.

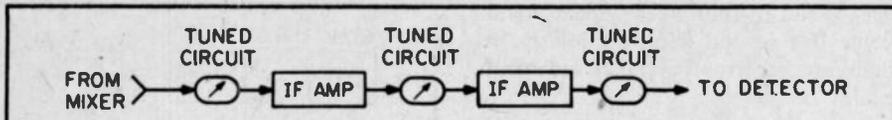


Fig. 5. Typical two-stage IF amplifier in CB rig.

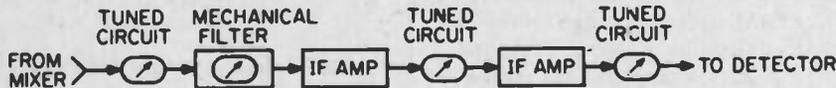


Fig. 6. Mechanical filter improves adjacent channel rejection.

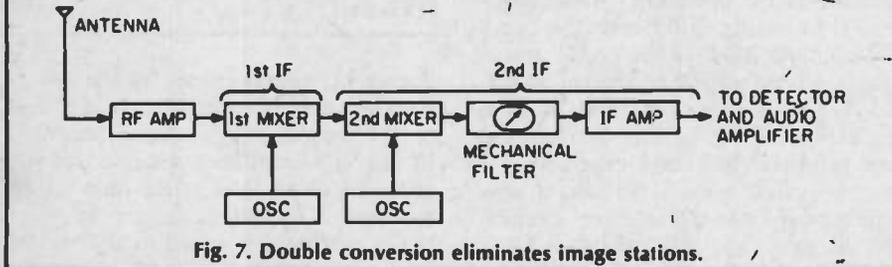


Fig. 7. Double conversion eliminates image stations.

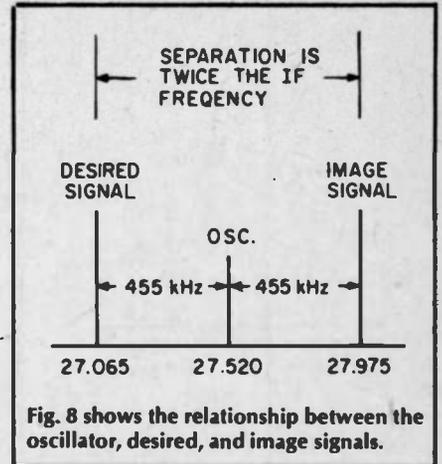


Fig. 8 shows the relationship between the oscillator, desired, and image signals.

thing like 25 dB to 45 dB or better.

In some CB transceivers the entire IF amplifier looks like not much more than a single transistor. The "transistor" is, in fact, an integrated circuit which represents not only all the IF amplification but the detector too. The only thing the IC doesn't have is tuned circuits for the necessary selectivity. The selectivity is almost always accomplished through a mechanical filter, so that the entire IF "strip" boils down to one small package for the mechanical filter and one for the IC. (That's a whopping savings on components.)

**Double Conversion.** The important justification for a double conversion IF strip is for the reduction of image interference. Double conversion means two IF frequencies; for example, the 27 MHz CB signal might be stepped down to 10 MHz and then to 455 kHz. Most of the amplification and almost all the selectivity is contributed by the second (low frequency) IF amplifier. Fig. 7 shows a typical double conversion IF amplifier. Note that the first IF is simply a mixer—it is not even an amplifier; it functions as an intermediate step for the signal between the front end and the second IF.

Fig. 8 shows how image interference is created, and why double conversion is needed if the interference is to be effectively suppressed. As you recall, we said the IF frequency—the mixer's output—was created by beating together the desired signal coming from the RF amplifier and the output of the oscillator which is higher (or lower) in frequency. As shown in Fig. 8, if the desired signal is 27.065 MHz and the oscillator output is 27.520 MHz the difference frequency produced by beating the sig-

nals together in the mixer will be 455 kHz.

But if a signal of 27.975 MHz also gets through the RF amplifier it will also beat with the oscillator signal in the mixer, producing a 455 kHz output for the IF amplifier. The IF amplifier cannot tell which is the desired and which the interfering signal, so it amplifies both; and the receiver's output is a jumble of interfering signals. The interference signal of 27.975 MHz is called the image signal and is always separated from the desired signal by two times the IF frequency.

The interfering image signal gets through the RF amplifier because the amplifier cannot effectively discriminate between two close frequencies; as we said, practically all of the receiver's selectivity comes from the IF amplifier.

To get around the problem of image interference we go to double conversion, and it works as shown in Fig. 9.

In Fig. 9, the input to the first mixer is 27.065 MHz; the oscillator is 37.065 MHz, producing an IF frequency of 10 MHz. Therefore, the image/frequency must be 47.065 MHz. Although an RF amplifier's signal rejection is not outstanding near the desired frequency (27.065 MHz) it can effectively reject an interfering signal 20 MHz higher in frequency (47.065 MHz). That part of the 47.065 MHz image frequency signal that does get through the RF amplifier

is so sharply attenuated that it causes virtually no interference to the desired signal. (An example of typical image rejection performance specifications would be nominally 15 to 20 dB for single conversion IFs and 60 to 80 dB rejection for double conversion. You can see that double conversion IF systems offer considerable image rejection advantages.)

The first mixer's output signal of 10 MHz beats against an oscillator signal of 10.455 MHz in the 2nd mixer, producing the desired IF output of 455 kHz, which is fed to the IF amplifier.

**Selectivity.** The receiver's adjacent channel rejection, known as *selectivity*, is determined, as previously stated, by the IF amplifier; the exact degree of selectivity is determined by the number and type of tuned circuits, mechanical or crystal filters, etc. In a typical AM receiver the carrier signal, which is the modulated IF output from the mixer, is positioned in the center of the IF selectivity passband so the adjacent channel on each side of the desired signal receives the same degree of attenuation. See Fig. 10 for the selectivity curve of a typical high-performance receiver. Note that unwanted signals  $\pm 10$  kHz from the center (IF) frequency are attenuated 60 dB. In a receiver without some form of high selectivity device such as a mechanical filter, the signals from adjacent channels might be attenuated only 20 to 30 dB.

Single sideband (SSB) receivers might use the type of carrier position in the center of the IF selectivity curve

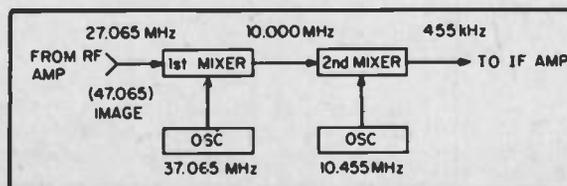


Fig. 9. To get the image out of the CB band and into a relatively unused portion of the spectrum, double conversion is used.

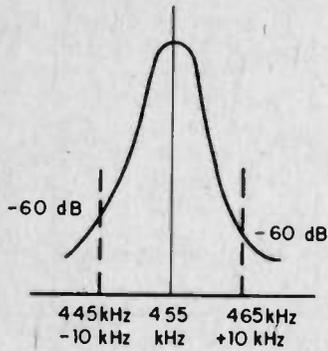


Fig. 10. IF response for AM reception covers both sidebands.

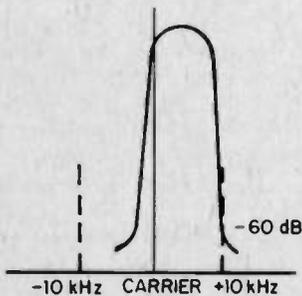


Fig. 11. For SSB reception narrow curve shifts to upper (or lower) sideband. Unused lower sideband can be used by another transmitter.

(passband), but they more likely will position the carrier to either side, using the entire passband for just the one sideband used, as shown in Fig. 11. Note that in Fig. 11 the interference from the higher adjacent channel has 60 dB attenuation while the interference from the lower adjacent channel isn't even in the IF passband. (The position of the SSB carrier signal—on the high or low side of the passband—depends on whether the received signal is using the upper or lower sideband.)

Because the IF passband accommodates only the sideband representing carrier modulation, it is possible for another station using the same center frequency to transmit on the opposite sideband, producing little interference. For example, assume the desired signal is transmitting with the upper sideband as shown in Fig. 11. You will note that the entire sideband (modulation) fills the IF passband, while virtually no passband is left for a lower sideband. If another station using the lower sideband comes on the channel, very little of the lower sideband modulation gets through the IF passband. Another re-

ceiver tuned to the lower sideband will receive this second signal; similarly, it would not receive the upper sideband signal.

Unlike receivers, which can be essentially similar up to the detector in both the AM and SSB rigs, there's a world of difference between AM and SSB transmitters; except for the oscillator (the circuit that generates the crystal-controlled operating frequency) there's no similarity between the two.

Amplitude Modulation (AM) transmitters are the easiest to design, adjust, check, and service, for there is little that can go wrong. In fact, between the least expensive and most expensive CB transceivers there might be little, if any, difference in the transmitter circuits. Fig. 12 shows the block diagram for a solid-state "single channel" transmitter—single channel meaning a transmitter with from one to five or perhaps eight channels. In these models the user adds channels by plugging in transmit and receive crystals for the desired channel coverage. The transmitter line-up usually consists of a crystal controlled oscillator, a buffer amplifier to prevent changes in the antenna circuit from reflecting back to the oscillator, and an RF power amplifier, which amplifies the miniscule RF drive from the oscillator to about 3 watts RF output. In some transmitters the buffer amplifier is eliminated and the oscillator feeds directly into the RF power amplifier, just as is done in tube-type transmitters.

High efficiency amplifiers, known as class "C" amplifiers, have efficiencies in the order of 80 percent, so if the DC power input to the RF amplifier is 5 watts the RF output will be about 4 watts or slightly less depending on the overall design parameters.

**Final Amplifier Facts.** In modern CB transceivers the RF amplifier feeds into a pi-network, bandpass, or low-pass filter before the signal is fed to the antenna. Any of these filters sharply attenuates the television-interference-pro-

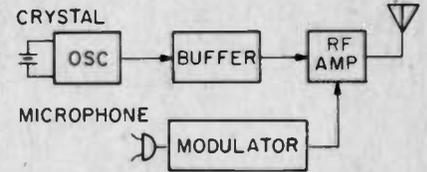


Fig. 12. This basic AM transmitter without crystal synthesizer is used in most 3 to 6 channel sets, although sometimes without a buffer.

ducing harmonics caused by the distortions of class C amplifiers. In addition to the harmonic attenuation produced by the RF amplifier's filter, additional attenuation of TVI (television interference) is generally secured by placing a notch filter—tuned to the second harmonic of 27 MHz—at the transceiver's output jack.

In the days when the vacuum tube was king, virtually all CB transceivers had the RF amplifier tuning controls on the rear apron, accessible to the user for so-called "peaking" of the transmitter. Because solid-state devices are extremely critical in regard to tuning, virtually all modern CB transceivers now have factory adjusted transmitter tuning which is usually sealed, or located inside the cabinet. As a general rule, the factory tuning cannot be improved, and "tweaking" the transmitter tuning controls can easily result in destruction of the RF amplifier transistor!

The TVI filter is something else. Maximum attenuation of harmonic interference is generally attained when the filter is specifically adjusted for the particular transmission line and antenna used, so you'll usually find the TVI filter tuning available on the rear of the transceiver.

When the transmitter has full 23-channel coverage, a crystal synthesizer is almost universal, and the basic transmitter is very similar to the arrangement shown in Fig. 12. The major difference is the synthesizer, a device that

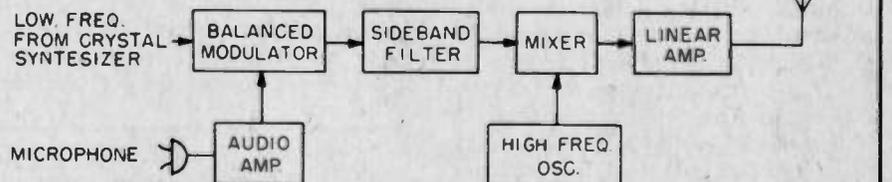


Fig. 14. Circuitry required to filter out the carrier and one, or the other, sideband is more costly but worth every penny in terms of improved communication capability. Sideband filter is usually the crystal type.

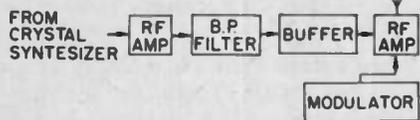


Fig. 13. A filter in series with the RF path removes those spurious signals produced by crystal synthesizers. The filter can be the LC type.

"beats" the outputs from two or more oscillators so that something like half the required 46 crystals are needed for full 23-channel coverage for both the transmitter and receiver. In the most modern transmitters, fewer than 15 crystals are needed for full-23 coverage.

The problem with "beating" the outputs of two or more oscillators is that the resultant output contains the frequencies needed plus many which are not needed; these are known as *spurious* signals. If these spurious signals get through the transmitter to the antenna they will cause interference to other radio services. The spurious signals are eliminated by passing the output of the crystal synthesizer through a bandpass or tuned filter which allows only the desired 27 MHz signals to pass on through the RF amplifier. A typical synthesizer transmitter arrangement is shown in Fig. 13.

**Single Sideband.** SSB has no resemblance to AM transmitters other than that it is a way to carry modulation to a distant point without the need for wires. SSB transmitters are highly complex, and would require so many different circuits that it would appear to be prohibitively expensive. Fortunately, as we'll show, a substantial part of the amplification required for SSB transmitters involves the same type of circuitry as needed for an SSB receiver; so that in CB transceivers, where both the receiver and transmitter are in the same cabinet, it is possible for both the

receiver and transmitter to share one of the most complex and costly circuits, thus making the whole bit economically feasible.

There are several types of SSB transmitter design. One of the most popular and easiest to understand is the so-called filter SSB generator, for which a basic arrangement is shown in Fig. 14. A low frequency output from the crystal synthesizer is fed into a balanced modulator where it combines with the modulation from an audio amplifier. The balanced modulator's output consists of both modulation sidebands but virtually no carrier; the carrier is suppressed in the modulator. This RF signal is then passed through a highly selective IF amplifier which sharply attenuates the undesired sideband. The IF amplifier might have a crystal or a mechanical filter; either type is adequate as long as the selectivity is such that only the desired sideband can pass through. In CB transceivers the transmit IF amplifier is also used as the receiver IF amplifier; this is the reason why SSB transceivers have such high receiver adjacent channel rejection.

**To Complete the Cycle.** The output of the IF amplifier, which now consists of only one modulation sideband, is fed into a mixer where it beats with a signal from a crystal controlled high frequency oscillator. Of the many different frequencies appearing at the mixer's output, one is a CB frequency corresponding to a single modulated sideband. The other mixer output frequencies are attenuated by a balanced mixer design, or the mixer's output is passed through a 27 MHz bandpass filter. The mixer's 27-MHz signal is then fed to a *linear amplifier*, for we cannot use an ordinary class C amplifier which would distort the RF signal, since that would also distort the modulation.

Linear amplifiers have an efficiency in the range of 50 to 70 percent. Though this is less than the nominal 80 percent efficiency of class C ampli-

fiers used in AM transmitters, the modulated RF output of SSB is actually greater than the modulation energy of a class C AM output.

Since without modulation there is no RF output from the transmitter, power input to the final RF amplifier cannot be calculated by multiplying the applied DC voltage by the average DC current; the DC current varies with the modulation. As a general rule it is nearly impossible to measure the equivalent average DC power input of a linear amplifier because the test will usually result in destruction of the amplifying stage. Instead, SSB transmitters—because of their linear amplifier—are rated in P. E. P., meaning *peak envelope power*, which is the input that would be indicated by a voltmeter and a milliammeter if the amplifier were driven continuously by a single RF signal with a peak amplitude within the limits the amplifier could handle (with allowable limits of distortion). Now that's a real mouthful, but it means you'll probably blow the amplifier if you try it.

**To Calculate SSB Power.** Quite often the differences in P.E.P. input power ratings between two or more CB SSB transmitters is more a question of how the manufacturer chose to calculate the value rather than any effective difference in RF power output. More than a numerical value supposedly representing power output, the important point to keep in mind about P.E.P. meter readings is that a meter, any meter, *cannot* represent anything about SSB P.E.P. other than to indicate that some energy is going into the amplifier or some energy is coming out.

Single sideband CB transceivers also feature the AM mode of operation, so a single unit can be used to communicate with *all* CB stations. AM is easily obtained in an SSB transceiver by simply re-introducing the carrier. As we said, the output of the balanced modulator consists of two sidebands and a suppressed carrier. By deliberately unbalancing the modulator the carrier is not cancelled, and the degree of carrier insertion can actually be controlled by design. Since the sideband filter following the balanced modulator has only sufficient bandwidth to pass one sideband, either the filter must be switched out of the circuit or the modulator's output must be routed around the filter so that the entire AM signal—which is twice the bandwidth of an SSB signal—can be transmitted. Some SSB/AM transceivers have been seen which incorporate a separate high-level AM

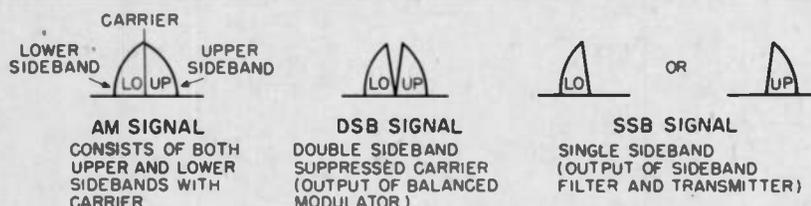


Fig. 15. In the process of removing the carrier signal in SSB transceivers, an insignificant part of the sidebands are sacrificed as depicted by the V-shaped gap in the double sideband signal representation, above.

# CB special section

modulator such as used in standard AM rigs.

**Don't Touch.** The best tuning advice concerning modern solid-state transceivers, whether AM or SSB, is *don't touch!* If the manufacturer doesn't provide a user adjustment control such as an antenna loading control, you will get optimum results with the factory tuning if you have a halfway decent antenna system. Actually, not only can a high standing wave ratio, say, 3:1, reduce the power output through normal SWR losses, it can also have such a drastic effect on the operating characteristics of a solid-state amplifier that the modulation turns to "mush." (This is not necessarily true of tube-type rigs which can absorb a high SWR without substantially affecting the modulation characteristics.)

The modern solid state rig delivers its maximum RF output and optimum talk power when working into a load impedance as close as possible to 50 ohms—meaning an SWR as close as possible to 1:1 (Yes, 1.3:1 or 1.5:1 is the same as 1:1, for CB use.) Because the antenna system directly controls the transmitter's performance, and because the antenna system is almost completely dependent on user installation and adjustment, as much time and effort as possible should go into securing the best possible antenna installation: no transmitter can be effective if you can't get the signal out.

So far in this article we've shown how the transmitter and receiver circuits work, and we've discussed how a specific design might be of particular importance to *your* CB application. A common thread when discussing these circuits has been crystal controlled single frequency vs. frequency synthesizers. In this section we'll go into the *why* and *how* of single frequency and synthesizer oscillators; we'll also look at *noise limiters*, because if you can't hear through the noise you might as well go look for a telephone.

The least expensive form of frequency control in transceivers of substantially less than full-23 coverage (say, 6 channels) is the crystal controlled oscillator. Each channel requires two crystals, one for the receiver oscillator and one for the transmitter. You usually buy these crystals in matched pairs for a particular model transceiver or a particular type of transmitter. Many crystals work in many different models. A pair of crystals usually costs well under \$10, and if all you need is single channel coverage you don't pay for

coverage you don't need. Similarly, if you need coverage on two or three channels, again, you have a minimum investment.

**Mushrooming Bucks?** But what about the CBer who wants full-23 coverage? If we stick with designs requiring a pair of crystals for each channel, the rig would require at least 46 crystals, and their basic price would add at least \$100 to the total transceiver cost!

We cut selling prices of modern 23-channel CB transceivers by using a crystal synthesizer to reduce the total number of crystals needed for full coverage. It is possible—as we mentioned in previous installments—to mix the outputs of two oscillators, or signals, together to produce a third signal (this is the principle of superheterodyne receivers). By extensive use of oscillator output mixing, or "eating" as it is commonly termed, we can secure full-23 coverage with only 16 crystals; fewer if we're willing to use some tuned, rather than crystal-controlled, low frequency oscillators.

Fig. 16 shows how a typical crystal synthesizer works. Oscillator 1 has twelve switch-selected crystals; oscillator 2 has two crystals selected by switch S1b, which is controlled by switch S1a; oscillator 3 also has two crystals, selected by switch S1c. At all times switch S1 determines which crystals are used for all three oscillators.

For illustration, assume we want to receive channel 1, which is 26.965 MHz. Channel selector S1 will select the 38.275 MHz crystal for osc. 1; the

11.310 MHz crystal for osc. 2; and the 11.765 MHz crystal for osc. 3. The signal arriving at the receiver's antenna is 26.965 MHz.

**Here's How.** First, the received signal of 26.965 MHz "beats" in the first mixer with the 38.275 MHz signal from osc. 1. One of the products of beating the two signals is a mixer output of 11.310 MHz (the difference between 38.275 and 26.965 MHz). Then the 11.310 MHz signal is fed to mixer 2 where it beats with the 11.765 MHz output from osc. 3. One of the output signals of mixer 2 is 455 kHz (the difference between 11.765 and 11.310 MHz), which is fed to the receiver's IF amplifier. Note, incidentally, that because of the two required receiver mixers the receiver is automatically double-conversion.

For the transmitter channel 1 signal, the outputs of oscillators 1 and 2 are beat in mixer 3. The difference between 38.275 and 11.310 MHz is 26.965 MHz, so this mixer output becomes the drive signal for the transmitter.

Note that the 38.275 MHz crystal also serves for channel 5 when S1b switches in the 11.260 MHz crystal for osc. 2. Just for fun, take time out to figure which crystal combinations serve for what channels.

If you've done the pen and pencil work, you'll discover a frequency combination which isn't an authorized CB frequency. Generally, the transceiver's channel selector will have an uncalibrated blank space for this frequency. And if you're on your toes you should

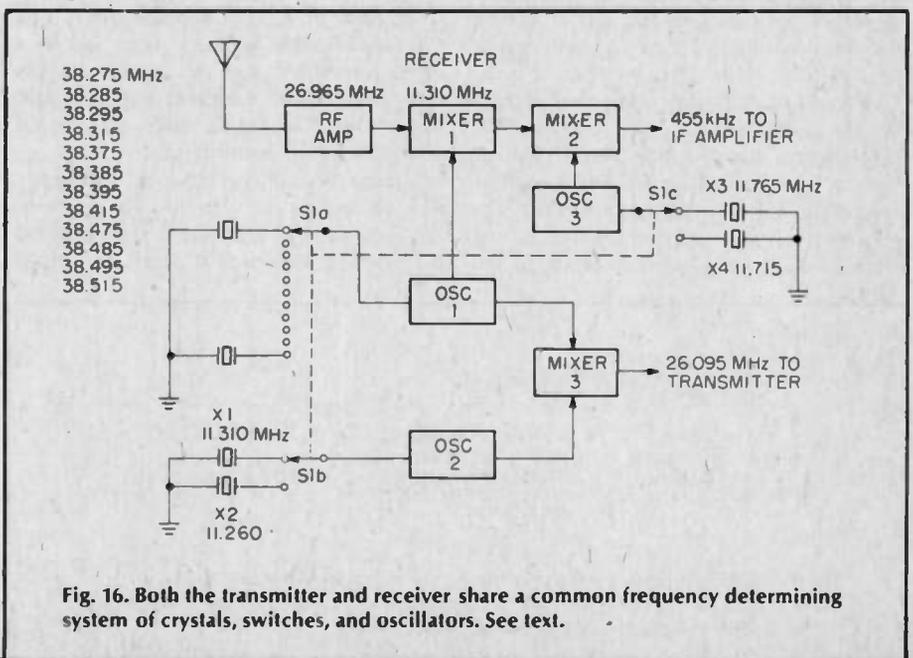


Fig. 16. Both the transmitter and receiver share a common frequency determining system of crystals, switches, and oscillators. See text.

be asking about the other output frequencies from the mixers; after all, we've been referring only to the difference frequencies. What of the sum frequencies, and the signal fundamental frequencies? Normally, the signal and sum frequencies lie outside the bandpass of the succeeding circuits and are not a problem. For example, the total signal output of mixer 1, when the receiver is tuned to channel 1, is 26.965 MHz, 38.275 MHz, 65.240 MHz (sum) and 11.310 MHz (difference); obviously the other signals are so far removed from the desired 11.310 MHz that they will be filtered by the normal tuned circuits of the mixer 2 input.

**Keeping It Clean.** When there is the possibility that harmonics of the mixer's output will beat with any other mixer output signal, including harmonics of harmonics, which could cause interference problems, the mixer's output will be passed through a bandpass filter to remove everything except the desired signal.

A logical question at this point is: "Where are the savings? Isn't the cost of the extra oscillators and mixers equal to or greater than the cost of the unneeded crystals?" The answer is *no*. A double-conversion receiver requires two local oscillators and two mixers—no more than used for a crystal synthesizer. The transmitter would still require an oscillator so the only "extra" stage is the mixer which often replaces a buffer amplifier; so again there are no extra circuits. When the mixer does not replace a buffer, it's an extra, but the cost of one transistor and a few components is actually *less* than the cost of one crystal—and the synthesizer saves at least 30 crystals!

To further reduce costs in this age of the shrinking dollar, some manufacturers now replace the two crystals needed for the receiver (osc. 3) with a fixed-tuned circuit, reducing the total number of crystals to 14. Savings are reflected in a lower transceiver price.

One manufacturer goes so far as to provide optional full-23 coverage through the use of a synthesizer. The rig is sold with the necessary crystals for oscillators 2 and 3, but only one crystal for osc. 1, which therefore provides coverage for *two* channels. The user can purchase crystals for additional channel coverage as required; but keep in mind that (generally) one additional crystal provides transmit and receive for two channels. The cost advantage is obvious.

**Noise Limiters.** Frequencies assigned

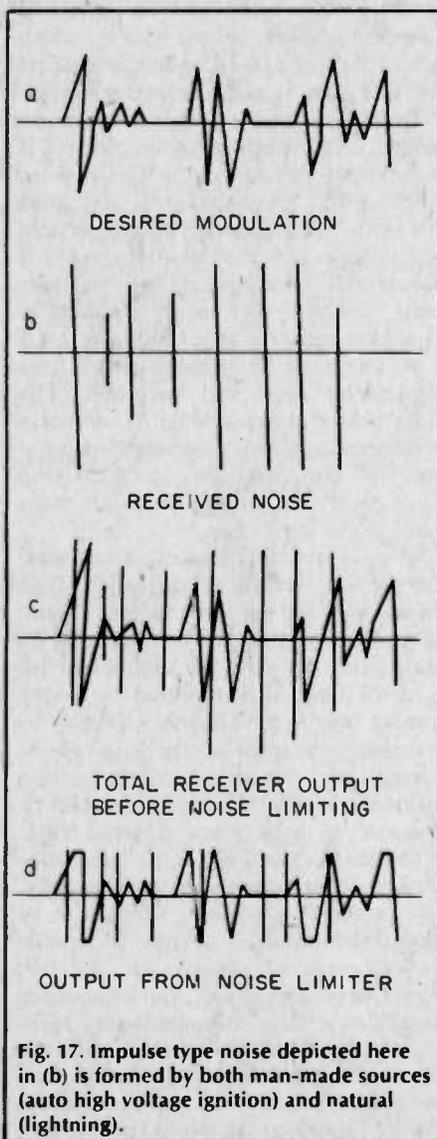


Fig. 17. Impulse type noise depicted here in (b) is formed by both man-made sources (auto high voltage ignition) and natural (lightning).

to the citizens band are among the noisiest in the whole radio spectrum. Everything from automobile ignition systems and medical equipment to the neighbor's sewing machine and electric drill produce enough hash to literally drown out a weak CB signal. Most noise is primarily *impulse noise*—sharp noise spikes received simultaneously with the desired signal, and all CB transceivers incorporate some sort of device to attenuate or actually remove the noise impulses.

The simplest form of noise limiter is the so-called floating series or parallel type, and it's unimportant to know precisely how they work; rather, it's important we know their limitations.

Both limiters do exactly what they say: they limit the amplitude of the noise impulses to a tolerable level. Fig. 17 shows how they work. Fig. 17a is the desired modulation from the re-

ceived signal. Fig. 17b shows, separately, the noise impulses received along with the signal. Fig. 17c is the resultant audio output before processing by a noise limiter. Fig. 17d is the final audio heard in the speaker after limiting.

Note that the combined unlimited output shown in Fig. 17c has noise pulses of greater amplitude than the desired modulation: it is these high level impulses that create the "grind" which irritates the listener and obscures the intelligence.

When limiting is applied for noise reduction, the maximum amplitude of the signal is allowed to approach between 50 and 80 percent of the maximum peak value; everything above this ceiling is clipped off the signal, as shown in Fig. 17d. In this manner the noise impulses are limited to a maximum value equal to the maximum peak modulation level. Since the modulation itself is peak limited, some distortion is added to the signal; but more importantly, the noise "grind" is sharply reduced.

**Old Days.** Some early gold-plated-special CB transceivers employed an adjustable noise limiter whereby the limiting ceiling could be established by the user. Naturally, the lower the ceiling the greater the noise reduction, and the greater the audio distortion. Operators using maximum limiting for maximum noise suppression also suffered maximum audio distortion, and their complaints of "excessive distortion" to the manufacturer's resulted in the elimination of the adjustable limiting feature. Today most CB transceivers use a "floating" limiter which automatically establishes an acceptable limiting level depending on the strength of the received signal. It's not the best limiting but it's not the worst—it's adequate for most users.

Ultimate noise suppression is obtained from a "noise suppressor," a special type of circuit which actually punches a "hole" in the received signal where a noise pulse normally would be. These holes have little effect on modulation distortion, but are almost 100 percent effective at reducing sharp impulse noise. Some manufacturers have described their ordinary noise limiters as "suppressors," but that's like comparing watermelons with lemons.

**And Today...** There are several types of noise suppressor circuits; the easiest to understand is the "RF suppressor" shown in Fig. 18. (All suppressors work on essentially the same principle.)

Note that in addition to the receiver's

# CB special section

normal front-end (RF amplifier, oscillator, and mixer), a 25 MHz RF amplifier is also connected to the antenna. The noise impulses received at 25 MHz are essentially identical to the noise impulses at 27 MHz; since there is little, if any, broadcasting activity around 25 MHz the output of the 25 MHz amplifier will be noise. (The actual "noise frequency" is selected for an unused part of the radio spectrum.)

The output of the 25 MHz amplifier is rectified into DC voltage pulses corresponding to the received noise impulses. This voltage (or current, depending on receiver design) is used to bias the receiver IF amplifier to cut-off, so no signal can pass through the IF amplifier when a noise impulse is received. (Often a separate noise-gate is inserted in the IF amplifier which is "closed" by the DC voltage pulses.) Each time the IF amplifier is cut off, a "hole" is punched in the received signal. Since the noise impulses are of very short duration in relation to the modulation, there is little, if any, distortion added to the received signal.

The noise suppression rectifier is usually designed only for sharp impulse noise. Long-term noise would produce a cut-off which would interfere with the received signal. To accommodate both short and long duration noise a noise suppressor is teamed up with a limiter, so the limiter can handle long duration noise. Together they provide the best possible noise suppression, though the extra circuits needed for the suppressor do increase the selling price.

**Final Limiter Facts.** A question often asked by many readers is, "Why do some transceivers have noise limiter switches?" The switch really serves no useful purpose unless you're operating on a mountain miles from man-made noise sources, and even then the normal atmospheric background noise might still require noise limiting. The only purpose of the noise limiter switch is to convince the user the noise suppression circuits are really working. No matter how bad the noise interference might be on your transceiver, it would be a lot worse without some form of noise reduction.

Only one manufacturer ever produced a CB rig without a noise limiter, and that was a mistake in design: the design engineer simply forgot about the noise limiter until after the unit went into production! Attempts to add a limiter to the finalized printed circuit board produced barely perceptible noise reduction and the transceiver was a failure—the few early purchasers quick-

ly spread the word and an informed CBER wouldn't touch one with a 15-foot pole. Effective noise limiting is the first consideration in any transceiver design.

Everything considered, the most important characteristic of a given CB communications system is the *modulation*. In fact, modulation is the most important characteristic of any system which relies on the human voice for transmitting intelligence—CB, amateur radio, military, or space exploration. The most sensitive receiver is worthless if an incoming S9 signal is garbled, or masked by noise and distortion. The most powerful transmitter is similarly worthless if there isn't enough modulation to get the intelligence-carrying voice over the atmospheric or man-made noise level.

If we assume that a transmitter's basic modulation system is distortion free, there exists a fixed limit to the amount of modulation that can be impressed on the carrier signal. If we attempt to exceed the limit of modulation by simply turning up the modulation level, say by increasing the gain of the microphone preamplifier, we then generate excess distortion which will tend to garble the voice when the received signal is weak. When the received signal is strong, distortion often *appears* to be increased talk power because there appears to be more modulation. It is this characteristic of *apparent* increase in the talk power of strong signals that often gives the CBER a false sense of accomplishment. He fails to realize that when the signal strength falls into the noise level the audio becomes almost unintelligible; it might sound to the ear as though a lot of *talk power* existed, but the truth is, little in the way of intelligence is extracted by the listener.

