THE FUN WAY TO LEARN ELECTRONICS

ELECTRONICS

Electronics Theory Handbook

1977 EDITION $1.50

02616

By the Editors of ELEMENTARY ELECTRONICS

ALL THE ANSWERS ABOUT COMMUNICATIONS:
Low Frequencies, Shortwaves, FM, TV, Microwaves, Satellites

SECRETS OF RADIO:
Phase and Frequency Facts, AVC, Superhet Circuitry, Power Supplies, Antennas

NEWEST SOLID STATE TECHNIQUES:
Thermistors, Op Amps, IC Learning Aids

LEARN ABOUT ELECTRONS:
Electricity and Magnetism, Inductance and Capacitance

TIME-SAVING SPECIALS: Electronic Prefixes, Parallel Resistance Nomograph

UNDERSTANDING SSB

RF FROM YOUR CALCULATOR

DESIGNING WITH ICs

MASTERING METER MECHANICS

MEASURING CB STANDING WAVES

SEEING TV DX

A DAVIS PUBLICATION

Which of these fascinating electronic gadgets would you like to build?

A photo print-timer that does everything but turn out the lights! Designed by a darkroom craftsman, it features instant reset, backlighted digit-set dials, pushbutton stop and start.

A battery-operated dickey flasher—guaranteed to liven up **any** party! Suddenly, your shirt buttons start flashing sequentially! Some people laugh. Others just stare. But it's funniest when they try to ignore you!

A shortwave station finder/ marker. Suppose you pick up an interesting but elusive station in Papeete, Kuwait or Kinshasa. This stable wide-band oscillator lets you relocate it any time you like—**without** hours of searching.

A nostalgic crystal radio set—just like the one your grandad had. You make it with a Quaker Oats box.

A futuristic pulse-width modulated mini-audio amplifier. It can boost the volume of a pocket radio to dancing level!

A solid-state wind-chill factor meter that can tell you instantaneously just how cold you feel!

A compact, portable gas alarm for home, trailer, car or boat. It detects many kinds of dangerous fumes—and could easily save your life!

Elementary Electronics features low-cost, practical projects like these in every issue!

Mail coupon today for your complimentary copy!

Yes, every issue of ELEMENTARY ELECTRONICS brings you step-by-step instructions, with photos and diagrams, for all kinds of devices you'll enjoy building—and be proud to own!

But that's not all. You also get instructive articles on electronics, CB and shortwave. Lively columns. Exciting features that make ELEMENTARY ELECTRONICS America's most absorbing, down-to-earth magazine for the electronics and radio hobbyist.

Invaluable Basic Courses in electronic theory!

For example, you get the fundamental training you need to construct your projects successfully—or lay the groundwork for an electronics career.

Each issue presents a Basic Course that helps you master an important aspect of electricity or electronics. Recent subjects included: *Resistors in Combination. Understanding Transformer Action. Introduction to Alternating Current.* And *Understanding Semiconductors.*

Our readers tell us these Basic Courses are one of the magazine's most popular and valued features.

A magazine with a personality all its own!

You'll meet a lot of interesting people in the pages of ELEMENTARY ELECTRONICS Like Hank Scott, our Workshop Editor. He conducts a regular letters-from-readers column called "Ask Hank, He Knows!" If you have any trouble on a project—or with *anything* electrical—just ask Hank. He knows!

And Kathi Martin, KGK3916, our Citizens Band Editor. She writes "Kathi's CB Carousel"—the most entertaining and informative CB feature you'll find anywhere!

Plus the people who contribute our columns on shortwave, antique radio, new products, electronics news tid-bits—and much, much more!

All our writers, editors and columnists know their stuff backwards and forwards. And they know how to make it interesting! With the same kind of straightforward language you use yourself when discussing electronics or radio.

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1977 EDITION

Electronics Theory Handbook

FEATURES

DEPARTMENTS

Hey, look me over

Showcase of New Products

AM/FM Stereo Receiver

Sony's new STR-2800 receiver features 20 watts per channel, minimum RMS at 8 ohms from 20 Hz to 20 kHz with no more than .5% total harmonic distortion. Intermodulation distortion is also .5%. The amplifier is direct coupled for high stability, wide frequency response, and low distortion. The tuner affords

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clear FM reception: 50 dB of quieting is reached with only 50 uV of input in stereo; ultimate signal-to-noise is a very quiet 68 dB. Selectivity is 50 dB, capture ratio 1.5 dB, and separation 35 dB (at 1 kHz). Price is $240.00. For more information, write to Sony Corporation of America, 9 West 57th St. New York, NY 10019.

Burn-Out Proof DC Power Supply

A new DC power supply designed for CB service application, designated Model 244 Mobil/Comm Power Supply, offers features of value to CB service technicians. The fully-adjustable voltage range of 10.5 to 14.5 VDC is accurately metered on large 2½ inch meter with the

CIRCLE 62 ON READER SERVICE COUPON

calibrated standard 13.8 volt setting clearly indicated. Full adjustability and 0.5% regulation permits duplication of actual storage-battery operating conditions such as low-voltage and over-voltage operation. Continuous-duty three ampere output is protected against short circuits by fold-back current limiting. Even dead shorts will do no damage. An additional advantage of fold-back current limiting is that during high current-load conditions that may exist in malfunctioning transceivers, the power supply will not shut off, but, automatically reduce the current output to a relatively safe level. When the meter switch is in the AMPS position the output current is indicated with 3% accuracy. After the short circuit is removed the unit returns to normal operation, no fuse to replace, no circuit breakers to reset. The Hickok Model 244 Mobil/Comm Power Supply is available now at Hickok distributors for $125.00. For further information write to Hickok Electrical Instrument Company, 10514 Dupont Avenue, Cleveland, OH 44108.

Preamp/Amplifier

Dynaco/Dynakit has introduced a new moderately-priced integrated preamp/amplifier, the SCA-50, which offers a number of features. The unit is available assembled or in kit form. As a kit, it is extremely easy to assemble, requiring only simple tools and a few evenings work. Most circuitry is factory-wired on printed circuit boards, and pre-tested. It

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(Continued on page 10)

CIRCLE 7 ON READER SERVICE COUPON

EVERY PROJECT ANOTHER REASON TO

Whether you're a hobbyist or serious experimenter, CSC's line of precision digital/electronics design and testing equipment can take the manual labor out of your labors of love.

In fact, we can not only save you literally hundreds of hours a year, but *hundreds of dollars* as well. On parts, accessories and test equipment.

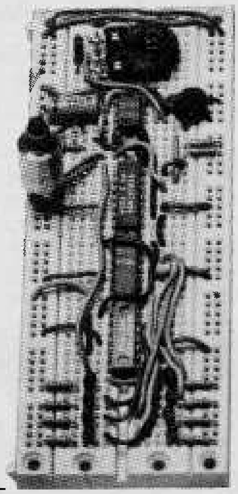
Want proof? Read on — you'll see why we're the fastest-growing company in the field!

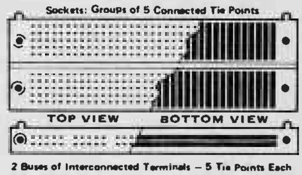
QT Sockets and Bus Strips* — time-saving, money-saving solderless breadboarding — the CSC way

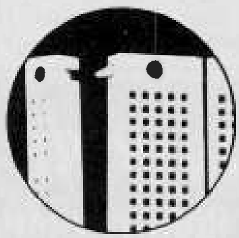
Our expandable, interlocking breadboarding system not only saves you hours of soldering, desoldering and resoldering, it also saves wear and tear on your components.

Resistors, capacitors, transistors, DIP's, LED's, micro-processors, etc., all connect with plug-in, plug-out ease. *Preassembled sockets with durable nickel-silver non-corrosive 5-point terminals* provide low-resistance interconnections you can arrange and rearrange at will. (And jumpers, where required, are short lengths of solid #22-30 AWG wire.)

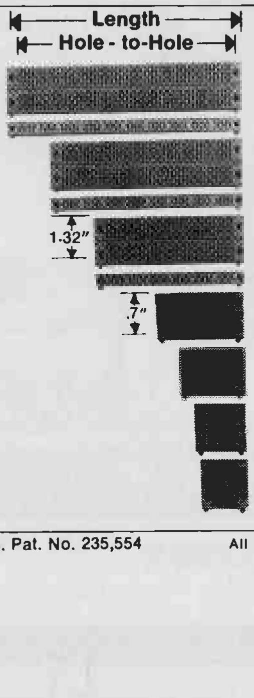
Use QT Sockets and Bus Strips for designing, troubleshooting, interconnecting, patching and dozens of other applications. Our unique snap/lock mechanism joins units in seconds, so you can add-on or take-off at will.







Check the chart below for sizes and prices.
10 modestly-priced models to choose from — still at our original low prices.
All can be top or through-the-panel rear mounted.



	Length	Hole-to-Hole	Terminals	Unit Price $
QT-59S	6.5"	6.2"	118	12.50
QT-59B	6.5"	6.2"	20	2.50
QT-47S	5.3"	5.0"	94	10.00
QT-47B	5.3"	5.0"	16	2.25
QT-35S	4.1"	3.8"	70	8.50
QT-35B	4.1"	3.8"	12	2.00
QT-18S	2.4"	2.1"	36	4.75
QT-12S	1.8"	1.5"	24	3.75
QT-8S	1.4"	1.1"	16	3.25
QT-7S	1.3"	1.0"	14	3.00

*U.S. Pat. No. 235,554

All Prices Shown Are Manufacturer's Recommended List. Prices and Specifications Subject to Change Without Notice.

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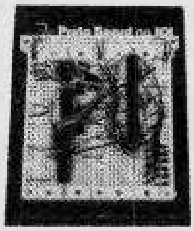
IN THIS MAGAZINE IS READ THIS AD.

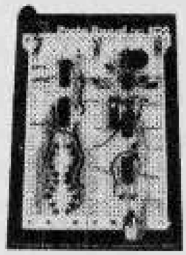
Build projects, test circuits, check components as fast as you can think... with CSC Proto-Board® Solderless Breadboards!

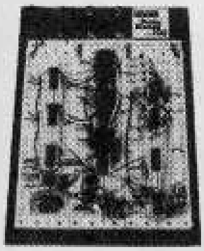
The right size for every circuit! The CSC Proto-Board system gives you the convenience and versatility of QT Bus Strips and Sockets *already mounted,* in use-tested configurations, on sturdy metal ground/baseplates** with non-marring feet. They're great for a wide variety of audio and digital projects, and you save money by using components over and over again.

PB-101—940 solderless tie points: ten 14-pin DIP capacity. Two QT-35S breadboarding sockets plus four QT-35B bus strips. Excellent for audio and smaller digital projects. Measures 4.5" wide x 5.8" long x 1.4" high (114 x 147 x 35mm); weighs 9 oz. (.26 Kg). **Price: $29.95**

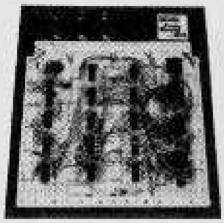


PB-102—1240 solderless tie points: twelve 14-pin DIP capacity. Two QT-47S breadboarding sockets, three QT-47B and one QT-35B bus strips. You'll want this one for intermediate digital needs, more complex audio projects among other things. Measures 4.5" wide x 7" long x 1.4" high (114 x 178 x 35mm); weighs just 10 oz. (.31 Kg). **Price: $39.95**





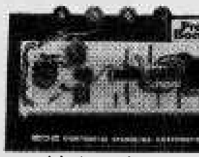
PB-103—2250 solderless tie points: twenty-four 14-pin DIP capacity. Three QT-59S breadboarding sockets, four QT-59B and one QT-47B bus strips plus four 5-way binding posts. For all but the very largest circuits. Lets you build calculators, interfaces, complex switching circuits, etc. Measures 6" wide x 9" long x 1.4" high (152 x 229 x 35mm); weighs 1.25 lb. (.57 Kg). **Price: $59.95**



PB-104—3060 solderless tie points: thirty-two 14-pin DIP capacity. Four QT-59S breadboarding sockets, seven QT-59B bus strips plus four 5-way binding posts. It's the largest breadboard we made for the largest projects you care to tackle—a CPU, encoder, complex display . . . just about anything. Measures 8" wide x 9.8" long x 1.4" high (203 x 248 x 35mm); weighs 1.75 lb. (.79 Kg). **Price: $79.95**

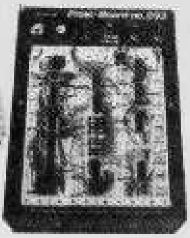
Save even more with Proto-Board Kits! Invest ten minutes of your time, using nothing more than a screwdriver and a pair of pliers, and you can have all the time-saving, money-saving features of CSC's Proto-Board system, for even less money! CSC Proto-Board Kits come with all hardware, non-marring feet and sturdy base-plate. And unlike other kits, *all sockets are pre-assembled,* eliminating tedious assembly and assuring long, trouble-free life.

PB-6 Kit—630 solderless tie points: six 14-pin DIP capacity. Most economical way to take advantage of Proto-Board speed and convenience. One pre-assembled QT-47S breadboarding socket, two assembled QT-47B bus strips, four 5-way binding posts, metal ground/plane/base-plate, all required hardware. 10 minute assembly with pliers and screwdriver. Measures 6" long x 4" wide x 1.4" high (152 x 102 x 34mm); weighs 7 oz. (.20 Kg). **Price: $15.95**



PB-100 Kit—760 solderless tie points: ten 14-pin DIP capacity. 21% larger capacity than PB-6 Kit. Comes with two pre-assembled QT-35S breadboarding sockets, one assembled QT-35B bus strip, two 5-way binding posts, pre-drilled and screened base-plate, non-marring feet and all required hardware. Fast 10 minute assembly. Measures 4.5" wide x 6" long x 1.4" high (114 x 152 x 35mm). Weighs 7.5 oz. (.21 Kg). **Price: $19.95**

Now! Proto-Board convenience, plus regulated power! No need to hunt for a power supply when you're working with these CSC Proto-Board units. Built-in power supplies give you the DC power you need, with laboratory-precision regulation, plus low ripple and noise. Choose the PB-203 for digital circuits and other projects requiring 5V or less (with external components) or for maximum flexibility, the PB-203A, with 5VDC plus two independently-adjustable voltage sources.



PB-203—2250 solderless tie points: twenty-four 14-pin DIP capacity. *The Ultimate!!* All Proto-Board features *plus* short-proof, fused 5VDC, 1A regulated power supply with only 10mV ripple and noise at 0.5A; on-off toggle switch and pilot light. Three QT-59S breadboarding sockets plus four QT-59B and one QT-47B bus strips. Power supplied via two of the four 5-way binding posts. It all adds up to lots of capacity plus the proper DC voltage for most digital and many analog IC's. Measures 9.75" long x 6.6" wide x 3.25" high (248 x 168 x 83mm). Weighs 5 lb. (2.27 Kg). For 117 VAC, 50/60 Hz (220 VAC, 50/60 Hz; also available at slightly higher cost). **Price: $75.00**

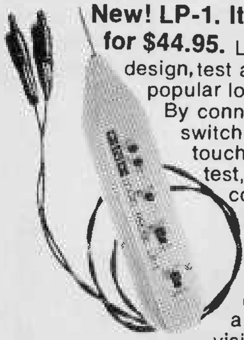
PB-203A—*The Ultimate . . . plus!!* All the features of the PB-203 including regulated 5VDC supply *plus* additional power supply flexibility (separate regulated +15VDC and −15VDC, 0.5A supplies, each with internally and independently adjustable output voltage; ripple and noise of + and −15V supplies, 10mV at 0.25A). Connections for 3 power supply voltages and ground available at four 5-way binding posts. Same size as PB-203; weighs 5.5 lb. (2.5 Kg). For 117 VAC, 50/60 Hz (220 VAC, 50/60 Hz; also available at slightly higher cost). **Price: $120.00**

TURN PAGE FOR MORE CSC PRODUCTS AND EASY ORDER FORM ▶

**PB-100 has fibreglass-reinforced plastic baseplate.

A LOT MORE PROJECTS-A LOT LESS MONEY.

CSC's Digital testers save your sanity. And your money.



New! LP-1. It digs up a lot of information for $44.95. Logic Probe 1 is a compact, versatile design, test and trouble-shooting tool for all popular logic families and digital applications. By connecting the clip leads, setting a switch to the proper logic family and touching the probe to the node under test, you get an instant picture of circuit conditions.

LP-1 combines the functions of level detector, pulse detector, pulse stretcher and memory—makes one-shot, low-rep-rate, narrow pulses—nearly impossible to see, even with a fast scope—easily detectable and visible.

LM-1. It lets you check digital IC's faster than a scope, safer than a voltmeter, for a lot less than you might guess—only $74.95. Logic Monitor™ 1 speeds digital design and testing by accurately and automatically displaying static and dynamic logic states of DTL, TTL, HTL and CMOS DIP IC's.

All in a compact, self-contained 16-pin circuit-powered unit. Use it to effortlessly trace signals through counters, shift registers, gating networks, flip-flops, decoders, etc. Clip it over any DIP IC up to 16 pins, and each contact connects to a single "bit" detector with high-intensity LED readout. Logic 1 (high voltage) turns LED on; Logic "0" (low voltage or open circuit) keeps LED off. A power-seeking gate network automatically locates supply leads and feeds them to the Logic Monitor's internal circuitry.

The MAX-100. 100 MHz 8-Digit Counter. At $134.95, nothing else does so much for so little.

The MAX-100 is a portable, battery powered, solid-state frequency counter. It gives effortless, yet accurate readings from 20Hz to a *guaranteed* 100 MHz. This makes it especially suitable for audio, ultrasonic, RF (CB, AM and FM), video and digital applications.

Easy operation: Clip leads, input cable or mini-whip antenna are attached or placed near the equipment being tested. Then both units are turned on. MAX-100 produces direct 8-digit readings *automatically*, in big, bright 0.6" LED display. Readouts are updated every second. Overflow signals (over 100 MHz) are indicated by the left hand digit flashing automatically.

The MAX-100 is extremely compact. Only 1.75 x 7.38 x 5.63" (4.45 x 14.30 x 19.69 cm) and weighs less than 1.5 lbs. (0.68 kg). It operates on six AA cells (alkaline or NiCad), 110 or 220 VAC (with charger/eliminators) or 12 VDC (with charger/eliminator). The MAX-100 will flash all digits when battery supply is low (this extends battery life even further).

There is a 3.379545 MHz crystal timebase with 3 ppm accuracy at the heart of the MAX-100. It insures precise readings with high temperature stability. An integral wide-range preamplifier permits readings as low as 30 mV with overload protection to 200 V (peak).