The fixed limit of modulation for an AM or SSB transmitter is termed 100 percent modulation. Actually, there is a condition known as 100 percent nega-

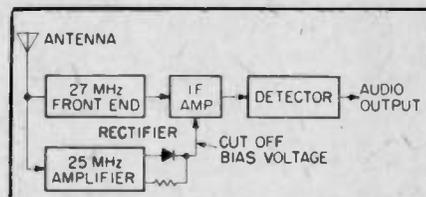


Fig. 18. Perhaps the finest form of noise eliminator in CB is the RF-type employing a separate front end at 25 MHz that listens for "noise."

tive modulation, as well as a condition of 100 percent positive modulation. Fig. 19 shows how modulation is handled for AM transmitters. Assume the carrier wave produced by the transmitter is 10 volts. If we impress a 10 volt peak-to-peak audio sine wave on the RF carrier, at the positive peak of the sine wave, the output voltage would be 20 volts peak—twice the RF level. When the positive peak is twice the quiescent RF value we say the modulation is 100 percent positive. Note that at the negative peak (trough) of the sine wave, the RF output voltage has been driven precisely to zero output; when the RF output is zero we say we have 100 percent negative modulation. The receiver strips away the RF in the detector, and what remains to be fed to the speaker is a sine wave which is a replica of the original sine wave modulation.

**Moving On.** But look what happens if we increase the modulation voltage as shown in Fig. 20. The positive peak simply increases the RF output more than twice the quiescent value. No great problem here, even though the FCC does not allow greater than 100 percent positive modulation of CB equipment. But now look at the negative modulation. The carrier has been driven to zero output (cutoff) for an extended period. The recovered waveform at the receiver no longer represents the original sine wave modulation: it is distorted. The greater the degree

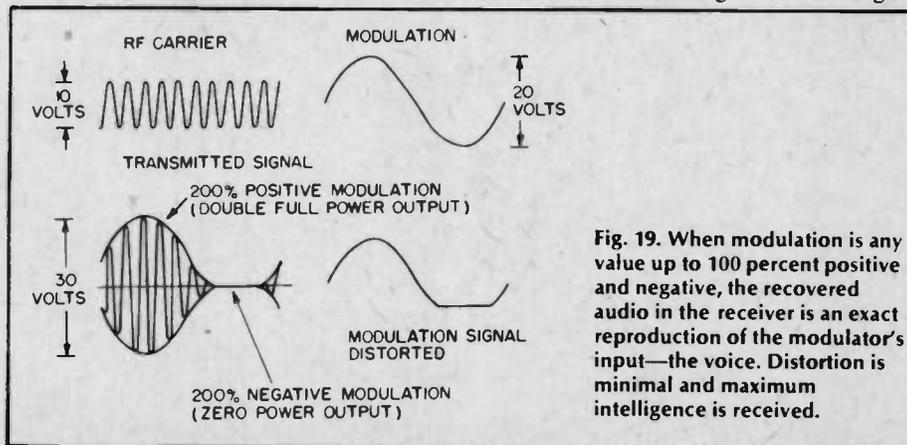


Fig. 19. When modulation is any value up to 100 percent positive and negative, the recovered audio in the receiver is an exact reproduction of the modulator's input—the voice. Distortion is minimal and maximum intelligence is received.

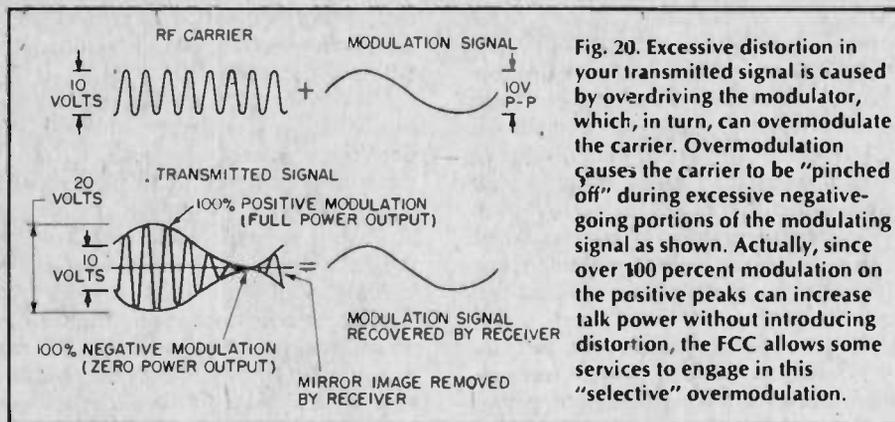


Fig. 20. Excessive distortion in your transmitted signal is caused by overdriving the modulator, which, in turn, can overmodulate the carrier. Overmodulation causes the carrier to be "pinched off" during excessive negative-going portions of the modulating signal as shown. Actually, since over 100 percent modulation on the positive peaks can increase talk power without introducing distortion, the FCC allows some services to engage in this "selective" overmodulation.

of excess negative modulation, the greater will be the distortion.

In addition to modulation distortion, the transmitter now produces sideband interference which doesn't exist if the modulation is limited to 100 percent. Up to 100 percent modulation, the sidebands are exactly as wide as the highest modulating frequency. If the modulating frequency is 3000 Hz, there will be a sideband 3000 Hz above and below the carrier frequency. That's as it's supposed to be. But when the RF signal is driven into negative overmodulation, the clipping produces *harmonics of the 3000 Hz modulation*; therefore, the highest modulation frequency becomes that of the harmonics: 6000 Hz, 9000 Hz, 12,000 Hz, and higher. The greater the degree of overmodulation, the greater the harmonic sidebands. These sideband frequencies now extend the carrier signal into adjacent channels, so the overmodulation (in addition to the signal's distortion) now interferes with users of other CB channels.

Since exceeding the 100 percent modulation limit results in severe modulation distortion and sideband interference, how then can we increase the talk power of a CB transceiver and still maintain no higher than 100 percent modulation? The answer is in the several varieties of talk power boosters.

**What Should You Boost?** Talk power boosters depend on two characteristics of the human ear. First, intelligence is carried predominantly by the higher voice frequencies; the lower frequencies provide the essential tone characteristics by which we can recognize the speaker. They convey little intelligence, yet they use the most modulation power. Secondly, the ear is primarily sensitive to average, not peak, power; yet the peak power of the human voice is 10 to 100 times that of the average power (10 dB to 20 dB higher). For most applications it is accepted that peak power of the voice is considered to be 10 dB higher

than average power.

Though the ear responds to average power, it is the peak modulation power which determines the percent modulation of the transmitter.

A first step to increasing talk power is the suppression of those frequencies which require modulation power but do not contribute much to intelligence. By eliminating the frequencies below approximately 300 Hz and above 3000 Hz—either at the microphone or through preamplifier design—better than 80 percent of the intelligence is preserved, while the power-hungry lower frequencies are eliminated. (The telephone is a good example of this technique; its "tinny" sound might not be natural, but most of the message gets through without much power behind it.) We can now raise the level of the 300 to 3000 Hz frequencies and still stay within 100 percent modulation, thereby increasing talk power at the receiver end of the system.

**What Can You Chop?** Next, we chop off the peaks of the signals, for they contribute very little, if anything, to what the ear senses. The earliest form of clipping was a device called . . . you guessed it, a *clipper*. Fig. 21 shows how it works. The audio signal is passed through the clipper and the peaks are eliminated. If this signal were fed to a transmitter, we might get anywhere from 10 to 50 percent modulation depending on the amount of clipping, called *clipping depth*. So we increase the signal level by exactly the degree of clipping, thereby raising the average voice level some 6 to 10 dB. But what of the harmonics caused by the clipper? Since we're distorting the modulation waveform through clipping, won't harmonics be generated which will cause sideband splatter? The answer is no. The output of the clipper is passed through a filter which attenuates all signals above 3000 Hz, thereby reducing or eliminating the harmonics and

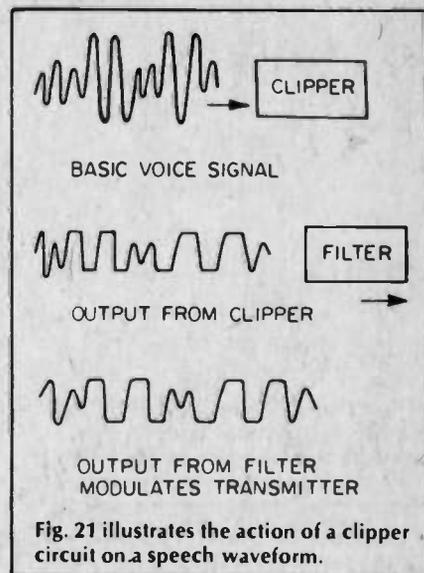


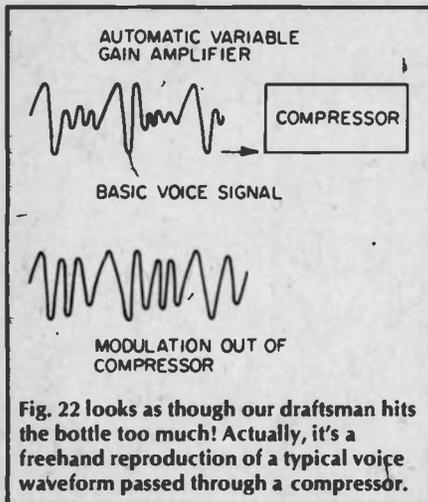
Fig. 21 illustrates the action of a clipper circuit on a speech waveform.

their interference.

But clippers are difficult to adjust to precise operating level, difficult to maintain once in adjustment, and good filters cost money. Thanks to modern solid state devices we can accomplish the same ends through *compression*, a form of automatic electronic microphone gain control which suppresses the peaks and boosts the weaker voice sounds *without* generating excess distortion. Not only is the compressor basically efficient and inexpensive, there is no need for signal filtering.

**Voice Cinch.** Fig. 22 shows how a compressor works. The compression amplifier normally works at maximum gain so the weaker sounds get maximum amplification. As the voice tends to get louder, electronic feedback control automatically reduces the amplifier's output so that the strong voice sounds are not much louder than the weaker sounds. Everything is now at more or less the same volume level, and the signal peaks of the stronger sounds have been eliminated. If this compressed modulation is applied to the transmitter so that the strongest sounds are at 100 percent modulation the weaker sounds will similarly be at 100 percent modulation, or close to it. Through one device we have substantially increased the average voice power and brought up the weaker voice sounds to 100 percent modulation—that's what talk power is all about. (It's the same technique used in making TV commercials, and is the reason the commercials sound so much louder than the normal program level.)

Combine a limited frequency response with compression and you end up with a transmitted signal that comes in like gang-busters on a wave of audio.



**Whisper or Shout?** Back in the early days of CB, very few transceivers incorporated a talk power booster such as a clipper or compressor; most were only available as optional accessories. As solid-state devices were improved, compressors were designed into some of the higher priced rigs; these talk power boost circuits were called range gain, range boost, or some such similar term which implied extra range through extra talk power. On the other side of the coin, however, some manufacturers tried to take advantage of the reputation of true talk power boosting devices by simply providing tremendous microphone preamplification, which saturated the following amplifier; in effect, the saturated amplifier functions as a clipper, but there is no harmonic filter. The signal is heavily distorted and when received at "S9" sounds terrific, but at low signal strengths the modulation is garbage. Many inexpensive transceivers still try getting away with this trick, and the only way to avoid garbled modulation is to drop the voice level to a whisper.

On the other hand, some CB transceivers do not have 100 percent modulation limiting at the lower voice frequencies, so the microphone preamplification was designed to be low to prevent overmodulation; with these rigs, you virtually must scream into the mike to get sufficient modulation on the carrier.

**How to Add Talk Power.** If your present transceiver doesn't already have some form of built-in talk power booster, you can easily add your own; several microphones are available which have some form of talk power amplifier built into either the case or the base.

For example, the Turner +3 stand base microphone and M+3 mobile microphone both have built-in preampli-

fiers and compressors. Other microphones such as the Shure 444T have built-in preamplifiers with output control for providing "extra" gain for those transceivers which require a shout for full modulation. Bear in mind, however, that a modulation meter must be used with amplified mikes to avoid overmodulation—not every transceiver which makes the claim to 100 percent modulation limiting really has it at all frequencies.

If your rig is putting out just the right amount of talk power for you, there's always the possibility of getting better sound quality with a better mike. CB transceivers are usually supplied with the least expensive microphone, and the sound quality isn't all that good to begin with. Every microphone manufacturer has a communications microphone line with sound quality ranging from just passable to superb. You can always upgrade your station with a quality communications mike from Astatic, Electro-Voice, Shure, Turner, etc. For those of you who would like *hands-free* operation, Telex has a line of headphones with attached boom microphones.

**SSB Is a No No.** While talk power devices are very effective for AM transmitters they can often result in the destruction of an SSB transmitter. In particular, the steep wavefronts caused by a clipper can attempt to drive an SSB RF amplifier towards infinite power output—it does nothing for the modulation and can destroy the amplifier. Compressors which work on the voice's dynamic range—boosting the lower volume but not affecting the signal peaks—offer some slight advantage in SSB, but not too much. Best SSB talk power boost is attained from compression built into the RF amplifiers of an SSB transmitter, and most better units already incorporate this feature. The best way to upgrade typical SSB transceiver modulation is to upgrade the microphone, and that's assuming the modulation needs an extra push. Most SSB rigs are premium models to begin with, and they provide the best SSB modulation possible for the particular transceiver.

**Summing Up.** If your transceiver already incorporates a talk power booster, you are probably already getting optimum modulation, and accessory equipment can only make things worse. If your modulator runs barefoot with nothing to give your voice an extra push, a compressor, an amplified microphone, or just a better mike will work wonders toward getting your signal out above the noise level. Remember,

maximum modulation makes a very heavy contribution towards getting your CB message through.

We've looked at the circuits and features that go into the typical AM and SSB transceivers, and now it's time to put it all together in terms of consistent "10-4" contacts.

First, and most important, you get the most from the transceiver itself by keeping your hands off the innards. Unlike older tube-type transceivers which had user adjustments for RF output tuning and loading, the modern solid-state transceiver has sealed RF output tuning controls—sealed in the sense that they are inside the cabinet and not readily accessible to the user. The reason for this is two-fold: FCC regulations absolutely prohibit anyone except licensed technicians from adjusting frequency-determining circuits, and solid-state circuits are so finicky with regard to tuning that the slightest error can often destroy the RF output transistors or turn the modulation into mush.

Regardless of what you have read to the contrary, the factory tuning for solid-state transceivers is optimum for a 50-ohm antenna system—you can't do better, and later we'll show you how to transfer all the RF power output into the antenna system.

Along with sealed adjustments for the final RF amplifier, the modern transceiver also has sealed "control" circuits. The transmit-receive relay is no longer an open frame construction which permits so-called cleaning of the relay contacts. Modern relays have plastic dust covers and any service you attempt on the contacts is certain to cause damage. Similarly, except for the few transceivers that permit the user to plug in specific crystals, crystals are generally soldered into the circuit. Even where the crystal is the plug-in type, removing and re-inserting the crystal does not clean anything; more than likely it will loosen the crystal socket's spring contacts, causing intermittent failure when the transceiver is subjected to vibration—such as in a mobile installation. In short, other than for a major repair, there is no reason to remove a transceiver from its cabinet.

**Pack It In.** The first step in equipment installation is to install the transceiver—and there's no need to go into "keep the rig away from radiators," or "use a firm under-dash mounting." Any place you could mount an ordinary radio is suitable for a CB transceiver. If a mobile transceiver has two power leads—one *positive* and one *negative*—just make certain the negative lead is secured to

the car body; if necessary, scrape away any paint that might serve as an insulator and use a lockwasher to secure the wire. There's no need to run the ground lead all the way to the battery. The car's electrical system gets its ground through a ground-strap from the battery, and if it's good enough for the rest of the car, it's good enough for the CB rig. (The positive power can be taken off the ignition switch terminals, the accessory fuse block terminal, or even the cigarette lighter power wire.)

If your CB transceiver doesn't have a negative power wire it means the ground connection is made through the transceiver's cabinet, so be certain at least one mounting screw between the transceiver and dashboard is free of paint, and use a lockwasher.

Don't depend on the antenna system coaxial cable shield to provide the ground connection. Often, the shield connection works loose at the antenna end and you wind up with a considerable voltage drop through the shield—with resultant intermittent operation or reduced RF power output. (Receivers always seem to work.)

**Base Antennas.** You've got to work really hard to louse up a base station antenna system. The gain type antenna—greater than  $\frac{1}{4}$  wavelength—is always 50-ohms impedance, as are coaxial antennas and almost all directional beams. A handful of inexpensive ground plane antennas might be somewhat less than 50-ohms impedance, but they're close enough, and we'll show later how to check them out.

All you have to do is secure the antenna to a mast (ordinary TV antenna mast is fine), connect the coaxial cable, tape the cable to the mast at several points so it can't sway in the wind, and run the line down to your rig. For cable runs up to 50 feet, ordinary, inexpensive RG-58A/U is perfectly satisfactory; the difference in RF losses between RG-58A/U and RG-8U (or some super low-loss coaxial cable) doesn't amount to a flea's whisper up to 50 feet. Actually, there isn't much difference in effective line losses up to 100 feet, but 50 feet is a good limit for the fussy CBer.

Quite often moisture can work its way into an antenna cable connection between the shield and the inner conductor's insulation at the antenna connection, or water can get into a coaxial connector (if your antenna uses one). Not only does the moisture corrode the shield and its connection, it upsets the system's SWR (standing wave ratio). The problem can be avoided by packing

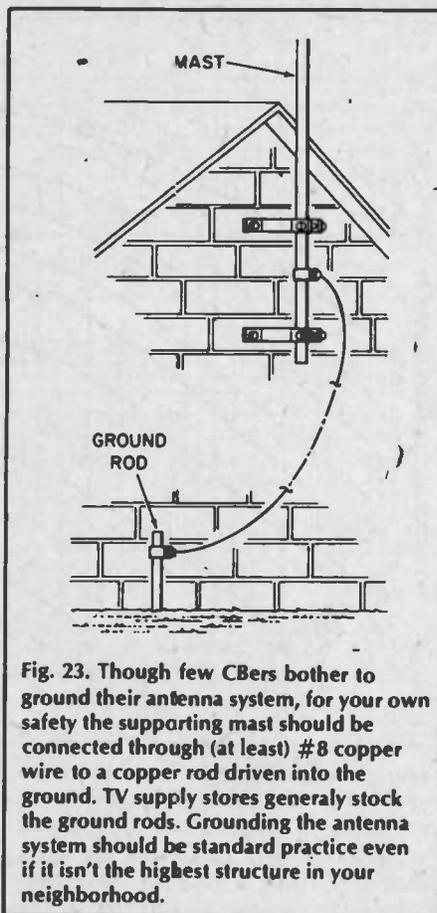


Fig. 23. Though few CBers bother to ground their antenna system, for your own safety the supporting mast should be connected through (at least) #8 copper wire to a copper rod driven into the ground. TV supply stores generally stock the ground rods. Grounding the antenna system should be standard practice even if it isn't the highest structure in your neighborhood.

the connection with General Electric RTV silicon rubber adhesive. Use only the G.E. product. Some similar adhesives are virtually dead shorts at RF frequencies.

Okay, you've got the antenna up, its coaxial cable is connected at both the antenna and transceiver ends and you're ready for operation. Right? Wrong! The system will work all right but you haven't made safety provisions.

Antenna masts should always be grounded with, generally, No. 8 copper wire to a copper ground rod (which you drive into the ground with a hammer), as shown in Fig. 23. Yes, yes—it's quite true that, (a) the masts for the TV antennas next door aren't grounded and, (b) you have no intention of stringing a ground wire down the side of the house. Neither attitude is correct, but that's the way things usually are. However, keep in mind that the new FCC regulations permit antenna heights to 60 feet for some CB antenna types (non-directional). If you use a tower or a high mast your CB antenna is probably going to be the highest point in your neighborhood, and you know what lightning usually seeks out . . . the highest point, or easiest path, to ground. If, your CB antenna is

king of the hill, it had better have a ground!

For those still too stubborn to go through the grounding procedure, there should be at the very least a solid (No. 8 copper wire) ground between the metal transceiver cabinet and a water pipe. A device known as a "blitz-bug," which connects between the coaxial cable and the transceiver's antenna jack, also provides lightning protection as well as a "bleed" for high electric charges that might build up during an electrical storm. The device provides a ground for the coaxial shield (and transceiver cabinet) as well as a "spark gap" for the cable's center conductor.

**Mobile Antennas.** Now here's something that can often create enough problems to drive the strongest person up the wall. The average full length whip antenna (108 inches) mounted on the rear bumper or fender usually has an impedance of 25 to 35 ohms, not 50 ohms. The shorter "loaded" whips, such as used in the center of the roof, often have a matching coil as part of the antenna which provides the 50-ohm matching impedance.

Here's another rub: a 50-ohm antenna might not be 50 ohms where you decide it should be installed. Regardless of the actual or rated impedance, maximum power transfer from the transmitter occurs if a  $\frac{1}{2}$ -wavelength matching section of coaxial cable is used between the transmitter and your mobile antenna. For RG-58A/U cable, a  $\frac{1}{2}$ -wavelength at the CB frequencies is 12 feet. Without getting too technical, the matching section is needed because, should there be a mismatch between the transmitter output and antenna (as there would be if the antenna were anything other than 50 ohms), the SWR factor could cause the impedance looking into the transmission line to be considerably beyond the value into which the transmitter could efficiently transfer its power output. A half-wavelength transmission line (or a multiple of a half-wavelength) acts as a repeater transformer which transfers, at the input to the line, exactly what appears at the output where the antenna is connected. (Excess coaxial cable can be coiled in the trunk.)

Most mobile antennas which employ loading coils (or "matching" coils) are supplied with the appropriate length of matching transmission line. If you make your own antenna, however, from "bits and pieces," or use a full length 108-in. whip with bumper or body mount, make certain your RG-58A/U transmission line is 12 feet.

# CB special section

**Getting the Soup Out.** The SWR meter is the best and possibly only device available to the CBER which indicates directly whether the power coming from the transmitter is reaching the antenna. (Once it gets to the antenna you can be reasonably certain it's being broadcast to the waiting world.) The SWR meter works on a very simple principle. If all the power coming from the transmitter flows into the antenna, none is reflected back to the transmitter. If the antenna is not the same impedance as the transmission line, all the energy is not absorbed by the antenna; rather, some is reflected back to the transmitter in proportion to the degree of mismatch. The SWR meter indicates this reflected power in terms of SWR (actually, VSWR); in fact, some SWR meters have two calibrations—one in SWR such as 2:1, 3:1, etc., the second in terms of actual forward and reflected power.

Fig. 24 shows how much power you lose through an antenna mismatch. Note that the total loss depends on the original loss in the transmission line; for example, RG-58A/U can have a loss of 3 dB per 100 feet. This means that if your transmitter puts out 4 watts of RF into a perfectly matched antenna system with 100 feet of RG-58A/U, 2 watts *maximum* would actually get to the antenna. But look what happens (Fig. 24) if the SWR is 3:1. You get an additional loss of 1 dB, and under optimum conditions with a 3:1 SWR only 1.6 watts gets to the antenna; and as the SWR increases, less and less power reaches the antenna. It's obvious from Fig. 23 that the SWR should be less than 1.5:1 (2:1 worst-case) if you want essentially all the transmitter's "soup" to get to the antenna.

To check SWR you need only install an SWR meter or "bridge" between the transmitter output and the transmission line as shown in Fig. 25. However, the SWR meter readings are invalid if the transmission line is an exact half-wavelength or multiple because, as we've said, a half-wavelength line behaves as a "one to one" matching transformer. You could have a 10:1, 15:1 or 20:1 actual SWR and still get a 1:1 SWR reading with a half-wavelength line. So you must be certain to "break up" or "tune out" a half-wavelength line. This is done by inserting a  $\frac{1}{4}$ -wavelength section of transmission line after the SWR meter as shown in Fig. 25.

**Tuning Out.** Install coaxial connectors (solderless type is okay) at both ends of a 6-foot section of RG-58A/U.

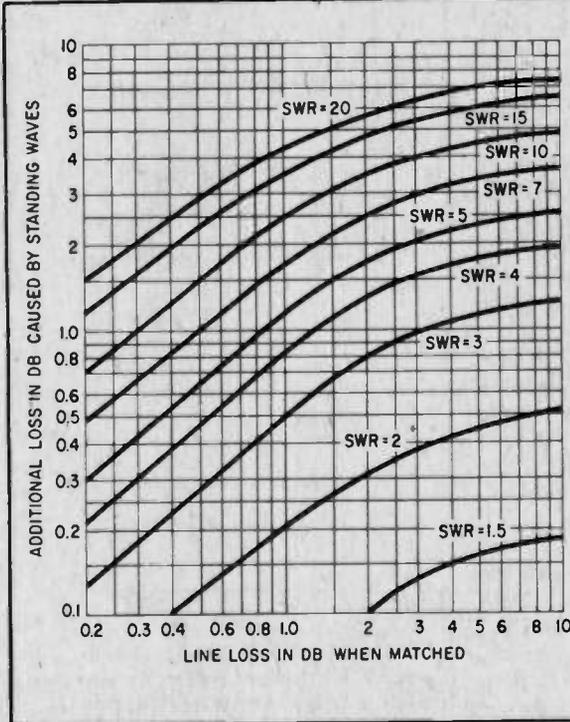


Fig. 24. All transmission lines have an inherent minimum line loss when perfectly matched to the antenna. The greater the inherent "matched" line loss, the greater the additional loss caused by the SWR, and the greater the SWR, the greater the additional SWR loss. An SWR of 2:1 should be the maximum acceptable value for CB.

Connect the SWR meter to the transmitter using the smallest length of coaxial cable (6 inches at most). Connect the  $\frac{1}{4}$ -wavelength section to the SWR meter and, using a "splice" connector, connect the  $\frac{1}{4}$ -wavelength line to the transmission line. Measure the SWR and note the reading. Then remove the  $\frac{1}{4}$ -wavelength line and again note the reading. If there is no difference between readings, or very little difference, the meter reading is the SWR. If there is a wide difference between readings, the higher reading is the SWR, or actually *lower* than the true SWR.

If there is no difference in readings and the SWR is less than 1.5:1, you have a great antenna system. If the reading is between 1.5:1 and 2:1 you have a fairly good antenna system. Keep in mind that some directional antennas are optimum at 2:1. If the reading is greater than 2:1 there's something wrong at the antenna if it's a base antenna. If you cannot lower the SWR by "retuning" the antenna try to use a multiple half-wavelength transmission line. Prepare 12 feet of RG-58A/U with solderless connectors at both ends. Install this length between the SWR meter and transmission line. Note the SWR reading. Cut off 3 inches from the  $\frac{1}{2}$ -wavelength section and again note the SWR. Keep removing 3-inch sections until you have attained the lowest possible SWR. Leave the section in the line, remove the SWR meter and connect the 6-in. SWR connecting cable to

the trimmed  $\frac{1}{2}$ -wavelength section (with a coaxial connector). You will now have a matched antenna system which is optimum for the particular antenna.

Using the  $\frac{1}{4}$ -wavelength section, test your mobile installation's SWR. Again, the higher of the two readings more closely approximates the actual antenna match. If your mobile antenna has some form of tuning adjustment, use the transmission line arrangement that gives the highest SWR reading and tune the antenna for minimum SWR. Get it as low as possible and then remove the SWR meter and the  $\frac{1}{4}$ -wavelength section so that the transmission line is exactly 12 feet. If you want to keep the SWR meter in the line permanently, measure the distance from the output jack of the SWR meter all the way back to the transmitter's output jack and trim this amount off the coaxial transmission line; the total length of the transmission line, plus the SWR meter, plus the SWR meter's connecting cable to the transmitter should equal 12 feet. If your transmitter has a built-in SWR meter forget it; use 12 feet of coaxial cable.

If your mobile antenna cannot be tuned because it is a standard length whip, you might wind up with an SWR as high as 3.5:1, and there is nothing you can easily do to correct it. If the SWR meter shows close to 1.2:1 *with the 12-foot cable* it's as good as you're going to make the system, short of re-

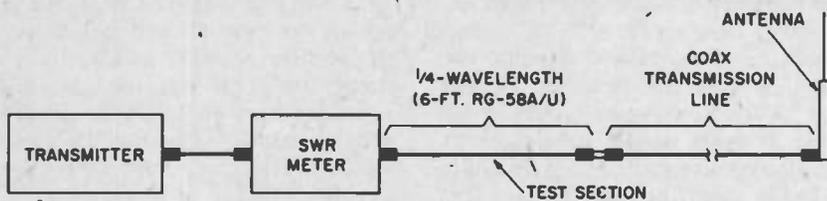


Fig. 25. If there is substantial change in SWR readings when a  $\frac{1}{4}$ -wavelength section of coaxial cable is installed between an SWR meter and the transmission line, the antenna is not 50 ohms. If the reading is the same, everything is well matched.

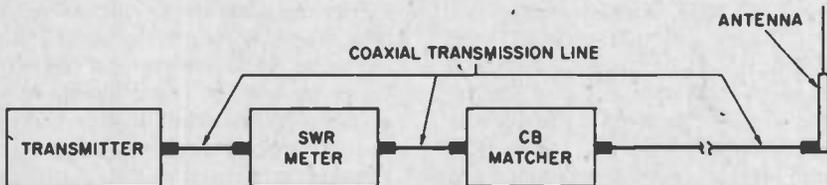


Fig. 26. After the antenna system is tuned, this is the correct instrument arrangement for adjusting an antenna tuner (CB matcher). Adjust the matcher for minimum SWR between the transmitter and matcher, coincident with maximum forward power. Best results are attained if the transmission line is 12 feet or an exact multiple of twelve feet such as 24, 36, etc. And remember, a matcher cannot improve what is already an excellent antenna system. All coaxial transmission cable is 50-ohm.

placing the antenna.

**Another Step.** Now just because you have attained a low *system* SWR by trimming the coaxial cable to a half-wavelength or its multiple does not mean the transmitter is putting out all the RF power it's capable of delivering. If the antenna is actually 25 ohms the transmitter will put about 50 percent to 75 percent of its potential power into the antenna system, depending on the design of the transmitter output circuit.

The only way you can get maximum power output from the transmitter when the actual transmitter to antenna mismatch is greater than about 2:1 is by using a matching device that will make the antenna system *appear* as a 50 ohm load to the transmitter. Such a device often goes under the description of CB Antenna Tuner, CB Matcher, CB Antenna Matcher, or some similar term. The important part of the description is "CB." Antenna tuners or couplers designed for other communications services can be "longwire" matching devices; for CB we need a device that matches a transmitter to a transmission line, not a transmitter to a random length of wire.

The CB matcher (at least those presently available) makes the overall antenna system load appear as 50 ohms, so the transmitter delivers all its potential energy into the matcher. The matcher then couples *all* this energy into the antenna system. If the transmission line is a half-wavelength or multiple, all the

energy flows into the antenna. This is true for base and mobile antenna systems.

Keep in mind, however, that the matcher does nothing if the system is matched to begin with, for it cannot improve what is already optimum. You know it will work for you if, (a) adding a  $\frac{1}{4}$ -wavelength section changes the SWR reading *and*, (b) if the transmission line is a half-wavelength or multiple. You must have both conditions.

If you use a matcher, the transmission line is measured from the output of the matcher to the antenna, with the SWR meter between the transmitter and the matcher—using short connecting cables as shown in Fig. 26. If you can set up this type of installation *after* you have adjusted the antenna system for minimum SWR, adjust the matcher for minimum SWR *between the transmitter and matcher* (which will usually also correspond to maximum forward power output).

**And Then Modulation.** Your final adjustment is the modulation. All CB rigs will work if you talk into the mike, but the clarity of the modulation will be determined by the overall microphone gain built into the transceiver. Too much gain and you get distortion, even with so-called compressors, for they have an optimum working range. Some CB rigs do not have modulation limiting, and too high a voice level produces excessive distortion. Too low a voice level will barely be heard. Somehow,

somewhere, borrow a modulation meter—it doesn't have to be laboratory grade. Hold the mike in your normal position and speak in a normal voice. Is the signal less than 100 percent modulated? If so, either raise your voice level or use an amplified mike (see next caution). If the meter indicates 100 percent modulation try lowering your voice. Does it still indicate 100 percent modulation? Reduce your voice level still further. If a whisper still produces 100 percent modulation you can be certain the distortion at normal voice level will turn your signal into hash or mud when it's coming in just above the noise level. Have a technician reduce the overall microphone sensitivity so your normal voice level just about produces 100 percent modulation on peaks. If your rig has a built in compressor, "range booster," talk power booster," or some such similar compression device, you'll find a moderate to loud voice level will give 100 percent modulation. This is normal. You have problems only when you must shout or whisper for 100 percent modulation.

**The Last Word.** This in-depth article, while giving you all you need to know about citizens band radio theory, is, at the same time, not the *whole* story of CB. No one article could ever hope to satisfy the avid CBer, and something new is happening in CB every day. So for the latest CB info, for a wealth of CB transceiver test reports, for a bonus copy of the completely updated FCC CB rules and regs, and for much, much more, watch for the 1976 CB YEARBOOK on your newsstand. And keep up with CB in the pages of ELEMENTARY ELECTRONICS every issue! ■

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# Inside AVC

□ A WORLD WITHOUT AVC—Automatic Volume Control—would be filled with fractured audio and video. Explanation is that AVC is the steadying force in receivers of most every description—from tiny AM portables to communications receivers, TV sets, and just about everything else that breathes in a signal. Remove AVC from your table radio and it would probably break up on local stations. Take it out of your TV set and color might scramble and spill through the image—or pictures turn negative because of signal overload.

**Blast It.** It's been said that AVC "makes strong signals weak and weak signals strong." That simple definition goes back to AVC's original objective of reducing "speaker blasting." The phrase is perfectly descriptive because an uncontrolled receiver produces excessively loud sounds in the speaker while receiving strong signals. You could adjust the radio's volume control by hand, but imagine doing it in an automobile while driving. Your hand might never leave the volume control!

This is where AVC comes to the rescue. It senses the wavering signal, develops a control voltage in proportion to that signal, then applies it as a continuous correction. It also cures a problem that no amount of volume-control fiddling can cure. It's an overload condition where strong signals drive the receiver's early stages into highly distorted operation, resulting in mushy, unintelligible audio in the speaker.

Though a car in motion is one cause of fluctuating signals, there are others. Atmospheric fading due to changes in the ionosphere has a tremendous effect on the strength of shortwave (3 to 30 MHz) stations. At higher frequencies (VHF and UHF-TV, for example), passing vehicles, changes in tree foliage, and even moisture content in the air vary the number of microvolts induced

in an antenna by a distant transmitter.

In all of these cases, an AVC circuit attempts to compress or expand the signal into some mid-range or average value. As you might suspect, AVC can't recover a signal deeply submerged in atmospheric noise and make it readable. Nor can it clean the snow from a far-away TV station arriving in a remote fringe area. But it is capable of some pretty miraculous stunts, as we'll see shortly.

**The AVC Idea.** Almost every AVC circuit follows a similar general route. First, it taps into the receiver circuit at some point to sample a bit of the incoming signal. The sample provides information on the relative strength of the arriving station. Next, the sampled signal is processed into a form which enables it to control the radio-frequency amplification of the receiver. This becomes the AVC control voltage and it's fed back to some earlier point in the receiver.

If a powerful station is being received, it produces a high AVC voltage, which reduces the receiver's ability to amplify. Upon receipt of a weak signal, little AVC voltage develops, so the receiver runs at high amplification.

**From Carrier to Control.** The overall idea appears in Fig. 1. We've shown a standard broadcast station transmitting a signal whose carrier is increasing from weak to strong in three steps. Note that the carrier is assumed to be originating from the station at three fixed levels, with no audio modulation at this time. (Audio causes a complication we'll get to in a moment.)

The changing carrier signal enters the receiver antenna and proceeds through RF and IF stages until it reaches the diode detector. Since the alternating carrier can go through the diode in one direction only, it's rectified so only the negative portion appears at the re-

sistor forming the diode load. The AVC signal, however, is still hidden within the rectified carrier, as shown by the dotted line. This means that it must be processed further before it becomes a suitable control signal—a DC voltage which varies in step with carrier strength.

This is where the problem of audio modulation (voice or music on the carrier) complicates AVC development. The trouble is that intelligence on the carrier is AM, or amplitude modulation, which is electrically similar to the changing carrier strength AVC will attempt to fight. It would hardly be suitable if AVC attacked loudness changes in the program, rather than average changes in carrier signal. Fortunately, it's possible to fashion a filter which ignores audio in the sampled carrier.

As shown in Fig. 1, there's an AVC filter comprised of a resistor and capacitor. In a typical tube circuit these values are a few megohms for the resistor and about .05  $\mu$ F for the capacitor. They form a filter which responds at the rate of about 0.1 second (its *time constant*). This interval of time has been carefully selected to fulfill certain boundaries of AVC operation.

First, the filter must remove any audio modulation from the sampled portion of carrier. Since audio variations occur much faster than 0.1 second (the lowest audio tone is about 20 times per second), the filter smooths out any audio in the AVC circuit. Yet, the AVC filter must not respond *too* slowly. When driving in a car, for example, you might receive a fluttering signal and need fast-acting AVC to exercise quick control.

The 0.1-second filter, therefore, is designed as a compromise which attempts to fit AVC response between the

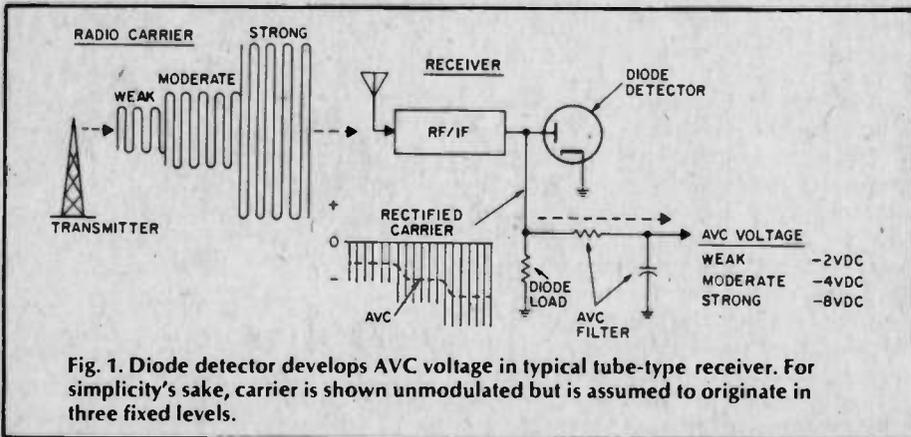


Fig. 1. Diode detector develops AVC voltage in typical tube-type receiver. For simplicity's sake, carrier is shown unmodulated but is assumed to originate in three fixed levels.



Fig. 2. Some receivers—this Hammarlund, for one—permit operator to control AVC rate.

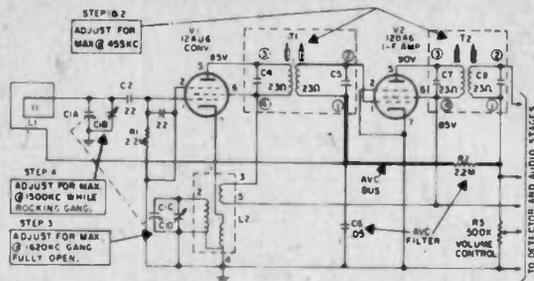


Fig. 3. Schematic of GE tube radio, showing AVC filter and bus. Since cathode of V2 is grounded, tube relies on AVC voltage on control grid (pin 1) for bias.

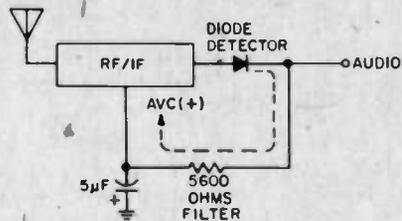


Fig. 4. As in tube sets, AVC in solid-state circuit is tapped from diode detector.

two extremes. In some advanced receivers, an AVC selector switch (Fig. 2) enables the operator to choose his rate to improve the receiver's performance on certain specialized signals such as code (CW), single sideband, or other non-standard carriers.

**DC Up Front.** To this point the circuit has developed a control voltage that's synchronized to incoming carrier strength. As shown in Fig. 1, the carrier has produced a shift of from  $-2$  to  $-8$  DC volts at the output of the filter. This is approximately the AVC voltage you'd measure in typical tube-type receivers. Now it's only necessary to provide a feedback loop to carry the AVC back to an earlier stage. How this is done is illustrated in the actual schematic of a typical tube radio in Fig. 3.

The AVC signal is developed across the diode load resistor and filtered in the resistor and capacitor indicated (R2 and C6). From there, the line is usually termed the *AVC bus* and extends back to the control grid of the IF amplifier. As an incoming signal grows stronger, a correspondingly higher negative AVC voltage is created. Result is that the gain of the IF stage is reduced accordingly.

**Solid AVC.** Millions of tube receivers still survive, but solid-state should end that era in a few years. Transistor receivers are subject to the same signal fluctuations and similarly require AVC circuitry. In looking at transistor circuits, you may find that the term *voltage* is often supplanted by *current*.

When discussing amplification in tubes, it's almost always a matter of controlling *grid voltage*, which is generally negative in polarity. (The current flow in a receiving tube grid is infinitesimal and usually ignored.) Transistors, though, may be discussed in terms of current since the terminal voltages (unlike tubes) are very low. Because of these differences, AVC action in tube circuits is usually described as *negative grid voltage*, while the solid-state version is in terms of *base current*.

Another difference is that the polarity of a receiving tube grid is almost always negative; transistor current, in contrast, may flow in either direction, depending on whether an npn or a pnp transistor is being controlled.

Schematics for solid-state AVCs are fairly close in appearance to tube versions, as shown in the typical portable in Figs. 4 and 5. Note that a sampling of carrier signal is taken at the output of a diode detector. At this point the carrier is already rectified to DC and needs only to be smoothed in the AVC filter. Note that the polarity of AVC voltage is shown as positive (+) since the transistors being controlled are of pnp type (Fig. 5).

In pnp semiconductors, a positive-going voltage applied to the base causes lower current and a reduction in amplification (the reverse of a tube circuit). You will also find transistor AVC which runs in the negative direction. This indicates an npn transistor is being controlled since its amplification decreases with the application of negative voltage.

Fig. 5 traces the major AVC points in a commercial solid-state circuit. Note

that the carrier sample isn't trapped from the regular AM detector; instead, a separate AVC diode is connected to an earlier point in the receiver (see lower right of Fig. 5). This car receiver has an RF amplifier up front and it produces sufficient AVC voltage for the tap-off to occur at this early point. The remainder of the AVC bus resembles the tube circuit; the carrier is rectified, filtered, and applied back to the input stage. Since the RF transistor is a pnp type, an increasing carrier produces rising positive voltage and a consequent drop in transistor gain.

**What's the Delay.** AVC circuitry described to this point works well for table and other consumer type radios. But there's always something better. One improvement is *DAVC*, for *delayed AVC*, to overcome one disadvantage of regular AVC on weak signals. To operate at highest sensitivity, a receiver should run wide open, or at maximum amplification. The trouble occurs when a weak signal entering the receiver commences to generate a small, but effective, AVC voltage. AVC comes on too soon and receiver sensitivity is prematurely reduced.

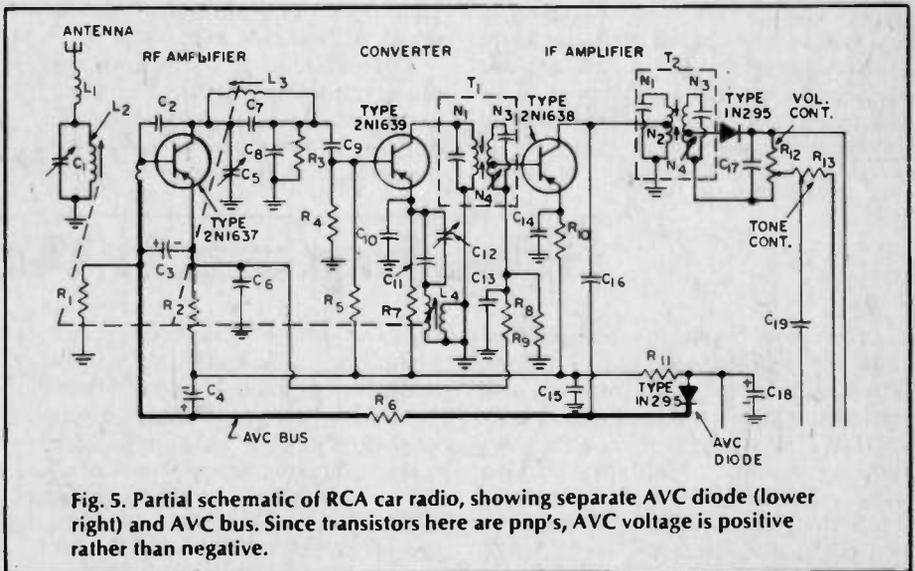
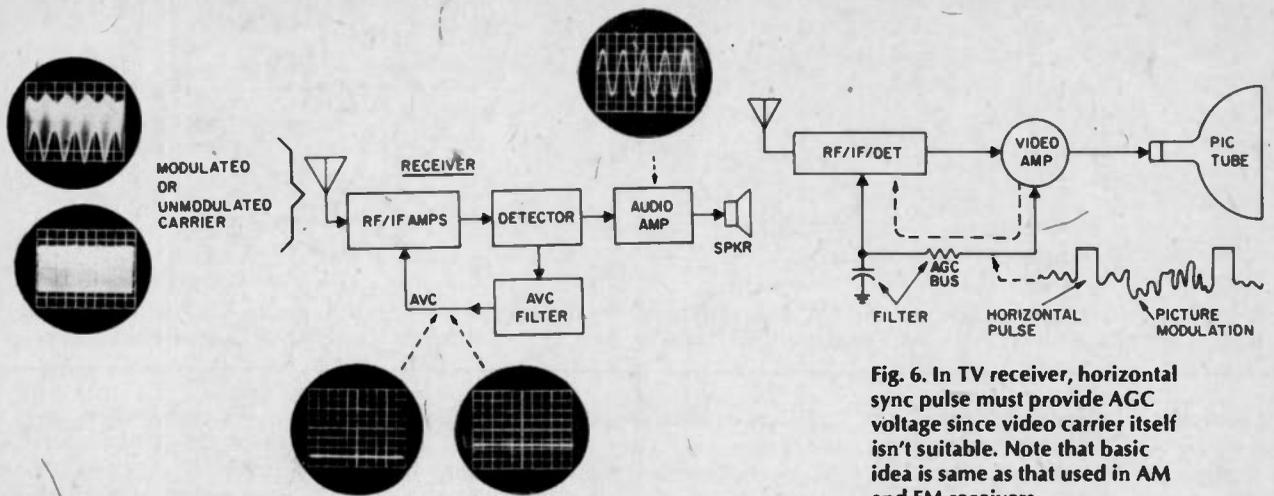


Fig. 5. Partial schematic of RCA car radio, showing separate AVC diode (lower right) and AVC bus. Since transistors here are pnp's, AVC voltage is positive rather than negative.



A scope's-eye view of AVC: actual photos of oscilloscope screen reveal role of AVC in receiver circuit. AVC is best defined as DC voltage which varies in accordance with strength of RF carrier.

Fig. 6. In TV receiver, horizontal sync pulse must provide AGC voltage since video carrier itself isn't suitable. Note that basic idea is same as that used in AM and FM receivers.

In the delayed AVC scheme, AVC must first overcome some fixed reference voltage before it starts to reduce amplification in the receiver's front end. For example, a conventional receiver may start to generate AVC voltage when a carrier of about 5 microvolts is in the antenna. A high-performance ham or communications set, though, might delay AVC action until the signal attains a strength of 10 microvolts.

Another improvement in deluxe receivers is amplified AVC, meaning the control voltage is boosted before being applied back to an earlier stage. This could produce AVC voltage swings of from 0 to 35 volts, instead of a more conventional range of 0 to 7 volts. The net result is better control of the receiver under dynamic changes in signal strength.

**It's AGC, Too.** Though AVC began as a technique for controlling average audio level, nearly identical concepts are applied in receivers which produce pictures, navigational read-outs, or other intelligence of a non-audio nature. Since latter-day AVC may no longer control volume, its designation changes to AGC, for Automatic Gain Control. In-

identally, this term is technically more accurate even for regular radios because it's receiver radio-frequency gain, *not* audio volume that's directly regulated. A good example of AGC is in TV receivers for keeping picture contrast reasonably constant over a wide swing of signal strength. Let's examine the TV signal in some detail because the method of generating a control signal is different from that of a radio.

The video carrier which brings the TV signal to the home is not a suitable source of AGC voltage. The picture carrier changes strength with lights and darks in the scene which happens to be on the screen during a particular moment. Back in our simple radio, we could filter out audio modulation fairly easily. However, video modulation can persist over long time periods which cannot be filtered with any reasonable time constant. What we need is a reference *other* than video modulation on which to base our AGC level.

That reference is the horizontal sync pulse transmitted at the beginning of each picture scanning line. Though its purpose is to lock the home set with the transmitter, it also serves as an AGC

reference. As shown in Fig. 6, the pulses are captured from the set's video detector, then filtered and fed back to the receiver front end (i.e., RF, IF, and detector).

Though AVC—or AGC—originated as an equalizer of speaker volume, then went on to do the same for pictures, the circuit has other applications as well. In color sets it keeps the color signal constant by adjusting the gain of a color amplifier according to incoming color signal strength. The reference here for developing a control voltage is the color burst, a brief shot of sine-wave energy transmitted during each horizontal scanning line.

To be sure, the burst is really intended to help the receiver create an accurate color subcarrier. However, it also contains strength information which can operate the automatic color control found in most current TV sets. It's just one more example of an old idea brought up to date. In fact, the next time you see the words *control*, *feedback*, or *automatic* used to describe a circuit, chances are it borrowed an idea or two from early AVC. ■

## How Squelch Works

□ YOU WON'T FIND a knob marked "Squelch" on your AM radio or TV set. But just about every CB receiver now manufactured sports one of these handy controls. The reason is that squelch can silence static that's heard in a speaker when no signal is being received, making it the greatest boon to noise-pollution elimination since the invention of ear muffs. Only an incoming message

trips the squelch noise mask so you're spared the static crashes, atmospherics and other electronic egg-scrambling during standby periods. Why is no squelch needed for regular radio or TV? Unlike mobile communications, the incoming signal is constant, so steady broadcast signals keep the receiver free of background noise.

And that's the starting point for un-

derstanding how a squelch circuit functions. The receiver can sense the presence of a signal, then automatically control the audio stages. As we'll see, squelch can also work the other way—sense the noise or static—and similarly regulate the audio. Finally, there's "tone" squelch, sometimes termed "selective call." In this specialized circuit not only is noise silenced, but also the

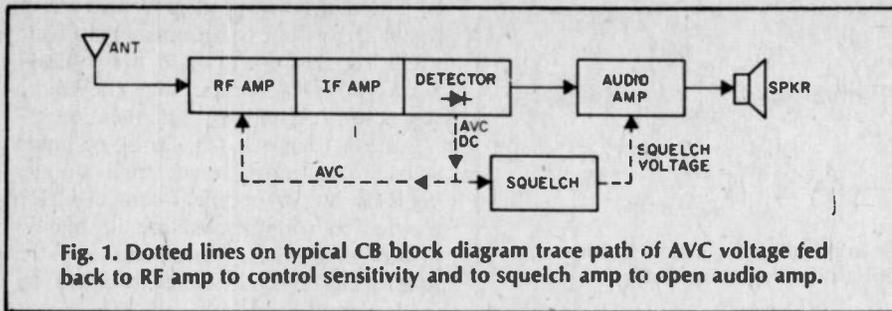


Fig. 1. Dotted lines on typical CB block diagram trace path of AVC voltage fed back to RF amp to control sensitivity and to squelch amp to open audio amp.

stations on the channel you don't wish to hear.

**Stealing AVC.** Simple squelch circuits are little more than electronic switches tripped by the receiver's AVC (automatic volume control) voltage. The overall idea is shown in the block diagram of Fig. 1 which represents a typical CB receiver. An incoming signal from the antenna passes through various stages until it reaches the detector where it's converted to audio. In the detector, too, a portion of the carrier signal (which is AC) is converted to DC by a diode rectifier. Since the DC signal will vary in strength with the carrier, it's used to protect the receiver against overload or excessive volume changes. This is the AVC voltage and, as shown by the dotted line in Fig. 1, is fed back to earlier stages in the receiver. If an incoming signal rises in strength, AVC is returned in a direction which reduces the RF (and sometimes the IF) amplifier gain.

If there is *no* signal in the receiver, there is no AVC voltage. Why not use AVC to directly control—or squelch—the audio along with earlier RF receiver stages? Squelch is, in fact, a brand of automatic volume control. The pitfall in using AVC directly to develop squelch action is that AVC changes too gradually, and over too limited a range. For squelch to do its assigned job, it should create an all-or-nothing effect on audio. Thus, AVC may *start* squelch action, but additional stages are needed to impart the snap.

As seen in the block diagram of Fig. 1, this will occur in a "squelch" stage connected to AVC voltage, and also to the audio amplifier to be controlled. Let's trace how a typical squelch circuit might appear in both tube and transistor CB receivers.

**Bottled Squelch.** A tube variety is shown in Fig. 2 and its operation boils down to this: AVC voltage is greatly boosted by an amplifier, then the magnified voltage controls the grid bias of a regular audio stage. Since AVC amplified voltage now swings over a much larger range, the audio tube switches briskly on and off. Let's trace it in some detail in Fig. 2. First, there's the con-

ventional audio amplifier shown connected to the detector. Since all audio signals must pass through it, the amplifier handily serves as a controlled stage. The other stage (near the bottom of the diagram) is the squelch control, nothing more than a *DC amplifier*. Note that the tube grid of the squelch control is operated by AVC voltage—and that the *plate* of this stage also connects upward to the grid of the audio amplifier.

Circuit action mainly occurs at the variable resistor which serves as the

cuts off any audio amplification through the stage. So the speaker is effectively silenced.

Now to see what happens when a signal arrives and trips open the squelch. Since an incoming carrier produces negative AVC voltage, it also cuts off current flow through the squelch tube. This kills the voltage drop across the squelch variable resistor and that 80 volts shown jumps up to 100 (the supply voltage). Since the controlled audio stage also receives 100 volts on its grid, that high negative bias developed earlier disappears. This places both grid and cathode at 100, so the grid bias now drops to a relative value of zero volts. The audio stage can now amplify and the receiver is unsquelched.

For the system to operate properly, you must set a squelch with care. The usual problem results when the knob is set too high and weaker stations cannot activate the squelch. As you can see in Fig. 2, a high setting could place the audio grid too far into the negative re-

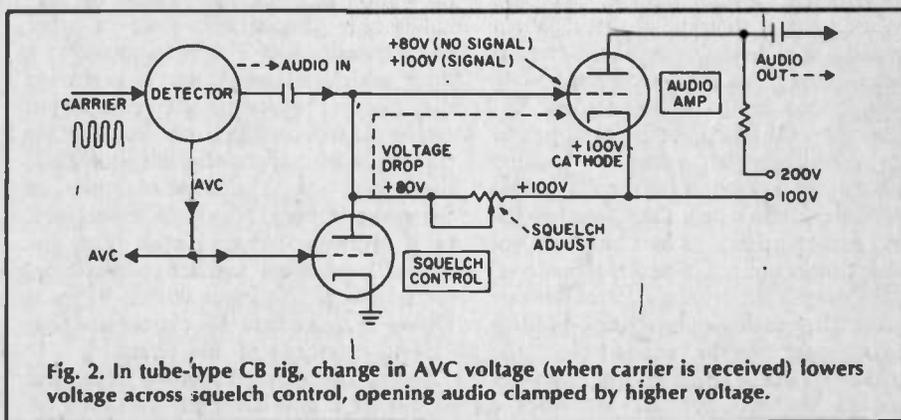


Fig. 2. In tube-type CB rig, change in AVC voltage (when carrier is received) lowers voltage across squelch control, opening audio clamped by higher voltage.

squelch adjust (a front-panel knob). As you can see, a voltage of 80 is at one side of the resistor, while 100 appears at the opposite end. The reason for the drop is current flowing through the squelch control tube. Assume there's no negative AVC voltage on the control tube grid; the resulting tube current flow produces the 20-volt drop shown across the variable resistor. The voltages are next applied to the audio amplifier. Note that 100 volts go to the tube cathode and 80 to the tube grid.

This set of voltages *cuts off* the audio amplifier completely—no audio signals can pass. The reason is, the tube is now experiencing a relatively high *negative* grid bias. How does a negative charge develop from +80 and +100? It appears because grid voltage is always measured with relation to the cathode. Thus, if the cathode operates at +100 volts, and the grid at +80, the grid will appear to be relatively 20 volts *negative*. This is a substantial amount of grid bias and it

gion and prevent the receiver from unsquelching except for strong signals. The technique for adjusting a squelch is to wait until no signal is being received, then rotate the knob until the background noise *just* disappears.

**Transistorized, Too!** The solid-state version of a squelch circuit is shown in Fig. 3. The idea in this circuit is based on the forward and reverse characteristics of a silicon diode we call the squelch diode. When the diode is biased in the reverse direction, it presents an extremely high internal resistance and blocks the flow of audio between the detector and following audio stages. Consider, first, how the receiver is squelched during a no-signal period. Note that the squelch diode in Fig. 3 is receiving two voltages (besides the audio from the detector). The one from the left is control voltage tapped from the collector of an IF amplifier stage. This transistor not only operates as an IF amplifier, but also serves to drive

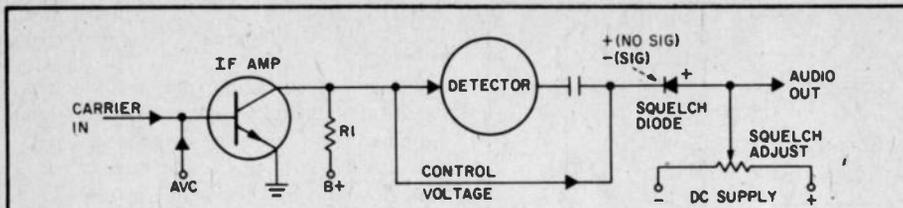


Fig. 3. Transistorized set depends on change in control voltage from IF amp (when carrier is present) to forward bias squelch diode, turning audio on.

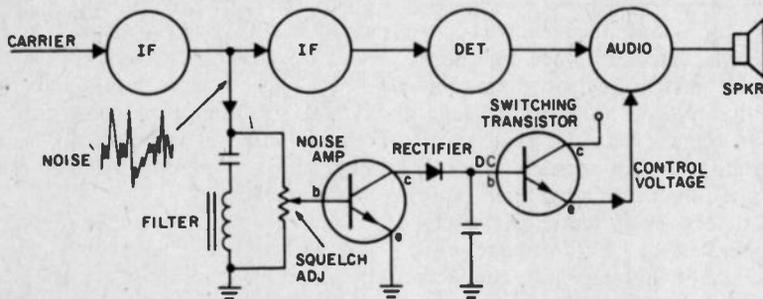


Fig. 4. Most sophisticated squelch: noise-operated rather than carrier derived. Filter separates white noise from other noise to develop squelch volts.

the squelch circuit (much like the squelch control tube did earlier). When no signal is received, collector current is high in that stage, and a corresponding voltage drop occurs across resistor R1. A sample of this drop is fed back to one side of the squelch diode for biasing. Notice that a second bias voltage also reaches the diode from the squelch adjust potentiometer. The net effect of these connections is a reverse-bias condition on the diode; the control voltage makes the cathode relatively positive with respect to the anode. Now the speaker is silent since nothing can get through the audio section. But when a signal enters the receiver, the IF amplifier conducts less current (because AVC voltage is being developed) and the collector voltage drop across R1 is greatly reduced. This makes the squelch diode relatively negative on its cathode—causing a forward bias condition. The diode's resistance plummets and the receiver is opened up for audio.

These squelch circuits are common in CB equipment and they do the job. But as the clerk in the discount store says, as you examine a sale-priced item, "Let me show you something better!" In the more expensive communications gear, the squelch will act snappier and have a more sensitive threshold for awakening on weak signals.

**Noise Is Nice?** One of the deluxe squelches is the "noise-operated" type. Circuits described earlier are carrier-derived, but a noise-derived system is more sophisticated. As shown in Fig. 4, the action begins by tapping a sampling of signal from one of the IF stages in the receiver. Assume at this time that

no station is being received so the signal is only atmospheric noise or other background static. This is fed down to a filter which sharpens the response to the steady "white" noise component rather than the clicks, clonks or other transients that might trip the squelch at the wrong time. The noise amplifier, as the name implies, boosts the noise level to a working value. Notice that the manually-adjusted squelch potentiometer is also at the input to the stage. It allows the operator to choose the operating threshold of the circuit.

Next, the amplified noise signal is rectified by a diode and smoothed to pure DC so it can exercise circuit control (as AVC did in the simpler squelches). But first the DC is applied to a switching transistor to obtain the necessary snap-action. The switching transistor stage is little more than a conventional amplifier, but with almost no bias on its base terminal. This causes the transistor to operate wide open and saturate rapidly on an input signal. The result of the DC signal, therefore, is a rather high positive voltage at the output of the switching transistor (at the emitter). This is sent up to the audio section as the control voltage and the stage is clamped shut . . . nothing can

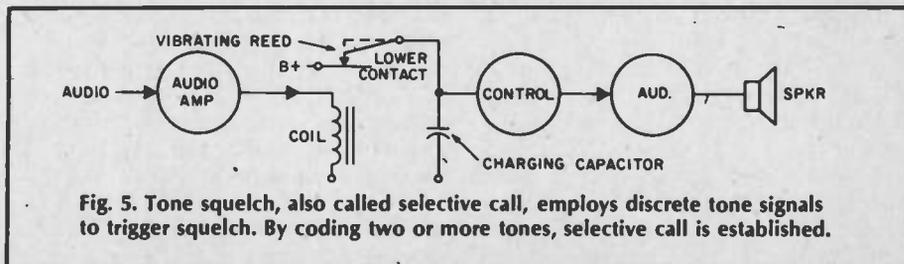


Fig. 5. Tone squelch, also called selective call, employs discrete tone signals to trigger squelch. By coding two or more tones, selective call is established.

be heard in the speaker. When an IF signal arrives due to a transmission from a CB rig, however, white noise disappears, no DC occurs, and the audio stages are released for amplification.

As you can see, the noise-operated squelch has more stages than simpler versions, but its excellent control action has led to wide application in higher-priced equipment. You can set the squelch to awaken these receivers on weak signals.

**Selective Call.** Squelch circuits may silence a speaker between incoming calls but they're non-selective. You hear not only your own units, but anyone else who happens to speak on the same channel. Where CB is used in a business establishment this can prove distracting to office workers. They'll hear every bit of chit-chat on the channel. They may be cured by the specialized squelch known as selective call. It relies on a tone-code signal sent by the calling station, and a special decoder in the receiver to activate the audio stages.

The most popular technique for achieving selectivity is shown in Fig. 5: the reed relay. The reed is a short strip of metal which resembles, and behaves like, the reed of a harmonica. Its valuable quality is that when it's set into motion (plucked), the reed vibrates very precisely on one resonant frequency, usually a few hundred hertz per second—a tone you can hear. How it operates is shown in the simplified diagram of Fig. 5. All incoming audio—noise, voice, etc.—is applied to the relay coil where turns of wire change the audio currents into corresponding magnetic fields. Poised just above the coil is the metal reed which starts to vibrate under the pull of various magnetic fields from the coil. The total movement, however, is not sufficient to cause the reed to strike the lower contact connected to the B+ voltage. But when a station sends the correct tone, the reed commences to vibrate at its resonant frequency. Motion is so great that the reed repeatedly strikes the lower contact and sends pulses of B+ voltage down to the charging capacitor. There the pulses are stored and shaped into a steady DC control signal which fires (turns on) the control stage. The audio amplifier is now activated and the calling unit

is heard. Only one reed is shown here, but in practical circuits it usually takes a combination of two reeds to create a code that won't cause false responses when the band is crowded with heterodynes that could simulate a single coding tone.

Similar circuits find their way into other applications. If you're watching a black-and-white movie on a color TV set, you won't be disturbed by a shower of colored confetti. Color receivers have a "color killer" which squelches any chroma feedthrough during B&W reception. And if you tune a recent FM stereo receiver, chances are you'll hear no noise between stations as you tune thanks to another squelch-type circuit. Squelch is working all out for you when you hear nothing! Just be sure that your receiver is not turned off! ■

## Single Sideband

□ ASK ALMOST ANYONE in Citizens Radio what the maximum transmitter power is and he'll say, "Five watts." And the number of CB channels assigned by the FCC is, as everyone knows, 23. Yet an increasing number of manufacturers are talking about transmitter power well over 5 watts and rigs that communicate on 46 channels! Is this a case for the Better Business Bureau? Not at all, since there's truth in all these claims. The reason is a special method of transmitting and receiving known as SSB, or single sideband. Nearly a dozen CB manufacturers now offer rigs that fall in the sideband category.

Sideband is so efficient and powerful that military services adopted it decades ago for long-distance voice transmission. The American Radio Relay League says that hams started using it back in 1933, and today it's the major mode for phone (voice) operation. Many hams, in fact, slyly ridicule regular AM as *Ancient Modulation*. Telephone companies have used sideband for point-to-point radio for years, and recent FCC regulations say that everyone on the 2-3 MHz marine band must switch to sideband within a few years. Citizens Banders got into sideband about eight years ago, and recently the number of CB sideband sets has multiplied in the marketplace, with an ever-increasing variety of interesting features being offered.

If sideband's so good, why doesn't the FCC make it the rule of realm? There are good reasons that delay a complete changeover from regular AM to sideband. For one, sideband is more complex than regular AM and is priced higher. A sideband receiver must be extremely stable for good reception. It requires extra circuitry and controls, like a speech "clarifier," since sideband is more critical to tune. Also, a sideband signal is not compatible; on a standard receiver it sounds like a dyspeptic Donald Duck. But the benefits of sideband for many operators could ultimately outweigh its shortcomings simply on an ability to double the number of channels that can be assigned a given band. There's also the sideband signal's excellent ability to penetrate interference.

**Conventional AM.** To grasp the mysteries of sideband, begin with regular AM. Sideband is, in fact, a form of Amplitude Modulation, but with major electronic surgery. Many students of radio have been brought up on the basic picture of AM shown in Fig. 1. It shows a radio carrier produced by an oscillating crystal, then amplified in a final radio-frequency stage of a transmitter. As the name implies, the carrier bears the voice or intelligence over long dis-

also subtract ( $1 \text{ kHz} - 27 \text{ MHz}$ ) and create 26.999 MHz, the lower sideband;

**Carrier**—The third product is the RF carrier, which emerges *without* a trace of modulation on 27 MHz.

Thus a CB rig's output is actually a three-part affair. The surprise, in terms of a conventional textbook picture of an AM signal, is the carrier: it contains none of the modulation. It is a steady-state RF waveform which remains con-

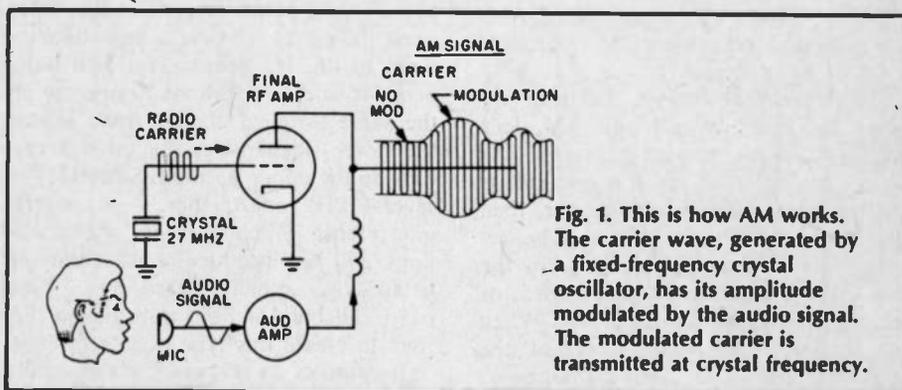


Fig. 1. This is how AM works. The carrier wave, generated by a fixed-frequency crystal oscillator, has its amplitude modulated by the audio signal. The modulated carrier is transmitted at crystal frequency.

tances. (It takes carrier frequencies far higher than audio to create electromagnetic fields that leave the antenna.) Note that an audio signal from the mike (after amplification) is joined to the carrier in the final RF stage. Since audio is delivered as a varying voltage to the tube plate, voice frequencies apparently control the amplitude, or strength, of the emerging carrier. This creates the classic AM signal:

**Upper sideband**—The audio tone and carrier add ( $1 \text{ kHz} + 27 \text{ MHz}$ ) and create 27.001 MHz, the upper sideband;

**Lower sideband**—The tone and carrier

stant in amplitude while the sidebands pulsate in step with the modulating signal.