MAX-100	8-digit frequency counter	$134.95
100-CLA	Mobile Charger/Eliminator	$ 3.95
100-CA1	110 VAC Charger/Eliminator	$ 9.95
100-CA2	220 VAC Charger/Eliminator	$ 9.95
100-MWA	Mini-Whip Antenna	$ 3.95

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CIRCLE 14 ON READER SERVICE COUPON

Hey, Look Me Over

(Continued from page 5)

is rated at 25 watts continuous average power output per channel. Both the tone control and preamplifier circuits use low voltage regulated power supplies so that AC line fluctuations will have no effect on audio performance. In the amplifier section, the output circuit is full complementary symmetry and the bias supply thermally tracks the output transistors. This cuts down on notch distortion—that type of distortion which many believe is the source of transistor sound. The SCA-50 has a price of $249.00 for the factory-assembled unit and $149.00 for the kit. Detailed information is available from Dynaco/Dynakit, Box 88, Cole Road, Blackwood, NJ 08012.

Aircraft Clock/Timer

If you're into flying, you may want to assemble a low-cost, five-function aircraft clock/timer kit by Heath. The 01-1154 has two digital LED displays that show various timing functions. The upper display shows GMT/ZULU time. The lower display shows any one of four time functions selected by the pilot; local time; 24-hour timer for total trip time; and a preset alarm time for fuel management or check point notification. The displays dim automatically for night flying. The 01-1154 mounts in a standard 3⅛-in. instrument panel cutout. It is

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FAA/PMA approved and meets all DO-160 requirements. Mail-order priced at $149.95. For further information, write for a free copy of the latest Heathkit catalog: Heath Company, Benton Harbor, MI 49022.

Desk Stand for Pocket Calculators

Calcrade is a desk stand for pocket calculators that tilts and pivots to that "just right" angle for glare-free viewing and easy keyboard operation. Accepts both vertical and horizontal pocket cal-

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culators. Hook and loop fasteners secure calculator to stand while non-skid feet provide stable footing. Unit completely disassembles and features special design which allows for passage of optional anti-theft accessory. Standard model of textured black onyx finish. Retail price $5.00. Available from One-Up, Inc., 1303 Avocado, #235, Newport Beach, CA 92660.

Record Cleaner

A new low-cost, record cleaner is available from Robins. The cleaner is used to remove dust, grime or other foreign material from delicate record grooves. If this is not done on a regular basis, sound quality suffers, high-frequency loss occurs, and annoying ticks and pops ob-

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scure musical passages on valuable phono records. The economy record cleaner, catalog No. 41195, carries a suggested retail price of $1.98. The disc cleaner consists of a closed-end tube covered with special, soft velvet material. It is simply held between the thumb and forefinger at right-angles to the record grooves. Records can be cleaned either before being placed on the turntable or they can be cleaned while they are rotating. Write to Robins Industries Corp., 75 Austin Blvd., Commack, NY 11725 for information.

Communications Desk

The Telco communications console, known as the Comm-Sol Model CS-50, is the answer to the space problem for all communications enthusiasts. It provides the user with an area for all of his communications equipment, and at the same time, serves as an attractive piece

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CIRCLE 5 ON READER SERVICE COUPON

of furniture that blends with your home's decor. Completely conceals all the equipment when not in use and prevents unauthorized use. Comm-Sol's modular concept and construction allows additional units to be arranged attractively to provide all the work, storage and functional space you desire. Easy to assemble and install, no specal tools needed, and can be assembled with only a dime. All holes are predrilled and specially reinforced with metal in all areas of stress. Finished in rich walnut veneer. Sells for $139 95 For additional information, write to Telco Products Corporation, 44 Seacliff Ave., Glen Cove, NY 11542.

Wire-Wrapping Kit

New Wire-Wrapping Kit from OK features selected items of particular value to the engineer and hobbyist alike. Includes a unique new wire-wrapping tool, a roll of wire-wrapping wire, and pre-stripped wire in 4 popular lengths. The tool, Model WSU-30 is a combination tool that wraps and unwraps 30 AWG wire on .025 square pins, plus strips 30 AWG wire using built-in stripper. The wire is top quality insulated silver plated copper. Supplied in the kit are a 50 ft. roll plus pre-cut and stripped wire in insulated lengths from 1 to 4 inches stripped on each end. Available with blue wire as Model WK-2B, white wire as WK-2W, yellow wire as WK-2Y, and red

CIRCLE 68 ON READER SERVICE COUPON

wire as WK-2R. Sells for $5.95, from O.K Machine and Tool Corporation, 3455 Conner Street, Bronx, NY 10475.

Disguise Antenna

A new disguise AM/FM/CB antenna, the Turner SK750, offers easy installation design. The SK750 Tri-Band antenna has low VSWR over the entire 40 channel bandwidth. It has a removable 42 inch stainless steel whip and mounting that adapts to sloping surfaces. The filters in the hermetically sealed, watertight housing act as band separators to keep the AM/FM and CB signals from mixing. The Turner Tri-Band Model SK70 offers clear reception for AM/FM radio and is tunable for CB. Tri-Band sells for $25.00. Turner also offers the SK755 which is the same antenna configuration in CB only (no

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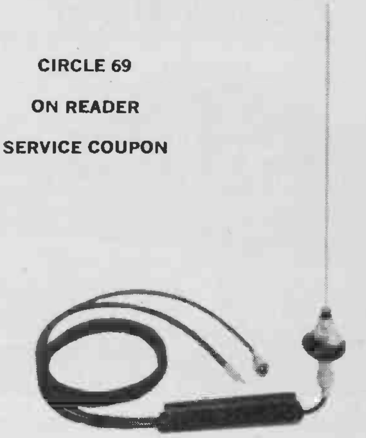
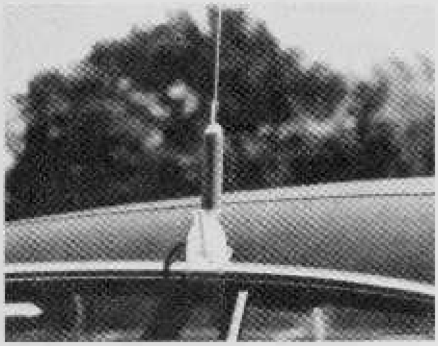


AM/FM), retailing at $19.95. For more information write to Turner, 716 Oakland Rd., N.E., Cedar Rapids, IA 52402.

Gutter Mount Antenna

A new, completely assembled, spring-loaded temporary gutter mount antenna capable of transmittnig and receiving on all 40 channels by The Antenna Specialists Co. is designed for use with grounded metal gutters of autos, not ornamental non-metalic gutters. The MS131 features a stainless steel whip for superior strength and flexibility. A 17 foot coaxial cable with attached connector is pre-wired and completely assembled. All mounting hardware is included for quick

Hey, Look Me Over

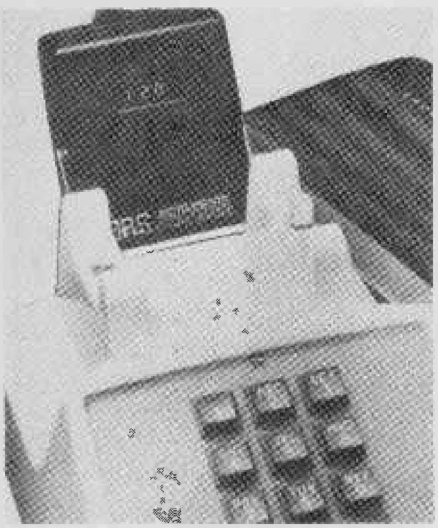


CIRCLE 66 ON READER SERVICE COUPON

installation. Price is $21.95. For further specifications on the MS131 and other antennas, write to The Antenna Specialists Co., 12435 Euclid Avenue, Cleveland, OH 44106.

Time to Time

You can keep telephone conversations short and your telephone bill down by using the GRS Model 100 Digital Telephone Timer. This new solid-state timing device starts and stops with a push of a button. It features a bright, 3-digit LED display that indicates tens of minutes, minutes and tenths of minutes. Power from 4 penlite Alakline batteries (not included) that will keep the GRS Timer timing for about a year under average use. The Digital Telephone Timer



CIRCLE 70 ON READER SERVICE COUPON

is fully portable and comes with a special bracket to mount on almost any phone. When not used to time phone calls, it can be simply removed from bracket and carried in pocket or purse and can be used to time conferences, speeches, in the dark room, plus anywhere else a timer is needed. The complete price with bracket carries a manufacturers suggested retail price of $29.95 (less batteries) and it can be ordered F.O.B. Dallas, Texas from GRS Instruments Inc., 8730 King George Drive, Dallas, Texas 75235. ■

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

Lend a Hand

I received a nice letter from one of our readers thanking me for giving him the opportunity to help a reader looking for a diagram. Now, I know for sure that it's better to give than to receive.

Here's a long list of readers in need of assistance. Help 'em out, boys!

Δ John Anderson, Rt. 2, Box 333, Superior, WI 54880 would like information and schematic diagram for American Borch Model 48 AM receiver and likewise for a National SW-54 4-band receiver.

Δ Dan Jenkins, Box 201, RD #1, Weare, NH 03281 is looking to acquire an ASCII TTY or CRT terminal with acoustic coupler (telephone) capable of handling 10 pps at least.

Δ If you have or know where to obtain a 7JP4 picture tube, please contact Charles Benson, 164-49 45th Rd., Flushing, NY 11358.

Δ Send schematic diagram and manual, if you have it, on the Universal Signal Generator Model 641 made by Jackson Electrical Instrument Co. of Dayton, OH to D. L. Paproski, Box 21, Sub. 69, Calgary, Alta., Canada.

Δ Harvey Pearson, P.O. Box 104, Greencastle, MO 63544 would like to buy a used Hallicrafters S-38E or Realistic DX-160 in good working order.

Δ Wayne West of 106 E. El Camino, Phoenix, AZ 85020 would like schematic diagrams for the following military items: RT-70/GRC transceiver, APN-9 Loran Navigation set, and ARC-3 receiver.

Why the Extra Bucks

Hank, everytime I have to replace a mercury battery, the price is staggering. Why do equipment makers design for mercury batteries?

—L. J., Memphis, TN

Mercury batteries have a high electrical capacity-to-volume ratio, flat discharge curve (sustained voltage under load), low internal AC impedance, ampere-hour capacity relatively independent of current drain level and duty cycle of load, and good shelf life. Over long periods of operational use, or after some 30 months of storage, voltage regulation within one percent of the initial voltage is still maintained. Silver-cadmium dry cells are similar to mercury cells, except the AuCd have a longer life. Mercury cells are often found in cameras where long shelf life is important. Silver-cadmium cells are lighter (high capacity-to-weight ratio).

Marine Listener

I know the marine band frequencies are between 156 to 162 MHz. But, what frequecies should I zero on for best results?

L. M., Staten Island, NY

Scan between 156.300 MHz to 157.425 MHz. Best frequencies (MHz) are 156.300 (intership safety), 156.350 (a good business working channel), 156.450 (marinas, public docks), 156.800 (distress, safety and calling) and 156.425 (non-commercial working channel). There are more, but space is limited. By the way, your standard-band SW receiver should be tuned to 2182 kHz.

Neon Blinker in Step

Hank, can you give me a diagram for a simple neon bulb circuit of three bulbs that light in sequence?

—K. L., Morristown, TN

The diagram is quite simple and you can see that, if you wish, you can add several more neon bulbs provided you include the corresponding resistors and capacitors. Keep the values for R and C constant to have the bulbs stay lit for equal periods. Oh yes, the bulbs are NE-2s.

A Tuff One

I hear some wierd music at slightly above 200 kHz. Who is it and where do I write for a QSL?

—O. J., Portland, ME

The long wave station you are hearing above 200 kHz with Arabic music is, most likely, the 800 kilowatt powerhouse of Radiodiffusion-Television Marocaine at Azilal, Morocco. The frequency is, in fact, 209 kHz. You can send a reception report to Radiodiffusion-Television Marocaine, 1 Rue Al Brihi, Rabat, Morocco. Nice catch!

Tantalum Is Terrific

I know the tantalum capacitor is better on performance than the aluminum electrolytic capacitor, but why?

—A. S., Fargo, ND

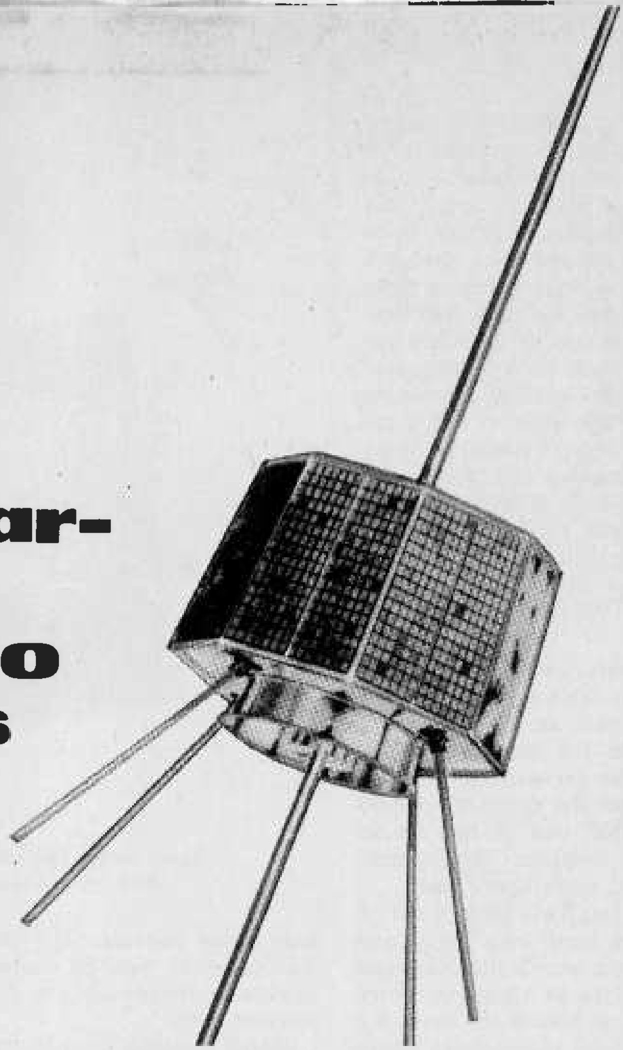
The tantalum has a much lower AC impedance than the aluminum type at higher frequencies. Also, tantalum types are cheaper to make as small units.

What's It Made Of?

Hank, my gutter mount antenna can't get the signal out on my car. In my

(Continued on page 102)

Talking With Oscar- The New Ham Radio Satellites



☐ You can now get, for the first time, a QSL (verification) card for monitoring transmissions from either of two earth-orbiting satellites—and you can do it without any souped-up exotic or sophisticated electronics. All you need is the simple know-how in this article about when and how to listen, plus a fairly good communications receiver.

I'm talking about the Oscars (Orbiting Satellite(s) Carrying Amateur Radio) which are in orbit and can be heard every day of the year. Here's the story on the birds' origins, how to eaves-drop on two-way radio conversations passing through these satellites and where to send for QSL cards just for listening!

Satellite History. Man-made satellites have orbited the earth less than 20 years, since Sputnik I first jolted the West in 1957. And for 15 of those years amateur radio operators have had their own earth-orbiting satellites, each called Oscar (1, 2, 3, etc.). Oscar 1 was put together by a pioneering group of California amateurs in their spare time. Using left over and used parts, their out-of-pocket expense came to less than $70! Next step was convincing the federal government to launch it "piggy-back" with another satellite in place of some ballast.

When a Thor-Agena rocket lifted on a pillar of flame from Vandenberg A.F.B. on Dec. 12, 1961, radio amateurs around the world had their own satellite. During its three-week lifespan Oscar 1 transmitted telemetry data with a power of one-tenth watt.

Oscar 2, launched June 2, 1962, was exactly like Oscar 1, with telemetry lasting 18 days.

Oscar 3, launched March 9, 1965, was the world's first privately constructed active communications satellite. It received amateur radio signals and retransmitted them with a transmitter power output of one watt. Oscar 3 was also the first free-access communications satellite, commercial or non-commercial, to be orbited. A total of 100 different ham radio stations in 16 countries communicated through the satellite during its two-week life.

Oscar 4, launched Dec. 21, 1965, was an active bird with three watts of transmitter power. It did not achieve a good orbit at launch, but hams did communicate through it (before it fell back to Earth) including the first direct U.S.-to-U.S.S.R. contact via satellite.

Oscar 5, launched Jan. 23, 1970, was built by students at Melbourne University, Australia, and launched from the United States. It transmitted a telemetry beacon and its batteries lasted 1½ months.

Oscar 6, launched Oct. 15, 1972 alongside an ITOS weather satellite and still going strong, is an active repeater—it picks up ham signals and retransmits them. The 40-pound satellite can store messages sent up from earth and repeat them on command from the ground. Its radio signals can be turned on and off by ground command. Transmitter power is one watt.

Oscar 7 was launched along with the NOAA-4 weather satellite and Spain's INTASAT satellite on Nov. 15, 1974, was built by hams in the U.S., Germany, Canada and Australia. It has two separate communications repeaters on board with two watts of transmitter power. It can receive and store messages for later replay and be turned on and off by ground command. Medical data, weather bulletins and other emergency communications have been transmitted through the 65-pound Oscar 7.

Both Oscar 6 and Oscar 7 are used for casual chit-chat among ham friends as well as for educational purposes and public service work. There's always something to hear when Oscar is overhead.

Better Oscars Ahead. The seven Oscars so far lofted for amateur radio may be divided into the Phase I satellites, consisting of Oscars 1 and 2, and the Phase II Oscars, numbers three through seven. One and Two were not active satellites, as were numbers three through seven. Now we come to Phase III Oscars, which will be launched before long. They will be a mighty leap ahead in ham radio satellite technology. They will do all the things 6 and 7 are doing but for longer periods of time. With 6 and 7, listeners can tune in the satellites for about 20 to 30 minutes every 115 minutes as the satellites circle the globe. The remainder of the time, 6 and 7 are out of sight, behind the Earth. Phase III Oscar(s) will be different.

Phase III Oscar(s) will be lofted into a 900-mile high orbit (like 6 and 7). But, once in orbit an on-board kick motor will push the satellite into an elliptical orbit as far as 20,000 miles from Earth over the Northern Hemisphere. The other end of the orbital path, over the Southern Hemisphere, will be only 900 miles above earth.