**Missing Links.** But that's only part of the picture. A closer look at an AM signal would reveal that it actually consists of *three*, not one, basic components. The reason is that audio within the final stage is actually *mixing* with the carrier. Assume, for example, that audio is a tone of 1 kHz (which may also be written as .001 MHz) and this intelligence is modulated onto the 27-MHz CB radio carrier. As shown in Fig. 2, audio and radio mix in the final amplifier and three distinct signals go to the crystal

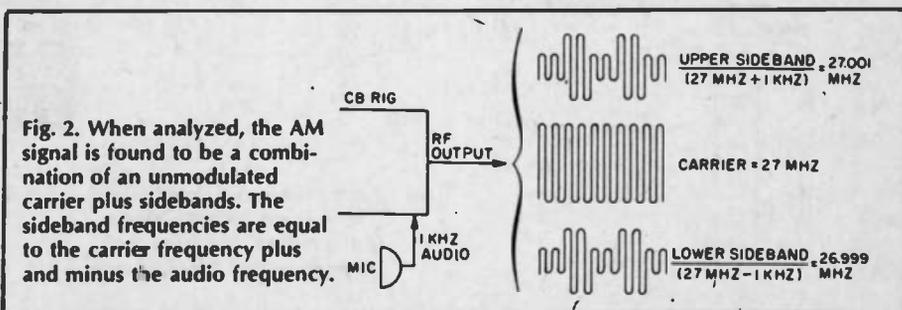


Fig. 2. When analyzed, the AM signal is found to be a combination of an unmodulated carrier plus sidebands. The sideband frequencies are equal to the carrier frequency plus and minus the audio frequency.

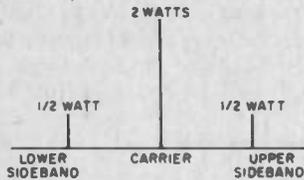


Fig. 3. The power distribution in an AM signal shows how much is wasted in the upper and lower sidebands.

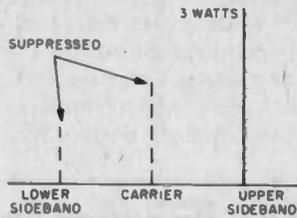


Fig. 4. One sideband receives all the power once used by the suppressed carrier and the other sideband.

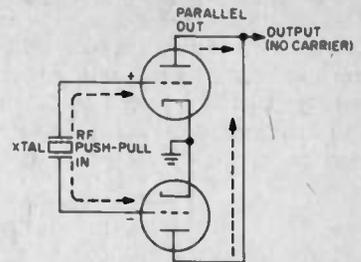


Fig. 5. This balanced modulator suppresses the RF carrier by cancellation in the plate circuit.

that produced it. And once it leaves the final stage it serves no further purpose. It has already done its job in the RF amplifier—mixing with audio to create sidebands, which actually bear the modulation. Another surprise is that *one* sideband is also useless. Since uppers and lowers are mirror images of each other—and carry identical audio—one can be cast aside without losing a syllable. (That's why conventional AM, the sideband supporters say, transmits a lot of air pollution.)

**Puckered-Out Power.** To heap another indignity on old-time AM, let's see how much power it wastes. As shown in Fig. 3, if a CB transmitter is putting out 3 watts of RF power, then two watts fall to the carrier. The remaining watt then divides between the two sidebands. Thus, fully two-thirds of the transmitter RF power is lost. When the duplicate sidebands arrive at the receiver, they add their voltages so there's no power loss here. But even though both sidebands can be ultimately used in receiving, there's still a major disadvantage in transmitting upper and lower, as shown in a moment.

**Suppressing the Villains.** Now take the array of signals and let's repack them in far more efficient fashion. As shown in Fig. 4, the same three RF watts have been completely jammed into the upper sideband. The carrier is now considered *suppressed*, its energy poured into the upper sideband. Similarly, the lower sideband is suppressed

and its energy also shifted to the upper sideband. Now, every bit of RF wattage is serving the cause: to send maximum voice power without violating FCC power restrictions. Before seeing how this three-into-one package is created, note another important benefit in Fig. 4. The signal—now single sideband—is far narrower than the original. It's about 3 kHz wide instead of 6 or more kHz. This is behind the claim that sideband takes 23 channels and doubles them to 46. It's possible for two independent sideband stations to operate on the same assigned channel; one selects the lower sideband as the other transmits on the upper position. Since they're several kHz apart, there's no mutual interference. What's more, these stations will not produce those annoying heterodynes usually heard on a busy band. Sideband stations transmit no carriers to create this type of interference.

Because of its efficiency, it's generally stated that single sideband will have about 8 times the effectiveness of an equivalent AM signal—and occupy half the bandwidth. Before seeing how the receiver is adapted for SSB reception, consider the basic transmitter circuits that create the sideband signal.

**Signal Splitting.** A popular circuit for producing sideband is the "filter" method. It begins by suppressing the carrier in the *balanced modulator* stage shown in Fig. 5. Although there are various ways to construct the circuit, the idea is to take the carrier, which alternates

between plus and minus, then rearrange it to cancel itself out. Note in Fig. 5 that a crystal is generating the RF carrier and feeding it to the grids of a pair of triode tubes. The key action is that the signal is applied in *push-pull* (one grid is driven positive while the other is driven negative), much like push-pull audio in a hi-fi amplifier. But the big difference is at the output connection. In conventional push-pull, the load is split so signals *add* in the output. In the balanced modulator, though, tubes are connected in *parallel*. The net effect is that each tube contributes a signal of opposite polarity—and the result is cancellation in the load. So push-pull in, and parallel out, phases out the carrier.

**Add Audio.** Now to introduce the voice intelligence. Let's modify the balanced modulator by adding a screen grid, which is a convenient point for introducing audio. Tracing the action in Fig. 6: when no audio occurs, there is no RF output because of the phasing-out process just described. But start to speak and audio is applied to the screen grids. The tubes are now unbalanced at an audio rate. Unbalance occurs as audio drives one screen more positive than the other, and unequal tube currents result. Now the RF signal sees an "unbalanced" modulator. This means the RF signal can no longer cancel itself completely in the output, so some carrier signal appears. That carrier, however, flows exactly in step with the voice, or rate of unbalance. The

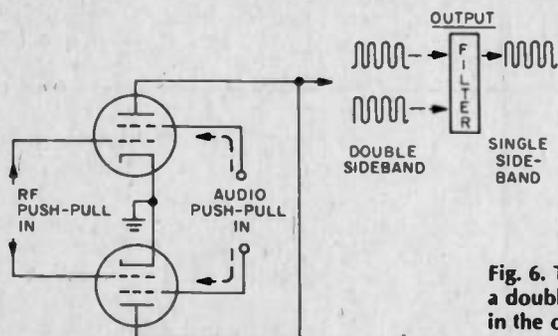


Fig. 6. The audio signal causes a double sideband to appear in the output. The filter then removes one of the sidebands.



Fig. 7. This is the type of filter used to remove the unwanted sideband from the RF output signal.

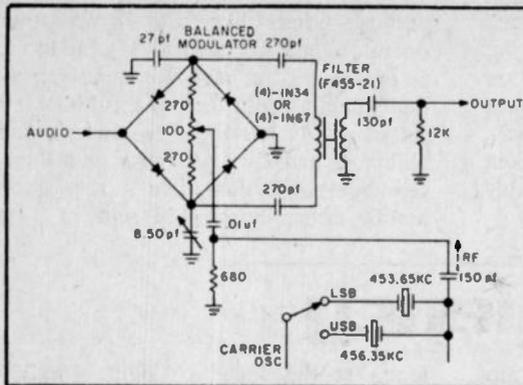


Fig. 8. Filtering circuit uses a 4-diode balanced modulator. The RF signal is generated by one of the two crystals, one for each sideband. The RF is fed up to the center of the modulator, and phasing of the signal cancels the RF. But when audio is applied to the modulator, the resulting imbalance allows RF to appear in the output. This RF is a double-sideband signal, minus the steady carrier. To get rid of one sideband, the composite signal passes through the filter. The resulting single-sideband signal is heterodyned in the transmitter's later stages, up to the final operating frequency of 27 MHz.

total effect is the appearance of the two RF sidebands—and a suppressed carrier.

**Filters.** There remains another major step. We want single, not double, sideband, so one sideband is passed through an extremely sharp filter with very high attenuation on the undesired sideband. One example is the Collins unit in Fig. 7, an electromechanical device which resonates very sharply on a single frequency (the desired sideband) and rejects the unwanted signal. Fig. 8 shows the actual circuitry.

This signal processing is done at very low-level stages in the transmitter and it wins sideband's great power efficiency. By eliminating carrier and sideband early in the circuit, these unwanted components never reach later stages for amplification. Only the desired sideband is boosted in the final tube or transistor and all the wattage goes into talk power.

**Receivers.** A conventional receiver picks up sideband as sheer gobbledygook. The reason is that the carrier is missing. The detection process in any receiver is exactly the opposite of modulation back in the transmitter, even for conventional AM signals. Recall that the carrier originally mixed with audio to produce sidebands. The identical mixing must be repeated in the receiver to convert the sideband back to audio. Since no carrier is supplied with an SSB signal, the receiver must "reinsert" it for sideband detection. This is easily done by switching on the receiver BFO (beat-frequency oscillator), the same type used to make code signals audible. The receiver, therefore, supplies a "local" RF carrier to beat, or heterodyne, against the incoming sideband. The mixture of the two recovers the original audio frequency. It is far more efficient for the receiver to supply a carrier of a few milliwatts than to use the powerful, but wasteful, carrier sent with a regular AM signal.

One reason why sideband is more difficult to tune than a standard signal is because of that local carrier. The receiver must supply an extremely accurate frequency so sideband and local

carrier mix to create the original frequency. This is never a problem in regular AM because you're always receiving the original carrier (the one that produced the sidebands) and frequency error can't occur. But the SSB receiver must be very accurately tuned. Unless you're within less than 100 Hz (cycles) of the correct frequency, speech is inverted or unintelligible. Fine control over the local frequency is done with the "clarifier" knob adjusted by the operator.

Another special quality in receiving sideband is selectivity. To fully exploit the system's ability to reject interference

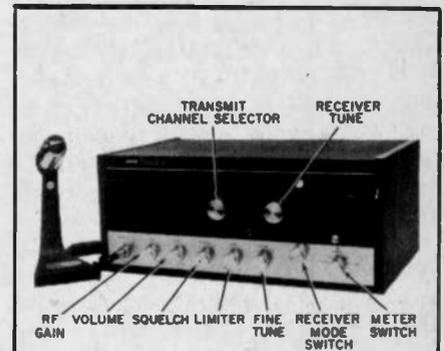


Fig. 9. Single-sideband transceiver by Tram gives choice of either sideband on any Citizens Band channel.

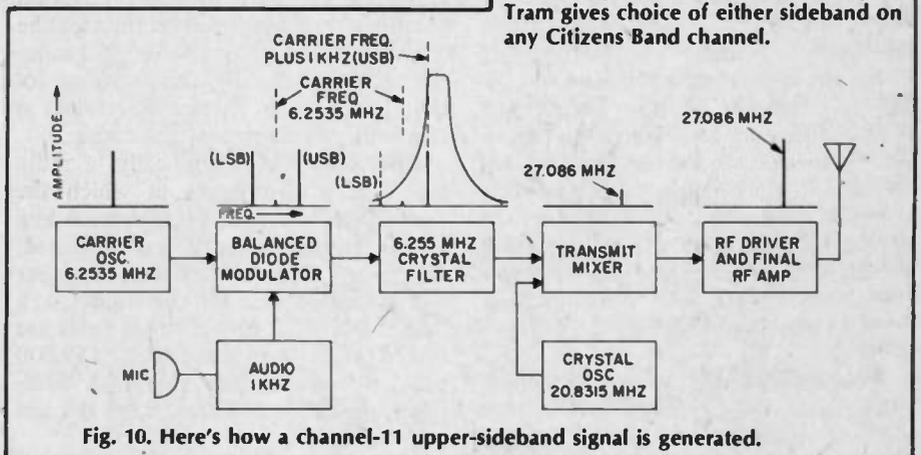


Fig. 10. Here's how a channel-11 upper-sideband signal is generated.

and noise, a receiver must narrow its response to signals of about 3 kHz in width. This is the approximate width of one sideband, and broader response by the receiver admits unnecessary noise and adjacent-channel interference. Such sharp selectivity in the receiver is usually obtained by crystal or mechanical filters.

**Commercial Circuits.** How the Tram Company achieved sideband operation in its Titan III is shown in Fig. 9. Note that a knob (Receiver Mode Switch) on the front panel allows the operator to choose upper or lower sideband on any channel, as well as regular AM for transmitting, to CBers not equipped for sideband reception. Fig. 10 is a block diagram of the same rig's transmitting arrangement for CB Channel 11. As

shown, the carrier is generated at about 6 MHz, then balanced out. The crystal filter chops away either sideband, and the final transmitting frequency is obtained by mixing the sideband up to 27 MHz. The reason for all these steps is that a sideband is easier to generate and filter at relatively low frequency of 6 MHz, then boosted to the final value by further mixing.

Another item peculiar to sideband because a carrier-less operation is the rating of the final power amplifier. In a regular CB set, output wattage is easily figured by measuring the voltage and current in the final transmitter stage, then multiplying the two figures for a rating in watts. Sideband, however, produces an RF signal that's varying at an audio rate, so the method of measure-

ment is different. It's done by using the peak value of signal as a reference. The power rating, therefore, is always greater than the customary five watts. It's always understood, though, that sideband measurements refer only to instants of peak power. The letters

"P.E.P." (peak envelope power) qualify the rating.

So the next time you hear a signal on the air that sounds like the Martians have landed in Grover's Corners, N.J., attribute it to single sideband. It's taken a long time to catch on in CB, probably

because CBers like to talk to other operators and sideband isn't compatible. Everyone has to have the same receiving capability. But the powerful boost of sideband, its narrower bandwidth and ability to cut through noise and interference should guarantee it a position among conventional AM sets. ■

## Facts on Frequency

□ IT WAS 4:00 A.M. and the thermometer read 15 degrees below zero. The squad car had to deliver the package without delay! Thanks to the flashing red light and the 2-kHz note screaming from the siren, the three miles from the bus terminal to police headquarters were covered in only 2½ minutes. The chief rushed out to get the package. He likes his coffee hot.

So the siren gave out a 2-kHz note. Is that anything like say, the 60-Hz current which lights a table lamp or, maybe, the 27.155-MHz carrier a CBer sends out from his 5-watt rig? The answer is yes—and no! No, because the siren note is actually a *disturbance of the air* which surrounds the whirling siren. The 60-Hz current which lights the lamp is actually a *disturbance of electrons* in the lamp cord. And the CB carrier is actually a *disturbance in the electro-magnetic field* which surrounds the transmitting antenna. But the answer is also yes because, in spite of their apparent differences, the siren note, the 60-Hz current, and the 27.155-MHz signal all have something in common—the characteristic way each of these "disturbances" go through their vibrations.

**Bouncing Air.** If analyzed scientifically, each type of disturbance is seen to be a repetition of identical actions. When the siren gives out a constant howl, tiny air particles are forced to collide and spread apart—in steady rhythm. If the howl is a 2-kHz note, the colliding and spreading takes place 2000 times a second. Although the in-

dividual air particles move hardly any distance at all in their back and forth motion, the rhythmic collisions of these particles radiate from the siren in all directions, from particle to particle. This radiation is, of course, "sound" and travels through air at a speed of about 1100 feet per second.

**Bouncing Electrons.** Alternating current flows back and forth through a wire because electrons, in varying quantities, are made to push one another first in one direction and then the other—in steady rhythm. If this AC is 60-Hz current, such back and forth motion takes place 60 times a second. The individual electrons don't move very far along the wire in either direction but their "bumping" travels through the wire at a speed of almost 186,000 miles per second. Naturally, this bumping action is made to change directions in step with the electrons that cause it.

**Bouncing Fields.** Basically, a radio signal is a disturbance in which the electric and magnetic fields surrounding a transmitting antenna are distorted, first in one direction and then the other—in steady rhythm. If this signal is a 27.155-MHz CB carrier, these fields are forced to change direction 27,155,000 times a second. This rhythmic, field-reversing action radiates from the an-

tenna at the speed of light, 186,000 miles per second.

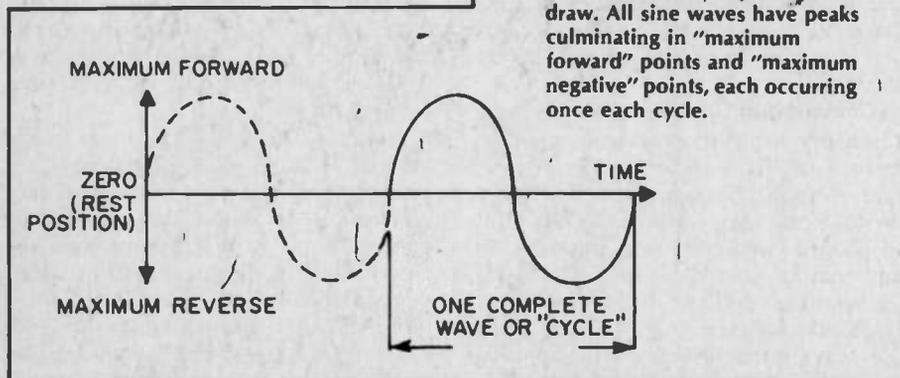
**Feel the Vibrations.** Now—it's the changing nature of these three types of disturbances that we are, really interested in! Aside from what is actually and physically happening, all three seem to follow the same pattern of change while going through their vibrations. True, the 27.155 MHz signal does its vibrating much, much faster than the other two but its vibration pattern is much the same.

Instead of using a lot of words to describe how each disturbance goes through its vibrations, let's use a helpful mathematical tool—the graph. The ancient Chinese said that *a picture is worth a thousand words* and that's exactly what a graph is and it's worth. More important, a graph provides us with a *lasting* picture, a permanent record, of how these vibrations change their speed and direction.

Our graph is set up in the usual manner. First there are the two reference lines, the "vertical axis" and the "horizontal axis." In our graph, the horizontal axis is made to show the *passage of time*. How the vertical axis is used depends on which type of disturbance we are portraying. For the 2-kHz siren note, the vertical axis is made to measure *how far* each air particle moves during its back-and-forth motion. For the 60-Hz AC current, the vertical axis measures *how many* electrons are in mass movement along the wire during their forward-and-reverse motion. As for the 27.155-MHz signal, this axis tells *how much* and in what direction the electric and magnetic fields are being distorted.

So much for the preliminaries. Next comes the most important item. It doesn't matter which disturbance we are graphing—for each *instant of time* that is represented on the horizontal axis, there is a *point* above or below the axis which measures how far the vibration is displaced from its resting position. If all these individual points (and there are an unlimited number of them) are "plotted" on the graph, a continuous curve will appear. The amazing thing about

Whether you're trying to graphically picture ripples on a sylvan pond, or the unmodulated carrier of a Citizens Band RF voltage, the familiar sine wave is all you need to draw. All sine waves have peaks culminating in "maximum forward" points and "maximum negative" points, each occurring once each cycle.



this curve is that its shape looks pretty much the same for the 2-kHz note, the 60-Hz current and the CB carrier.

Study the special shape of this curve. While examining the curve (and this must be done from left to right, never from right to left!), notice that it rises abruptly, gradually tapers off, levels out for an instant, starts to fall, picks up downward speed, and falls below the horizontal axis only to repeat the process in upside-down fashion. The 2-kHz note will make 2000 of these waves in just one second while the 60-Hz current goes through only 60 of them. But the CB carrier will turn out 27,155,000 of these double swings during each second.

**You Had Better Believe.** This curve we have been discussing is something very special! It is fundamental to many different areas of science and engineering. It is the famous *sine curve*. The current leaving a simple AC generator varies according to a sine curve. So does the output of a vacuum-tube or transistor oscillator in an AM radio. Even the pendulum on a grandfather's clock swings back and forth in accordance with a sine-curve pattern.

But it must be understood and understood well! The sine curve is only a graph which shows the changing character of sound waves, alternating currents, and radio transmissions, etc. To be sure, a sine curve is a picture but it is *not* a picture of sound waves, currents and radio signals as they really look (if, in some way, we could actually see them).

Ironically (and students of electronics must not be misled because of this), there are sine-curve relationships in

other fields of science where the physical occurrence actually looks like a sine curve. If a pebble is dropped into a calm pond, for example, ever-enlarging circles (ripples) will be seen leaving the splash. However, if these ripples are viewed from the side, at water level, a train of honest-to-goodness sine curves will be observed as they leave the splash area. As another example of real-life sine curves, if two persons suspend a rope between each other and one of them whips it up and down, a beautiful sine wave will run along the rope. Nevertheless, sine curves *don't* travel through electrical circuits, they *don't* travel through air as sound waves, and they *don't* radiate from transmitting antennas! Radio signals, AC currents and sounds vibrate in unison with sine curves but they *don't* look like them! However, a check of their graphs indicate they do!

**Discovering Frequency.** At this point, the true meaning of "frequency" should become clear. It doesn't matter if we are talking about sound waves, AC current, or radio carriers. Frequency is the number of times these various disturbances repeat their vibrations during *one second*. From a graphical standpoint, frequency is the number of times *each* complete cycle of sine curve is repeated during *one second*. Either way you look at it, frequency can be classified by its number of "cycles per second." As everyone should now know, however, this once common designation for frequency has been replaced by, simply, "hertz" (Hz) in honor of that great German scientist of the Nineteenth Century, Heinrich Hertz.

**To Sum Up.** The 2000-Hz sound energy from the police-car siren, the 60-Hz AC from the wall outlet, and the 27,155,000-Hz carrier from the CB rig are three different scientific phenomena. But they have the common property of being able to be described by sine curves and, because of this, all can be measured by a common yardstick—frequency.

But hold on! Are these three so-called disturbances really so different from each other? (After all, electronics wouldn't be electronics without sound and radio signals!) They are different, but not as much as you would think. With the aid of a "transducer," one type can be transformed into another! Thus, a *microphone* will change 2-kHz sound waves into 2-kHz alternating current in a wire. A *loudspeaker* will change the AC back into sound waves. A *receiving antenna* will change 27.155-MHz electromagnetic energy into 27.155-MHz alternating current (AC) in a wire (the antenna feedline, that is). A *transmitting antenna* will make the opposite change.

That's it. If the interrelation between sound, electrical, and electromagnetic frequencies now makes sense to you, you've learned a tremendously important bit of electronics theory. And don't forget the almighty sine curve. The sine curve can be used to explain theory in many fields of science, not just electronics. Nevertheless, keep clear in your mind just how the sine curve fits into electronics—what it is and what it isn't. Maybe you don't care whether your coffee is hot but you better stay *hot* on the *sine curve*. ■

## Oscillating Amplifiers

□ AS ANY SLIGHTLY CYNICAL experimenter can tell you, if you want an oscillator, build an amplifier—it's sure to oscillate. Conversely, if you want an amplifier, (this same cynic will tell you), build an oscillator—it's sure to fail to oscillate, and you can then use it as an amplifier! This is well known as a corollary to Murphy's famous law, "If anything *can* go wrong—it *will*!"

Our informed cynic must have had long and unhappy experience with negative-feedback amplifiers, which are known to have at least two outstanding characteristics:

1. They function beautifully if carefully designed and built.
2. Otherwise, they oscillate!

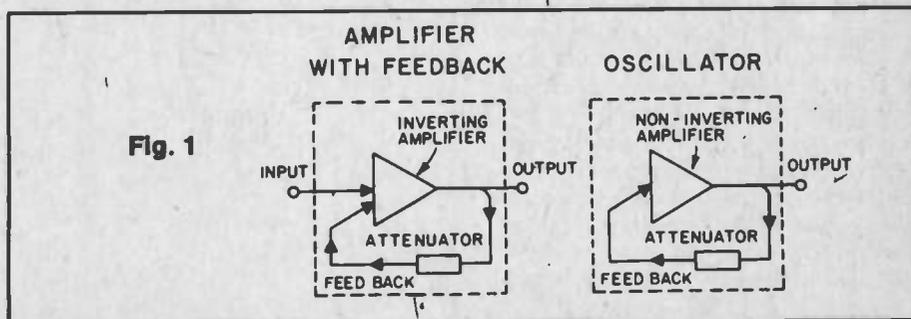
Why do they oscillate? Or, more basically, how does a feedback amplifier differ from an oscillator?

The fundamental block diagrams of an oscillator and an amplifier with feedback bear a strong resemblance to each other, as you can see from Fig. 1. From a block diagram viewpoint, both diagrams are *very* similar. Both contain some type of amplifying device, and both have part of their output signal

fed back to their input. There are only two major differences between them:

1. The amplifier with feedback contains an *inverting* amplifier; the oscillator contains a *non-inverting* amplifier.
2. The oscillator doesn't have an input.

The circuit action obtained from



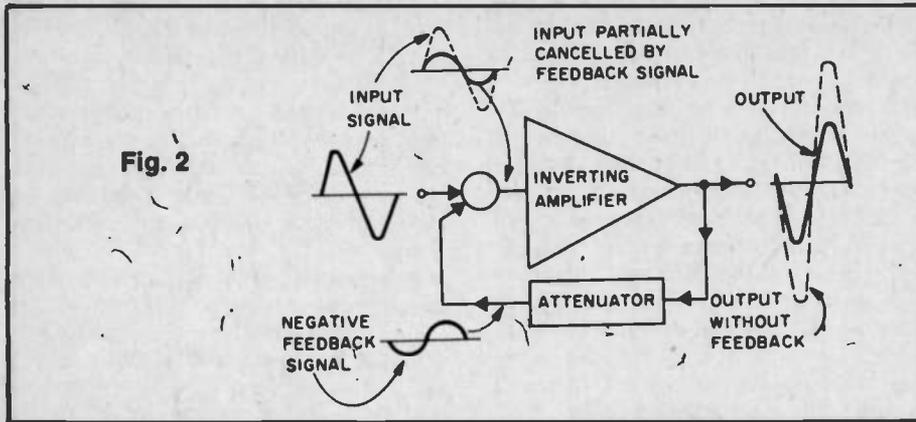


Fig. 2

these two circuits is entirely different. In the amplifier with feedback, the output waveform is upside down with respect to the input, so when it is fed back to the amplifier input, it cancels a portion of the input waveform. The output is therefore less than it would be without feedback. See Fig. 2.

The feedback signals from inverting amplifiers are not "in phase" with the input signal and subtract (or reduce) the input signal level to the amplifier. When a feedback signal does this, it is called *negative feedback*.

**So Why Negative Feedback?** Of course, if you merely want the biggest possible gain for your money, negative feedback's not your game. However, negative feedback offers other advantages, which can be summed up by saying, that the amplifier's output, though smaller, is always nearly constant for the same input signal. For example, if the amplifier weakens with age, and the output tries to drop, there is less signal to be fed back; hence there is less cancellation, and the output is restored almost to its former level. Similarly, if you feed a high-frequency signal through the amplifier—so high in frequency that the amplifier can barely amplify it—the resultant drop in output reduces the fed-back voltage, produces almost no cancelling feedback signal, and keeps the output nearly the same as it was at lower frequencies. Moreover, any clipping or other distortion of the waveform inside the amplifier produces an output waveform which does not match the input; hence the non-matching part is not cancelled, and the distortion is removed, or at least greatly reduced. Without this action, hi-fi amplifiers would not exist.

So the loss in output you obtain from negative feedback repays you by providing less distortion, better long-term stability, and better frequency response—that is, the best and most uniform output in response to *all* input frequencies.

**On the Flip Side.** The oscillator, on

the other hand, is not supposed to give the best output from all input frequencies, but is instead made to give an output at a *single* frequency—with no input at all. It's not surprising that the opposite type of internal amplifier (non-inverting) is used to obtain this opposite result. See Fig. 3.

In the oscillator, any output at all (probably the result of some random noise in the internal amplifying device) is fed back, non-inverted, to the input, where it does not cancel but instead serves as the signal at the input. This feedback signal causes an even larger output, which results in an even larger signal-fed back, further reinforcing the input signal, and so on.

You guessed it—this type of feedback signal is commonly referred to as *positive feedback*. In theory, the output waveform should continue to get larger forever. In practice, the amplifier is limited in the maximum size of the signal it can deliver, so the output waveform stops growing in this amplitude. As it

stops to grow, so does the positive feedback signal. Now the signal reduces rapidly and the positive feedback signal lends a hand until the signal can get no lower. This is the beginning of the first cycle of many to follow.

All well and good, you say, but if the major difference between feedback amplifiers and oscillators is the inverting or non-inverting nature of their internal amplifiers, why does an amplifier sometimes oscillate? What turns an inverting amplifier into a non-inverting one?

To answer this question, first observe that an inverting amplifier, in passing a sine-wave signal, *effectively* shifts the signal's phase by  $180^\circ$  as shown in Fig. 4. We say *effectively*, because it doesn't really shift the timing by delaying the signal (which is what a real phase-shifter does) but, by turning the signal upside down, the amplifier makes it look like a signal which has been delayed (phase-shifted) by  $180^\circ$ .

A real phase-shifter, on the other hand, is normally nothing but a fistful of judiciously connected resistors and capacitors (and sometimes inductors) which can be designed to give a  $180^\circ$  phase shift at a *single* frequency, such as 1,000 Hz, for example. In contrast to an inverting amplifier, it provides this phase shift by actually delaying the signal. See Fig. 5.

What happens if we combine an inverting amplifier and a  $180^\circ$  phase-shifter? Take a look at Fig. 6.

This combination will shift the phase of a given frequency by a total of  $360^\circ$  (an entire cycle) so the output is identical to the input. In effect, this com-

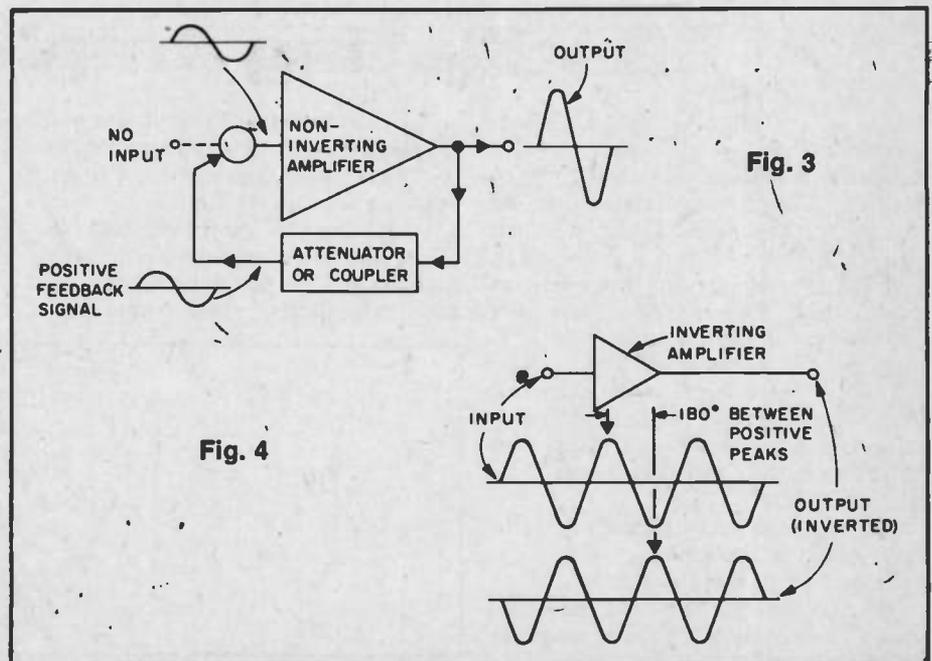


Fig. 3

Fig. 4

bination (at 1,000 Hz) will behave the same as a non-inverting amplifier. See Fig. 6.

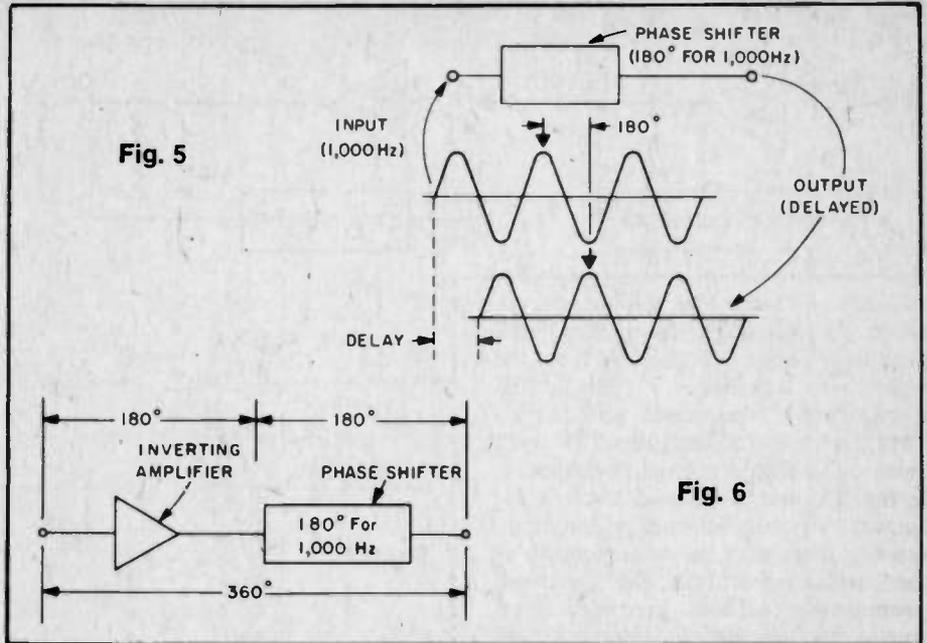
Therefore, if we build a feedback amplifier which contains the normal inverting amplifier but also (inadvertently) contains a 180° phase-shift network, the resultant circuit will oscillate at the particular frequency, (1,000 Hz in the figure) for which the phase-shifter provides 180° phase shift. See Fig. 7.

How can one "inadvertently" make a phase-shifter? It's easier than you might think. The circuit shown in Fig. 8A will provide 60° phase shift at 1,000 Hz. Three such networks connected in a "ladder" (see Fig. 8B) will provide  $3 \times 60^\circ = 180^\circ$  of phase shift. (But not at 1,000 Hz. Because of the way the networks load each other, the 180° shift occurs at 707 Hz. However, if an amplifier were located between each network, then the amplifier will oscillate at 1,000 Hz.) This network, if dropped into a normal feedback amplifier circuit, will convert it to an oscillator.

This circuit (Fig. 9) is known as a *phase-shift oscillator* and is widely used in electronics.

Of course, when you set out to build a phase-shift oscillator, you *deliberately* insert a phase-shifter to make the circuit oscillate. How could one ever *inadvertently* place such a circuit in a feedback amplifier, thereby producing unwanted oscillations?

Phase-shift circuits can "hide" within an amplifier, posing as other circuits. For example, vacuum-type amplifiers often have grid circuits arranged as shown in Fig. 10A. Does that resistor/capacitor circuit look familiar? In form, it's just like the phase-shift circuit



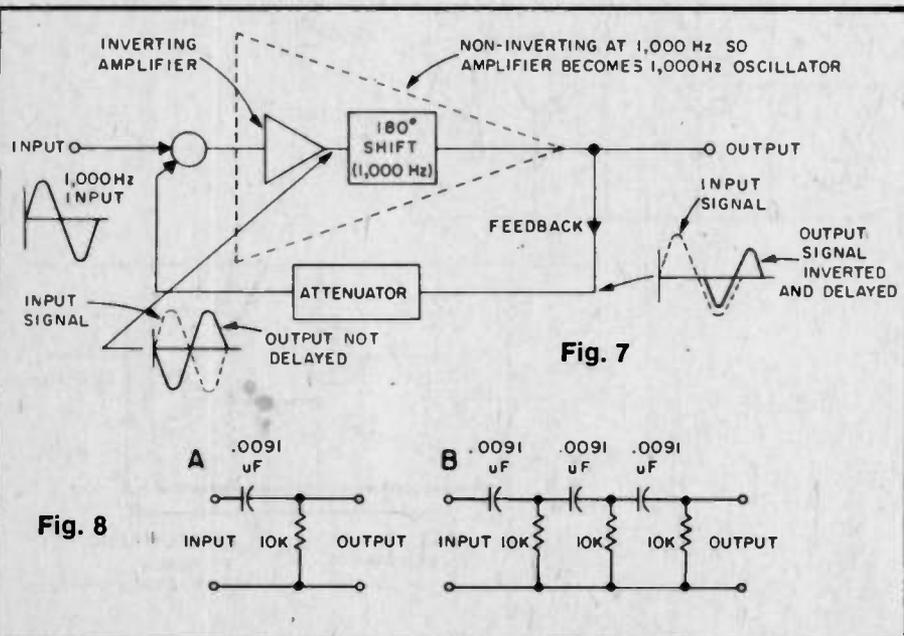
above. And transistor amplifier circuits often take the form shown in Fig. 10B.

Again, the coupling/biasing network looks just like the basic phase-shifter network. At some frequency, this network will provide 60° of phase shift. If we use three such identical networks in a three-stage amplifier we have a 180° phase-shift network "buried" inside the amplifier, masquerading as three normal coupling networks. If this three-stage amplifier is used as part of a feedback amplifier arrangement, the amplifier will oscillate at some frequency, and be quite useless for the purpose for which it was intended.

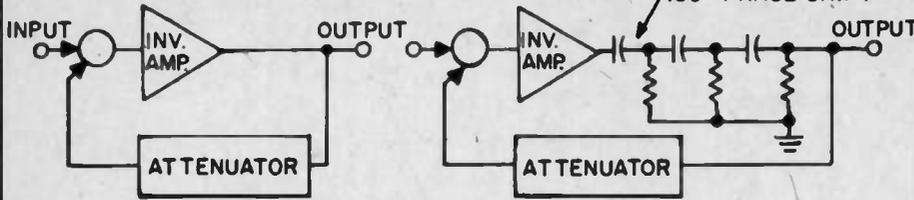
**More Trouble.** This is not the only way an amplifier can get into trouble. There are other types of phase-shifters

than can creep into amplifiers, unrecognized, and drive the unwary experimenter up the nearest wall. This circuit (shown in Fig. 11A) can also produce a phase-shift of 60° at 1,000 Hz. Three of them, can produce the 180° phase-shift required for oscillation. See Fig. 11B. This particular network can invade amplifiers in an even more insidious fashion. The "masquerading" part of the circuit is shown heavy in Fig. 11C. The dotted capacitor doesn't appear physically in the circuit, because it is the so-called "stray capacity" associated with wires, sockets, terminals, etc. Three of these circuits hiding in an amplifier, can produce an unwanted oscillation. See Fig. 12. Since the stray capacities are so small, this "osc-plifier" will oscillate at a very high frequency; often so high that it is undetected as an oscillation. However, such oscillation can make an amplifier behave erratically; sometimes distorting, sometimes not; sometimes overheating, sometimes not. Fig. 7 and Fig. 12 have a lot in common.

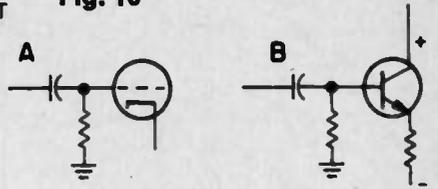
Are feedback amplifiers the only culprits in this oscillating-amplifier business? Absolutely not! Often, so-called "straight" amplifiers—with no *intentional* feedback—will gaily oscillate away. But watch that word *intentional*. Close inspection of these misbehaving circuits usually uncovers an *unintentional* feedback path hiding within the amplifier. Consider the innocent-looking circuit in Fig. 13. This is an ordinary two-stage amplifier, obviously assigned the task of converting a small, positive-going signal into a large, positive-going signal. To help it along, the designer has even provided a decoupling network, R1 and C1. At high fre-



**Fig. 9**



**Fig. 10**



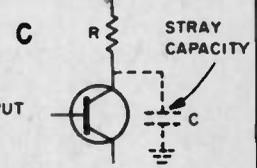
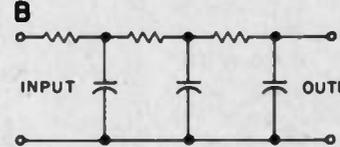
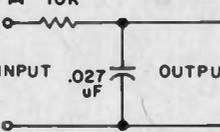
quencies, C1 acts like a short circuit, effectively isolating (de-coupling) the amplifier's power bus, Ecc +, from the main power bus, Ecc + +. But, at low frequencies, the capacitor acts like an open circuit—it just isn't there! A small part of the output voltage now appears across R1, and is coupled through the amplifier's power bus back to the input, arriving there with the same polarity as the normal input. True, the signal unintentionally fed back isn't very large, because the unintentional feedback path provides substantial losses for this stray signal. For example, the signal may arrive back at the input 100 times smaller than it was at the output. However, if the amplifier has a gain of 101, it makes an even larger output signal out of the fed-back signal, which then is fed back as an even larger voltage and oscillation begins.

Careless construction can get you into trouble, too. The amplifier shown in Fig. 14 is trying to convert a 10-millivolt input into a 200-ma signal needed by the load, R2. The builder has tied all ground returns to a heavy ground bus, and returned this bus to ground at only one point. Unfortunately, that single ground wire has to carry both the tiny input signal and the large output current. And, since every wire has some resistance, the actual circuit includes an 0.06-ohm resistor that does not appear in the original construction schematic diagram, but must be considered and is shown in Fig. 14.

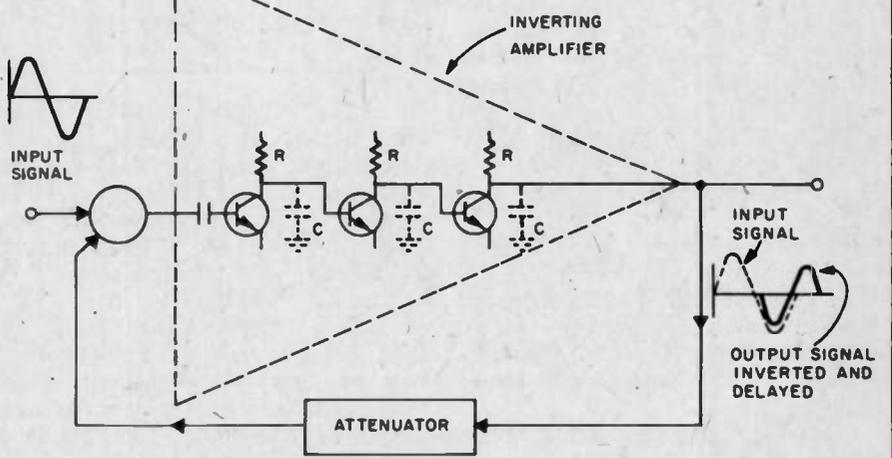
Again, an uninvited, unintended feedback path has appeared, coupling the output back to the input. In the sketch, the large output current, flowing through the tiny ground-lead resistance, produces a voltage which is even larger than the original input voltage. And, since this voltage is also connected to the input (through the bias resistor R3), the fed-back voltage appears uninverted (and uninvited!) at the input, and will cause the amplifier to oscillate. What is to be done to convert these oscillators back into well-behaved amplifiers?

The general rule is *divide and conquer*. In the example just above, we can conquer the oscillation by dividing the ground returns, making sure that the high-current output circuits and the

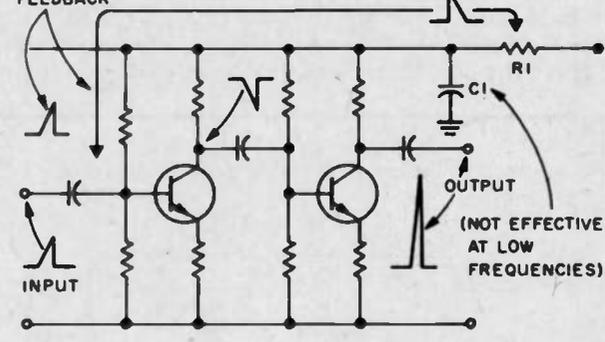
**Fig. 11**



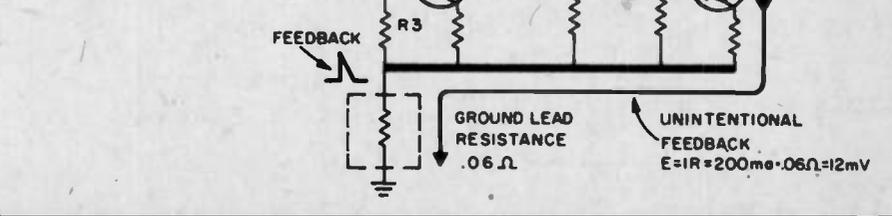
**Fig. 12**



**Fig. 13**



**Fig. 14**



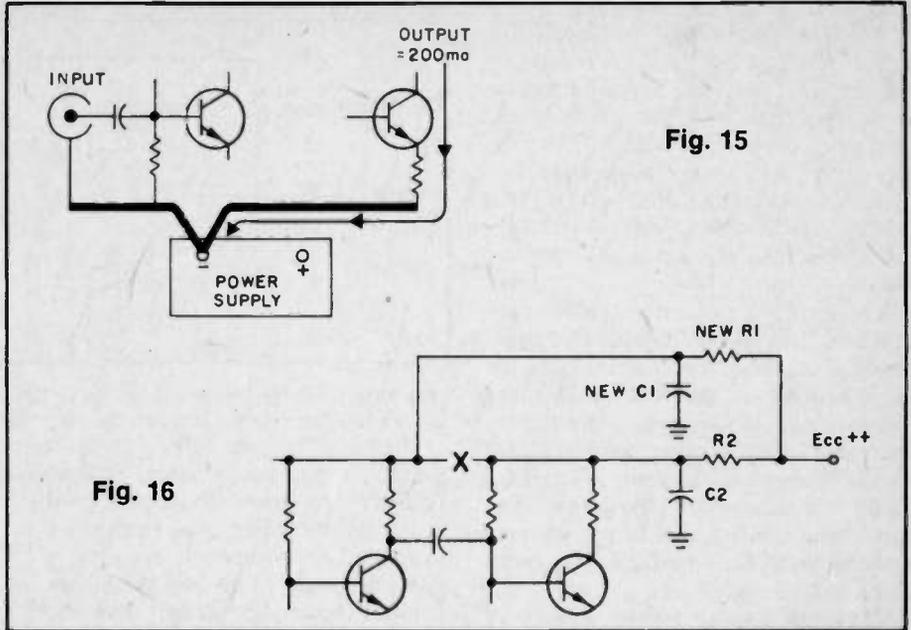
sensitive input circuits have their own private and individual paths to the power supply. See Fig. 15.

Short leads to the input connector are also helpful in squashing oscillations.

The misbehaving decoupling network, R1 and C1 in Fig. 13, can also be brought under control by dividing the network into two decoupling networks as shown in Fig. 16 below.

The stray capacities causing the unwelcome phase shifter to hide in the best divide-and-conquer approach to this amplifier are harder to exorcise. Your amplifier is to put feedback around only a pair of stages instead of three or more. This way, there are only two pairs of stray Rs and Cs lurking in the amplifier, and it takes at least three such pairs to make an oscillator.

The coupling capacitors, which combined to make a phase shifter in the very first example, can be prevented from ganging up on the amplifier and making it oscillate by making the product of each capacitor times its associated resistor (called the "RC product") 5 or 10 times larger or smaller than the other RC products. For example, in a three-stage feedback amplifier which has all its base resistors the same values, you could make the three coupling capacitors 2  $\mu$ F, and 10  $\mu$ F, and



50  $\mu$ F, respectively. Again, you have divided the coupling capacitors into three widely-separated values, and conquered the oscillation.

All three problems and solutions are by no means a comprehensive list of all the ways an amplifier can get into trouble, nor of all the tricks of the trade that can be used to bail them out. For that matter, we've said nothing at all

about the opposite problem—how to persuade a balky oscillator to "take off" and do its thing. But we've said enough to indicate that the cynic mouthing Murphy's law would be well-advised to look to his basic theory and construction, because both amplifiers and oscillators answer to certain basic circuit laws, and will behave themselves impeccably if those laws are not violated. ■

## Taking the Gamble Out of Gain

□ GAMBLERS AND AMPLIFIERS have one thing in common: their goal is to get more *out* than is put *in*. But, while successful gambling requires the smiles of Lady Luck, amplification is not a matter which should be left to chance. All too often, however, amplifier circuits are used whose actual gain is a complete unknown until the circuit is actually built and tested.

And gain is not the whole story. The bias, or DC operating point, must also be known and predictable, or the amplifier may clip and distort the signal it is passing. In extreme cases, it will fail to pass a signal at all. Again, we often see amplifier circuits whose DC operating points are left to chance, or are "tweaked" into place only after the circuit is built and fails to operate correctly.

Such gambling with gain and bias is unnecessary. Very simple and straightforward methods can be used to predict the gain and DC operating conditions of an amplifier, making its behavior a matter of logic, not luck. These techniques succeed because they make the gain and DC operating points depend upon resistor values, which are

predictable, instead of depending upon transistors and ICs, which are notoriously unpredictable, even at the present state of the art.

In the following paragraphs, we shall give examples of both *long shots* and *sure things* in the amplifier world, and show how to convert a long-shot risk into a much more reliable amplifier.

**Russian Roulette Special.** If you like to gamble, the circuit of Fig. 1 will give you a *lot* of gain—if it works at all! But even if you get it working, the first hot day may send it into raspy distortion as the hot transistor shifts its DC operating point, brutally destroying your clean hi-fi signals. And even if

you can get it to keep its cool, you will find that the resistor values shown won't work if you change transistors, or if you try to build another identical circuit. In brief, this circuit requires, first, that you hand-tailor it to fit each and every transistor, and second, that you keep the circuit's transistor cool.

So in spite of the high gain available from this circuit, it represents a bad gamble—a real long shot—because it may not work at all, or it may work one day and not the next, or it may work with one transistor and not another. Even if Lady Luck smiles on you and the circuit works, you cannot readily predict how high the gain will be.

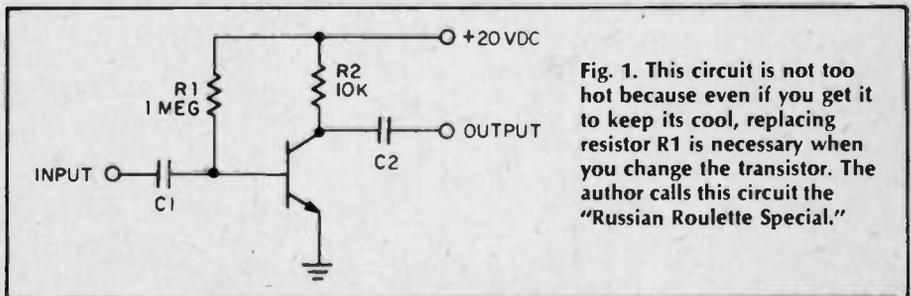


Fig. 1. This circuit is not too hot because even if you get it to keep its cool, replacing resistor R1 is necessary when you change the transistor. The author calls this circuit the "Russian Roulette Special."

**A Better Gamble.** If you don't like long shots, you can add one resistor to the *Russian Roulette Special* and improve its reliability considerably. But, as in most gambling operations, the payoff—in this case, the gain—goes down.

Take a look at Fig. 2 and you will see that it is just the *Russian Roulette Special* with a resistor added in the emitter circuit.

The gain of this circuit is, for all practical purposes, completely independent of the transistor. In fact, the gain is simply the value of the collector resistor, R2, 10,000 ohms, divided by the value of the emitter resistor, 2,000 ohms. Therefore, the gain is  $10,000/2,000 = 5$ . A one-volt signal applied to this circuit can be relied upon to produce a five-volt output signal, every time.

The new emitter resistor also does nice things for the DC operating point, by making it more predictable and less susceptible to high temperature difficulties. Although this circuit is still not the best we can do, it is a much better bet than the *Russian Roulette Special* shown in Fig. 1.

**The Sure Thing.** Adding yet another resistor, R4, to the circuit of Fig. 2, gives us Fig. 3, which is a real *sure thing* in the amplifier world.

Just as for the circuit of Fig. 2, the gain of this circuit is  $R2/R3$ . Since the value of R2 has to drop a little for this circuit—for reasons explained below—the gain of this circuit is  $9,100/2,000 = 4.55$ . Note that, just as in Fig. 2, the transistor has nothing to do with this value of gain. Only the fixed resistors determine the gain, which is just the way we like it.

The DC operating point of this circuit is extremely stable and predictable—far better, even, than the circuit of Fig. 2—and is determined by the resistor values only.

**Putting It Together.** If you're a compulsive gambler, or for some reason like to play *Russian Roulette* with your amplifier designs, you may opt for the simple but unreliable circuit of Fig. 1. In such a case, you can reduce your

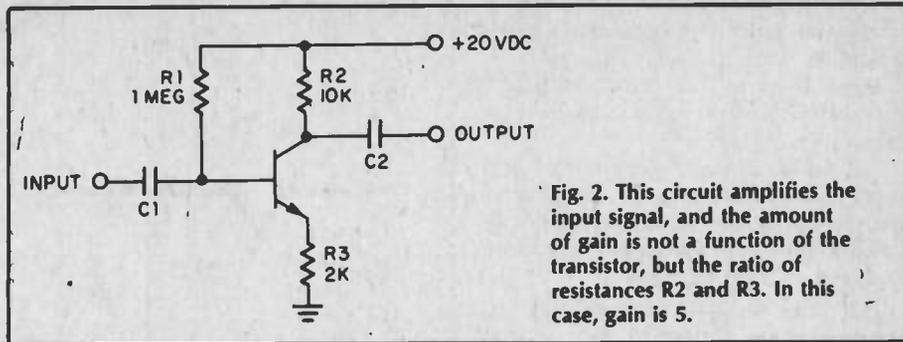


Fig. 2. This circuit amplifies the input signal, and the amount of gain is not a function of the transistor, but the ratio of resistances R2 and R3. In this case, gain is 5.

risk somewhat by following the step-by-step design arrangement given below:

1. Choose your power supply voltage. In Fig. 1, we chose 20 volts, a good round number. For most transistors, values below 2 volts will make for a difficult design. In no case should the voltage chosen be greater than the value given in the transistor data for  $BV_{CEO}$  (Breakdown Voltage; Collector-to-Emitter, with the remaining electrode (base) Open).
2. Second, choose the current desired in the transistor. For economy, especially for battery operation, this should be as small as possible. However, many small transistors do not operate well below 0.5 milliamperes; often the transistor databook will indirectly recommend a current by saying something like "Beta (or  $h_{fe}$ ) is 35 at  $I_c = 2$  mA." This is a broad hint that the particular transistor type you're considering has been manufactured to work best at 2 mA. Under no circumstances should you choose the current value given under "Maximum Ratings." This is the red-line, never-exceed value of current; one increment beyond this value and the transistor may vanish in a puff of silicon smoke! If in doubt, 1 or 2 mA is a reasonable value for small transistors. In our example, we chose 1 mA.
3. Having chosen the current, calculate R2, the collector resistor, with the formula

$$R2 = \frac{500 \times E}{I_c \text{ (mA)}}$$

$$R2 = \frac{500 \times 20}{1} = 10,000 \text{ ohms}$$

4. For the next steps, you need a voltmeter, an ohmmeter, a 2-megohm potentiometer, and a resistor somewhere between 10,000 and 100,000 ohms. Put the circuit together with the pot, resistor, and voltmeter as shown in Fig. 4.

5. Adjust the potentiometer in Fig. 4 until the voltmeter reads one half the supply voltage—10 volts, in this case.
6. Without disturbing the potentiometer setting in Fig. 4, remove the pot and its associated resistor and measure their combined value with the ohmmeter.
7. Use the value obtained in step 6 for the R1 of Fig. 1.

To complete the design, C1 and C2 should be chosen to have values in the 100- $\mu$ F region for most audio work, with voltage ratings equal to or greater than the power supply voltage.

If you ever have to replace the transistor, you will probably have to repeat steps 4, 5, 6, and 7.

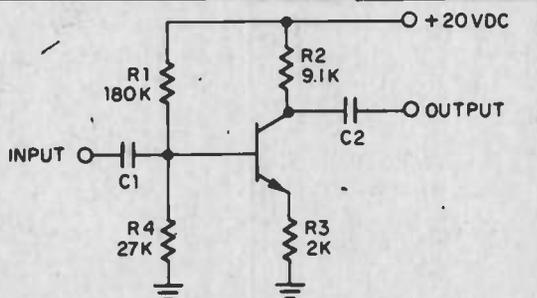
The above effort, which includes all that playing around with meters and pots, yields you an amplifier of unpredictable gain and doubtful reliability. The circuit of Fig. 2, though better, offers not enough real improvement to warrant a detailed discussion. Fig. 3 is the circuit that removes us from the ranks of risk-takers, so we should next see how this superior circuit may be designed, step-by-step.

**No-Gamble Gain:** Here's the step-by-step procedure that is foolproof.

A. Select the supply voltage and transistor current just as in steps 1 and 2, above.

B. Select a DC voltage, smaller than the supply voltage, which you want to appear at the emitter. In the example in Fig. 3, we chose 2 volts. If this voltage is chosen too small (less than  $1/20$ th the supply voltage), gain predictability and bias predictability will be poor. If chosen too large (more than half the supply voltage), then so much of the avail-

Fig. 3. Stability is the name of the game played with gain. The addition of R4 removes the circuit's tendency to self-destruct like the one shown in Fig. 1. Gain is still the ratio of  $R2/R3$ , but notice value is lower, with a loss of some gain.



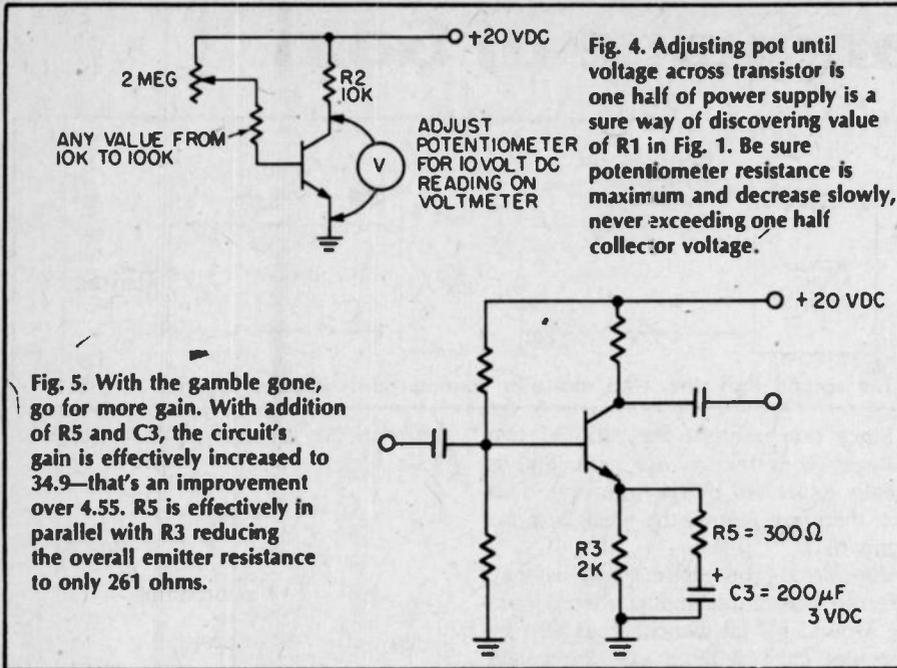


Fig. 4. Adjusting pot until voltage across transistor is one half of power supply is a sure way of discovering value of R1 in Fig. 1. Be sure potentiometer resistance is maximum and decrease slowly, never exceeding one half collector voltage.

Fig. 5. With the gamble gone, go for more gain. With addition of R5 and C3, the circuit's gain is effectively increased to 34.9—that's an improvement over 4.55. R5 is effectively in parallel with R3 reducing the overall emitter resistance to only 261 ohms.

able voltage is "used up" on the emitter that there's very little left to produce signal output. So, it's a trade-off between good stability and a large output. A good rule of thumb is to let about one-fifth to one-tenth of the supply voltage appear at the emitter. C. Calculate the emitter resistor, R3, by the formula

$$R3 = \frac{1,000 \times E(\text{emitter})}{Ic (\text{MA})}$$

$$R3 = \frac{1,000 \times 2}{1} = 2,000 \text{ ohms}$$

D. Add 0.6 volt to the emitter voltage, to obtain the base voltage:

$$E(\text{base}) = E(\text{emitter}) + 0.6 = 2 + 0.6 = 2.6 \text{ volts}$$

(Note: Use 0.6 volt for silicon transistors; use 0.2 volt for germanium transistors.)

E. Calculate R4 by the formula

$$R4 = \frac{10,000 \times E(\text{base})}{Ic \text{ mA}}$$

$$R4 = \frac{10,000 \times 2.6}{1} = 26,000 \text{ ohms}$$

(use EIA Value, 27,000 ohms)

F. Calculate R1 by the formula

$$R1 = \frac{10,000 \times [E(\text{supply}) - E(\text{base})]}{Ic \text{ mA}}$$

$$R1 = \frac{10,000 \times (20 - 2.6)}{1}$$

R1 = 174,000 ohms (Use EIA value, 180,000 ohms)

G. Calculate R2 by the formula

$$R2 = \frac{500 \times [E(\text{supply}) - E(\text{emitter})]}{Ic (\text{mA})}$$

$$R2 = \frac{500 \times (20 - 2)}{1}$$

R2 = 9,000 ohms (use EIA value, 9100 ohms).

Notice that using up two volts on the emitter caused us to have only 18 volts left for output. The mathematics then forces us to drop the 10,000-ohm collector resistor to 18/20ths of 10,000 ohms, which is 9,000 ohms. This causes some loss of gain (from a gain of 5 for the circuit of Fig. 2, to a gain of 4.55 for this circuit) which is the price paid for stabilizing the amplifier. Again, it's just like gambling—when the risk goes down, so does the return.

Can we hedge our bets? That is, can we keep the DC operating point stable, and still get more gain? Indeed, we can. The circuit of Fig. 5 shows how this is done:

In this circuit, a 300-ohm resistor, R5, has been added in parallel with the 2,000-ohm emitter resistor, R3, but with a capacitor C3 in series with the new resistor. Since the capacitor is an open circuit to DC, the DC stabilizing effect of R3 is unchanged—it's just as though R5 weren't there, as far as DC is concerned. However, for the signal, which is AC, the capacitor looks like a short circuit—it looks exactly as though R5 were soldered directly across the emitter resistor.

So, for the signal, the total resistance

in the emitter circuit is effectively the parallel combination of R3 and R5:

$$R = \frac{R3 \times R5}{R3 + R5}$$

$$= \frac{2,000 \times 300}{2,300}$$

$$R' = 261 \text{ ohms}$$

And, since the gain is given by R2/R3, the addition of R5 in parallel with R3 has changed the gain thus:

Before R5 and C3 were added:

$$\text{Gain} = (9,100)/(2,000) = 4.55$$

After R5 and C3 were added:

$$\text{Gain} = (9,100)/(261) = 34.9$$

The addition of R5, then, gave us nearly eight times as much gain, and did so without disturbing the excellent DC-operating-point stability of the basic circuit. What price do we pay for this improvement—that is, beyond the money cost of the resistor and capacitor? And, if dropping in a 300-ohm resistor yields eight times the gain, would a 30-ohm resistor give 80 times the gain?

Obviously, the smaller we make R5, the more gain we get, until finally, when R5 = 0, we get the most gain we can obtain from this transistor. At this point—with R5 shorted out, and the capacitor C3 therefore directly across the 2,000-ohm resistor, R3—the gain is identical to the gain obtained from the Russian Roulette Special circuit of Fig. 1. It is just as large, and just as unpredictable. Such a circuit, with R5 shorted out and C3 directly across R3, is sometimes used to obtain the most AC (signal) gain available from the transistor, while still preserving the top-notch DC-operating-point stability of the Fig. 3 circuit. Any transistor plugged into such a circuit will have the same DC operating point as any other transistor in that circuit, or one like it; however, the gain for the signal will differ markedly from one transistor to another.

So gambling with gain and bias is completely unnecessary, since simple methods let us predict accurately the exact values of resistors needed to obtain optimum operation and reliability from our transistor amplifiers. Hook-up a few circuits today and check out what you have learned. Don't gamble on your memory.

# The Language of Gain

□ WHEN YOU GLIDE the old heap into a gas station and ask the attendant for "two bucks worth of hi-test," he's sure to know you want high octane gas and can part with two dollars.

But just try to ask for "two liters of Ethyl" and you just might end up with an empty gas tank and seven or eight kittens!

In this article we want to discuss gain—the kind electronics is made of. But instead of explaining gain in textbook style (to help avoid something akin to our two liters of Ethyl misunderstanding), we think we've found a sort of black box dialect that'll help you understand electronic terms associated with gain.

Mu, beta, and gm. We know that each term describes gain. Why, then, such a variety of terms?

Can a triode have its gain described by mu, or can a FET have a beta? Exactly what do all these terms mean?

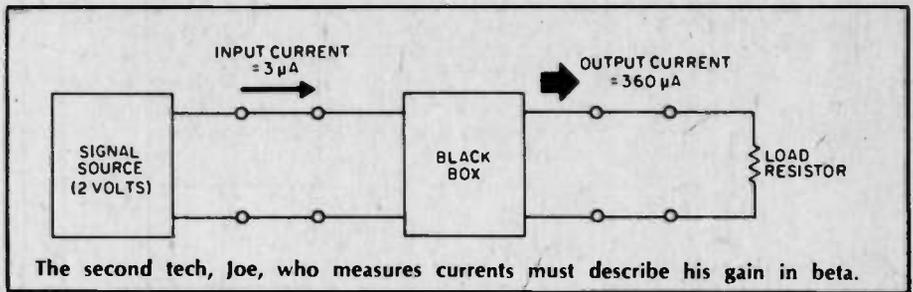
**Read On.** . . . To answer these questions let us suppose that we concealed some type of amplifying device in a black box, and sent it to an electronics lab with a request that its gain be measured. The input and output leads are brought out and identified, but the lab is not told whether the box contains a vacuum tube, an ordinary bipolar transistor, or a FET. We also supply the lab with a 2-volt signal source for the input, and give them a load resistor to be connected across the output leads.