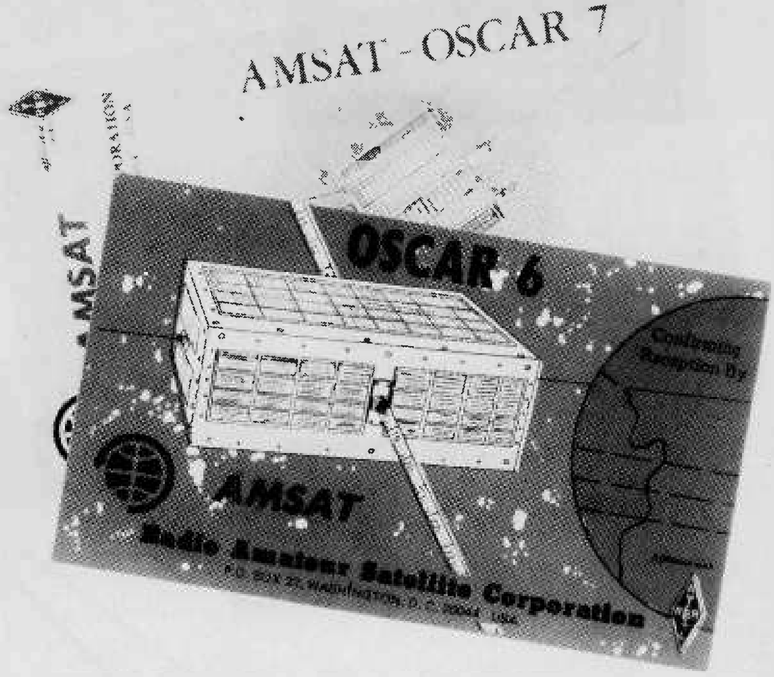
Phase III Oscar(s) will thus be out of sight behind the earth only about one hour and in sight above the Northern Hemisphere as long as 12 hours before disappearing again behind the earth for one hour. It will be usable from North America, Europe and Asia for 23 hours of each day. Hams will be chatting through Phase III Oscar repeaters without regard to time of day or signal skip.

Receiving Satellite Transmissions. Here's how to eavesdrop on Oscar. All that's needed to hear Oscar 6 and Oscar 7, now in orbit, is an inexpensive general-coverage shortwave receiver tuning 550 kHz to 30 MHz. You will be listening to the 10-meter ham band so any receiver capable of tuning approximately 29.4-29.55 MHz will let you hear the satellites.

Fancy equipment is not needed to hear Oscar. The author regularly listens with an inexpensive Kenwood QR-666 all-band communications receiver, and the satellite comes in loud and clear. Bob Peters, operator of ham radio station K3EZS at State College, Pa., listens to the satellite with a 25-year-old National tube-type receiver. The author has even listened in on a Panasonic RF-1150 all-band portable radio. So you see it's not hard to hear Oscar.

Signals go up to Oscar in the two-meter ham band in the frequency range of 145.850-146.00 MHz. You won't be able to hear these signals directly from a ham earth station unless, by chance, that station is very near where you live.

Signals come down to Earth from Oscar for you to hear in the 10-meter ham band between 29.4-29.55 MHz. You can hear these by tuning when the satellite is overhead and in view of your listening post.



These are the QSL cards you can get to prove you caught transmissions from either or both Oscar satellites now transmitting to earth.

Hams transmit through the satellites in radiotelegraph code (CW) and single-sideband (SSB) voice. To hear these signals and understand what is being said, your receiver will have to have a BFO (beat frequency oscillator) or other means of detecting SSB and the beep-beep of Morse code. Most shortwave sets have a switched marked *BFO On/Off* or a mode switch which can be turned to select CW, Code, or SSB.

Many conversations are relayed through the satellite at the same time. If you tune your receiver carefully, up and down the dial from 29.4 to 29.55 MHz you can hear several different QSOs (amateur conversations) going on at the same time.

Listen On These Frequencies. Here are the exact frequencies used by each satellite: Oscar 6 transmits down to Earth between 29.45 and 29.55 MHz. Oscar 7 transmits down on 29.4-29.5 MHz.

Since these satellites are at an altitude of 900 miles you can be as far as 2,450 miles away and still receive signals from Oscar when it comes into view over your horizon. So two hams up to 4,900 miles apart can talk through the satellite when it is between each ham station and up to 2,450 miles away from each!

As the satellite moves along its orbital path, stations in different parts of the world come in and go out of its range.

Antennas. Antennas for receiving do not need to be fancy either. The author heard Oscar with both vertical and long-wire antennas cut for a wide variety of other short-wave and ham bands. Almost any outdoor antenna can be hooked to your shortwave receiver to bring in the satellite. Bob, K3EZS, uses a 130-foot length of wire from his ham shack out to a tree, and regularly makes contacts through Oscar!

A very good antenna cut especially to hear Oscar is a simple horizontal wire dipole antenna. This kind of dipole is constructed with two eight-foot lengths of wire running from a center insulator. A length of RG-8U or RG-58U coaxial cable (available at your Radio Shack store) serves as lead-in from the center insulator to your receiver. This is the familiar center-fed half-wave dipole described in most radio manuals. I have one hanging between two chimneys on my house which puts the antenna about 30 feet up in the air. It works fine.

If your shortwave receiver is nearly dead on the 10-meter band, you can pep it up and get Cadillac-quality reception by installing a small transistorized preamplifier. These can be purchased for about $6 in kit form (or $12 wired and tested) from dealers such as Hamtronics Inc., 182 Belmont Road, Rochester, N.Y. 14612.

As the satellite tumbles slowly in orbit, its signals are affected by passing through the ionosphere, so don't be discouraged if voices seem to fade slowly in and out. That's normal. One way around the fading would be to use two matching antennas, one mounted horizontally and one mounted vertically. While listening with one antenna, when the signal from the satellite starts to fade, switch quickly to the other and signals will come back to original strength. Such two-antennas systems are ideal, but are not needed for casual listening to Oscar. It's easier to put up with the slow fading. In fact, it's not usually necessary to put together a special 10-meter antenna just to hear Oscar the first time. Unless your receiver is pretty dead on 10 meters, just use whatever shortwave antenna you have available.

The earth is moving under the satellite so Oscar appears to move westward. For instance, if the satellite comes up south-to-north over the southeastern United States one hour, it will come up over the Rocky Mountains a few hours later. And even later it will come northward over the Pacific Coast. And so on, around the Earth in a corkscrew pattern, Oscar covers the United States, and the world.

Since Oscars 6 and 7 were launched at different times and are in slightly different orbits, they will not be overhead at the same time. Their distance apart varies. Twice a year they come close enough together for hams to talk through both at the same time.

What To Listen For. Both satellites have telemetry beacons, transmitters which send strings of numbers in radiotelegraph code (CW) which can be easily copied and deciphered to determine temperatures, voltages and current drain from batteries in the satellites.

Oscars are powered by rechargeable nickel-cadminum (NiCad) batteries, constantly revitalized by the sun through solar cells.

Oscar 7 telemetry beacon can be heard at 29.502 MHz and Oscar 6 telemetry beacon can be found at 29. 450 MHz. Listen for those continuous strings of numbers in Morse code.

First-time listeners usually listen for the telemetry beacons. Then they tune for chatting hams. They also might hear such serious uses as transmission of medical electrocardigrams (EKGs) from California to the National Institutes of Health at Washington, D.C., or Miami hams maintaining hurricane watches and transmitting weather bulletins, tests in locating downed aircraft or using portable Oscar Earth stations transported in suitcases flown to earthquake and other natural disaster sites.

When To Eavesdrop. A sure-fire way to hear Oscar is to turn on your shortwave receiver any night except Tuesday, when they're often switched off. Oscars will pass overhead or near enough for you to hear at least twice in an evening. Oscar 6 is turned on for hams on Sundays, Wednesdays and Friday nights local time in the United States. Oscar 7 will be turned on during odd-numbered days of the year.

A pass near or over eastern North America will take place between 7:00 and 9:00 p.m. Eastern Standard Time, and pass over or near western North America will take place between 9:00 and 11:00 p.m. EST (6:00 to 8:00 p.m. PST). You should be able to hear, at the least, the stronger signals coming through the satellite for 10 to 30 minutes each pass depending upon how close Oscar is to you.

How To Get QSL Cards. Here's how to get a QSL card for listening. Copy the radiotelegraph code (CW) numbers being transmitted by the satellite itself as its telmetry beacon. Get as many in the string of numbres as possible, hopefully 100 or more. If you miss a number, write in a dash and continue to copy down following numbers. Send the numbers you copied and a reception report (including exact time and date, and signal strength) to the Radio Amateur Satellite Corp. (AMSAT), Box 27, Washington, D.C. 20044.

AMSAT is an international organization of hams and listeners interested in amateur satellite work. AMSAT sponsors the satellites and coordinates activities.

AMSAT will send you a QSL (verification) card. If you can't copy the Morse code, you also could send AMSAT a report of voice-transmitted satellite news bulletins about Oscar-related events you may hear transmitted by bulletin stations through the satellites.

You can get additional QSL cards by listening for the call letters of individual hams you hear talking through the satellites. Let's say you hear me, K3RXK, taking with another ham in single-sideband (SSB) voice through the satellite. Jot down my call and make note of how well you receive my signal. Look up my mailing address in the Radio Amateur Callbook Magazine (published by Radio Amateur Callbook Inc., 925 Sherwood Dr., Lake Bluff, Ill. 60044). Then mail your SWL QSL card or letter-of-reception report to me. In turn, I would check my logs to make sure you did hear me when I was operating and I would send you my QSL card. It's as easy as that!

The American Radio Relay League (ARRL), in Newington, Conn., a national organization of hams, makes available free to interested teachers a curriculum book for classroom use of Oscar in teaching math, physics, astronomy, communications, electronics and space science. The book explains in elementary language how to use a simple shortwave receiver to teach and learn what keeps a satellite in orbit, what governs its speed and how to use Oscar for many other math and science classroom activities. Thousands of students already have participated in the program.

Students using the educational package learn how to determine the satellite's period (how long it takes to go around the globe), its increment (how many degrees farther west it will be when it crosses the equator the next time) and its inclination (the angle at which the satellite's path crosses the equator).

For more information about the educational programs or how to tune in Oscar, write ARRL, 225 Main St., Newington, Conn. 06111. Other information, such as how you can become a member of the AMSAT organization to be kept up-to-date on wave lengths and orbiting times of Oscars launched in the months and years ahead will be sent to you on request if you write to AMSAT, Box 27, Washington, D.C. 20044. ■

Antennas That Pull Them In!

☐ BEGINNERS to the shortwave listening (SWL) hobby have no difficulty in obtaining good receivers, either budget jobs or gold-plated specials, when starting their first listening shack. Putting up antennas is their downfall.

Antenna theory is beyond the grasp of most novices. It is very complex at the beginning and rapidly becomes incomprehensible as different antenna types are introduced. So, why not take a shortcut approach to your first antenna installation. Get your new receiver pulling weak signals as you pile up listening hours with exotic DXing. What about antenna theory? It'll come if you work at it by reading theory books, but in the meantime here are three recorded case histories to low-cost antenna shortcuts which may be profitable.

Case No. 1—The Dangler. Harry is

a youngster I met while giving a talk to the local high school student body during Science Fair Week. Harry was fascinated by the idea of English language newscasts from far-away places, so he bought a Realistic DX-160 receiver and set up a listening corner in his upstairs room in his folks' Colonial-style house. For an antenna, he dangled an odd length of wire out the window, letting it drop to the ground. The BBC and Radio Moscow came in fine except on rainy nights. In fact, it was a rainy evening when he rang my doorbell for help.

Harry's long wire was long and that's all it had going for it. It was vertically polarized (wrong) by hanging down and shorted out to ground (not good either) on damp nights. What Harry needed was a length of wire extended from the window to a distant pole, outbuilding, garage, or tree. In Harry's case, some sturdy trees outlined the houses's property line and he could run a 60-foot antenna with no difficulties. The antenna pointed due North-West and in his area of the U.S. was able to pull in Europe, North Africa, and the Near East with ease. Here's how we went about licking Harry's problem.

First, I told Harry that a good long-wire antenna should be at least 30 to 100 feet long for good reception performance on 2 to 30 megaHertz (MHz). As mentioned earlier, a 60-foot run was possible. A sturdy tree was selected because it hardly swayed in strong winds at the 20-foot level where the antenna would be secured. Some slack (one foot of droop) was left in the antenna to compensate for tree sway and strong winds. Harry's antenna details can be seen in Fig. 1.

Antenna wire and antenna long wire kits are available everywhere. Harry actually used the Radio Shack shortwave antenna kit (278-758) which consists of 75 feet of bare copper antenna wire, 50 feet of lead-in wire, four insulators, and instructions. Harry had no trouble at all getting the antenna up.

Harry was a little smarter than me. He remembered to protect against lightning. Since shortwave lightning arrester kits are usually not available locally, Harry made do with lightning arrester parts made for TV. The parts available from Radio Shack include the arrester (15-911), ground rod (15-530), 40 feet of aluminum wire (15-035), and other small parts. The TV arrester has two screw-tight terminals with star washers for the 300-ohm TV line, however Harry only used one for his antenna and the other was left unused. The whole lightning installation bit came to about $5.00. That's cheap. To bring the antenna lead-in into the house, Harry used a "Wall-Thru" tube (Radio Shack 15-1200).

Now I don't see much of Harry. Maybe once in a while he's at the Pizza joint with a date, but you can be sure Harry's getting a lot of DXing and veries every week.

Case No. 2—The Specialist. I've known Mort for over 20 years. We knocked about through high school and somehow the paths of our lives are forever crossing. At one such juncture, Mort invited me to his home to see his new shortwave listening shack which sported a brand-new freshly assembled Heath GR-78 receiver. The GR-78 is a hot receiver. Unfortunately, I couldn't say the same for Mort's antenna. Mort was always inclined to specialize, and he had rigged up a dipole antenna with 300-ohm TV antenna lead-in wire. Mort wanted to log the 41-meter band and found it offered poor reception in his area. Besides, the noise was too high. He was asking, if not pleading, for advice.

First of all, I told Mort that dipole antennas are cut to exact dimensions for specific frequency bands as shown in Fig. 2. The dipole consists of a wire of a specific length which is cut in half. At the mid-point and both ends, each half of the wire is insulated from each other and insulated from ground. The lead-in cable from the antenna is actually two wires, and it's best to use a 73-ohm coaxial cable (coax) because it is inexpensive and commonly available. Without getting into theory, let me say that a 73-ohm coax lead-in cable "matches" a dipole antenna with less signal loss than does a 300-ohm TV twin-lead cable. On the design board, dipoles have a 75-ohm impedance and match pretty well into 73-ohm coaxes. The 300-ohm cable Mort was using was a bust.

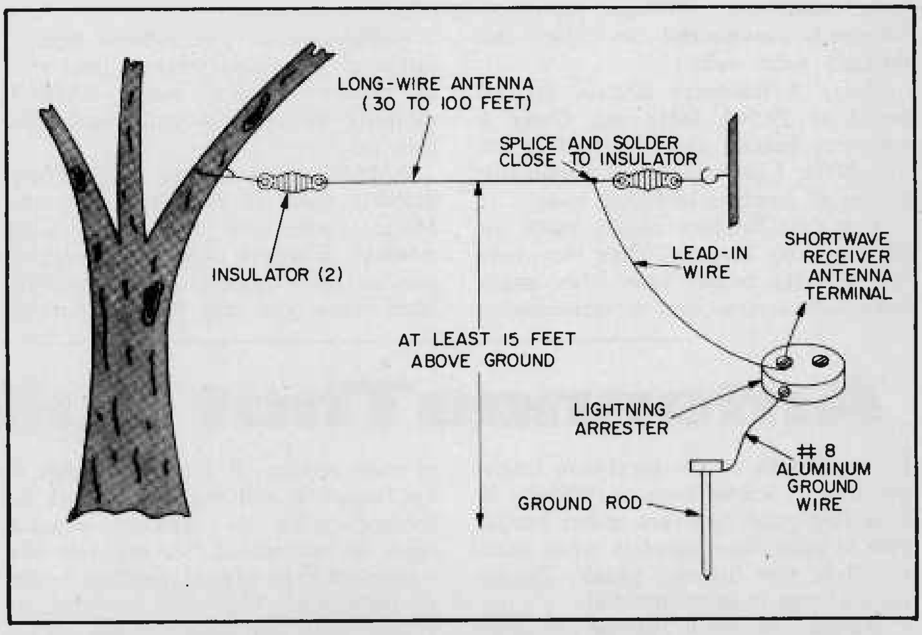
The equation for determining the overall length for a dipole antenna at a given frequency is determined by dividing the given frequency in kiloHertz into the number 468,000. Or, as seen in the text books:

$$L = \frac{468{,}000}{f}$$

Where L is the overall length of the dipole in feet and f is the desired reception frequency in kiloHertz (kHz). I computed the overall length for dipole antennas to receive the international shortwave broadcast bands using the mid-frequencies of each band and listed them in a table that appears on this page.

When buying materials for a dipole antenna, wire and insulators are the same type as required for the long wire antenna. The lead-in coaxial cable should be RG-59/U or RG-11/U, each of which exhibits 73-ohms impedance. Stay away from unknown coax types or those with different impedances (ohms). As a guide, a table given on this page lists commonly available coax cables and their impedances. Any coax exhibiting an impedance in the 70's is good for the purpose. Let price dictate your selection.

I did not forget the lightning arrester in Mort's antenna. At the window, out of reach of the rain, I installed a Radio Shack coax static discharge unit (21-1049). This gadget requires PL-259 connector on the coax lead-in cable. It's worth the trouble. A grounding screw on the connector attaches to the



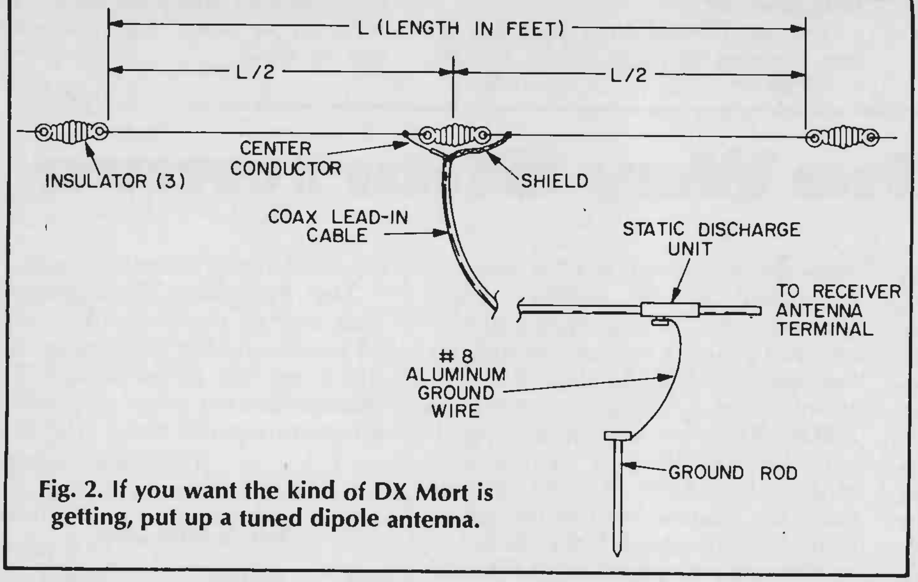


Fig. 2. If you want the kind of DX Mort is getting, put up a tuned dipole antenna.

grounding wire and ground rod. An ounce of prevention can save your home.

A dipole has some bonuses. For example, a dipole works equally as well on frequencies three times the designed frequencies. Thus, a 41-meter band dipole which will pull in 7100-7300 kHz signals will also receive 21300-21900 kHz which covers the 13-meter band. Or, if there is sufficient space to string a 195-ft. antenna for the 120 meter band (2300-2495 kHz), then you could pull in the 120, 41 and 13-meter bands. Of course, if you want all the shortwave bands, then your best bet is a commercial dipole antenna with built-in wave traps.

Don't see much of Mort anymore except at the supermarket. Seems he's a "stay-at-home" type lately. Happy DXing, Mort.

Case No. 3—The Cliff Dweller. Carl is a fun guy to know except when he's upset. For example, Carl drove over on Sunday afternoon to tell me a story he was barely capable of getting out. He had picked up a used Drake SPR-4 receiver at a fantastic price at a flea market and wanted to get involved with DXing in a hurry. It was important to Carl since he teaches French and German, and shortwave DXing would keep his foreign language skills sharp. Unfortunately, Carl lives on the 14th floor of a 24-story apartment house near the city center. His landlord, actually an agent representing the owner, refuses to let any tenant hang anything out of the windows, let alone permit Carl to install an antenna on his patio. In fact, the American flag is taboo.

I heard his sad story and told him to have his lease available when I visited him the following weekend. When I came to visit, I could see that the lease was "ironclad," so much so that it made baseball's reserve clause seem wishy-washy. That was it, no outdoor antenna for Carl.

I did make him somewhat happy by showing him an old trick. I connected the antenna lead-in wire to the metal finger stop on his phone's dialing mechanism. Reception was good considering the construction of the building, which which killed reception even for parts of the AM broadcast band. This was a temporary measure since Carl was soon to get pushbutton phones.

Carl was all set to return to the flea market and unload his Drake receiver. He even told me he had planned to panel his room to give the listening shack a comfortable air, but now he wouldn't. "Now just a minute, before you quit," I said to Carl, "let's give it a try." We swiped his wife's kitchen roll of wrapping aluminum and hung it on the wall with masking tape. Two walls were outside walls, so this is where we placed the foil. Fig. 3 shows what we did. It looked kind of silly until we attached a clip lead from the foil to the antenna post of the receiver. Wow! Carl practically cried as he tuned the bands. His wife practically cried too when she saw the wall but calmed down

Dipole Overall Length for the Shortwave Broadcast Bands

Band	Frequencies (kHz)	Mid-Frequencies (kHz)	Length (feet—inches)
120	2300-2495	2397.5	195—2
90	3200-3400	3300	141—10
75	3800-4000	3900	120—0
60	4750-5060	4905	95—5
49	5950-6200	6075	77—0
41	7100-7300	7200	65—0
31	9500-9775	9637.5	48—7
25	11700-11975	11837.5	39—6
19	15100-15450	15275	30—8
16	17700-17900	17800	26—3
13	21450-21750	21600	21—8

Coax Lead-in Cable

Cable Type	Typical Ohms
RG-11/U	75
RG-59/U	73
RG-59A/U	75
RG-59B/U	75
F-11/U	75
F-59/U	73

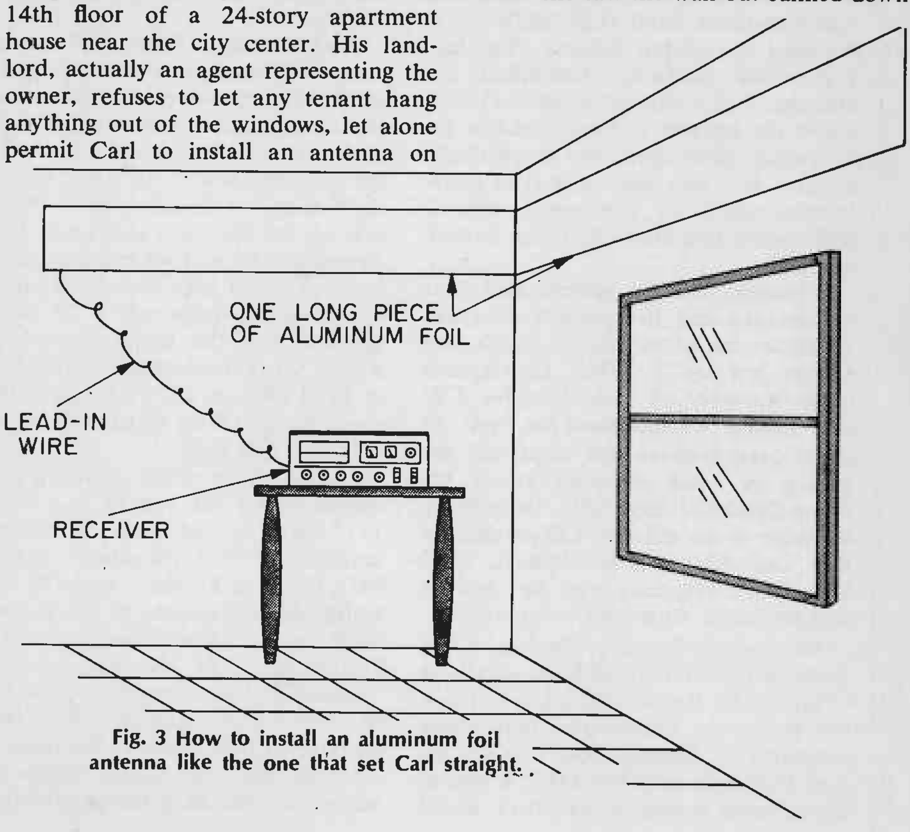


Fig. 3 How to install an aluminum foil antenna like the one that set Carl straight.

once she realized that wall panels were going up. This antenna cost only 59¢ for the aluminum foil and $45 for the wall panel job.

The last I heard from Carl was he was planning to move to the suburbs where he had purchased an old homestead on six acres. I wonder what he had in mind. ■

Out of the Way Shortwave

☐ The frequency range between 2000 and 3000 kHz is a subject of ongoing debate and fascination amongst DXers and SWLs. The questions is, "Should reception here be classified as Medium Wave (the same as the standard AM broadcast band) or as shortwave?" Officially it is defined as Medium Wave but hard-and-fast definitions are too arbitrary to settle this debate, and the real answer lies somewhere between the opposing points of view. Here are five experiments which the reader can carry out with his own receiver which will shed some light on the subject. All the stations discussed, incidentally, just happen to also be fine DX catches.

Latin America. When one talks of comparing 2 MHz with shortwave, one means of course a comparison with the lower shortwave bands; 90, 60 and 49 Meters. No SWL would ever suggest a similarity between 2 MHz reception and that on frequencies above 7 MHz. Also, there is no night of the year during which Latin American signals cannot be heard on every band below 7 MHz down to and including the standard AM Broadcast Band (the "BCB" as it is called by veteran DXers). The factor which primarily determines the amount of LA (Latin American) DX above the equator on each band is interference from upper and mid-latitude stations. It is this relative level of interference you'll be comparing with 2 MHz when checking out Latin American DX.

It should also be remembered that interference and the number of Latin American broadcast signals, both, are always low on 2 MHz. Interference consists mostly of radio-teletype, CW and similar transmissions as well as those coast stations and ships still engaging in voice communications between 2000 and 2850 kHz. Included in the latter is the primary Cuban ship-to-ship and ship-to-shore channel, 2760 kHz. This frequency can be used in making Latin American comparisons.

Most widely heard of the *legal* Latin American 2 MHz broadcast signals is (TGDF) *La Voz de Atitlan,* a missionary station in Guatemala transmitting programs in Spanish and various Indian languages on 2390 kHz. A similar Guatemalan station is (TGBA) *Radio Maya de Barillas,* on 2360. A Mexican educational station, (XEJN) *Radio Huayacocotla,* has also been heard irregularly Saturday evenings on TGDF's frequency. In addition, there is a variety of illegal LA broadcast signals on 2 MHz. These are harmonics of standard AM transmitters. A different crop of BCB harmonics seems to turn up every few months, but one that's been there year after year is YNQ (*El Lider*) at Managua, Nicaragua on 2200 kHz.

Okay, with these basics in mind, you are ready to conduct the first, relatively simple, experiment. Whenever Cuban signals are heard on 2760 kHz, and/or one or more of the broadcast stations listed above, immediately check and determine (1) whether LA shortwave reception has improved, and (2) if Latin American BCB reception has improved. To be scientific about it, keep a list of every night when *two* or more 2 MHz LA signals could be heard (count Cubans on 2760 as one station) and for each night note whether *improved* LA reception spilled over into the frequencies above and below 2 MHz.

Transatlantic. There are no conventional broadcast stations in Europe on 2 MHz. However certain aeradios and coast stations have regularly-scheduled weather broadcasts which serve our purpose almost as well. These include *Shannon Aeradio* (Eire) on 2889 kHz on the hour and half hour, *Prague Aeradio* at 15 and 45 minutes past the hour on 2980 kHz and *Paris Aeradio* on the same frequency at 25 and 55 minutes past the hour, *Shenveningen Radio* (near Rotterdam, Netherlands) at 1800 EST on 2830 kHz, and *Norddeich Radio* (West Germany) on 2614 kHz at 1615 EST.

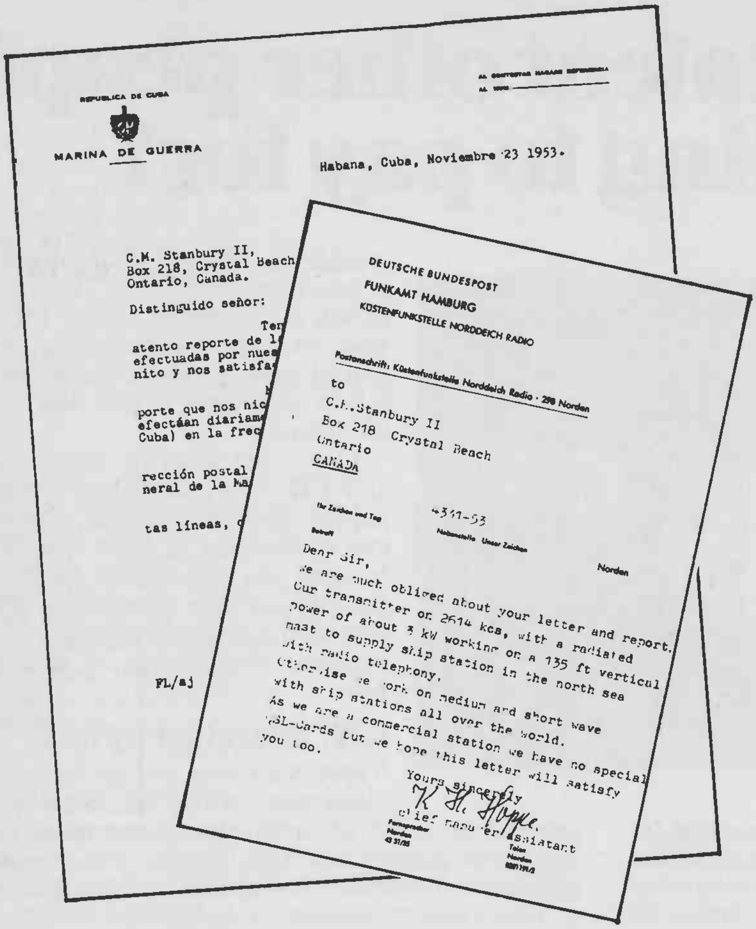
If any of the above are logged, you should spend the rest of that evening (1) checking reception of European aeradios on 5533 (Shannon) and 5557 kHz (Paris & Prague), and (2) monitoring signal strengths of the European BCB regulars (West Germany on 1586, France on 1554 etc.—see the article "Secrets of Split Frequency DX" page 46, September—October, 1976. In describing each of these experiments it is assumed that the reader DXes often enough on the BCB to know what reception he can normally expect.

The Pyongyang Phenomenon. Up until now all the comparisons suggested have been of a very general nature. But if you live in the western U.S. or Western Canada some very exact observations can be made. The first in-

(Continued on page 22)

THE 2 MHz LOG

kHz	Station	Notes
2200	"'El Lider" (YNQ), Managua, Nicaragua	BCB harmonic
2310	China	Home service, exact location unknown.
2336	Rhodesian Broadcasting Corp.	Status uncertain
2360	Radio Maya de Barillas, Huechuetenango, Guatemala	
2390	La Voz de Atitlan, Santiago, Guatemala	
2390	Radio Huayacocotla, Mexico	Irregular
2425	Rhodesia Broadcasting Corp.	Status uncertain
2446	O.R.T.F., Reunion Islands	
2614	Norddeich Radio W. Germany	Coast station
2760	Cuba & International Waters	Cuban coast stations & ships
2830	Schenveningen Radio, near Rotterdam, Netherlands	Coast station
2850	Pyongyang North Korea	
2889	Shannon Aeradio, Eire	
2980	Prague Aeradio, Chechoslovakia	
2980	Paris Aeradio, France	


REPUBLICA DE CUBA

MARINA DE GUERRA

Habana, Cuba, Noviembre 23 1953.

C.M. Stanbury II,
Box 218, Crystal Beach
Ontario, Canada.

Distinguido señor:

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DEUTSCHE BUNDESPOST
FUNKAMT HAMBURG
KÜSTENFUNKSTELLE NORDDEICH RADIO

Postanschrift: Küstenfunkstelle Norddeich Radio · 298 Norden

to
C.M.Stanbury II
Box 218 Crystal Beach
Ontario
CANADA

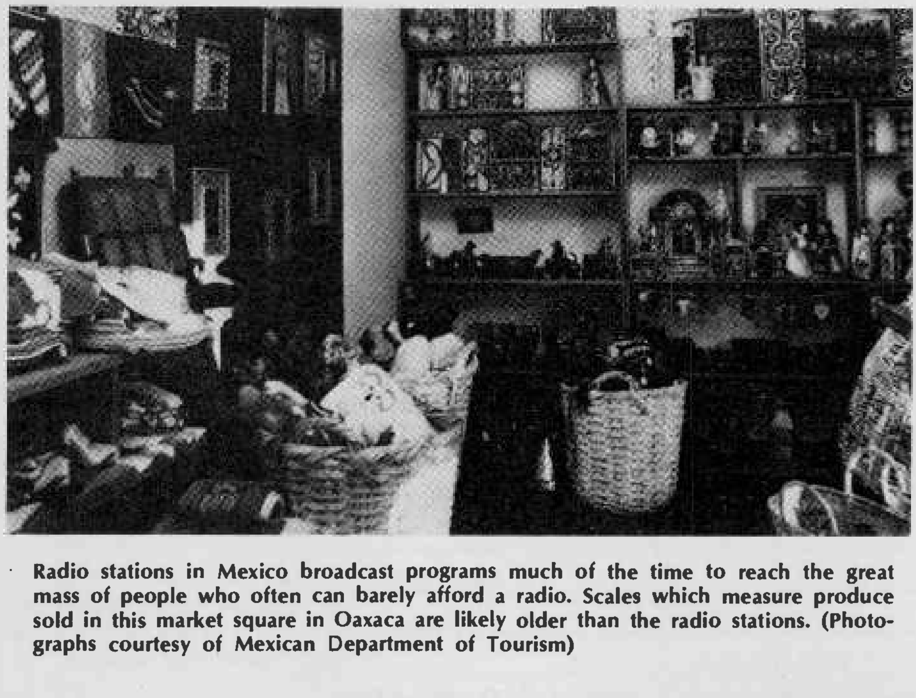
Ihr Zeichen und Tag
Betreff
4341-53
Nebenstelle Unser Zeichen
Norden

Dear Sir,
We are much obliged about your letter and report.
Our transmitter on 2614 kcs, with a radiated
power of about 3 kW working on a 135 ft vertical
mast to supply ship station in the north sea
with radio telephony.
Otherwise we work on medium and short wave
with ship stations all over the world.
As we are a commercial station we have no special
QSL-Cards but we hope this letter will satisfy
you too.

Yours sincerely
K. H. Hoppe
chief manager assistant

Fernsprecher Norden 43 31/35
Telex Norden

Many overseas and Latin American broadcast stations are so unused to receiving reception reports from North America that they don't have regular QSL cards and respond with personally-written letters. Shown here are two such acknowledgements received by the author, one from Cuba, and one from Germany.



Radio stations in Mexico broadcast programs much of the time to reach the great mass of people who often can barely afford a radio. Scales which measure produce sold in this market square in Oaxaca are likely older than the radio stations. (Photographs courtesy of Mexican Department of Tourism)

Shortwave

(Continued from page 18)

volves *Radio Pyongyang* (North Korea) home service transmissions on 6290, 2850 and 655 kHz. The 6290 outlet is a commonly reported logging in western NA but it may surprise many SWLs to learn that the other two frequencies are also often heard during early AM hours, beginning about 0200-0300 PST.

The questions are: (1) on what percentage of good 2850 nights is 6290 reception also improved? (2) on what percentage of good 2850 nights is 655 comparatively better? (3) which percentage is higher? A similar and equally interesting series of tests can be conducted using Radio Peking's home service transmitter on 3450 kHz, a home service outlet on 2310 kHz (location unknown but probably in central China).

More Far East. If, instead of 1040 we substitute Radio Peking's Russian language powerhouse on 1525 kHz (in the central Asian province of Urumchi), then this Chinese trio may be used during late fall and winter for experiments in eastern North America between approximately 1730 and 1900 EST. This sort of eastern NA reception from Asia in that time period during the last few years has been an especially hot topic in DX circles. If nothing else, it has shown that the average shortwave listener, as contrasted to the average BCB DXer, has only the sketchiest understanding of radio.

When the Orient is heard in eastern NA at that time of the day, veteran SWLs tend to refer to it as long path reception—via the south pole. Yet for distant reception to occur on either the BCB or 2 MHz, the great circle path between transmitter and receiver must be entirely in darkness or something close to it. And this is only slightly less true for distant reception on 3 and 4 MHz. Thus reception of our Chinese trio can only be via the north pole (large portions of the long path in daylight), and this opening ("window") to the Orient would theoretically begin at North American sunset and end at Asian sunrise. In practice, the window is probably open a little longer.