The lab, to enhance its reputation, decides to make four independent measurements and compare the results. The entire set-up is therefore handed to the first of four lab technicians with the only instruction, "measure the gain of this box."

The first tech takes the straightforward approach and measures input signal voltage and output signal voltage as shown.

Finding that the black box has a 2-volt input and a 12-volt output, he takes the ratio of these two voltages, and obtains the gain.

$$\text{Gain} = \frac{e(\text{out})}{e(\text{in})} = \frac{12 \text{ volts}}{2 \text{ volts}} = 6$$



Since this result is the ratio of two voltages, it is the *voltage gain*, and is usually expressed by the term mu. This tech therefore reports the black box has a mu of 6.

**Joe Trys.** The entire set-up is then taken to a second technician, who, looking around his lab bench, finds that he does not have at hand any convenient way to measure voltages, but has some excellent current-measuring devices all ready to use. He therefore measures the input and output *currents* as shown.

A signal current of 3 microamperes flows into the box, he discovers, causing an output signal current of 360 microamperes. Taking the ratio of these two currents, he obtains the *current gain*.

$$\begin{aligned} \text{Gain} &= \frac{i(\text{out})}{i(\text{in})} \\ &= \frac{360 \text{ microamps}}{3 \text{ microamps}} \\ &= 120 \end{aligned}$$

Since current gain is usually expressed by the term beta, the tech reports to his boss that the black box has a beta of 120.

Now, remember that these two numbers, a mu (voltage gain) of 6 and a beta (current gain) of 120, are measurements made on the same amplifier, with the same signal source and the same load. The only difference between the two measurements is that voltages were measured in one case, and currents in the other.

This same setup now is passed to a third technician, who, with a mischievous glint in his eye, proceeds to measure the output *voltage* and the input

*current*. He gets yet another figure for gain.

$$\begin{aligned} \text{Gain} &= \frac{e(\text{out})}{i(\text{in})} \\ &= \frac{12 \text{ volts}}{3 \text{ microamps}} \\ &= 4 \text{ megohms} \end{aligned}$$

**Fred's Folly?** Hold on there! Gain—in megohms? Yes, indeed! Ohm's law states very clearly that when volts are divided by amperes, the result is in ohms. It's perfectly legitimate to express the gain of an amplifier in ohms, or kilohms, or megohms; whatever the ratio of its output voltage to its input current yields.

Does this mean that the amplifier can be replaced by a 4-megohm resistor? No, for the 4 megohms defined by the ratio is a special kind of resistance, called a transfer resistance, meaning that it indicates the voltage transferred to the output when a certain current is applied to the input. It is sometimes shortened to transresistance and is also called *mutual resistance* ( $r_m$ ).

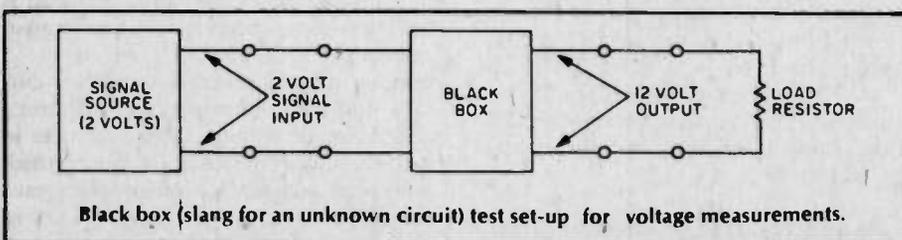
This way of expressing gain is a bit unusual, which accounts for the mischievous glint in the third tech's eye. It is not found among the more common gain expressions given in the first paragraphs. Nonetheless, it is a perfectly valid way to describe an amplifier's gain.

**Sam's System.** The fourth technician, who now inherits the black box for the final measurement, has seen the stir created by his colleague's mixed measurement of current and voltage, so he decides to try for another flurry, only this time by reversing the measurements, getting readings for *output* current and *input* voltage. He obtains yet another gain measurement.

$$\text{Gain} = \frac{i(\text{out})}{e(\text{in})} = \frac{360 \text{ microamps}}{2 \text{ volts}}$$

$$\text{Gain} = 180 \text{ micromhos.}$$

This is another variation on Ohm's law. Just as volts divided by amperes



gives resistance (ohms), so the inverse (amperes divided by volts) gives conductance—the inverse (reciprocal) of resistance. The unit of conductance is the mho, which is ohm spelled backwards.

The special conductance used to describe an amplifier's gain is called transfer conductance, for the same type of reason given above for transfer resistance. Similarly, shortened forms include *transconductance* and *mutual conductance*, symbolized as *gm*.

So the fourth and final measurement on the black box yields an answer of 180 micromhos for the gain. In summary then, four different measurements on the same amplifier gave the following differing figures for gain.

*mu* (voltage gain) = 6  
*beta* (current gain) = 120  
*RM* (mutual resistance) = 4 megohms  
*gm* (mutual conductance) = 180 micromhos

Whatever device is in the box, it certainly can use any of the familiar gain expressions—*mu*, *beta*, or *gm*—to characterize its gain and, moreover, can even have its gain stated by the less familiar *RM*.

**What's Relevant.** In general, any device—triode, pentode, transistor, or FET—could theoretically use any of these four terms to state its ability to provide gain. But, in practice, the technique chosen to measure gain depends on how relevant one method may be over another.

For example, a triode's negative-biased grid, sticking into a stream of electrons in a vacuum, draws almost no current, and even that tiny current it does draw doesn't mean much in determining the triode's output. Since the input current is so tiny, and the output current so much larger, a triode vacuum tube's *beta* (current gain) is extremely large, but it is difficult to measure, it would vary widely from tube to tube, and doesn't mean much anyway when it comes to practical gain calculations.

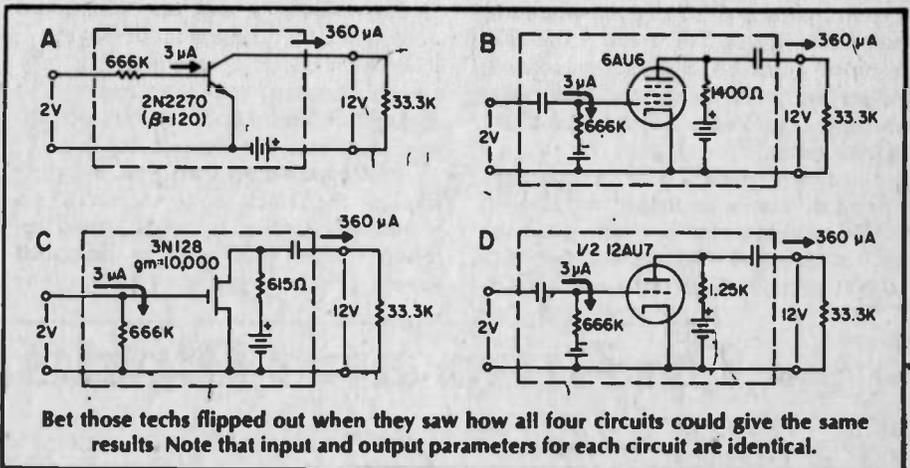
On the other hand, the voltage on the grid is very easy to measure and is very meaningful in controlling the out-

put. So, the triode's input signal is always stated in terms of voltage.

Similarly, the pentode's grid and the FET's gate draw so little current that their *betas* would be astronomical but meaningless, while, like the triode, their grid or gate voltages are easily measured and relate closely to the output.

DEVICE	INPUT PARAMETER
Triode	Voltage
Pentode	Voltage
Transistor	Current
FET	Voltage

DEVICE	INPUT	OUTPUT	OUT/IN	WHICH IS
Triode	Voltage	Voltage	Volts/Volts	<i>mu</i>
Triode	Voltage	Current	Current/Volts	<i>gm</i>
Pentode	Voltage	Current	Current/Volts	<i>gm</i>
Transistor	Current	Current	Current/Current	<i>beta</i>
FET	Voltage	Current	Current/Volts	<i>gm</i>



**Something Different.** The ordinary bipolar transistor, however, is quite a different animal. Instead of having a grid in a vacuum or an insulated gate, it has an input consisting of a turned-on PN junction—the base-to-emitter diode.

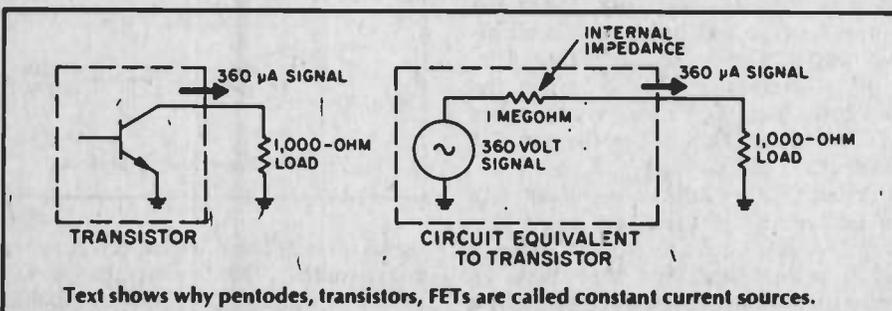
This diode is almost a short circuit for signals; input voltages are therefore very hard to measure, never go above approximately 0.6 volt, and bear a very unwieldy relationship to the transistor's output. However, this turned-on diode draws an appreciable current which also happens to be the parameter that controls the transistor's output. Therefore, the quantity most conveniently measured at the bipolar transistor's input is *current*.

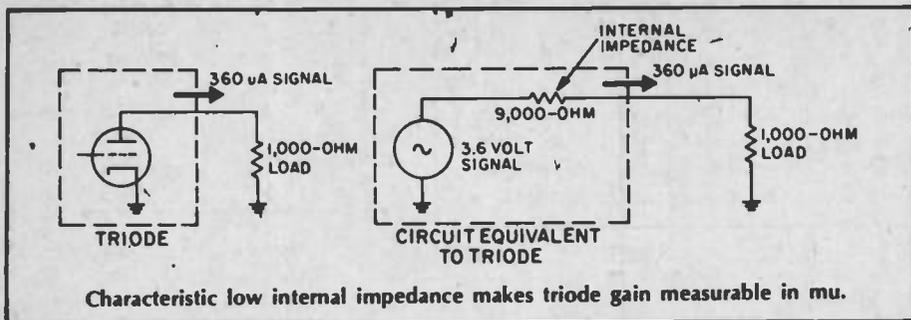
The output circuits of these devices are the other half of the story. All of

them certainly produce current, but three of them—the pentode, transistor, and FET—produce it in a most unusual way: the same way a very high voltage and a very large resistor combine to produce current in the following example.

Notice that it would make almost no difference in the 360-microampere output signal current if we dropped the 1,000-ohm load down to 10 ohms, because the total resistance (internal + load) would drop from 1,001,000 ohms to 1,000,000 ohms—an imperceptible change. An upward change of load from 1,000 ohms to, say, 10,000 ohms also has very little effect on the 360-microampere output current, because the huge resistance inside the device overwhelms the relatively small change contributed by the load. So a device that has a large internal resistance will pump out the same unvarying current, almost without regard for the value of the external load, as long as the load is much smaller than the internal resistance.

Such devices are called constant-current sources, and pentodes, transistors, and FETs behave in just this manner to provide an output signal current which is not influenced by typical load resistors. The current from these devices is,





therefore, the logical parameter to be measured.

The triode, on the other hand, is not quite so single-minded about producing current as are FETs, pentodes, and transistors. Instead of some 1,000,000 or more ohms of internal impedance, triodes run from as low as 5,000 ohms equivalent resistance to approximately 50,000 ohms.

Since the triode is not a constant-current device (note that it makes quite a difference in the total resistance if the load is changed from 1,000 ohms to 10,000 ohms), we normally try to meas-

ure both current and voltage in characterizing triode gains.

This accounts for the association of beta with transistors,  $g_m$  with pentodes, triodes, and FETs, and mu with triodes alone. Note that there is no device available which is best characterized as producing an output voltage in response to an input current; hence  $r_m$  does not appear as a relevant item in the list.

**The Unanswered Question.** So, what was in the black box? Actually, no present-day device, by itself, could respond to the four tests as described above. For example, a vacuum tube

would not draw in its grid circuit the 3 microamperes measured by the second and third techs, while a transistor would be destroyed if we attempted to impress 2 volts directly across its input, as measured by the first and fourth techs. Therefore, the box's contents must have included some other components. In fact, any of the four circuits shown would give the four techs the measurements they reported. However, only the transistor circuit will work with both AC and DC inputs. Coupling capacitors are used in the remaining three circuits, so only AC measurements are possible with these.

So we can conclude that mu, beta, and  $g_m$  (and the unfamiliar  $r_m$  as well) all describe gain in their own way and can, in general, describe any amplifier's gain. The individual peculiarities of tubes and transistors cause us to prefer certain terms for certain devices, and understanding what these terms are trying to tell us is very important as we learn to speak the language of gain. ■

## Op Amp and Diode Circuits

□ THERE ARE A GREAT number of circuits in use which involve severe compromise because of the non-ideal characteristics of the diode. This article presents a variety of circuits in which the operational amplifier and diode are used together, so the amplifier can extract ideal performance from the diode.

A basic silicon or germanium diode has several outstanding imperfections. There is an effective voltage offset. The voltage offset varies from diode to diode. This offset is strongly affected by temperature. The diode has a nonlinear volt-current characteristic. The diode exhibits a resistance which varies with temperature.

Figure 1 illustrates all of these characteristics. Note that when the forward voltage is below a certain level, but greater than zero, the diode does not conduct. After the diode begins to conduct, it can be seen that the conduction is nonlinear. This is shown by the curvature of the lines on the graph. Curve No. 1 is a relative representation of a diode at a low temperature while curves 2 and 3 represent the conduction at higher and higher temperatures. The fact that the curves are not vertical just points out that there is a certain amount of resistance inherent in the diode at all times. As the diode current increases we see the curve becomes more and more vertical in nature, which means the resistance of the diode is dropping.

**Get Together.** When we combine a diode circuit with an operational amplifier, we do it in a manner that makes the operation of the amplifier sensitive to imperfections in the diode. Generally speaking, we can say that the diode imperfections are reduced by an amount equal to the "open loop" gain of the amplifier. This gain, for practically all operational amplifiers, is 10,000 times or greater. Thus, our diode in conjunction with an op-amp will exhibit offset voltage only 1/10,000, or less, as great as normal!

Figure 2 shows two circuits in which a diode has been incorporated. These circuits are the same except for the routing of the feedback loop (any circuit path from the output to an input; here a piece of wire from terminal 6 to terminal 2). Circuit 2a might as well have never been built! The diode here is not contained within the path of the feedback to the inverting input, hence the output voltage will be subject to *all diode errors* in their full magnitude. Circuit 2b contains the diode *within* the feedback loop. In other words, there will be no feedback unless the diode is involved.

**Read On.** For sake of simplicity, let's assume that the amplifiers have zero offset voltage and are perfect in every other respect and that they have an open loop, or maximum gain, of 10,000. Circuit 2a is connected with the output

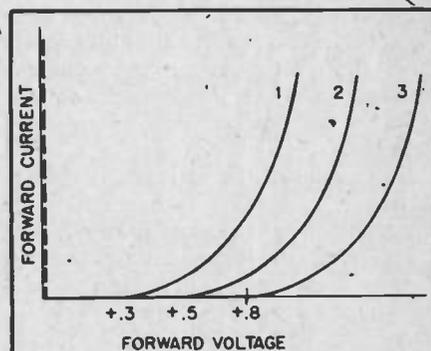


Fig. 1. Current change is tied to temperature and voltage.

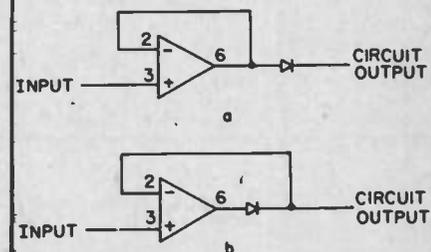


Fig. 2. From imperfect to perfect.

wired directly back to the inverting input terminal. This means that it will exhibit a voltage gain, not of 10,000, but of *one* all the time. If we apply an

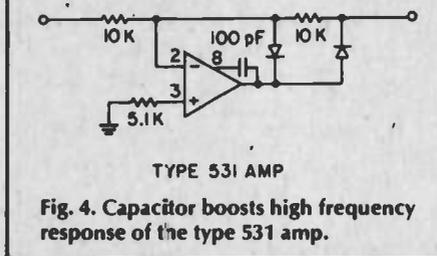
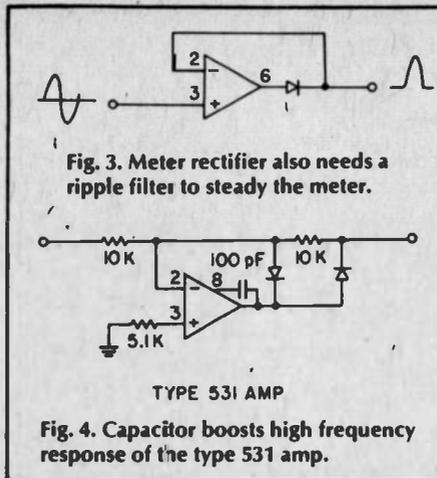
input voltage to terminal 3 this exact voltage will appear at the output terminal of the *op-amp*, pin 6, and will exactly follow input excursions (within the limits of the amplifier). However, the voltage present at the output terminal (to the right of the diode), will be altered by the voltage drop of the diode plus all its other inherent characteristics. Of course, this applies only to a positive voltage. A negative output at pin 6 will never be passed to the circuit output terminal because the diode will be turned off.

The circuit of Fig. 2b operates differently. This amplifier does not always operate with a voltage gain of one. Any time the voltage at pin 6 is below the turn-on level of the diode (approximately +0.5 volts for silicon) the diode will be "open" thereby disconnecting the feedback loop from pin 6 to pin 2. In this state we have an operational amplifier which is operating at its maximum gain of 10,000. This means that any input voltage below about +0.5 which appears on input pin 3 should be amplified 10,000 times.

Keeping in mind that at room temperature a silicon diode will begin to conduct at about +0.5 volts, let's compare the voltages that appear at the circuit output, when an input voltage goes from 0 toward a positive value. In circuit 2a we saw that the voltage at pin 6 follows the input voltage exactly. As the input (and output) begins to go positive from a 0 value, no voltage appears at the circuit output terminals until the pin 6 output has reached a level sufficient to start the diode conducting. Regardless of what value of output voltage appears at pin 6, the circuit output will always be (1) less by the diode drop and (2) nonlinear.

**Continuing.** Now let's start with zero volts at the input of circuit 2b and increase it in a positive direction. Any positive input value that is very small will be amplified 10,000 times. Hence, when the input voltage has reached only 0.05 millivolts the output at pin 6 will be 0.5 volts and the diode will begin to conduct. In other words, in circuit 2b an output voltage begins to appear at the circuit terminals immediately, and in circuit 2a, only after the input has reached +0.5 volts. For this reason, circuit 2b is sometimes referred to as a "perfect" rectifier. The output curve of this circuit is illustrated by the dotted lines in Fig. 1.

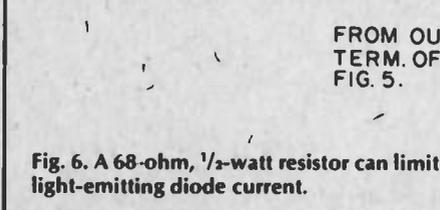
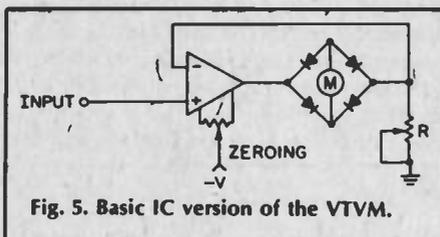
**Applications for Experimenters.** Try a simple half-wave rectifier. If negative output from Fig. 3 is desired, just reverse the diode. This circuit makes an excellent meter rectifier since a linear scale can be used on the meter. The



meter can even be connected from output to ground through a multiplier resistor for higher additional ranges. This circuit can be used quite effectively for low frequency signals.

Figure 4 shows a circuit that will give excellent high frequency response and precision rectification. This circuit is useful for comparing the voltage at the input and output of high quality audio amplifiers.

The circuit in Fig. 5 is deceptively simple looking. This metering circuit will read AC voltage and + or - DC inputs without any "lead swapping." On DC, the bridge always routes the DC current through the meter in the same direction, regardless of the input polarity. The circuit operates best using low current meters, particularly on AC. Variable resistor R is adjusted to give the desired full-scale reading. This circuit will accept input voltages of up to ten volts peak if a  $\pm 15$  volts is used for the power supply. Higher input voltages should be divided down with a divider. Any type of op-amp can be used here, but for high frequency operation an amplifier such as the 709-type will give good wide-band operation. Just remember, some types, such as the 709, will have to be "compensated"



sated" according to the manufacturers instructions. If DC-only or AC-only operation is desired, a low pass RC network or a high pass RC network can be inserted in the input lead. This circuit also makes an excellent high impedance meter similar to the vacuum tube or FET voltmeter. The input impedance is extremely high permitting it to be used with a standard 10-megohm voltage divider. For greater accuracy when measuring very small voltages, a "zeroing" pot should be used with the op-amp as shown. This pot is not necessary when handling only higher voltages.

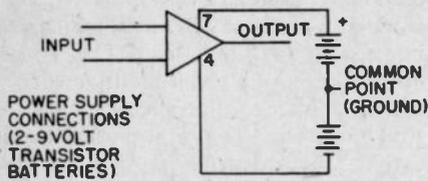
Figure 6 shows a polarity indicator that can be used with the previous circuit to indicate a "negative" input. Limit LED current to 20 mA with a series resistor.

**Hold that Sample.** A diode can also be used with an op-amp to read true peak voltage. Peak voltages of pulses and other non-sinusoidal waveforms are not accurately measured by conventional circuits. Figure 7 shows the diagram of a simple, positive-peak-reading circuit. A positive input to IC1 will cause its output (at the "top" of C) to go positive by an amount equal to the peak of the input. The capacitor C "stores" this value.

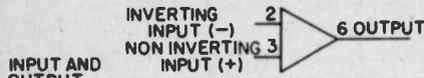
When the input voltage starts to go less positive than its most positive value, the op-amp output immediately swings negative. Diode D2 is now reverse-biased, and the capacitor with the peak value stored in it is isolated from the IC1 output. Also, IC2, connected as a voltage follower, exhibits an extremely high input impedance to the capacitor, so it will lose minimum charge between positive peaks of the input. This IC2 can also furnish enough power to drive a meter or other circuitry. The charge on C is "refreshed" by each positive excursion of the input waveform. D1 conducts during negative excursions and prevents the output of IC1 from "slewing" all the way to the "minus" power supply value.

This extreme excursion would result in a slower response of IC1 to positive peaks. For short-duration waveforms, the IC1 should have a high slew rate. A 709 or equivalent amplifier can be used here for greatest accuracy of fast waveforms. Note that IC2 only handles relatively slow inputs and does not need

## OP AMP CONNECTION TIPS



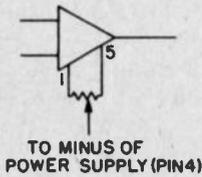
531, 709, 741



INPUT AND OUTPUT CONNECTIONS

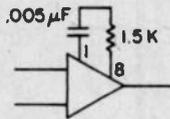
531, 709, 741

OFFSET REDUCTION CONNECTION

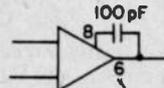


531, 741

FREQUENCY COMPENSATION CONNECTION



709 (REQUIRED)

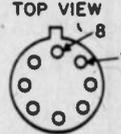


531 (OPTIONAL)



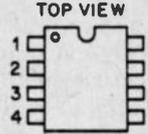
741 (NONE)

METAL "CAN" TOP VIEW



531, 709, 741

MINI DIP TOP VIEW



531, 741

to have a high slew rate. For best storage, C should be of a very low leakage type capacitor (any of the "poly" types).

When making current measurements, the internal resistance of the meter is important because it adds to the circuit resistance; that tends to alter the circuit current while the measurement is being made. Ideally, then, a current meter with absolutely zero resistance is needed for maximum accuracy. This stipulation is a bit hard to meet, especially in the case of an AC current meter.

**More Current Facts.** Figure 8 presents a "zero drop" AC current meter. In this circuit, the op-amp supplies enough current to the meter to keep its inverting input at the exact same potential as its non-inverting input. By keeping these two terminals at the same potential, they are, in effect, shorted together!

The full-scale current reading will be equal to the FS of the meter itself. The meter can be shunted to increase the range; however, it must be kept in mind that the op-amp has to supply all the current flow. This will limit the full-

scale range to that of the op-amp.

Current multiplication is easily accomplished by adding resistors as shown in Fig. 8. This scheme will allow much smaller currents to be measured than the full-scale value of the meter. In this circuit, the current through the meter is greater by the rates ( $R1/R2$ ) than the current being measured. These resistors directly control the gain of the op-amp so it can be set to any fixed amount of gain; 10 would allow a 1 mA meter movement to measure 0.1 mA full scale.

This current meter is not limited to AC measurement but will respond equally well to positive or negative DC currents. The polarity indicator of Fig. 6 can be used with this circuit if desired.

An important aspect of the preceding current measuring circuits is that their input terminals cannot effectively be "shunted" to extend the range of measurement as with a standard all-mechanical meter. As mentioned before these terminals are effectively shorted together; therefore, a shunt would accomplish no purpose.

A rather unusual circuit, which, at

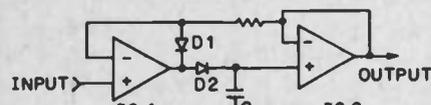


Fig. 7. Some call it "sample and hold."

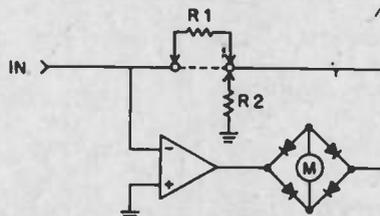


Fig. 8. Current multiplication means greater overall meter sensitivity.

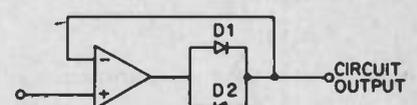


Fig. 9. A useless circuit?

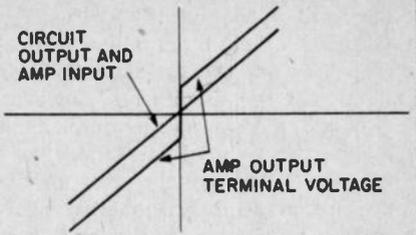


Fig. 10. Basis for a "zero crossing" detector is shown in graph form.

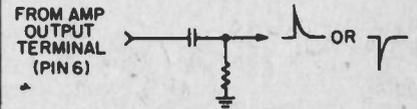


Fig. 11. Differentiator bi-polar output.

first glance, might appear to be useless is shown in Fig. 9. According to the previous analysis of how the amplifier overcomes the diode offset voltage, the two diodes (back-to-back in this circuit) would appear to be a plain piece of wire! With a positive DC output, D1 will conduct and the voltage will appear in its entirety at the output terminal of the circuit. Likewise, a negative DC voltage will be passed through D2 to the output terminal unabated. However, you can see that the amplifier output voltage jumps suddenly at the zero crossing of the input voltage as shown in Fig. 10.

With the addition of a differentiator to the amplifier output terminal, a voltage pulse will be generated whenever zero crossing of the input occurs. These pulses will indicate, by their polarity, the direction of the crossing (from plus to minus, or a minus to plus transition).

We have presented some problems, solutions, and simple experiments associated with the combined use of diodes and operational amplifiers. Some circuits such as the AC meter can stand alone and be useful while the circuit of Fig. 9 and Fig. 11 can be used to gather information in larger systems such as automatic checkout devices or industrial process control. We hope it has added something more to your knowledge of the broad electronic spectrum.

# All About Crystals

□ CAN YOU IMAGINE the chaos on the AM broadcast band if transmitters drifted as much as those inexpensive table radios? The broadcast station engineer must keep his station carrier within 20 hertz of its assigned frequency. How does he do it? What about the CBER unable to contact his base station with an unstable, super-regen walkie-talkie. Lost calls don't often happen to a CBER who can keep his receiver frequency right on the assigned channel center.

This and much more is, of course, all done with a little help from a very basic material, the quartz crystal. It is the single component that serves to fill a basic requirement for precision frequency control. Quartz crystals not only fix the frequency of radio transmitters (from CB installations to multi-kilowatt-broadcast installations), but also establish the frequency of timing pulses in many modern computers. In addition, they can provide the exceptional selectivity required to generate and receive single-sideband signals in today's crowded radio spectrum. Yet this list merely touches upon the many uses of quartz crystals. No exhaustive list has ever been compiled.

**A Real Gem.** This quiet controller is a substance surrounded by paradox. While quartz composes more than a third of the Earth's crust, it was one of the three most strategic minerals during World War II. And despite its plentitude, several semiprecious gems (including agate and onyx) are composed only of quartz.

Unfortunately, quartz exercises its control in only a relative manner. When it's misused, the control can easily be lost. For this reason, if you use it in any way—either in your CB rig, your ham station, or your SWL receiver—you should become acquainted with the way in which this quiet controller functions. Only then can you be sure of obtaining its maximum benefits.

**What Is It?** One of the best starting points for a study of quartz crystals is to examine quartz itself. The mineral, silicon dioxide ( $\text{SiO}_2$ ), occurs in two broad groups of mineral forms: crystalline and non-crystalline. Only the large crystalline form of quartz is of use as a controller.

The crystalline group has many varieties, one of which is common sand. The variety which is used for control, however, is a large, single crystal, usually six-sided. The leading source of this type of quartz is Brazil. However, it also is found in Arkansas. Attempts have been made to produce quartz crys-

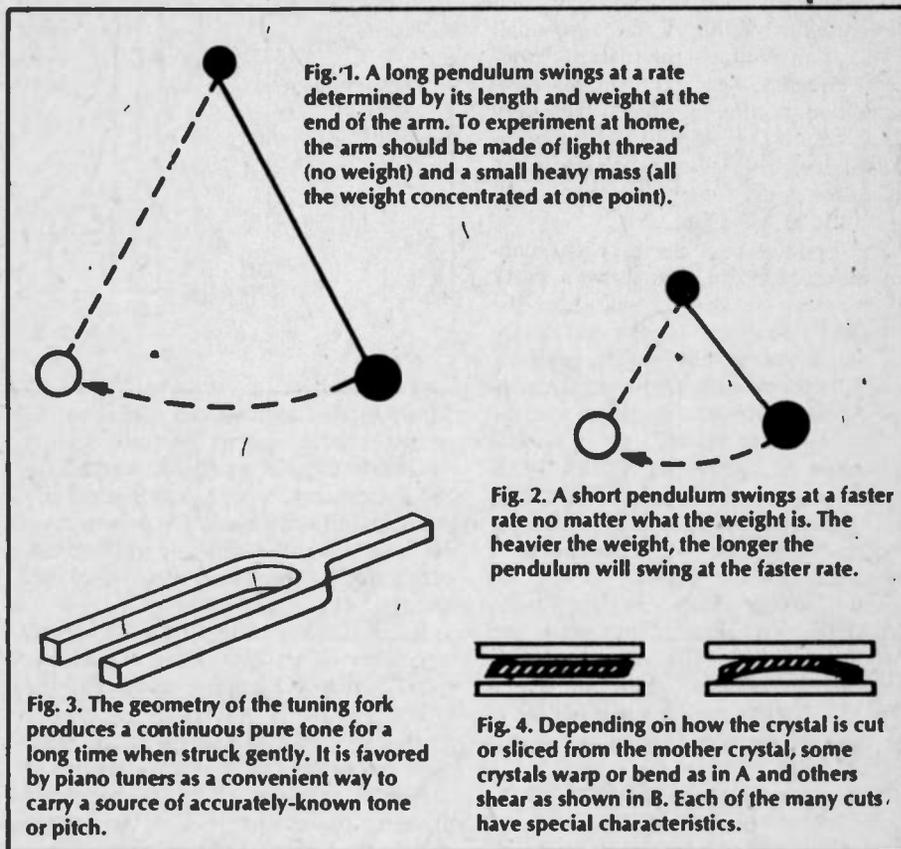


Fig. 1. A long pendulum swings at a rate determined by its length and weight at the end of the arm. To experiment at home, the arm should be made of light thread (no weight) and a small heavy mass (all the weight concentrated at one point).

Fig. 2. A short pendulum swings at a faster rate no matter what the weight is. The heavier the weight, the longer the pendulum will swing at the faster rate.

Fig. 3. The geometry of the tuning fork produces a continuous pure tone for a long time when struck gently. It is favored by piano tuners as a convenient way to carry a source of accurately-known tone or pitch.

Fig. 4. Depending on how the crystal is cut or sliced from the mother crystal, some crystals warp or bend as in A and others shear as shown in B. Each of the many cuts have special characteristics.

tals in the laboratory, but to date synthetic quartz has not proven practical for general use.

A property of crystalline quartz, the one which makes it of special use for control, is known as *piezoelectricity*. Many other crystals, both natural and synthetic, also have this property. However, none of them also have the hardness of quartz. To see why hardness and the piezoelectric property, when combined, make quartz so important, we must take a slight detour and briefly examine the idea of resonance and resonators.

**Resonators and Resonance.** As physicists developed the science of radio (the basis for modern electronics), they borrowed the acoustic notion of resonance and applied it to electrical circuits where it shapes electrical waves in a manner similar to an acoustic resonator. For instance, both coils and capacitors store energy and can be connected as a resonator (more often termed a resonant circuit). When AC of appropriate frequency is applied to the resonator, special things happen.

**Pendulum Demonstrates.** The principle involved is identical to that of a pendulum, which is itself a resonator closely similar in operation to our quartz crystals. To try it you can hang

a pendulum of any arbitrary length (Fig. 1), start it swinging, then time its *period*—one complete swing or cycle. The number of such swings accomplished in exactly one second is the *natural* or *resonant* frequency of the pendulum in cycles per second (hertz).