It is interesting to note that the station which touched off all this DX discussion, the first 2 MHz Oriental station to be logged at sunset EST, was Pyongyang on 2850 kHz. In view of this, the experimenter might ask, why not make eastern NA comparisons of Pyongyang on 2850 and 655 as west coast DXers can? Well, anytime the reader hears 2850 he should certainly try for Pyongyang on 655 kHz. The difficulty is that this EST sunset/ Korean sunrise window is open for such a relatively short time that both frequencies would have to peak almost simultaneously, probably within 15 minutes of 1700 EST. Even when the same location can be heard at opposite ends of the BCB, for example, Portugal on 655 and 1578 kHz, it is seldom that both frequencies will peak within a few minutes of each other. Further, there is a lot more interference is eastern North America around 655

Pilot Stations. When we suggest you use 2850 to know when to challenge the interference around 655, we are using Pyongyang's 2850 kHz transmitter as a pilot signal. On most days that you hear 2850 around sunset you will not hear 655 but you will *never* log 655 unless you can hear 2850. Even more interesting, pilot station experiments can be performed in the area of trans-equatorial reception. For example, if you can hear ORTF's broadcast station in the Reunion Islands (Indian Ocean, not too far from the African coast) on 2446 kHz at 2130 EST (1830 PST) S/On, you should then try for Radio Zambia's 818 kHz when it signs on around 2200 EST. ■

Calculators Transmit Too!

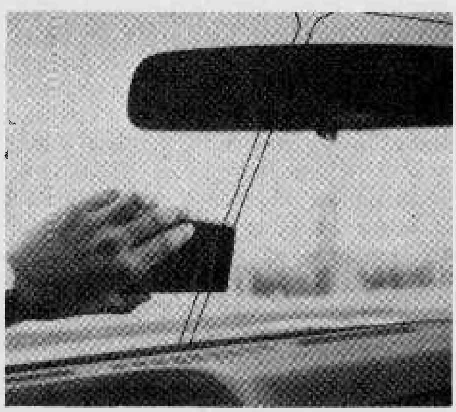
☐ The virtues of portable electronic calculators are by now so well-known and their prices have dropped so low that the units are found almost everywhere. Many presently-available machines—especially those employing LED displays—can be used as quick trouble-shooting aids in addition to performing their usual day-to-day calculating chores. Whenever you need a fast, convenient, and portable amplitude-modulated RF source for equipment checkout, your calculator can often fill the bill.

Here's why. Just about all battery-powered calculators emit strong, wide-band RF signals which extend well up into the tens of megahertz. These signals are generated primarily as side-effects by the operation of two components of the calculator: the power supply's DC-to-DC converter and the multiplexed LED digital readout.

Not every calculator has a DC-to-DC converter. But those operating from two or three penlight or nicad cells usually do, using it to step the low battery voltage up to a higher level more suitable for operating the MOS ICs which do the arithmetic. The converter produces a harmonic-rich square-wave output at a fundamental frequency typically between 20 kHz and 100 kHz—but the harmonics extend well up into the megahertz region.

Even if your calculator is one of those without a DC-to-DC converter, it's still almost certain to use a multiplex system to drive the output digital display. Multiplexing means that each selected segment of the digital readout is rapidly turned on and off many times each second rather than staying on continuously. When this switching is done rapidly enough, the readout appears to stay on all the time because of the relatively slow response time of the human eye. Readout devices are multiplexed for two reasons. First, multiplexing drastically reduces the power required to operate the readout at any given *apparent* brightness level because the readout is actually on and drawing current for only a small percentage of the time. As a consequence, batteries last much longer. Secondly, multiplexing permits a great reduction in the total number of IC's needed to actuate the calculator's readout display with an attending cost reduction at the time of purchase.

With a standard calculator's seven-segment LED readout and anywhere from 8 to 12 display digits, the multiplexing frequency is typically around 100 kHz. When currents of 20 mA or so are abruptly switched on and off through the LED display segments, significant amounts of RF energy at multiples of the multiplexing frequency are generated. These harmonics may extend well into the tens of megahertz. In fact, this harmonic radiation is one of the main reasons there are so few AM clock radios with LED time displays on the market today. The standard AM broadcast band is almost totally obliterated if the receiver's RF sections are within a foot or so of the multiplexed readout display unless extensive shielding is employed. Fortunately, there are two more practical and less expensive solutions than shielding. The first is the addition of resistance-capacitance networks to slow the rise and fall times of the multiplex waveform—and consequently filter out most of the higher-order harmonics. The second method is to drive each display digit directly and not use multiplexing at all. This second technique is much more practical in a clock radio than in a calculator for two reasons. First, clock radio displays normally have considerably fewer digits than most calculators; hence, the circuit problem isn't nearly so complex. And secondly, with a clock operated from the AC power line, the problem of rapidly discharging the batteries unless the output is multiplexed is eliminated. National Semiconductor Corporation has recently introduced a clock chip with direct drive of all readout segments to eliminate RF interference. It was designed with clock radio applications in mind.



One of the many uses for your calculator other than calculating. Here it is being used to check a windshield antenna.

But now back to your calculator, which almost certainly is multiplexed and unfiltered and produces a rich harmonic output. Turn it on and slowly bring it near a standard AM radio which is tuned either to a weak station or between stations. You should hear a mixture of buzzes and tones as the calculator is brought within several inches of the radio or its antenna. These tones probably will shift in frequency if you key different numbers into the display.

Now that you've verified that your calculator is a portable, wideband, RF source, what can you use it for? Well, a number of applications are obvious. Anytime you need a quick check to see if the RF and IF stages of an AM receiver are working, your calculator can provide a test signal. Probably its handiest use, though, is in continuity testing antennas and connecting cables. Auto antennas and their accompanying cables and connectors are easily tested for opens and shorts by bringing the calculator near the antenna while monitoring the radio output. Perhaps the ultimate example of this technique you can perform in your automobile. Place a calculator near the windshield antenna of a late model General Motors car. In cases of poor or non-existent reception, one or both of the two thin antenna wires imbedded inside the glass may be broken. By carefully tracing the path of each individual wire, a break or faulty connection can be located when the radio's output changes abruptly.

And one final thought. Those of you with LED digital watches might experiment with them. The power is much lower, and the metal watch case provides a lot of shielding, but there just might be enough RF coming from the display to be useful. ■

Breaking the TV DX Barrier

☐ In this day of satellite telecasts from all continents, the idea of watching a television program originating from a mere thosuand miles distant doesn't sound too exciting. But how about receiving that same TV signal without the aid of a satellite? Sound interesting? Well, that's what TV-DXing is all about.

Even if you're an "old pro" in DXing circles, you're probably not too familiar with TV-DX. Sometimes it seems like many DXers even doubt that TV-DX is possible. What's surprising to many is that TV-DX is actually quite common! TV-DXers around the world regularly pull in distant video signals from 200 to 2000 miles away. As we'll soon see, a station 1000+ miles distant may actually appear with greater clarity than your local stations!

The real key to successful TV-DXing is not massive antenna systems and exotic equipment (though they help!), it is simply tuning in at the times when DX openings are occurring. Unlike the shortwave or broadcast band DXer, the TV-DXer can't just turn on a receiver on most any day and start DXing. The TV-DXer must carefully survey daily and even hourly conditions, watching for a band opening. When openings do occur, the results can be quite rewarding. Instead of just hearing a distant station, you're actually seeing it as well.

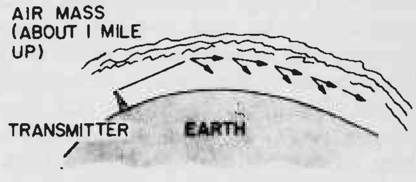
You can greatly increase your odds of catching TV-DX by knowing when and on what channels it's most likely to occur. For this introduction, we'll go into a brief description of the most common forms (or modes) of wave propagation that affect television signals. Don't get worried by the sound of that—wave propagation is simply what happens to a signal from the time it leaves the transmitting antenna until it reaches a receiving antenna. A solid understanding of the basics of V-UHF propagation is essential to the TV-DXer.

The television bands are located in the VHF and UHF ranges of the electromagnetic spectrum. Signals in these bands are much higher in frequency than shortwave broadcast signals and as such are not propagated in the same manner. Layers of the earth's ionosphere that regularly reflect shortwave signals to points thousands of miles distant, normally fail to reflect VHF signals. Under "normal conditions," TV signals travel in straight lines and pass through the ionosphere into outer space. This limits the range of broadcast TV stations to line-of-sight. Broadcasters call the area covered under normal conditions, their coverage area. Typically, the coverage area of a VHF TV station is between 50 and 75 miles. Under *abnormal* conditions, this coverage area can very greatly increase. Stations do not hope for such conditions to occur often or with greater strength. Chaos might result as stations would compete on the same channels.

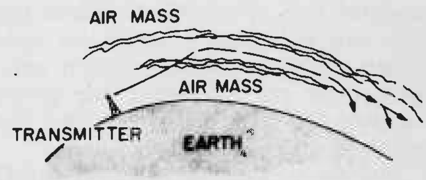
Just what are the "abnormal conditions" that result in TV-DX? They are various changes in the condition of the earth's atmosphere that cause VHF or UHF signals to be bent or reflected beyond the horizon. Different modes of propagation are created by these conditions and they carry signals over varying distances. Certain modes of propagation have very different effects on the range of particular TV channels. Now let's take a close look at each of the common modes of propagation.

Tropospheric Bending. Tropospheric bending, tropo for short, is the most common mode of VHF-UHF propagaiton. Tropo is the only form of propagation that is *directly* related to weather. Frequently dubbed "extended groundwave," tropo extends the range of VHF and UHF signals by 60 to 1000 miles. Distances to 350 miles are common.

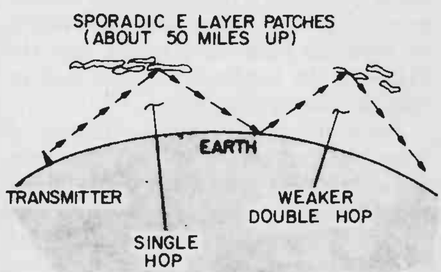
Tropo can occur in several ways, but the influence of a high-pressure area is always required. When a temperature inversion occurs (warm air meeting a cool air mass), a low-level barrier to VHF and UHF signals is formed above the earth. Tropo is most common in early morning and evening when rapid warming and cooling of the air takes place. Fall is considered the favorite season for tropo, but openings are common in the spring and summer as well. In northern regions, tropo is uncommon in the spring and summer but it happens during an unseasonably warm weather period.



Tropospheric Bending causes TV signals on all channels to be "bent" over the horizon.



Tropospheric Ducting occurs when a TV signal (usually UHF) is trapped between two air masses and is "ducted" to a distant point, several hundred to a thousand miles away.



Sporadic E Skip causes signals to be refracted to points 450 to 1400 miles distant on a single hop. On very rare occasions, a signal may bounce off the earth and refract off a second sporadic patch causing "double hop" reception to 2800 miles. Sporadic E normally only affects channels 2-6

Tropo is characterized by steady signals. It usually affects the *highest* channels most. That is, a good opening on UHF *may* produce fair results on the VHF high band (channels 7-13) and poor results on the low band (channels 2-6). Tropo may also affect only a narrow range of channels. When this type of reception occurs, look for some fantastic catches because it's probably a sign of tropospheric ducting. Ducting is aptly termed, as signals become trapped between two air boundaries of different heights. This condition causes TV signals to behave in much the same manner as if they were being fed into a giant metal duct, following the curvature of the earth. A ducted signal may travel a thousand or more miles above the earth before returning down. Ducts are frequency-selective–they will carry only a limited range of channels. This range may include all of the UHF band or only a few channels. Ducts are very unstable and may last for hours or only minutes. Tropospheric ducting is most common in the UHF channels, but also shows up at the VHF high-band channels. A high-performance antenna system is vital for successfuly DXing tropo ducts.

Sporadic E Skip. Frequently called "short skip" by ham radio operators, sporadic E skip (Es) can produce spectacular TV-DX results. Es commonly brings in TV-DX signals from 450 to 1400 miles distant on a single hop (that's short for the ham bands)–frequently with snow-free pictures. This is the same type of skip that produces the summer skip on CB.

Sporadic E skip occurs when a signal strikes sporadic patches of ionization in the E layer of the ionosphere (about 50 miles above ground). The ionized patch refracts the signal back toward a distant point on earth, much in the same way that a mirror reflects a beam of light.

The *lowest* TV channels are affected most by Es. Es will normally appear on channel 2 before it hits 3; 4 before 5, and so on, but is very rarely found above channel 6. Openings frequently occur on channels 2 or 3 that never reach the higher channels. Even more frequently, Es produces activity on CB and the 10 meter ham band without reaching the TV channels. Generally, the stronger openings effect the greatest number of channels. A weak opening may only bring in distant stations on channels 2 and 3. If signals on 2 and 3 are quite strong, skip is likely to also be in on channels 4 and 5.

The best seasons for Es are late spring and early summer, with a lesser peak occuring from mid-December to early January. Best times to look for Es signals are from mid morning to early afternoon and again from early evening to about 10:30 PM, local time.

Strong signals and deep fading characterize Es. Signals are commonly strong enough to be received on indoor "rabbit ears" style antennas! Best results will still be obtained with an outdoor rotatable antenna, but it needn't be very high. Es reception can last for minutes, hours or even days. A typical opening lasts for a few hours and may bring in a half dozen or more distant stations. It's even common for two or three different DX stations to be received on the same channel at the same time.

Frequently check channel 2 for indications of Es openings. If you have a local station there, the DX stations will produce an interference pattern of horizontal black bars, more about this later. If you're using a rotatable antenna, this check should be made with your antenna pointed away from the local station.

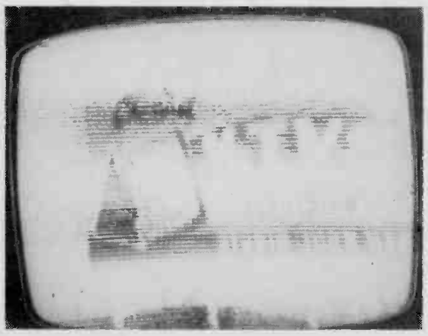
Outside of the seasonal variations, Es is very unpredictable. It is *not* directly related to weather, sunspots or the moon. Little is known but that it makes for exciting TV-DX!

F2 Skip. Every eleven years, sunspot activity reaches a peak. When this oc-

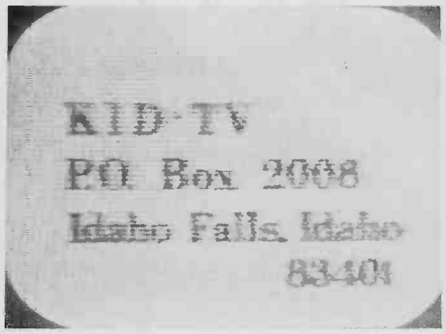
TV-DXing can sometimes turn up some real surprises, like reception of this experimental station operated by Zenith on UHF-TV channel 38.

WKEF-TV, channel 22, in Dayton, Ohio, received by Tropospheric Skip at 260 miles.

990 mile E Skip at a distance of over 1250 miles. Reception of this channel 3 staion is common most summers.



830 mile E Skip reception of KTVS-TV, channel 3, Sterling, Colorado. Both zero and 20 kHz offsets appear in this picture.



KID-TV received by E Skip at a distance of over 1250 miles. Reception of this channel 3 station is common most summers.

Meteor Scatter reception of WMAR-TV, Channel 2, Baltimore, Maryland, 725 miles.

curs, the radiation projected from the sun builds up the density of the F2 layer of the ionosphere. This layer is about 200 miles up, much higher than the E layer. If sunspot activity is great enough, the F2 layer becomes dense enough to refract signals on the lowest TV channels. Because the F2 layer is so high, distances covered are seldom less than 1700 miles. The world's TV-DX record was set by F2 skip in 1957 when George Palmer of Williamstown, Victoria, Australia, received BBC-TV from England over a 10,400 mile distance.

Sunspots, in fact, affect all of the communication services to some degree. The last cycle resulted in much "skip" on the CB frequencies along with prolonged openings on the ham 10 meter band.

The next sunspot maximum will be reached around 1979-1980. As the intensity of sunspot cycles varies, we can't yet predict whether activity will again be great enough to produce transcontinental TV-DX. During the most recent cycle, I received the audio of TV transmitters in France and England. The video signals for these channels are on slightly higher frequencies and were not received. The last cycle was no where near as intense as the previous cycle which produced George Palmer's record catch. In the late fifties, several US TV-DXers received almost daily reception from European TV stations on modified TV receivers.

Meteor Trails, Lightning and the Northern Lights. The ionization produced when a meteor burns up from friction as it enters the atmosphere, does a good job of reflecting TV signals. Meteor trails last only a short time, so they produce very brief "bursts" of TV-DX. Meteor bursts commonly last from a fraction of a second to four or five seconds. Bursts may also appear in clusters, permitting reception for thirty seconds or more.

If you watch for meteor scatter when TV stations are running their test patterns (typically 4 to 8 AM local time), a second or two of reception can be long enough to identify (ID) your DX catch. With a good outdoor antenna, a great many meteor bursts can be seen on channels 2-6. For results on channel 7 or above, a very elaborate antenna system must be used. As most meteors burn in the E region of the ionosphere, distances are somewhat similar to Es, but somewhat shorter—500-900 miles. Meteor scatter occurs literally every day, but results are best during meteor showers. A list of major meteor showers can be found in most almanacs or *The Radio Amateur's VHF Manual*, published by the American Radio Relay League.

Sometimes, when an intense lightning storm is between a DXer and a UHF TV station (200-500 miles away), signals can be reflected by the lightning strokes to produce TV-DX. Signals burst in much as if propagated by meteor scatter. NEVER attempt to DX while a storm is in your area—wait until the storm has passed. When the storm is safely out of your area, point your

EXPOSURE TABLE
(Suggested Camera Settings for Pictures of Television Images)

Film (Use)	Black-and-White Television Set		Color Television Set	
	Leaf-Type Shutter	Focal-Plane Shutter	Leaf-Type Shutter	Focal-Plane Shutter
Verichrome Pan Plus-X Pan (Black-and-White)	1/30 sec f/4	1/8 sec f/8	1/30 sec f/2.8	1/8 sec f/5.6
Tri-X Pan (Black-and-White)	1/30 sec f/5.6-8	1/8 sec f/11-16	1/30 sec f/4-5.6	1/8 sec f/8-11
Kodacolor-X (1) (Color Prints) Kodachrome-X (1) Ektachrome-X (1) (Color Slides)	1/8 sec f/2.8 or 1/15 sec f/2	1/8 sec f/2.8	1/4 sec f/2.8 or 1/8 sec f/2	1/4 sec f/2.8 or 1/8 sec f/2
High Speed Ektachrome (1) (Daylight)—with Normal Processing ASA 160 (Color Slides)	1/15 sec f/2.8-4	1/8 sec f/4-5.6	1/8 sec f/2.8-4	1/8 sec f/2.8-4
High Speed Ektachrome (1) (Daylight)—with ESP-1 Processing for a Speed of ASA 400 (Color Slides)	1/30 sec f/4	1/8 sec f/8	1/30 sec f/2.8	1/8 sec f/5.6

NOTE: When two lens openings are given, such as f/4-5.6, lens setting is midway between these stops.

(1) Pictures of color television taken without a filter will look blue-green. With the color films in the table, you can use a Kodak color compensating filter, CC40R, over your camera lens to help bring out the reds in your pictures. Increase the exposure suggested in the table by 1 stop.

CLUES TO IDENTIFYING AN UNKNOWN STATION

- Channel
- Network
- Local Commercials
- Local Public Service Announcements
- Antenna Direction
- Offset Frequency
- Propagation
- Other Stations Received About the Same Time
- Recognition of Local Weather Map, Announcer, Logo, etc.
- Time Zone (Caution: Some stations delay broadcasts, causing them to appear to be in a different time zone.)

QSL Information Card

WQLN-TV

Channel 54 Erie, Pa.

Effective Radiated Power: **915 kw**

Carrier Frequency: Visual **711.26 mc** Aural **715.76 mc**

RECEPTION CONFIRMATION

Date	Program	Time
1/20/69	Test Pattern	8:58 EST

antenna at the storm and tune around the UHF dial. Results will be best if you are looking for a particular station that appears to be within range.

The Northern Lights (aurora) can also produce TV-DX results. TV signals are sometimes scattered by the auroral curtain to produce very fluttery reception. Distances covered can extend to several thousand miles. Most often however, signals are so garbled by auroral flutter that they are impossible to identify. Auroral scatter is most common in the years close to and following a sunspot maximum. This form of DX is most common in Northern areas and is rarely observed south of the Mason-Dixon Line. All of the low- and high-band channels are affected, but chances for IDs are best on the low channels.

What Equipment Is Necessary For TV-DXing? A surprising amount of TV-DX can be observed on a simple antenna system, however the serious DXer must employ a high-performance installation. Of prime importance is that a TV set in top working order be used. The set should be sensitive and selective (eliminating low-end budget sets with only two video IF stages), and should be capable of locking sync on a weak signal. In other words, a weak signal should not roll vertically or lose horizontal sync. Many DXers have found that sets with screen sizes of 19″ or smaller are easiest to DX with. Either a color or a monochrome set will do fine.

Most active TV-DXers use separate VHF and UHF antennas. The antennas must be rotated by an accurately calibrated antenna rotor. The best consumer UHF TV antennas are of the 7′ parabolic dish variety. The best such antenna is probably still the Finco P-7. If a large dish antenna cannot be used, other "fringe area" designs can still provide good results. A talk with your local distributor or antenna service should probably provide some helpful advice.

A UHF antenna should always be mounted as high as possible. In metropolitan areas, a minimum of fifty feet above ground may be necessary to provide acceptable results. A good quality low-noise UHF preamp will also be quite helpful. A preamp of this type is mast mounted at the antenna and fed by a remote power supply indoors. Two excellent UHF preamps are the Blonder-Tongue CMA-Ub and the Winegard AC-4990. The Winegard unit is less likely to "overload" in a strong signal area, but has less gain than the Blonder-Tongue CMA-Ub. Again, consult a local expert for your best choice.

For VHF, a large fringe area broadband Yagi or log-periodic design antenna should do the job well. Channel Master VHF antennas have long been popular with TV-DXers, but all of the major antenna manufacturers make antennas of this type. Height is somewhat less important for the VHF antenna, though it should be clear of surrounding obstacles. Unless you live 'way out in the sticks and away from strong local stations, don't use a mast mounted VHF preamp. Most tend to overload badly when used in strong signal areas.

As we said a bit earlier, a good antenna rotor is essential. An outdoor antenna that cannot be rotated is of almost no value to a DXer. Make sure that you use a rotor that's strong enough to handle a large TV antenna array. It's a nasty feeling to have a rotor fail during a DX opening!

If you're one of those unfortunate DXers that can't use an outdoor antenna, don't despair—when the bands are open, there'll still be plenty for you to see. You can improve your results by using adequate antennas. For VHF, stick with the old reliable rabbit ears. Expensive and elaborate looking rabbit ears usually don't work any better than the $3 or $4 kind. Some DXers have found it convenient to use a small outdoor style antenna, indoors. Mounting such an antenna on a pole lamp is a handy trick.

For UHF, forget about that little loop that came with your TV set and buy a small outdoor UHF antenna. The Blonder-Tongue Golden Dart would be an excellent choice. The same UHF preamps we recommended for outdoor use should be useful here as well. If you live on an upper floor of a high-rise building, you can most likely pull in excellent UHF DX with a modest indoor antenna system.

Now on to DXing. TV-DXing, especially for beginners, requires a good deal of patience. It's strange, but a beginner frequently watches carefully for a long while before catching a good opening, then suddenly starts seeing many openings. This usually means that the DXer is getting accustomed to spotting signs of an opening. You'll also get used to quickly recognizing what mode of propagation you're receiving. After a bit of DXing, you'll recognize the characteristics of each mode.

While DXing, you should have on hand an accurate listing of US, Canadian and Mexican TV stations. If you live in the South, a list of Central American stations will also likely be helpful. White's Radio Log in *Communicaitons World* is a good start for US and Canadian stations, but an even more detailed list is best. One of the most useful references available is the *WTFDA TV Station Guide* ($5 pp from the Worldwide TV-FM DX Association, PO Box 163E, Deerfield, IL 60015). The *Guide* is a comprehensive reference of North and Central American television station data. Features include maps (by channel) showing the call letters, location, network and offset frequency (more about this latter) for almost every TV station in the Western Hemisphere. The respective station lists provide additional data including city of license, state of transmitter location (if other than state of license), whether or not the station is a "satellite" of (rebroadcasts) another station, originating station for the satellite, antenna height, effective radiated power, and even what edition of *TV Guide* lists the station's program schedule. When trying to identify a DX station, there is no substitute for detailed station information. Information of this type will also help you spot what other stations are in the same region as a DX station you've identified. This will help you make the most of the opening.

Identifying DX Signals. As in other areas of DXing, identifying a DX signal is not always as easy as we might like. Signals may fade before a station break, or be buried under another station's signal. Frequently however, enough bits of information can be observed that will help you identify the mystery signal without actually seeing an ID slide.

The Table illustrates some of the common clues that can help you ID an unknown station. If enough clues point to one station, you *may* have solved the mystery. One of those clues is called "offset frequency." This frequency indicates whether a station is assigned to operate exactly on channel, 10 kHz high in frequency or 10 kHz low. Stations around the country are staggered in offset frequency to minimize interference between them. When one station does interfere with another on the same channel, an offset pattern of horizontal black bars is created on the receiver's TV screen. When a station with a +10 kHz offset frequency interferes with a 0 offset station, a 10 kHz offset pattern appears (about 10-15 black bars). If a +10 kHz offset station interferes with a −10 kHz offset station, the difference is 20 kHz, producing a pattern of many fine horizontal lines. Two stations of exactly the same offset produce a zero offset pattern of 5 or 6 thick black bars.

As long as you definitely know the

identity of one of two stations being received on the same channel, you can refer to your station list and determine its offset frequency. If that frequency is + or −10 kHz, you can readily determine the offset frequency of the unknown station. If your known station is a zero offset and a 10 kHz offset pattern is observed, the unknown station may have either a + or −10 kHz offset frequency. Unfortunatley no offset list is 100% accurate, so offset patterns alone won't identify an unknown station.

Only you can decide whether you have enough data to identify an unknown station. Carefully analyze the information you know about the station. If all else fails, write to the station's chief engineer or program director and ask whether they think you received their signal.

Photographing your DX. You can get an "instant QSL" by photographing the ID slides and test patterns of the TV-DX stations you receive. It's not too difficult to get results comparable to the photos in this article. Many DXers get by with simple box cameras, but you'll need a camera with adjustable exposure and speed settings for best results. Your camera should be mounted on a tripod or steadied on a firm surface. For starters, try a setting of 1/30th second at F/5.6 using Kodak Tri-X film. Never a flash! Be sure to properly sight the camera so that the entire screen is in the frame.

Kodak has prepared an excellent 8-page booklet entitled, "Photographing Television Images," and it's available free of charge by writing to the Eastman Kodak Company, Consumer Products Division, Rochester, NY 14650. Ask for Customer Service Pamphlet AC-10. This booklet covers the use of color and black and white film, and even describes how to take movies of your DX.

QSL Cards and Letters. Most TV stations will verify your reception by letter or QSL card. Reports should be addressed to the Chief Engineer and include full details of the programming, commercials, and announcements you received. Response will be best if you include a self-addressed stamped envelope.

TV-DXing in England. If you'd like to see what TV-DXing is like in England, a new third edition of *Long Distance Television* is now available from Weston Publishing, 33 Cherville Street, Romsey, Hants SO5 8FB England, for $3 postpaid.

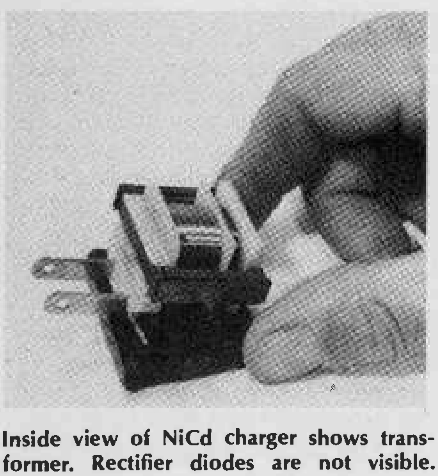
TV-DX Club. For almost ten years, one non-profit organization has been serving TV, FM and public service band DXers—The Worldwide TV-FM DX Association (WTFDA). WTFDA publishes station guides, booklets, log pages, and other supplies for DXers. Most importantly, WTFDA publishes the monthly *VHF-UHF Digest*, featuring columns reporting DX received by members, new station news, and theory, construction and feature articles.

A sample copy of the *VHF-UHF Digest* and full information about the club is available for 75¢ or information only, for a self-addressed stamped envelope. A one year membership is $11 in the US and Canada and $18 overseas. A booklet entitled, *"Beyond Shortwave. . . . An Introduction to TV, FM and V-UHF Radio DX,"* is $1.25. You can write to WTFDA at PO Box 163E, Deerfield, IL 60015. ■

Charging With New NiCad

☐ Do the batteries in your pocket calculator poop out just when you're calculating your share in the family's million dollar lottery ticket? Did the flashlight fail in the middle of the last power failure? Or maybe you're not a stockholder in Burgess or Eveready, and you're tired of the endless purchase of batteries for those never-ending battery-powered devices you get as gifts.

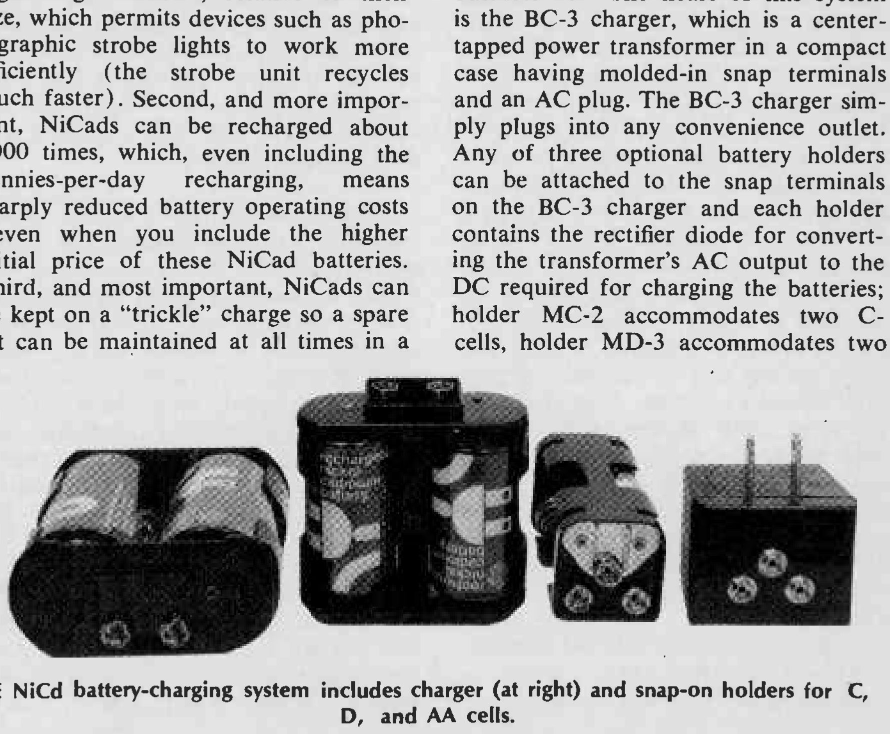
Whatever your battery problems, many of them can be solved by General Electric's latest *Ni-Cd* (NiCad) battery system.



Inside view of NiCd charger shows transformer. Rectifier diodes are not visible.

NiCad Advantages. As you know, NiCad (nickel cadmium) batteries (or cells) have three important characteristics: First, NiCad can deliver very high surge currents, relative to their size, which permits devices such as photographic strobe lights to work more efficiently (the strobe unit recycles much faster). Second, and more important, NiCads can be recharged about 1000 times, which, even including the pennies-per-day recharging, means sharply reduced battery operating costs —even when you include the higher initial price of these NiCad batteries. Third, and most important, NiCads can be kept on a "trickle" charge so a spare set can be maintained at all times in a fully charged, ready-to-use condition.

The General Electric system gives you the most convenient way to utilize NiCad batteries for home, office and business use. The heart of this system is the BC-3 charger, which is a center-tapped power transformer in a compact case having molded-in snap terminals and an AC plug. The BC-3 charger simply plugs into any convenience outlet. Any of three optional battery holders can be attached to the snap terminals on the BC-3 charger and each holder contains the rectifier diode for converting the transformer's AC output to the DC required for charging the batteries; holder MC-2 accommodates two C-cells, holder MD-3 accommodates two



GE NiCd battery-charging system includes charger (at right) and snap-on holders for C, D, and AA cells.

D-cells, and holder MA-1 accommodates four AA-cells.

The BC-3 charger always charges at least two NiCad cells—it cannot handle just one, as the circuit continuity is made through the two cells in the holder. When AA NiCad cells are charged the holder's snap terminals automatically provide the proper connection for two cells and the correct charging current.

How to Stay Charged Up. All NiCad batteries take 16 hours for full charge and can be left permanently on charge to keep a fresh set available. Both the C and D cells take the same charge rate and have the same capacity of 1.2 ampere-hour, so if you use the cells in a homebrew project you can use C-cells to conserve space with no reduction in available current capacity in comparison to the D-cells.

Each item is available as an individual component so you buy only what you need. Presently, the NiCad battery holders are blister packaged with two C, D, or AA cells. The cells are also available individually so once you have the charger and basic holder/battery package there is no additional expense other than for the batteries themselves.

The GE NiCd battery system, as well as extra cells, are sold nationally. ■

Broadcast Band DX

☐ It's a safe bet that if you're into electronics at all, you have fooled around with DX (long distance) reception of medium wave AM broadcast stations. And you probably thought it quite an accomplishment when a station from the opposite side of the continent showed up on your dial, at least until you heard about other DXers who have logged 50 or more countries on the regular AM broadcast band. How do they do it? Simple, they chase stations from the other side of the continent which lie between some of the 10 kHz channels assigned to U.S. broadcasters by the FCC. For example, if this evening you tune to 1265 kHz, chances are at least 50/50 you will hear *Radio Paradise* on tiny St. Kitts in the West Indies—because no other station in the world operates on that same frequency!

Caribbean Mini-States. St. Kitts is one of nine "associate states" which formerly made up the British Leeward and Windward Island colonies. Britain still controls their defense and foreign policies but all "states" have the power to license radio stations—and on split frequencies if they wish. Needless to say, any group interested in reaching an international audience on the AM broadcast band in this part of the world is likely to approach one or more of these governments for permission to set up a station. Since Caribbean locations are not bothered by ionospheric disturbances, they are especially attractive as broadcasting sites. In fact tropical locations *benefit* from such disturbances because they reduce interference from upper and mid latitude stations.

Radio Paradise is an American-owned religious station: a great deal of the money going into international broadcasting all over the world these days is raised by evangelical organizations. *Radio Paradise* broadcasts entirely in English and its schedule includes a number of programs also heard on U.S. AM broadcast and shortwave stations. The operation began in the mid 1960s as PJD2 on the Dutch island of St. Maarten with 5 kw. It switched to the present 50 kw St. Kitts transmitter just before Christmas of 1972 and, according to a report aired by *Radio Sweden,* a further power boost is now in the works. If that happens, U.S. stations on 1260 and 1270 kHz may have something to complain about.

A second split-frequency station which the novice DXer can look for is *Caribbean Radio Lighthouse* at St. Johns, Antigua on 1165 kHz. This is another religious station which went on the air with 10 kw late in the summer of 1975. It should be especially good in the east except in the Wheeling, West Virginia and Montgomery, Alabama areas.

Both *Radio Paradise* and *Caribbean Radio Lighthouse* are audible in many parts of the U.S. on the simplest of receivers. But if you own a communications-quality receiver, or something approaching it, you should also try for *Radio Grenada* on 535 kHz, *Radio Dominica* on 595 kHz, *Radio Montserrat* on 885 kHz, and *Radio Anguilla* on 1505 kHz. Each of these stations is owned by its respective government.

Central America. Another major split-frequency operation in this hemisphere with extensive English language programming is *Radio Belize* on 834 kHz. Although it has only 20 kw as compared with *Radio Paradise's* 50 kw, *Radio Belize* is just as widely heard because there is less adjacent channel interference. At night in the continental U.S. and Canada, DXers only have to contend with WCCO, 830 kHz, Minneapolis, and WHAS, 840 kHz, Louisville. Belize is the former colony of British Honduras and currently a British dependency, as are the Caribbean mini-states. Belize would be fully independent if it were not for neighboring Guatemala's claim to the territory. Because of this situation, *Radio Belize,* a government station, could provide some very newsworthy listening in the near future.

But the most interesting split-frequency station of all is the one now calling itself *Radio Million.* The station is well-named as it uses a million watt transmitter near San Jose, Costa Rica and is the most powerful standard broadcast station in the western hemisphere. Its story began in the mid 1960s when a Texas broadcaster purchased pioneer San Jose station *La Voz de La Victor* and contracted with Continental Electronics (best known as a supplier of high-powered transmitters for military purposes) and its Costa Rican subsidiary ELCOR for supply and con-

Glossary of DX Terms

DX—Distant and/or difficult to hear radio stations.