You can, by experiment, prove that the frequency at which the pendulum swings or oscillates is determined by the length of the pendulum. The shorter the pendulum (Fig. 2), the faster it swings (the greater the frequency). The weight of the pendulum has no effect on frequency, but has a marked effect upon the length of time the pendulum will swing after a single initial push—the heavier the pendulum, the greater the number of cycles.

**A Real Swinger.** Once the pendulum begins to swing, very little effort is required to keep it swinging. Only a tiny push is needed each cycle, provided that the push is always applied just as the pendulum begins to move away from the pushing point. If the push is given too soon, it will interfere with the swinging and actually cause the swing to stop sooner than it would without added energy; while if too late, added push will have virtually no effect at all. It is this principle—a tiny push at exactly the right time interval—which makes

a resonator sustain sound or AC waves. You can prove it with the pendulum by first determining the resonant frequency of a pendulum, then stopping it so that it is completely still. A series of small pushes, delivered at the natural resonant frequency, (each too tiny to have more than a minute effect) will very rapidly cause the pendulum to swing to its full arc again. Pushes of the same strength at any other frequency will have little or no effect.

The pendulum is an excellent control mechanism for regulating a clock to keep time to the second, since the resonant frequency of the pendulum can readily be adjusted to be precisely one cycle per second. However, for control of audio frequencies from tens of hertz (cycles per second) up to tens of thousands of cycles per second (kilohertz), or for radio frequencies ranging up to hundreds of millions of cycles per second (megahertz), the pendulum is too cumbersome a device.

**The Tuning Fork.** In the audio range, the equivalent of the pendulum is the tuning fork. This is an extremely elongated U-shaped piece of metal (Fig. 3), usually with a small handle at the base. When struck, it emits a single musical tone.

The operating principle is exactly the same as the pendulum. Each of the arms or tines of the fork corresponds to a pendulum arm. But here the arms are extremely short and much heavier in proportion to their size than the pendulum. (The shorter the arms of a tuning fork, the higher the resonant frequency in the audio range.) This greatly increased mass causes them to oscillate much longer when struck.

Not all tuning forks operate precisely like pendulums. The pendulum principle is based on a *flexing* of the arm upon its long dimension. While this is the most common operation, the fork may flex along any dimension.

It's even possible for a single, solid resonator such as a tuning fork to flex along several dimensions at once. A main part of the design of a good tuning fork is to insure that only a single dimension flexes or, in the language of resonators, only a single mode is excited.

**Area Too.** There's no requirement that the resonator be a completely solid substance. A mass of air, suitably enclosed, forms a resonator. This is the resonator that works on a classic guitar or violin. Here, single-mode operation is distinctly *not* desired. Instead, multiple-mode operation is encouraged so that all musical tones within the range of the instrument will be reinforced equally.

Now, with the principles of resonance

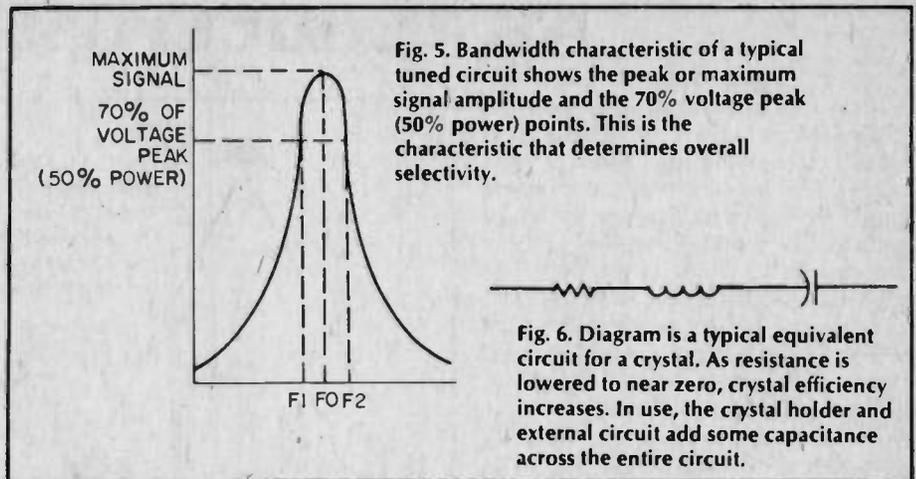


Fig. 5. Bandwidth characteristic of a typical tuned circuit shows the peak or maximum signal amplitude and the 70% voltage peak (50% power) points. This is the characteristic that determines overall selectivity.



Fig. 6. Diagram is a typical equivalent circuit for a crystal. As resistance is lowered to near zero, crystal efficiency increases. In use, the crystal holder and external circuit add some capacitance across the entire circuit.

firmly established, we can return to the quartz crystal and its operation.

**Quartz Crystal as Resonators.** Like the tuning fork or, for that matter, any sufficiently hard object, the quartz crystal is capable of oscillation when struck physically or in some other way excited.

But unlike the tuning fork, or indeed any other object except for certain extremely recent synthetic materials, the quartz crystal is not only sufficiently hard to oscillate at one or more resonant frequencies, but is piezoelectric.

**Piezoelectricity.** The piezoelectric property means simply that the crystal generates an electric voltage when physically stressed or, on the other hand, will be physically deformed when subjected to a voltage (see Fig. 4). Other familiar objects making use of piezoelectricity include crystal and ceramic microphone elements and phonograph cartridges.

This virtually unique combination of properties (sufficient hardness for oscillation and piezoelectricity) found in quartz crystals, makes it possible to provide the initial push to the crystal by impressing a voltage across it. To provide the subsequent regular pushes, a voltage can be applied at appropriate instants.

**Quality Factor.** Almost any discussion of resonance and resonant circuits (or for that matter, inductance) eventually gets to a rather sticky subject labelled in the earliest days of radio as *quality factor* but now known universally as *Q*.

As used in radio and electronics, *Q* is usually defined by other means. Some of the definitions put forth at various times and places include:

- The ratio of resistance to reactance in a coil.
- The ratio of capacitive reactance in a resonant circuit to the load resistance.
- The impedance multiplication factor, and others even more confusing-

ly worded.

All, however, come out in the end to be identical to the definitions cited above: The *Q* of a resonator is the ratio of the energy stored per cycle to the energy lost per cycle.

In a resonator, high *Q* is desirable. *Q* is a measure of this energy loss. The less energy lost, the greater the *Q* of the circuit.

Not so obvious (and rather difficult to prove without going into mathematics) are some of the other effects of *Q*. A resonant circuit is never completely selective; frequencies which are near resonance but not precisely equal to the resonant frequency pass through also!

**An Interesting Fraction.** The greater the *Q*, the narrower the band of frequencies which can affect the resonator. Specifically, the so-called half-power bandwidth (Fig. 5) of a resonator (that band in which signals are passed with half or more of the power possessed by signals at the exact resonant frequency) is expressible by the fraction  $F_0/Q$ , where  $F_0$  is the resonant frequency and *Q* is the circuit *Q*. Thus a 455 kHz resonant circuit with a *Q* of 100 will have a half-power bandwidth of 455/100 kHz, or 4.55 kHz. This relation is an approximation valid only for single-tuned circuits; more complex circuits are beyond this basic discussion.

**The *Q* of Quartz Crystals.** When we talk of the *Q* of conventional resonant circuits composed of coils and capacitors, a figure of 100 is usually taken as denoting very good performance and *Q* values above 300 are generally considered to be very rare.

The *Q* of a quartz crystal, however, is much higher. Values from 25,000 to 50,000 are not unheard of.

The extremely high *Q* makes the crystal a much more selective resonator than can be achieved with L-C circuitry. At 455 kHz, for example, the bandwidth will be between 10 and 20 hertz

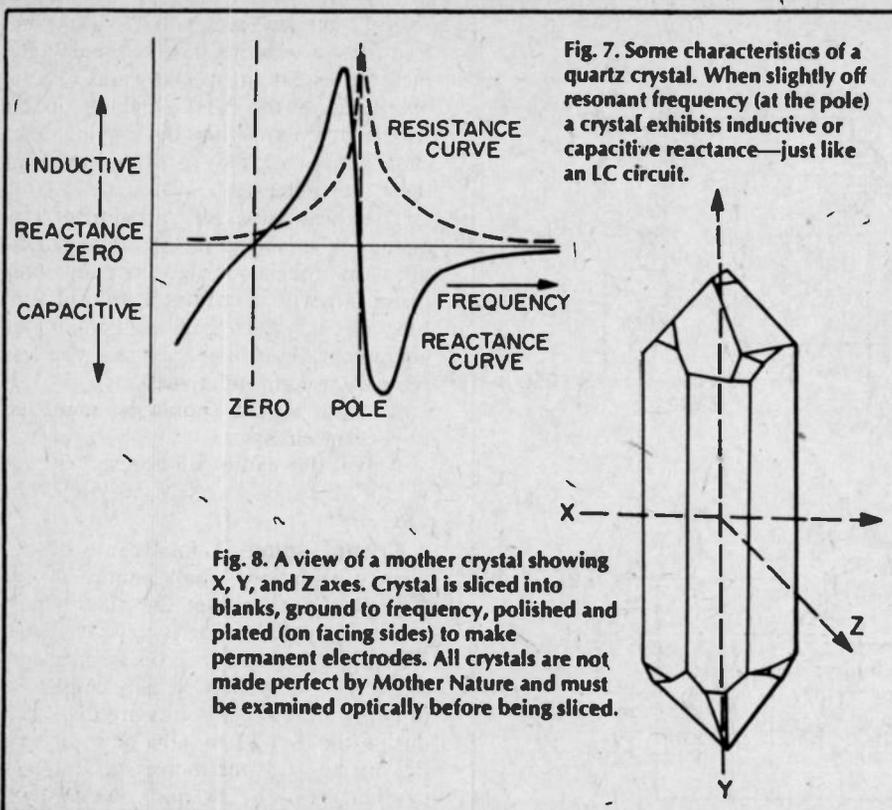


Fig. 7. Some characteristics of a quartz crystal. When slightly off resonant frequency (at the pole) a crystal exhibits inductive or capacitive reactance—just like an LC circuit.

Fig. 8. A view of a mother crystal showing X, Y, and Z axes. Crystal is sliced into blanks, ground to frequency, polished and plated (on facing sides) to make permanent electrodes. All crystals are not made perfect by Mother Nature and must be examined optically before being sliced.

(cycles per second) unless measures are taken to reduce  $Q$ . Even in practice (which almost never agrees with theory), 50-hertz bandwidths are common with 455-kHz crystal filters.

So far as external circuitry is concerned, the crystal appears to be exactly the same as an LC resonant circuit except for its phenomenal  $Q$  value. See Fig. 6.

At series resonance, the crystal has very low impedance. You may hear this effect referred to as a *zero* of the crystal. At parallel resonance, impedance is very high; this is sometimes called a *pole*. Fig. 7 shows a plot of *pole* and *zero* for a typical crystal. The special kind of crystal filter known as a half-lattice circuit matches the *pole* of one crystal against the *zero* of another, to produce a passband capable of splitting one sideband from a radio signal. Such filters are widely used in ham, commercial and, to a lesser extent, in CB transmitters.

When a crystal is used to control the frequency of a radio signal or provide a source of accurate timing signals, either the *pole* or the *zero* may be used. Circuits making use of the *pole* allow more simple adjustment of exact frequency, while those making use of the *zero* often feature parts economy. Later we'll examine several of each type.

**From Rock to Finished Crystal.** To perform its control functions properly, a quartz crystal requires extensive processing. The raw quartz crystal must be

sliced into plates of proper dimension, then ground to the precise size required. Each plate must be as close to precisely parallel, and as perfectly flat, as possible. The electrodes must be in proper contact with the polished plate; in many modern units, the electrodes are actually plated directly to the crystal surface, usually with gold.

The crystal plate is known as a *blank* when it is sliced from the raw crystal. The blank is cut at a precise angle with respect to the optical and electrical axes of the raw crystal, as shown in Fig. 8. Each has its own characteristics for use in specific applications. Some, notably the X- and Y- cuts, are of only historic interest. The Y- cut, one of the first types used, had a bad habit of jumping in frequency at critical temperatures. The X- cut did not jump, but still varied widely in frequency as temperature changed.

Today's crystals most frequently use the AT cut for frequencies between 500 kHz and about 6 MHz, and the BT cut for between 6 and 12 MHz. Above 12 MHz, most crystals are specially processed BT or AT cuts used in *overtone* modes. These cuts are important to crystal makers and not relevant to our layman's theory.

The blanks are cut only to approximate size. The plates are then polished to final size in optical "lapping" machines which preserve parallelism between critical surfaces. During the final stages of polishing, crystals are frequent-

ly tested against standard frequency sources to determine exact frequency of operation.

If electrodes are to be plated onto the crystal surfaces, frequency cannot be set precisely by grinding since the electrodes themselves load the crystal slightly and cause a slight decrease in operating frequencies. These crystals are ground just a trifle above their intended frequencies, and the thickness of the electrodes is varied by varying plating time to achieve precision.

**Accuracy.** The precision which can be attained in production of quartz crystals is astounding. Accuracy of  $\pm 0.001$  percent is routine, and 10-times-better accuracy is not difficult. In absolute figures, this means an error of one cycle per megahertz. In another frame of reference, a clock with the same accuracy would require more than 11 days to gain or lose a single second.

However, such accuracy can be achieved only when certain precautions are taken. For instance, the frequency of a crystal depends upon the circuit in which it is used as well as upon its manufacture. For an accuracy of  $\pm 0.005\%$  or greater, the crystal must be ground for a single specific oscillator. If  $\pm 0.001\%$  (or better) circuit accuracy is required, it must be tested in that circuit only. Thus, CB transmitters are on the narrow edge of being critical. This is why all operating manuals include a caution to use only crystals made specifically for that transmitter.

When one-part-per-million accuracy is required, not only must the crystal be ground for a single specific oscillator, but most often the oscillator circuit must then be adjusted for best operation with the crystal; this round-robin adjustment must be kept up until required accuracy is achieved. Even then, crystal aging may make readjustment necessary for the first 12 to 18 months.

**Frequency Variation—Causes and Cures.** Possible variations in frequency stem from three major causes, while cures depend entirely upon the application.

The most obvious cause of frequency variation is temperature. Like anything else, the crystal will change in size when heated and the frequency is determined by size. Certain cuts show less change with temperature than do others, but all have at least some change.

For most noncommercial applications, the heat-resistant cuts do well enough. For stringent broadcast station and critical time-signal requirements, the crystal may be enclosed in a small thermostatically-regulated oven. This assures that the steady temperature will cure one cause of frequency change.

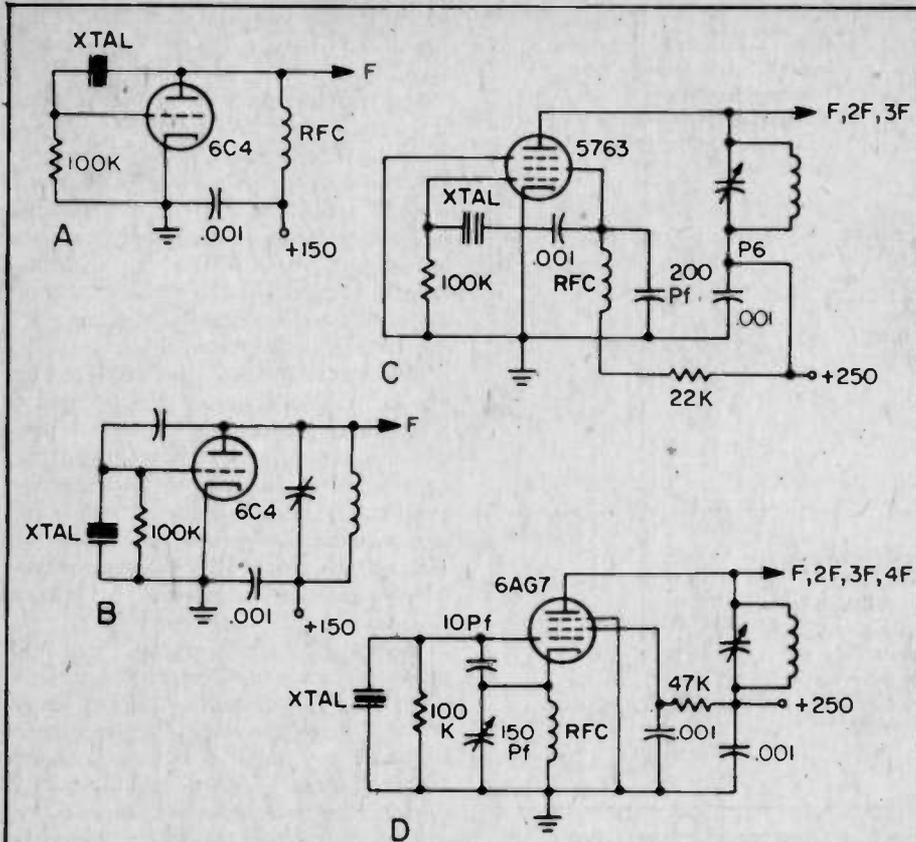


Fig. 9. The simplest crystal oscillator circuit (A) has no tuned circuits. To change frequency it is only necessary to change crystals, although a small variable capacitor across the crystal will cause some small frequency change. Miller oscillator (B) is nearly as simple as Pierce type shown in (A). Tuned circuit can pick out fundamental frequency or harmonics. Pierce electron-coupled oscillator (C) derives its feedback from the screen circuit, eliminating need for a buffer amplifier in most cases. Colpitts oscillator (D) gets its feedback from cathode circuit. Variable capacitor in the grid-cathode circuit can trim frequency.

The second well-known cause for variation of frequency is external capacitance. Some capacitance is always present because the crystal electrodes form the plates of a capacitor where the crystal itself is the dielectric. Most crystals intended for amateur use are designed to accommodate an external capacitance of 32 pF, so if external capacitance is greater than this, the marked frequency may not be correct. Crystals for commercial applications are ground to capacitance specifications for the specific equipment in which they are to be used. CB crystals also are ground for specific equipment, although many transceivers employ the 32 pF standard set for ham applications.

**Trim a Frequency.** When utmost precision is required, a small variable capacitor may be connected in parallel with the crystal and adjusted to change frequency slightly. The greater the capacitance, the lower the frequency. Changes of up to 10 kHz may be accomplished by this means, although oscillation may cease when excessive changes are attempted.

Like temperature-caused variations, frequency variations due to capacitance may be useful in special cases. Hams operating in the VHF regions obtain frequency modulation by varying load capacitance applied to the crystal in their transmitters.

The third cause for variation of frequency is a change in operating conditions in the associated circuit. This cause is more important with vacuum-tube circuits than with semiconductor equipment. As a rule, operating voltages for any vacuum-tube oscillator providing critical signals should be regulated to prevent change.

Again, this cause can be used to provide FM by deliberately varying voltages.

**Crystal Aging.** A final cause of frequency variation, small enough to be negligible in all except the most hypersensitive applications, is crystal aging. When a crystal is first processed, microscopic bits of debris remain embedded in its structure. These bits are displaced during the first 12 months or so of use, but during that time the crystal frequency changes by a few parts per million. Extreme accuracy applications must take this change into account. For most uses, though, it may be ignored.

**Using Quartz Crystals.** After all the discussion of crystal theory, it's time to examine some typical circuits. While dozens of special crystal circuits have been developed for special applications, a sampling will suffice for discussion. Fig. 9 shows four typical vacuum tube

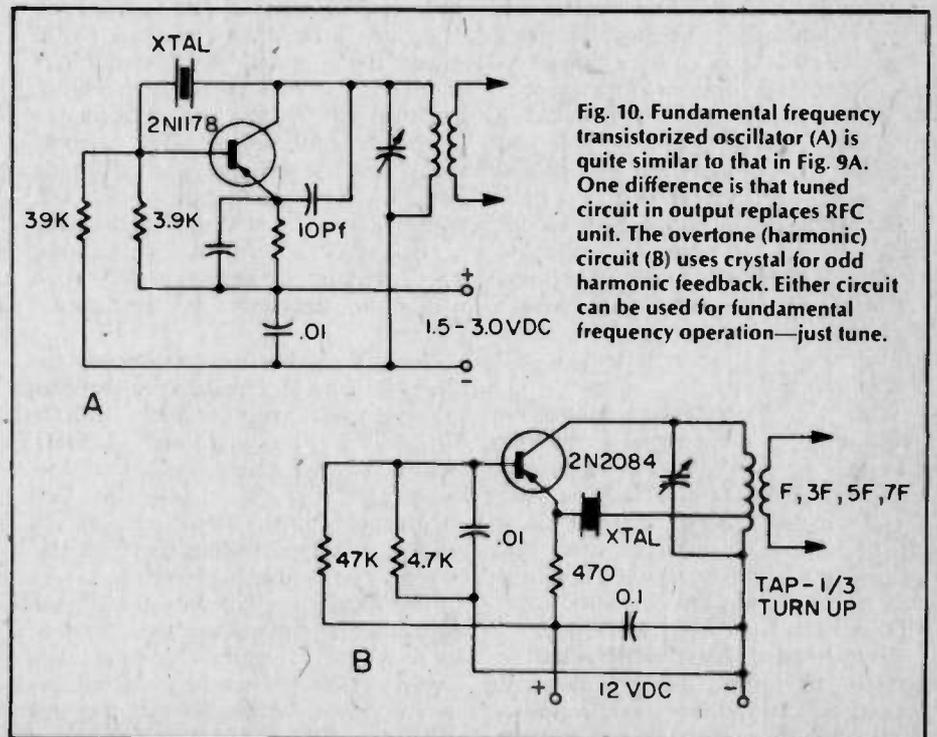


Fig. 10. Fundamental frequency transistorized oscillator (A) is quite similar to that in Fig. 9A. One difference is that tuned circuit in output replaces RFC unit. The overtone (harmonic) circuit (B) uses crystal for odd harmonic feedback. Either circuit can be used for fundamental frequency operation—just tune.

crystal oscillator circuits.

The simplest of these is the Pierce circuit, Fig. 9A. While at first glance this circuit appears to employ the crystal's *zero* to feed back energy from plate to grid, the *pole* is actually used through a mathematically-complex analysis. This circuit has one unique advantage: it contains no tuned elements and, therefore, can be used at any frequency for which a crystal is available. This makes it an excellent low-cost test signal source. The major disadvantage is that excessive current may be driven through the crystal if DC plate voltage rises above 90 or so.

The Miller oscillator (Fig. 9B) is almost as simple to construct and operate as is the Pierce and has an additional advantage of operation with overtone crystals. This is the circuit recommended by *International Crystal Mfg. Co.* for use with their overtone crystals. The capacitor shown between plate and grid is usually composed of grid-plate capacitance alone. The *pole* is used here also, energy feeds back through the grid-plate capacitance, and the *pole* selects only the parallel-resonant frequency (shorting the rest to ground).

**ECO.** The electron-coupled Pierce oscillator (Fig. 9C) is similar to the basic Pierce. The tuned circuit in the plate offers the possibility of emphasizing a harmonic—an RF choke may be used instead if freedom from tuning is desired and fundamental-frequency operation will suffice.

**GPO.** One of the most popular oscillators of all time is the Colpitts Crystal oscillator of Fig. 9D, sometimes known as the *grid-plate* oscillator. The feedback arrangement here consists of the two capacitors in the grid circuit; feedback is adjusted by means of the 150 pF variable capacitor (the greater the capacitance, the less the feedback) until reliable oscillation is obtained. Like the other three oscillators, this circuit employs the crystal *pole* frequency.

Since all four of these oscillator circuits utilize the *pole* for frequency control, exact frequency adjustment capability may be obtained by connecting a 3-30 pF trimmer capacitor in parallel with the crystal.

Crystal oscillators may, of course, be built with transistors, too. Two typical circuits are shown in Fig. 10. Feedback mechanisms differ somewhat because of the basic differences between tubes and transistors. In general, transistorized oscillators are more stable.

**As a Clock.** To use a crystal as the timing element of a clock, an oscillator identical to those shown in Figs. 9 and 10 is the starting point. Crystal frequen-

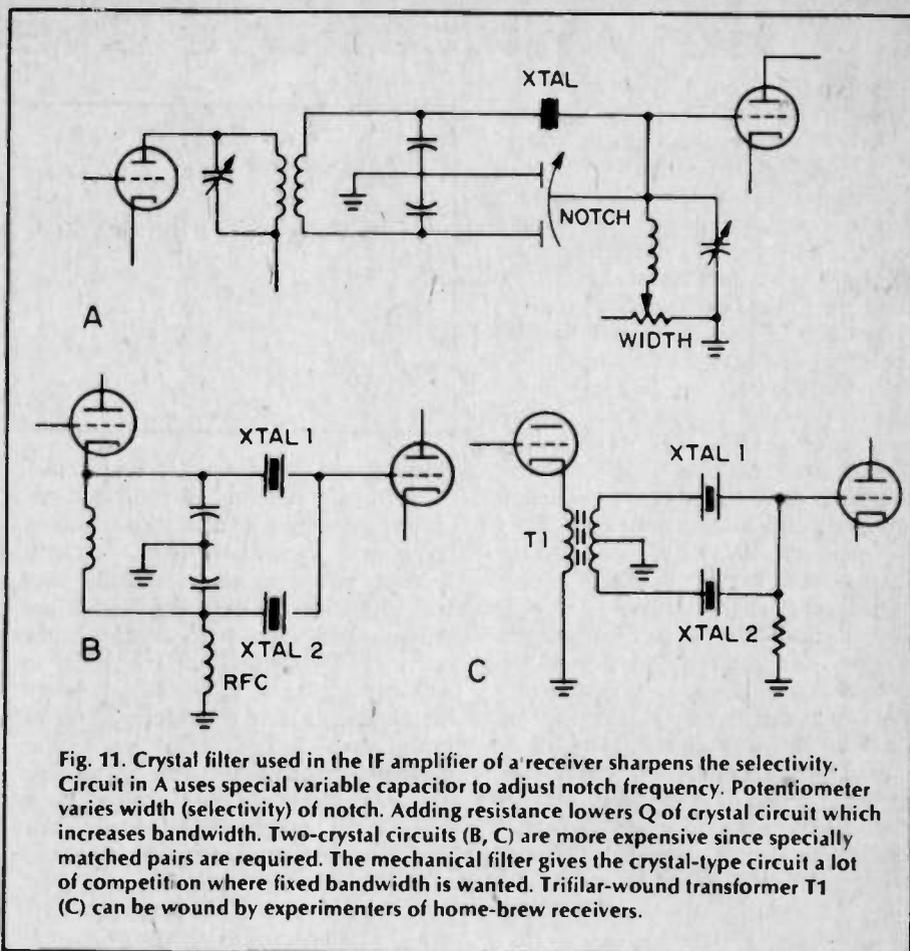


Fig. 11. Crystal filter used in the IF amplifier of a receiver sharpens the selectivity. Circuit in A uses special variable capacitor to adjust notch frequency. Potentiometer varies width (selectivity) of notch. Adding resistance lowers Q of crystal circuit which increases bandwidth. Two-crystal circuits (B, C) are more expensive since specially matched pairs are required. The mechanical filter gives the crystal-type circuit a lot of competition where fixed bandwidth is wanted. Trifilar-wound transformer T1 (C) can be wound by experimenters of home-brew receivers.

cy is chosen at a low, easily-checked value such as 100 kHz. This frequency is then divided and redivided by synchronized multivibrators to produce one-cycle-per-second pulses. These may then be counted by computer counting circuits.

In addition to being used as oscillators and timing elements, crystals find wide application in filters. Fig. 11 shows some typical crystal-filter circuits. While all circuits shown use vacuum-tubes, transistors may be substituted without modification of the filter circuits themselves if the impedances are right.

The single-crystal filter circuit shown in Fig. 11A provides spectacularly narrow reception. When the notch control is set to precisely balance out the crystal stray capacitance, the resonance curve of the filter is almost perfectly symmetrical. When the notch control is offset to one side or the other, a notch of almost infinite rejection appears in the curve (the *pole*). The width control varies effective Q of the filter.

More popular for general usage today is the band-pass filter, shown in Figs. 11B and 11C. These filters pass a band

of frequencies without excessive loss and reject all frequencies outside this band. Both circuits make use of matched crystals (X1 and X2)—the *pole* of one must match the *zero* of the other for proper results. When this condition is met, the reactances of the two crystals cancel over the passband. The passband is roughly equal to the *pole-zero* spacing.

While the two circuits shown are virtually identical in operation, the transformer-coupled circuit of Fig. 11C is easiest for home construction. The only critical component is the transformer.

It should be tightly coupled, with both halves of the secondary absolutely balanced. This is done by winding a trifilar layer of wire (wind three wires at the same time); the center wire becomes the primary winding and the remaining two wires become the secondary. The left end of one secondary half connects to the right end of the other, and this junction forms the center tap. The remaining two ends connect to the crystals. If you have sufficient patience to wind on it, a toroid form is recommended. The only absolute critical requirement of the transformer, however, is that it have no resonant frequencies. ■

# How Microwave Ovens Work

□ **MAKING WAVES!** That's the best way to describe the coming of the microwave cooking oven into America's homes. And it is a long time coming. Although not recorded in the Army's archives, a World War II tech-sergeant may have been the first person to find "consumer" microwave application when he kept his coffee warm with microwaves from an SCR-584 radar. Or was it a radio station chief engineer in the same era who kept his fried chicken warm near an FM tank circuit while Kate<sup>®</sup> Smith sang *God Bless America*? And there must have been a two-letter-call ham who sizzled a wiener on a 10-meter coil following the departure of his wife to Reno.

Different kinds of radiations can be grouped into two sets. First are the *ionizing radiations* such as X-rays, gamma rays, cosmic rays, ultra-violet rays which can cause chemical change to take place in foods with little or no temperature rise. Non-ionizing radiation will not chemically alter food, but will raise its temperature provided the radiation is of sufficient intensity. The non-ionizing radiations are radio waves, microwaves, infrared waves, and visible light, to name a few.

These waves also radiate outward from the center like the waves on the surface of the pond. They travel, however, at the speed of light, 186,282 miles per second, and carry small bundles of energy called photons which vibrate at various frequencies. Radiant waves are characterized by their wavelength and their frequency of vibration (number of complete cycles per second).  $Wavelength \times frequency = the\ speed\ of\ light$ . Thus, as the frequency increases the wavelength becomes shorter. Microwaves vibrate millions of times per second (that is, they have a very high frequency) and are, therefore, very short waves, hence the term *microwaves*.

There are two microwave frequencies in general use for microwave ovens: 915 MHz (wavelength is 32 cm or about 12.5"), and 2450 MHz (wavelength is 12 cm or about 5"). These are two of the frequencies allocated by the Federal Communications Commission (FCC) for industrial, scientific and medical use (sometimes called the ISM frequencies).

**Microwave Energy Produces Heat.** All matter is made up of atoms and molecules. Some of these molecules are electrically neutral, that is, they have no electrical charge. Carbon tetrachloride,

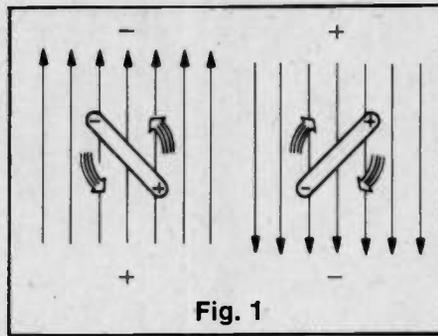


Fig. 1

benzene, and paraffin wax are examples of electrically neutral materials, and microwave energy will pass through these compounds as if they weren't present.

Most matter is *not* electrically neutral, and when an electrical field is applied the molecules tend to behave like microscopic magnets and attempt to line up with the field. See Fig. 1. When the electric field is reversed millions of times each second, these molecular magnets are unable to keep up because of other forces acting to slow them down. Such forces which restrict their molecular movement may be mechanical, such as is the case with ice or solid fats, or viscous, as is the case with a syrup like molasses. The energy of the microwaves in trying to overcome these forces is converted to heat. The material converts the energy to heat, or it might be said that the material heats itself. Another way to look at it is, consider billions of molecules rubbing elbows to keep warm.

**Microwave Properties.** So far two characteristics of properties of microwave energy have been mentioned: absorption and transmission. Like light waves, microwave energy is also reflected. See Fig. 2. Metals reflect microwaves, and since there is no absorption, metals *do not heat*. Many materials in addition to glass transmit microwaves, and again, since there is no absorption, there is no heating. Paper, china, and some plastics transmit microwaves and are therefore likely candidate materials for utensils for use in microwave ovens. The overall result is that foods can be cooked or heated in an oven on utensils which are relatively cool to the touch. Hopefully, no more burnt fingers.

**Fast Cooking.** An additional characteristic of microwave energy is its ability to penetrate deeply into food materials and to produce heat instantaneously as it penetrates. This is in sharp contrast to conventional heating, which depends on the conduction of heat from the food surface to the inside. Conduc-

tion heating can be accelerated only by increasing the surface temperature, and obviously there are limits, for who would enjoy a roast beef that is charred on the surface and raw inside?

Measurement of the temperature distribution in an item heated in a microwave oven reveals another difference. The surface will be usually cooler than an inch or so below the surface. This is caused by radiation of heat from the food surface to the cooler surroundings of the microwave oven. It does not happen in a conventional oven because the oven heat is outside the food and must slowly conduct through the food to the cooler interiors.

**Power Is Heat.** To properly develop a sense of timing in microwave cooking, it is first necessary to know how much power is available in the oven. A microwave oven is not like a conventional hot oven. There is no excess of heat available. All of the microwave energy is absorbed by the food. There is no wasted energy.

You can measure the power by converting microwave energy into heat and measuring it in a simple calorimeter. The tools needed are a Pyrex measuring cup, a thermometer, a clock, and some cold water. See Fig. 3.