DXing—Listening to such stations as a hobby.

Medium Wave—The band of frequencies found on your regular AM radio dial, 540 to 1600 kHz.

Split Frequency—The frequencies between the 10 kHz channels assigned by FCC for use by U.S. broadcasters.

Communications Receiver—A receiver designed for reception of voice or code signals from stations operating in the various communications services from 1.6 to 30 MHz, i.e. marine radio, point-to-point, land mobile, amateur and international broadcasting.

Adjacent Channel Interference—Undesired signals received on one frequency from a transmitter operating on a frequency immediately above or below.

Ionospheric Disturbance—Change in the part of the earth's outer atmosphere (ionosphere) that affects transmission and reception of radio signals.

QSL—A card or letter used to confirm listener's reception reports. Also exchanged by radio amateurs to confirm contacts with each other.

struction of the present megawatt outlet. *La Voz de La Victor* tested its newly acquired super power for about three years entirely in Spanish and without any visible means of support such as commercials or listener supported religious programming. At the end of 1969 some English religious programming was aired on a trial basis, then the whole operation disappeared from sight.

But during the first half of this decade ELCOR continued to hold down 625 kHz with its own station, *Radio Omega,* which first used 2.5 kW and then a 50 kW transmitter, while Continental tried to negotiate the sale or lease of the megawatter. As "Omega" means the end, or the ultimate, *Radio Omega* was certainly well named in light of what came next. *Radio Million* made its first official broadcast this year during the early a.m. hours of March 8. It was a test conducted in cooperation with two DX organizations, the International Radio Club of America and the National Radio Club. The broadcast consisted of ID tapes in English, Spanish, and Portuguese.

SPLIT SIX SPECIAL

The first half dozen split frequency stations that every novice DXer should concentrate on first.

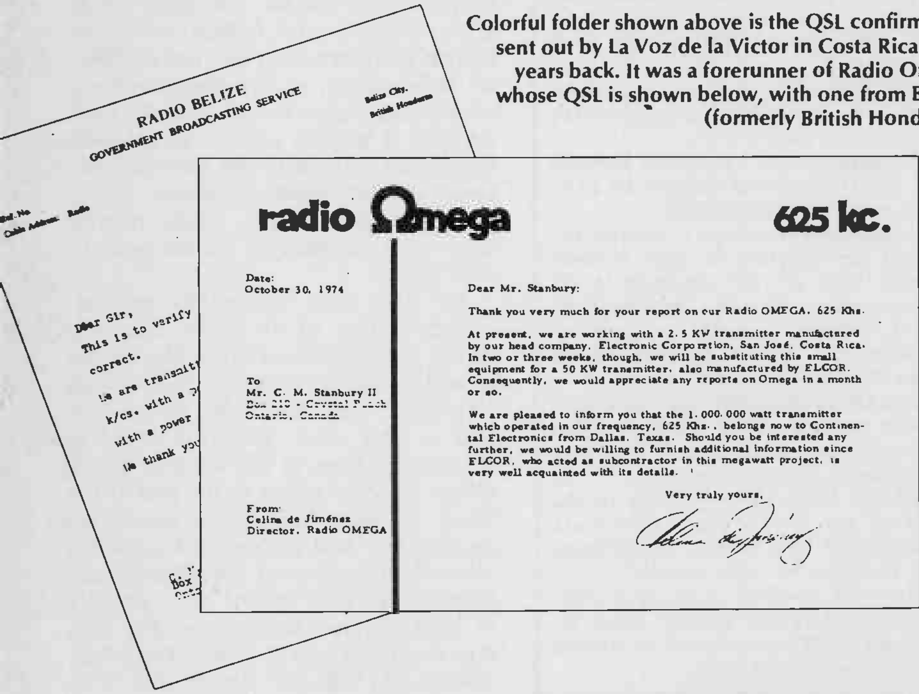
East of the Mississippi kHz	Station	West of the Mississippi kHz	Station
625	Radio Million, San Jose, Costa Rica	625	Radio Million, San Jose, Costa Rica
834	Radio Belize, Belize City	655	Radio Nacional de El Salvador, San Salvador, El Salvador
1265	Radio Paradise, Basse Terre, St. Kitts	655	Pyongyang, North Korea
1525	Radio Peking, Urumchi, China	834	Radio Belize, Belize City
1554	Radio France, Nice, France	1265	Radio Paradise, Basse Terre, St. Kitts
1586	Western Germany Radio, Langenberg, G.F.R.	1475	Voice of Malaysia, Sabah, Malaysia

This was a major milestone in DX history. It is the first time that a million watt standard AM broadcast station is known to have put on a program especially for DXers. In 1971 a similar transmission from *Voice of America,* Okinawa on 1178 kHz was reported, but *VOA* subsequently denied making any sort of special transmission for a radio club. What happens now with *Radio Million?* Tune in and find out.

More Latin American Splits. Even with only 2.5 kW, *Radio Omega* was occasionally heard in Canada and the U.S. on communications quality receivers. And when it went to 50 kW, *Radio Omega* became almost as widely heard as *Radio Paradise* and *Radio Belize*. The truth is that there are so many Spanish speaking split-frequency stations which you might log that we could fill a book with them. Elsewhere in Central America, for example, you could go after *Radio Nacional de El Salvador* on 655 kHz, *Radio Aeropuerto Internacional,* San Pedro Sula, *Paraiso,* at Paraiso (pronounced "Para-ee-so"), Honduras on 1163 kHz, after *Caribbean Radio Lighthouse* signs off at 2100 EST, and until *Radio Paraiso* itself goes off at 2200 EST.

In South America one can DX all the way to the equator, and beyond, depending upon your receiver. Some of the better prospects include *Radio Nacional del Peru* at Lima on 854 kHz (a potential Latin American hot spot), *Radio Suceso* Guayaquil, Ecuador on 995 kHz, and *Radio Caaguazú,* Coronel Oviedo, Paraguay on 645 kHz. The later operates all night.

Transoceanic DX. We have already mentioned the *VOA's* 1178 kHz Okinawa megawatt transmitter, and this can be heard on the west coast of North America with a comparatively good receiver. But there are other powerful Honduras on 1085 kHz, and Radio Asian splits which can be heard on much simpler receivers. Topping the list are the North Korean outlets on 655 and 877 kHz. The power for these is unknown (the Pyongyang government



Colorful folder shown above is the QSL confirmation sent out by La Voz de la Victor in Costa Rica a few years back. It was a forerunner of Radio Omega, whose QSL is shown below, with one from Belize, (formerly British Honduras).

won't even verify their reception) but it is probably somewhere in the 500-1000 kW range. Others to watch for include the Soviet home service relay at Vladivostok on 1376 kHz, and the 600 kW, 1475 *Voice of Malaysia* relay broadcasting to the Philippines and Indonesia from the Malaysian state of Sabah on the island of Borneo.

Okinawa, North Korea and Vladivostok have probably been logged in eastern North America but circumstances were such that none of the DXers involved (including the author) were able to positively confirm what they heard. But one far east split which is definitely heard east of the Mississippi around sunset is *Radio Peking's* megawatt relay in western China (Urumchi state) which beams programs to the Soviet Union on 1525 kHz. The Russians operate several high powered transmitters of their own around 1525 kHz designed to interfere with *Radio Peking* and these are also heard in North America.

Finally, there are at least three European splits which regularly punch their way through to east coast AM dials. They are West Germany's *Westdeutscher Rundfunk* (WDR) 800 kW transmiter at Langenberg on 1586 kHz, the 300 kW *France-Inter station* at Nice on 1554 kHz, and *Emisora Nacional de Radiodifusao* at Lisbon, Portugal with 135 kW on 665 kHz. These three stations operate all night European time which means they might be heard anytime during the evening EST —depending again, as with all split-frequency DX, upon the listener's local interference picture. ■

Basics of Electricity

☐ ONE OF THE MOST thought-provoking discoveries of modern physics is the fact that matter and energy are interchangeable. Centuries of scientific head-scratching 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 utilizing 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 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. How-

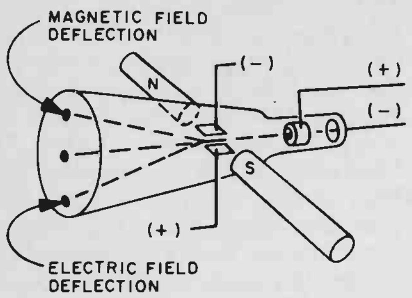


Fig. 1. Electron beam, like that in a TV picture tube (CRT), can be deflected magnetically or by an electric field. Force needed "measured" the electron.

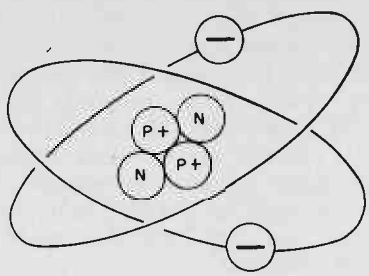


Fig. 2. Charge of each electron balances that of a proton. Other particles affect atomic mass but can be ignored in study of electronics.

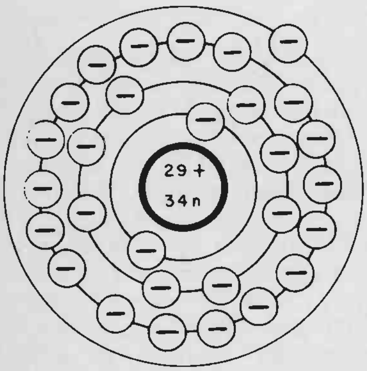


Fig. 3. The number of electrons to each ring are limited—2 in first; 8 in second; 18 for the third; and a total of 32 in fourth orbital ring.

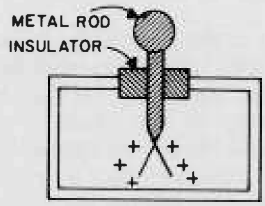


Fig. 4. Electroscope is a simple device to indicate electrical charges that are too weak to be measured with standard meters.

ever, 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 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)

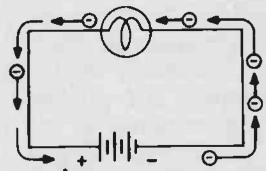


Fig. 5. Electron flow in any circuit is from negative to positive.

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 chages 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 6,240,000,000,000,000,000 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 current 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.

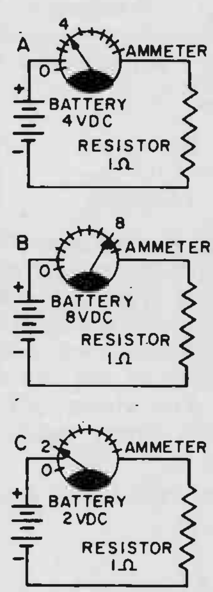
In Fig. 6C the same circuit appears again; this time, however, the battery voltage is one half its original value. The ammeter shows that one half of the original current, or 2 amperes, is now flowing in the circuit. This shows us that halving the voltage applied to the circuit will halve the current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

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

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.



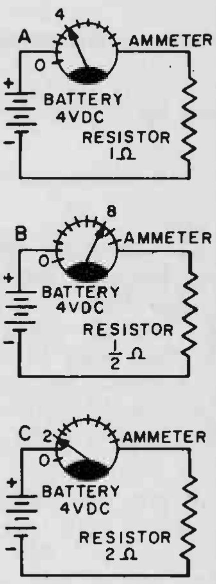


Fig. 7. Battery voltage A, B, and C is held constant while resistor is halved and doubled in value. Resulting current changes are basis for Ohm's law.

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 voltage 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 (voltage) = I (current) × R (resistance)
To find current:

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

To find resistance:

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

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 × R or $\frac{E}{I}$, respectively.

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 voltage 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?

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

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

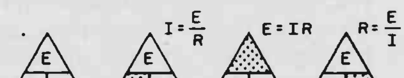


Fig. 8. Shaded portion of triangle indicates unknown quantity in the formula. Visible factors appear in their proper mathematical relation. Just fill in the known values and go on with multiplication or division.

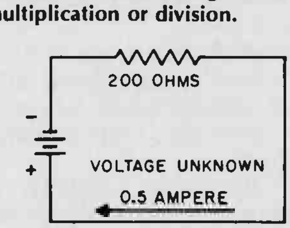


Fig. 9. Unknown quantity, voltage, found easily by applying Ohm's law.

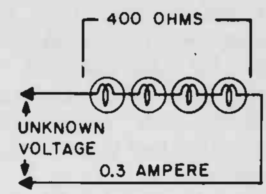


Fig. 10. Although problem looks different the basic circuit is same as that for Fig. 9.

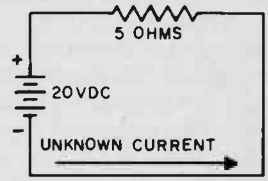


Fig. 12. Basic circuit is same as that in Fig. 11. Although three factors are given, current is unknown quantity.

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

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 line 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.

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

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

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:

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

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

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

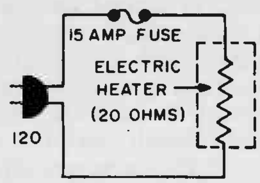


Fig. 11. Formula needed here is different since current is unknown. Just look for triangle in Fig. 8 that has I shaded.

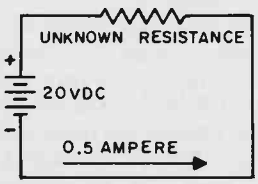


Fig. 13. Most Ohm's law problems are simple series circuits or can be reduced to simple series circuits.

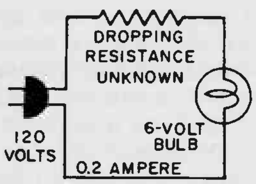


Fig. 14. This Ohm's law problem is somewhat more complex.

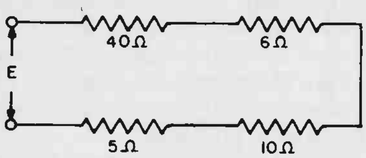


Fig. 15. Resistance in series is added. As far as voltage applied and current flow is concerned the individual resistors are only one.

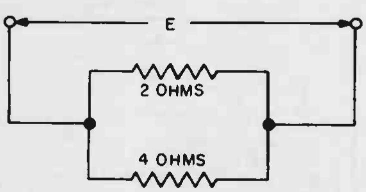


Fig. 16. Resistors in parallel are added algebraically—the result will aways be a value less than that of the lowest in the circuit.

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 (6). 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 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:

$$R \text{ (total resistance)} = R1 + R2 + R3 + \text{etc.}$$

where R1, R2, R3, etc. are the individual resistances. Thus, in Fig. 15 the total of the individual resistances is R (total) = 40 + 6 + 10 + 5 = 61 ohms.

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

$$R \text{ (total)} = \frac{R1 \times R2}{R1 + R2}$$

Thus, in Fig. 16 the effective resistance of R1 and R2 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:

$$I = \frac{E}{R1} = \frac{6}{2} = 3 \text{ amperes}$$

$$I = \frac{E}{R2} = \frac{6}{3} = 2 \text{ amperes}$$

$$I = \frac{E}{R3} = \frac{6}{6} = 1 \text{ ampere}$$

Next, add the individual currents flowing through the circuit:

2 amperes + 3 amperes + 1 ampere
I = 6 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:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots \frac{1}{Rn}$$

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 is solved as follows:

R (total) = 6 + 4 or a total of 10 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 x I where E = voltage in volts, I = the current in amperes. Also:

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

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

P = 115 x 5 or 575 watts.

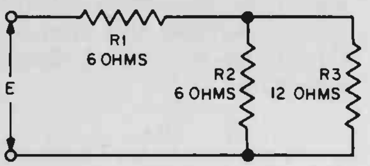


Fig. 17. Ohm's law can be used to determine the equivalent resistance of two or more resistors in parallel. Total current—then solve for ohms.

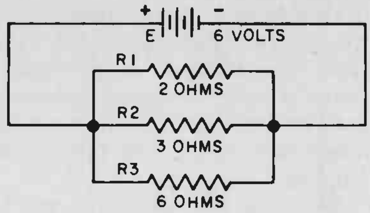


Fig. 18. Series-parallel circuit is not really difficult. Add R2 and R3 algebraically. Add effective resistance to R1 for total resistance.

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 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 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 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:

Ampere turns = 200 turns x
2 amperes or 400 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 passed 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

(Continued on page 40)

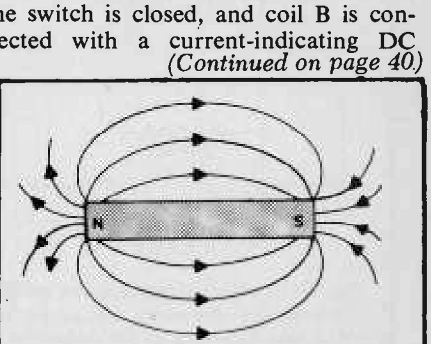


Fig. 19. Lines of force around bar magnet can be made visible by sprinkling iron filings onto white paper over magnet.

Electricity

(Continued from page 36)

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 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.

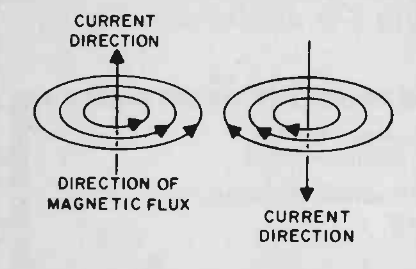


Fig. 20. Direction of flux lines is changed by direction of the current. Heavy current is needed to make flux lines visible with sprinkled filings.

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

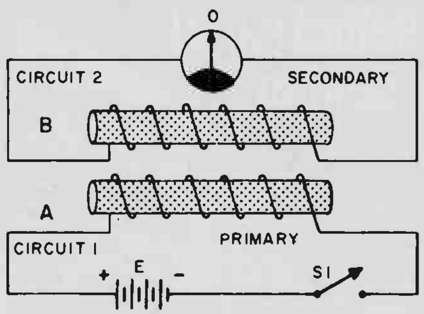


Fig. 21. Two-core transformer is inefficient since an air gap at either end does not have permeability of a ferrous metal and some flux lines do not go through core of secondary winding (B)—their effect is lost.

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:

$$\frac{Ep}{Es} = \frac{Np}{Ns}$$

where Ep = primary supply voltage
Es = voltage developed across secondary
Np = number of primary turns
Ns = number of secondary turns

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.

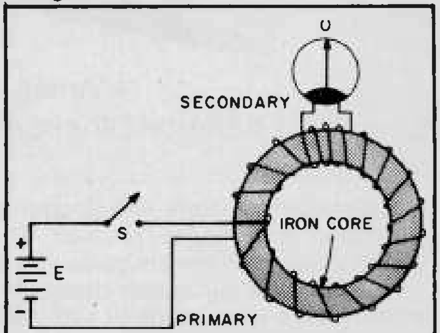


Fig. 22. Toroidal core is highly efficient but is very difficult to manufacture. Familiar C- and E-shape core has less waste and windings are slipped over the core. Efficiency is good—about 90 percent for most designs.