Pour two measured cups of cold tap water into a Pyrex dish or cup. Note the temperature. Heat the water in the microwave oven for exactly one minute and measure the temperature again. The difference in temperature times 17.5 is the power in watts. This is the

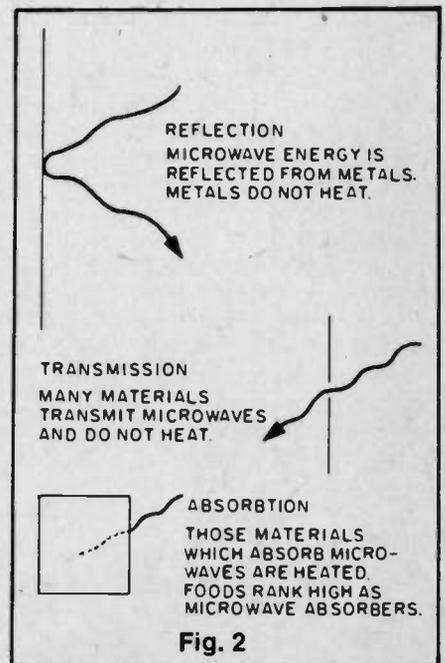
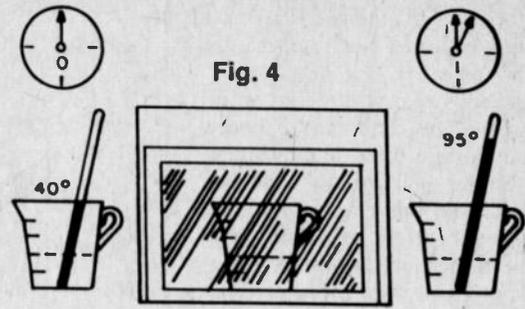
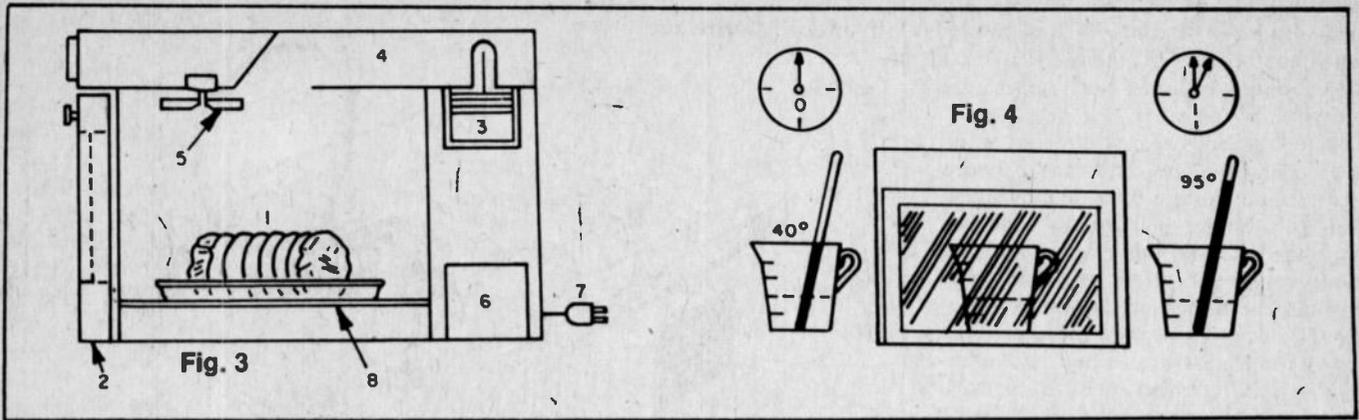


Fig. 2



amount of power generated in the oven in one hour. One-sixtieth (1/60th) of this power is available every minute.

A British thermal unit (Btu) is the amount of heat which will raise the temperature of one pound of water one degree Fahrenheit. In terms of Btu then, a one kilowatt oven puts out 57 Btu each minute, and if one pound of water were placed in the oven it should increase in temperature 57°F. in one minute.

Most foods contain moisture in varying amounts with the exception of pure fats like salad oils, shortening, and lard. Another exception is dehydrated foods which do not depend on moisture to convert microwave energy into heat. The amount of moisture in a food has a direct bearing on its heating rate in a microwave oven.

One pound of food with 50% moisture will take less time to heat to a specific temperature than one pound of food with 75% moisture. Or if both are heated for the same length of time, the food with less water will reach a higher temperature than the food consisting largely of water. One pound of water, however, will heat only half as fast as one pound of fat. The reason for this requires an explanation of the term *specific heat*. This is a measure of a material's ability to hold heat as compared to water. Water has a value of one (1.0). Fats are about 0.5. Thus water takes twice as much heat as fat to increase its temperature by one degree. Therefore in our one-kilowatt oven one pound of fat will increase in temperature by 114°F. while the same amount of water will only increase 57°F. (It should be noted that this does not apply at high temperatures where some of the water may be changed to steam. This change uses up much more energy.)

A simple formula shows the relationship between the heat required and these other factors:

"Heat required in Btu's (Q) equals weight in pounds (W) times specific

heat (s) times temperature difference in degrees Fahrenheit (F), or

$$Q = W \times s \times t$$

With this simple equation you can compute how long it would take to heat 12 ounces of canned green beans to 160°F. in a one-kilowatt microwave oven. The specific heat of most vegetables, because of their high moisture content, is around 0.9. Let us assume that the beans would be at an initial temperature of about 70°F. (off the shelf).

$$Q = 0.75 \text{ lbs.} \times 0.9 \times (160^\circ\text{F.} - 70^\circ\text{F.})$$

$$Q = 0.75 \times 0.9 \times 90$$

$$Q = 60.75 \text{ Btu}$$

Since our oven (1 kW) provided 57 Btu per minute, then the heat required (Q) divided by 57 Btu/minute would give the time, or

$$T = \frac{Q}{57} = 63 \text{ seconds}$$

How long would it take if the green beans were just removed from a 40°F. refrigerator?

When two foods at different starting temperatures are heated simultaneously in a microwave oven the colder food takes longer than the warmer food. An interesting example is that of apple pie and ice cream. With the pie at room temperature and a scoop of hard frozen ice cream on top, the pie can be warmed without melting the ice cream. About 15 seconds in a 1-kilowatt oven will do the trick.

**Inside the Microwave Oven.** Unlike most cooking appliances in which the food to be cooked is overwhelmed with heat, a microwave oven operates essentially at room temperature. In fact, if anything, the food heats the oven.

The basic parts of a microwave oven are shown in Fig. 4: the cavity (1), the door (2), the magnetron (3), waveguide (4), the mode stirrer (5), the power supply (6), and the power cord (7). The main function of the power supply is to convert low voltage line power to the high voltages required by the microwave energy generator, the magnetron.

When the magnetron is energized it generates high-frequency energy which then passes down the waveguide to the cavity. The mode stirrer as it turns interrupts the energy as it enters the cavity and causes it to be distributed more uniformly about the cavity before it is absorbed by the food load. Without the mode stirrer, standing waves would occur in the cavity and there would be regions that would receive more energy than others, causing *hot spots* and *cold spots*.

The food load is shown positioned off the floor of the oven on a glass shelf (8) for a reason. This position permits some of the energy to be reflected from the oven floor into the food from below. If this were not done the bottom of the food would lag behind in cooking giving uneven doneness.

The purpose of the oven door is to provide an access to the cavity and also to confine the microwave energy. A properly fitting door is essential to completely confine the energy, and it, as well as the door flange, should be wiped clean regularly to insure good contact of the door and the door flange. Considerable ingenuity has gone into microwave oven door design because it is such a critical feature of the oven. Good metal to metal contact is only one means whereby microwave tightness of the oven is assured. Another approach utilizes a quarter wave slot or "choke" seal around the perimeter of the door which acts to choke off or cancel out microwave emissions at this point. On ovens in which tightness is effected by a metal to metal contact, food spatters and spills on or between the door and the flange provide a pathway for microwave energy leakage from the oven. Food buildup should not be permitted to accumulate on the door seals.

Oven controls consist mainly of a timer, indicating lights, a start or cook button, and a master switch. Timers vary from one manufacturer to the next, but are usually marked so that

short heating cycles can be set with some degree of accuracy. The timer is important because all microwave cooking is gauged by time, not temperature and time.

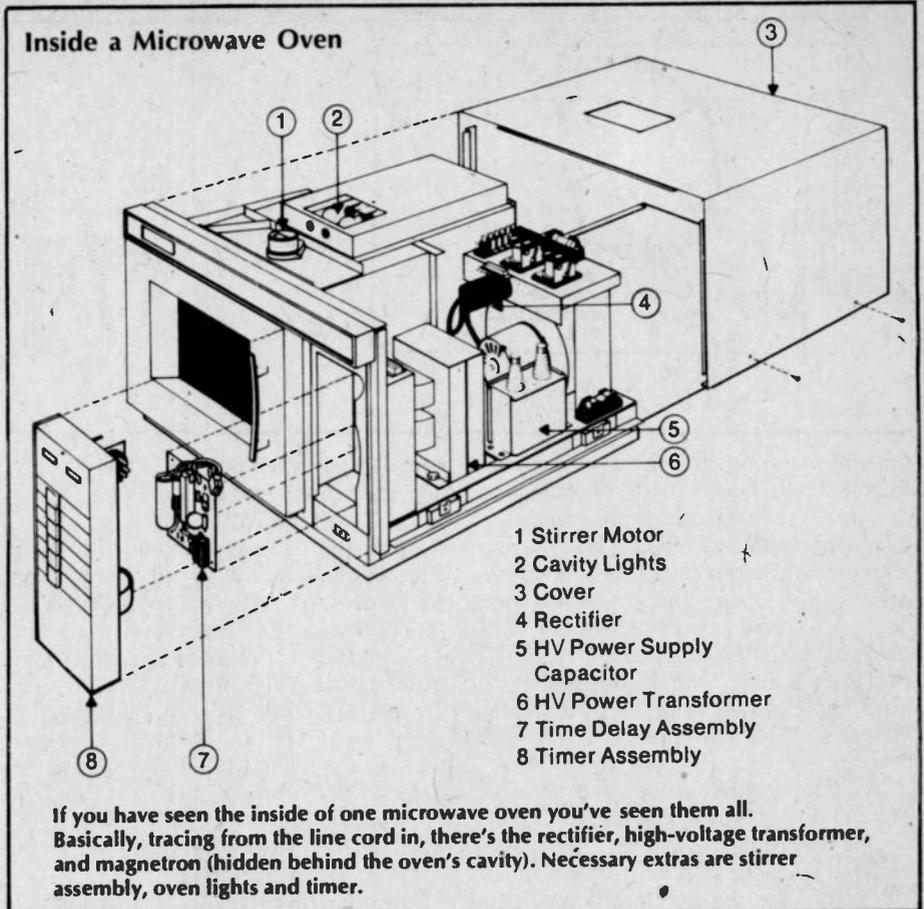
A few seconds excess time in some cases can mean the difference between success and failure. An audio signal such as a buzzer bell usually indicates when the set time has elapsed and the oven has turned itself off. The oven may also be turned off simply by opening the door. To protect the user from unnecessary exposure to microwave energy is a requirement of all microwave ovens. Two or more interlocks operate when the door is opened, any one of which could turn off the oven.

The oven can also be turned off by turning the timer back to zero time or by turning off the master switch. In some oven designs the cook button is omitted and cooking action is initiated simply by closing the door.

**Browning.** The brown surface color of foods is due to a chemical reaction between food sugars and amino acids; the reaction proceeds slowly at low temperatures and is accelerated by increasing the temperature. In microwave cooking the surface temperature of foods rarely exceeds 212°F., the boiling point of water, and is usually much lower. Because of this, most foods cooked in microwave ovens lack the surface coloration expected of certain foods. A steak or a meat pattie, for example, would have a gray, unappetizing surface appearance. Baked goods would not have a brown crust. The appearance of such foods can be enhanced by placing them in a hot oven for a few minutes, or in the case of the steak and meat pattie, on a grill or under a broiler. Restaurants which do a sizable steak business pre-sear a quantity of steaks in advance and finish them in seconds in the microwave oven when ordered. Some foods which because of their size take longer to cook in a microwave oven do take on an acceptable surface appearance. This is aided by the presence of surface fats as in beef roasts or roasting chickens and turkeys. These fats reach temperatures above 212°F. and act to accelerate the browning reaction on the meat surface.

**Some Cooking Tips.** Since small items cook faster than large items, it is good practice to do all of one size at a time. In baking potatoes, for example, if they are nearly alike in size they will all be finished at the same time. The alternative to size grading is to remove the smaller items as they are done and continue to cook the larger items. This requires considerably more attention.

Since metals, including aluminum



foil, reflect microwave energy you can use this phenomenon to advantage in certain cooking operations to restrict heating in certain areas. A good example to illustrate this effect is in the cooking of a large beef roast. See Fig. 5. First, wrap aluminum foil over the outer two inches at each end of the roast and cook for 2 to 3 minutes per pound (in a 1-kW oven 20 to 30 minutes for a 10-lb. roast). The roast should be turned at least once during this time. Remove the foil and cook for an equal period of time, again turning at least once. Remove the roast from the microwave 30 to 45 minutes or until a meat thermometer inserted into the center of the roast reads 140-150°F. Shielding the roast in this way during cooking will insure a more uniform degree of doneness from one end of the roast to the other. If a more well-done roast is desired, it can be returned to the oven for an additional 5 to 10 minutes.

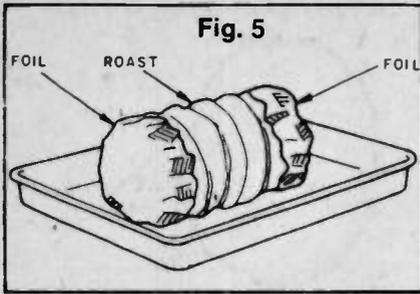
A circle of foil placed in the center of a slice of left over roast will keep it from becoming too well-done while warming it for service. When heating a casserole, the use of a strip of foil around the edge will slow down the heating effect in this area and insure a hotter center. There are many other possibilities using foil and metal forms

to control microwave heating.

Regular shapes heat more uniformly in a microwave oven. When the shape is irregular the thin, narrow parts tend to overcook and may be dried out by the time the thicker parts are done. This of course, happens in conventional cooking but is less pronounced because cooking is slower. Where it is possible to control the shape, as for example with a meat loaf or by tying a beef roast into a more cylindrical form, much more uniform results are obtained. Where this is not possible, thin parts may be covered with aluminum foil for a part of the cooking cycle. The same technique can be applied in protecting the wing tips and legs of roasting chickens and turkeys.

**Dinner Is in the Bag.** One of the principal advantages of microwave cooking is that it often can be accomplished in the serving dish or in the package in which the food was purchased. With the exception of metals, all packaging materials are transparent to microwave energy. The list includes oven-proof glass, ceramics, chinaware, plastic ware, paper containers of all types, and plastic films.

It is not entirely true that in microwave cooking only the food is heated. Some plastics must be used with cau-



tion. Melamine plastic ware, for example, absorbs enough energy to cause charring in places. Such plastic ware quickly becomes too hot to handle. Styrenes give off a strong odor and deform if heated too long.

The amount of energy containers absorb can be determined by making an oven power measurement with and without the container in the oven. The difference is the amount of energy absorbed by the container.

Some ceramic dinnerware may absorb several watts of power for each ounce of weight. Considering the weight of such containers, the total power absorbed can be considerable. In some cases this is a desirable feature since foods in these dishes tend to remain warm longer after serving.

Care should be taken not to use chinaware with metallic trim designs, as the thin metal trim will tend to arc and pit, thereby damaging the appearance

of the chinaware. The container is also likely to be quite hot in these regions and care should be taken in handling such dishes. It should be pointed out that no harm will come to the oven if such dishes are inadvertently used.

**Save the Nutritive Value.** The effect of microwave energy on vitamins in foods is negligible with a slight edge in favor of the microwave oven. Generally the effect is about the same as for conventional heating methods.

In many instances more of the natural vitamins are retained when vegetables are cooked in a microwave oven because in most cases this is done without the addition of water; there is thus no leaching out of vitamins. ■

## Filter Design

□ FILTERS ARE PERHAPS the most widespread type of circuit used in electronics. The tuning circuits which every TV and radio set uses to select the desired station are filters; the IF circuits which shape the bandpass of TV sets are also filters, as are the standard roll-off circuits in tape decks and phonograph amplifiers. FM receivers use filters to remove the pre-emphasis put into the signal at the transmitter, while yet another type of filter is used at the transmitter to provide the pre-emphasis in the first place. And, of course, all electronic circuits drawing power from the AC power line use a filter to smooth the ripple from the pulsating DC delivered by the rectifier.

Although they are found everywhere, filters have long been something of a mystery to the experimenter. For example, if an experimenter needs to design a filter for his circuit and turns to a textbook for assistance, he will be met with a barrage of *poles, zeroes, s-planes, integro-differential equations*, and a host of other subjects, all of which presuppose that he has at least a graduate degree in electrical engineering. So, although these texts certainly contain the information for designing excellent filters, the techniques are so well hidden under the advanced math that the average experimenter can't make use of them.

However, there some very simple techniques for filter design which may be easily used by anyone with a very elementary math background to make filters usually more than adequate for the job at hand. In the following pages we shall outline some of these simple approaches to filter design, which should enable you to "roll-your-own" filters as the project requires.

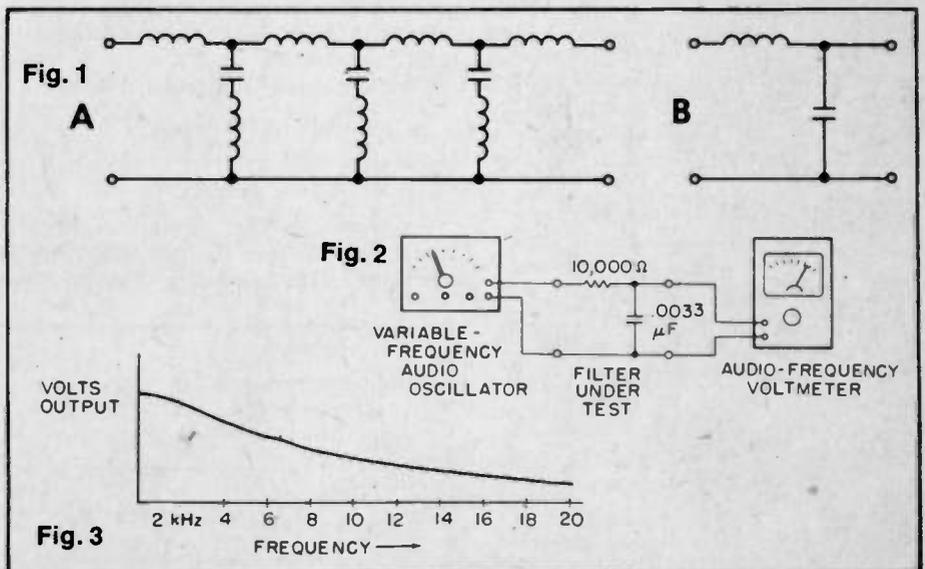
**What Is a Filter?** A filter is an electronic frequency-sieve. Just as a sieve can hold back large particles in a mixture and pass small ones, a filter can eliminate the low frequencies in a signal and pass the high frequencies. Such a filter is called a *high-pass filter*. Placed at the antenna terminals of a TV set, a high-pass filter can eliminate the unwanted low-frequency interference from nearby amateur or CB transmitters, and pass the wanted, higher-frequency TV signals.

Unlike a normal mechanical sieve, however, a filter can also be built to pass "large particles" (low frequencies) and eliminate "small particles" (high frequencies). Such a filter is called a *low-pass filter*, and can be used, for example, to eliminate the high-frequency scratches, pops, and hisses from a record reproducing system while passing

the music signals through to the loudspeaker.

A third type of filter is an even more clever "sieve," for it eliminates both very large and very small particles, (low and high frequencies), passing only particles of a specific size (signals of a particular frequency or group of frequencies). This type is called a *band-pass filter*, for it passes only a narrow band of frequencies, eliminating signals both above and below the desired signal frequency. Every radio and TV receiver uses a tunable bandpass filter at its input, to select signals from the desired station while eliminating all signals on higher and lower channels.

The fourth and final type of filter is the opposite of a band-pass filter, because it eliminates a particular frequency, while passing all others. This is called *band-elimination filter*, or, if the



band eliminated is very narrow, it is called a notch filter.

**Complex or Simple.** Although there are only four basic types of filters—high-pass, low-pass, band-pass, and band-eliminate—the circuits that can perform these functions are many and varied. They can be even more complex than the low-pass filter shown in Fig. 1A or they can be as simple as the two-element low-pass filter shown in Fig. 1B.

**Measuring a Simple Filter.** To understand what a filter is trying to do, let us make a laboratory set-up to measure the performance of the very simple filter of Fig. 1B, using the test set-up of Fig. 2. Here, a variable-frequency oscillator is connected so as to produce any desired audio frequency at the input terminal of the filter, while an audio frequency voltmeter measures the amount of signal emerging from the filter. Starting out with the oscillator set at some very low frequency, such as 10 Hz, we find that the filter has very little effect, passing almost the entire oscillator signal through to the output meter. This you might expect, since the capacitor is almost an open circuit at low frequencies, and the filter will therefore act almost like a series resistor alone, which, in this circuit, has negligible effect on the signal.

As the frequency is increased, however, the capacitor becomes a lower and lower impedance, effectively shorting out the signal as it emerges from the filter. The degree of "shorting out" depends upon the frequency; at very high frequencies almost no signal emerges from the filter.

The clearest display of the behavior of a filter is made by graphing the results obtained in the above experiment. If we plot the meter reading versus the audio oscillator's frequency, we obtain the graph of Fig. 3.

As you can see, the filter is removing the higher frequencies, as shown by the downward sweep of the graph as the frequency is increased. The graph is called the *frequency response* of the filter.

**Enter the Decibel.** Although the plot of Fig. 3 is easily made and understood, it is not the most useful way to display filter output versus frequency, and hence is not the way frequency response is normally graphed. Usually, instead of reading voltage off the voltmeter's scale, its decibel scale will be read by the experimenter (every good audio-frequency meter has a decibel scale in addition to its normal voltage scale), and decibels will be used on the graph instead of volts. Also, instead of marking off the frequency scale of the graph in equal steps of 1,000 Hz, 2,000 Hz,

3,000 Hz, etc., we mark it in equal steps of 1,000 Hz, 10,000 Hz, 100,000 Hz, etc. When these changes are made in the graph, a very useful display results, as shown in Fig. 4.

What makes Fig. 4 so useful is that it is essentially two straight lines connected by a short curved line, as shown in Fig. 5 and for purposes of practical design, the frequency response may be approximated by two straight lines as shown in Fig. 6.

Note that in Fig. 6, a corner is formed where the two straight lines intersect. A perpendicular line, dropped straight down from this corner, hits the frequency scale at a point known as the *corner frequency*. This is a very important frequency, and is generally taken as the cut-off frequency; that is, the frequency above which the filter rejects signals. The corner frequency for the particular filter shown is 5 kHz. Frequencies lower than 5 kHz are passed well by the filter; frequencies above 5 kHz are passed relatively poorly.

**Rules for Cornering.** To make the straight-line approximation of frequency response for a given resistor/capacitor low-pass filter such as the one measured above, you need know only two facts:

1. The corner occurs at a frequency given by

$$f_c = \frac{159,000}{RC}$$

where R is in ohms, and C is in microfarads.

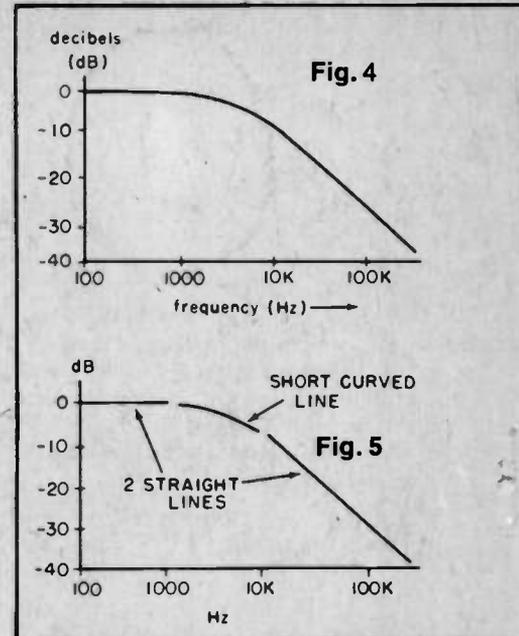
2. The downward-sloping straight line falls off at such a rate that between any two decades (such as between 10 kHz and 100 kHz, or between 250 kHz and 2,500 kHz) the line will drop by 20 decibels.

Using these two facts, let us draw the approximate frequency response of a filter with R = 2,000 ohms and C = 0.22 microfarads.

First the corner is calculated as

$$f_c = \frac{159,000}{RC} = \frac{159,000}{2,000 \times .22} = 367 \text{ Hz}$$

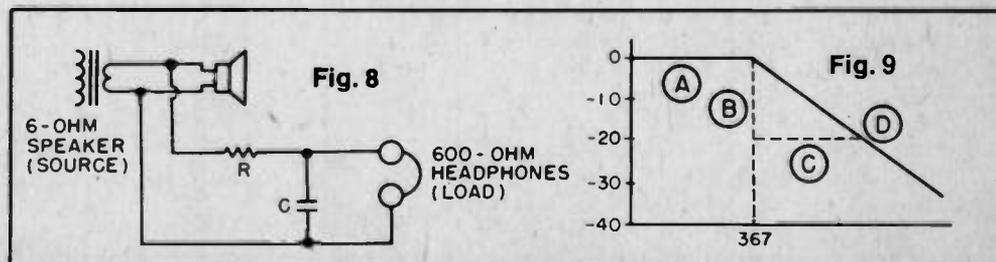
As shown in Fig. 7, draw a horizontal line A from the zero dB mark out to 367 Hz, then a line B down 20



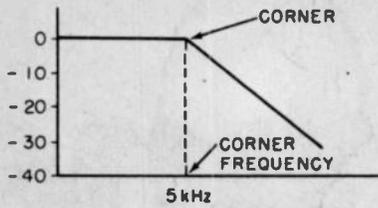
dB, and then a horizontal line C over a distance of one decade, from 367 Hz to 3,670 Hz. Now draw a straight line D from the point where A and B intersect, through the tip of C, as shown in Fig. 8. You have now sketched a very good approximation to the frequency response of the RC low-pass filter.

**Down to Earth.** In a real-life situation, a filter doesn't lie on a lab bench, driven from an audio oscillator and having its output measured by a voltmeter, but instead resides in a circuit, where it is driven by a very businesslike signal source with a job to do, and delivers its output to a loudspeaker, headphones, telephone line, TV picture tube, or what-have-you. In such a circumstance, our simple RC filter likes to be driven from a low-impedance source, such as a 6-ohm speaker output, and likes to deliver its output to a high impedance such as the base of a transistor amplifier or a pair of high-impedance headphones. Ideally, the high impedance load should be 100 times larger than the low-impedance driving source, although you can get away with as little as a 10 to 1 ratio. At this ratio, however, performance can not be accurately predicted by the simple relationships given in this article.

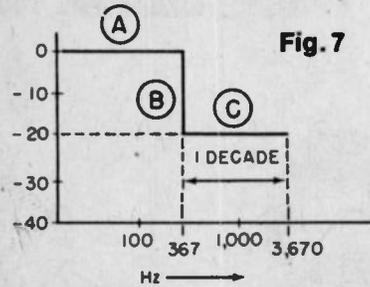
For a good example of a practical



**Fig. 6**



**Fig. 7**



use, consider the case of an SWL who would like to drive a 600-ohm headset from his 6-ohm speaker output, and wants to filter the output to eliminate the frequencies above 3,000 Hz. The circuit he would use is shown in Fig. 9.

He must first calculate the value of R for his filter, using the formula

$$R = \sqrt{R_s R_L}$$

where  $R_s$  is the source impedance, 6 ohms and  $R_L$  is the load impedance, 600 ohms. By the formula,

$$R = \sqrt{6 \times 600} = \sqrt{3600} = 60 \text{ ohms}$$

(Use the EIA value, 62 ohms)

He must then calculate the capacity, C, through an algebraic rearrangement of the equation given earlier for corner frequency:

$$C = \frac{159,000}{f_c R}$$

where  $f_c$  is the desired corner frequency, 3,000 Hz

and R is the resistance above, 62 ohms

Therefore,

$$C = \frac{159,000}{3,000 \times 62} = .855 \mu\text{F}$$

Replacing the 0.855  $\mu\text{F}$  value with the

nearest EIA value, 0.82  $\mu\text{F}$ , our SWL can now build his filter.

**Review of Low-Pass Filter.** In our design of the simple low-pass filter we arrived at the circuit values shown in Fig. 10A and the frequency response shown in Fig. 10B.

The filter circuit in Fig. 10A was designed to have a corner frequency of 3,000 Hz, meaning that it would pass all frequencies below 3,000 Hz rather well, but eliminate those above this frequency. What if we desired the opposite of this effect? What if, instead, we wished to pass all frequencies above 3,000 Hz, and eliminate those below this frequency? A circuit having these characteristics is called a high-pass filter, and its frequency response would be as shown in Fig. 11.

**Flipped Circuit for Flipped Response.** In one sense, the frequency response of Fig. 11 is a flipped-over version of the low-pass response shown in Fig. 10A. It should not be too surprising then to learn that the circuit producing this flipped-over response is itself a flipped-over version of the low-pass filter. The two circuits are compared in Fig. 12.

If the same values are used (.82  $\mu\text{F}$  and 62 ohms) in the flipped circuit, it yields the same corner frequency (3,000 Hz) as the low-pass design, except the roll-off (the part of the response that goes down-hill) goes down to the left instead of to the right. Just like its low-pass cousin, this high-pass circuit likes to be driven from a low impedance (the same 6-ohm voice coil would do nicely) and it likes to drive into a high impedance (the same 600-ohm headset would also be suitable). However, the SWL who designed the low-pass earlier in this article would be very disappointed in this filter. Instead of cutting out unwanted high-frequency noise to enable him to hear the signal from that distant station, this filter would cut out the signal and let him hear the noise!

**Designing by Flipping.** If it's a high-pass filter you need, there is almost nothing to the design. You simply design the "cousin" low-pass, using the formulas in the first part of this article, and then "flip" it to be a high-pass, as in Fig. 12B. Just choose the corner frequen-

cy for the "cousin" to be the same corner frequency that you desire in the final high-pass.

For example, let's design a high-pass filter to eliminate the hum (60 Hz) on a 600-ohm phone line before we connect it into a 100,000-ohm input of a public address (P.A.) amplifier. In this case, we would chose a corner frequency for our high-pass which was well above the 60-Hz hum, to be certain of eliminating enough of the hum. Choosing a 240-Hz corner frequency, we proceed to design the low-pass just as we did earlier:

First, compute R as follows:

$$R = \sqrt{R_s R_L} = \sqrt{600 \times 100,000}$$

$$R = \sqrt{60,000,000} = 7,750 \text{ ohms}$$

Next, compute C:

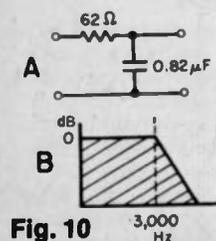
$$C = \frac{159,000}{f_c R}$$

$$C = \frac{159,000}{240 \times 7,500} = 0.88 \text{ mF}$$

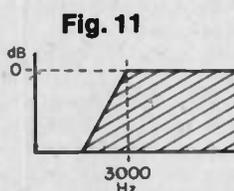
You would be quick to admit that the values 7.750 ohms and 0.0088  $\mu\text{F}$  for a resistor and capacitor, respectively, are difficult to find. Therefore, select the nearest stock EIA values, which are 7,500 ohms and 0.091  $\mu\text{F}$ .

Although we designed this using the low-pass formulas, we can directly draw the high-pass circuit and plug in the calculated values. See Fig. 13.

It is here that the shortcomings of these very simple filters first become apparent. We tried to make this filter eliminate 60-Hz hum from the telephone line, while still passing voice, speech, and music well enough to yield a good-sounding audio signal. However, the roll-off—the sloping part of the frequency response—is so gradual in these very simple filters that you must start it rolling down very far above the unwanted frequency in order to make sure that it gets down far enough to be effective in eliminating the unwanted frequency. In this filter (Fig. 13) we started the roll-off on its way at 240 Hz, which is right in the middle of some very important audio frequencies. Consequently, some important low frequencies will be lost, and the output of the system will sound "tinny." ■

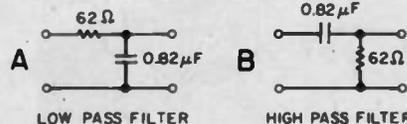


**Fig. 10**

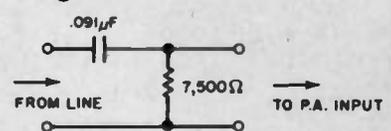


**Fig. 11**

**Fig. 12**



**Fig. 13**



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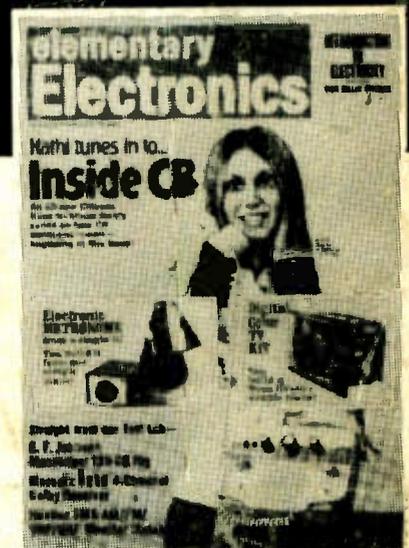
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