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 satellities 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! ■

Moving Coil Meter

☐ Learning electronic theory is dull, dull, dull. Right? Not necessarily. In some cases you can learn a lot and still have a lot of fun. How? Leave your theory textbook behind and build a current-measuring gadget that will allow you to see electronic theory in action.

Moving coil meters are used universally in all types of test instruments to measure DC current because they are highly sensitive, rugged and reliable, and relatively inexpensive. They may also be used to measure AC current by first rectifying the AC with a small meter rectifier.

Our project uses the moving coil principle in a simplified form of indicating meter. You can learn more about this form of meter by building our easy-to-construct project.

How It Works. The operation of the moving coil type of meter is based on the attraction between a permanent magnet and the magnetic field of a movable coil of fine wire. The coil is pivoted in the center of the space between the poles of the magnet, and has a return spring (to return the meter pointer to zero). This spring is usually of a spiral form in commercial meters, but our meter unit uses a rubberband coil suspension in place of both the pivot and spiral zero return spring.

When DC current flows through the coil, it produces a magnetic field that is attracted to the permanent magnet's magnetic field. This attraction imposes a turning force on the coil, that rotates the coil and moves the attached pointer over the meter scale. The amount of turning force is dependent on the amount of DC current flowing through the coil. The more DC current, the more the coil rotates. The meter is calibrated in DC current indications.

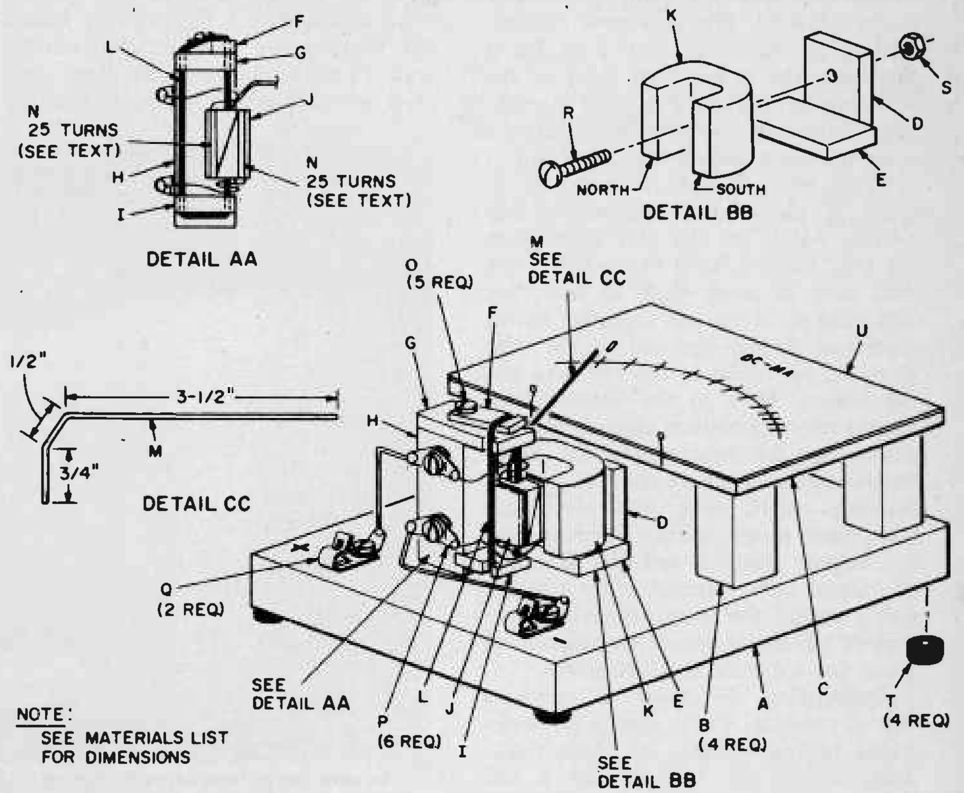
Construction. As can be observed from our photos and drawing, our model of a moving coil meter has been made in a very simplified form to facilitate construction. It's a taut-band moving coil instrument by virtue of the rubber band suspension of the moving coil assembly. We used wood for the various supporting structures because it's easier to work with and most everyone has the few hand tools required.

Size is relatively unimportant. However, we suggest you follow the dimensions and construction details given in the drawing and Parts List. In this way you should have no difficulty in making the meter and you won't have to fiddle with changing the number of turns of wire for the moving coil to compensate for a change in physical size.

You should cut out all of the various pieces of wood and sand them smooth before actually starting to assemble the meter. Mount rubber feet on the bottom four corners of the base (A) and then glue the 4 supports (B) to base (A), as shown in the pictorial drawing. Next cement the scale platform (C) to these supports. We used our electric glue gun, but epoxy cement, Elmer's glue. Pliobond, or similar adhesives can be used with equal success.

Now you're ready to cement the magnet and moving coil assembly supports to base (A). Pieces D, E, G, and I are made from ¼-inch plywood. First step is to cement D and E in their respective locations and fasten the magnet in place. The magnet used in our unit has a mounting hole. If the magnet you use isn't drilled at the bottom center of the *U* to allow a bolt to go through it to hold the magnet in place, it too can be cemented to D and E.

At this point the main support block (H) should be readied for cementing. But first you must notch it out so that piece I can be properly fastened to it. Hold H on the base (A) near piece E and mark H so that the top of the notch will be even with the top of E. The notch should be about ¼-inch deep. The best way to determine its depth is to hold piece G in position at the top of H and place piece I so that its notched end is even with the notched end of G. Mark the depth of the notch in block H based on the position



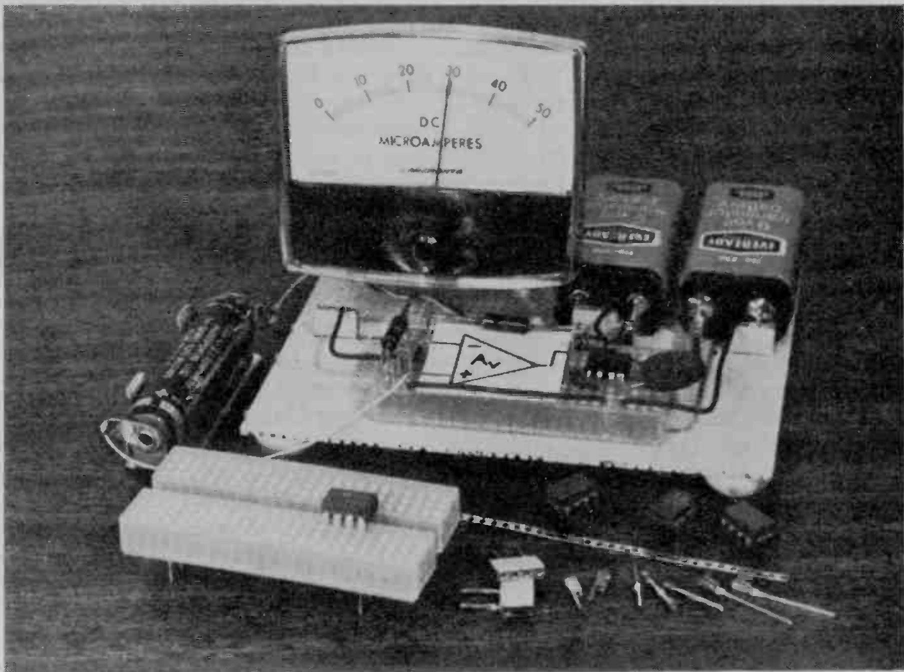
of the end of piece I that will be inserted in the notch where its end is matched with piece G as mentioned above. Be sure that the notch in block H is cut square so that the surface of piece I will be square with the surface of block H where I is cemented in place. The notches in the free ends of I and G are required only to hold the rubber band in position. Cement block H in position, and also piece G to block H as shown in drawing.

The form block J for the moving coil is made from balsa wood, which is lighter in weight than any other wood and therefore contributes to the sensitivity of the instrument. Cut a notch in the center of J as shown in our drawing. The rubber band (L) is cemented in this notch. We used a rubber band approximately 6¾ x ⅜ x 1/16 inch. The coil is made in two sections by winding 25 turns of #38 enameled magnet wire on one half of J and by repeating this winding process in the same direction on the other half of J. Put a touch of cement to the ends of each coil to hold the wire in place and have 6-inch lengths of the start and finish of the 2-section coil for future connection to it. Mount the coil assembly by stretching the rubber band over pieces G and I, centering it vertically within the height of the pole pieces of the magnet.

Now for a Pointer. Straighten out a 4¾-inch length of #18 gauge bare copper wire and then form it as shown in the drawing. The pointer is cemented into the notch in block J so that it rests near the O end (left side) of the scale platform. Piece F is used to make final O rest position adjustments after a scale has been cemented in position.

Fasten two double solder lugs to block H; these are intermediary connecting points for the two wires from the coil. Form a helix like a hairspring with each of these leads so that they will wind up as the coil assembly moves clockwise. Solder the end of the wire from the top helix to the top lugs and the bottom helix to the bottom lugs. Mount two Fahnestock clips or binding posts along the front edge of the meter baseboard and connect them to the solder lugs on H, using #18 solid base wire. Since meter polarity is determined by magnet polarity and the direction of current flow, established by how the coil is wound, the correct polarity markings of the meter should be determined when you calibrate the instrument.

Calibration. In order to calibrate this instrument, you'll need a potentiometer having roughly 20 ohms resistance, a 1½-volt battery and a DC milliammeter, preferably a multi-range one available as part of a VOM.

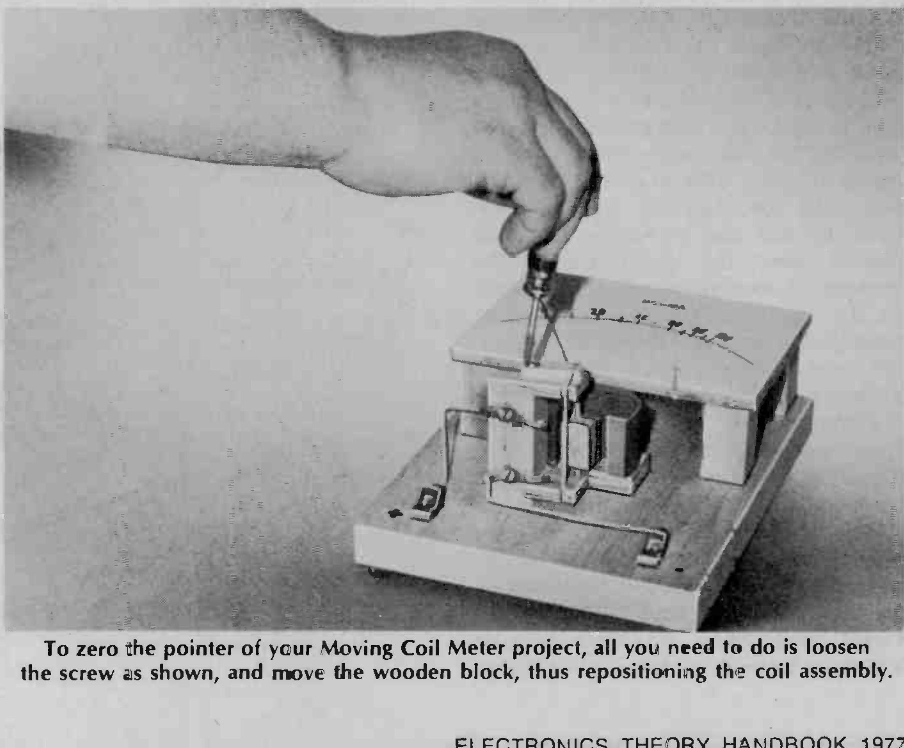


A volt-ohmmeter is very helpful in calibrating the Moving Coil Meter project. If you don't have a VOM handy, try a 0-100 mA milliameter in the same circuit.

Now you are ready for the calibration scale that's mounted on the platform C made during the framework construction. The scale is drawn on a piece of heavy white paper (U) which will be cemented to the platform after the calibration marks have been drawn. (Rub-on numerals, such as Datak, make a neat scale.) Temporarily fasten this white paper (U) to platform C, draw an arc as shown in the photo and place a mark on the left-hand side for a zero reference point.

Connect a 1½-volt battery, a 200-ohm potentiometer (used as a rheostat) a multimeter set on DC milliamp ranges (or a milliammeter), and the moving coil meter you have just built, as shown in the calibration diagram.

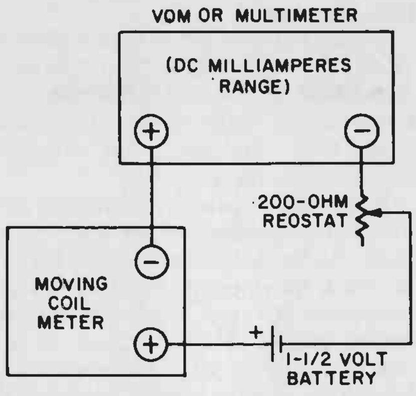
Set the potentiometer for maximum resistance and at the start use the highest milliamp range of the multimeter. If the pointer on your moving coil meter deflects to the left, below the established O point, reverse connections



To zero the pointer of your Moving Coil Meter project, all you need to do is loosen the screw as shown, and move the wooden block, thus repositioning the coil assembly.

to it and then mark the binding posts + and —. Use the connection diagram to determine their polarity markings after connecting the meter so that the pointer moves to the right.

Slowly turn potentiometer to reduce resistance in the circuit and note the readings of the multimeter milliamp range selected. Mark your moving coil meter with the same readings shown on the milliammeter. We divided the 0-100 scale into 10 mA divisions. In the manufacture of DC moving coil meters spring tensions, spacing and coil weight are carefully controlled so that these meters are linear. For this reason commercial milliammeters have uniform spacing between divisions. Our moving coil meter doesn't have such



Any 0-100 mA or higher milliameter will test your MCM just as well as a VOM or multimeter, provided its accuracy is fairly good.

uniformity because of the variations in the rubber band used for suspension and tension, and because it's difficult to maintain accuracy of positioning the various pieces and to be assured of the strength of magnetic field developed by the magnet. Once you have established the calibration points they can be considered accurate.

Now that you have marked the scale in pencil you can remove it from the platform and apply the permanent markings. Permanently fasten the scale in position and stand back to admire your work. If you used reasonable care in following the instructions, you'll have good reason to be proud of your handiwork. ■

C-Zn Battery Theory

□ 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

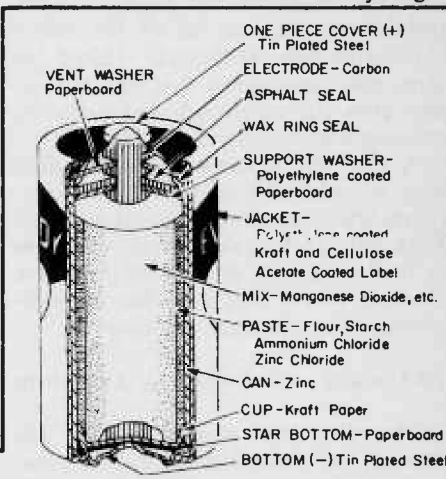


Fig. 1. Cutaway view of a flashlight cell, either AA, C, or D size. This view shows various components making up cell. Study of this and reference to text helps to understand general makeup of carbon-zinc battery.

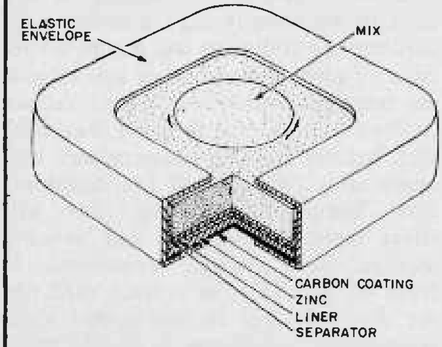


Fig. 2. Cutaway view of square "mini-max" zinc-carbon cell. It develops 1.5V— the same as round cells; chief advantage is that for the same volume of space it has a greater capacity.

gas bubbles polarizes the cell, which, in 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 electricity 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:

$$Zn\ (metal) \rightarrow Zn^{++}\ (ion) + 2\ electrons$$

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:

$$2MnO_2 + 2NH_4 + 2\ electrons \downarrow Mn_2O_3 + 2NH_3 + H_2O$$

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 ½ 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 depletion 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.

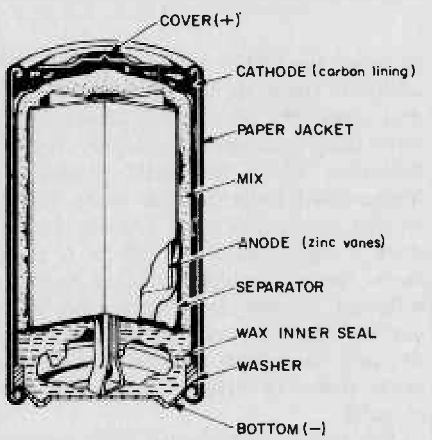


Fig. 4. Cutaway view of external cathode or "inside out" type of battery. Molded carbon wall is both container and current collector. Zinc vanes are inside cell, ensuring efficient zinc consumption.

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° will effect rapid deterioration and possible leakage. Ideal storage temperature is from 40° to 50°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 battteries (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

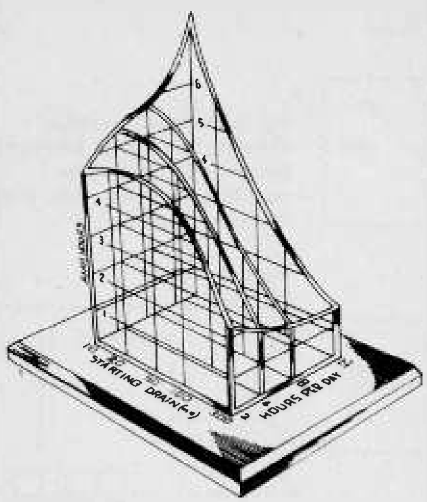


Fig. 6. This three-dimensional graph plots service life as a function of initial current drain and duty cycle of a typical D-size carbon-zinc cell.

of other manufacturers.

There is a certain minimum amount 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 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. ■

Inside Your Power Supply

☐ 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

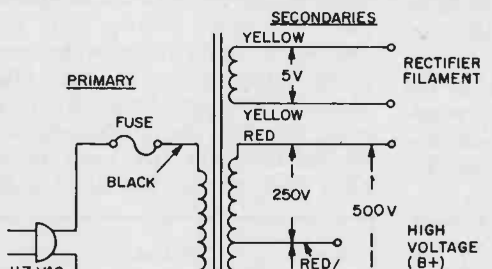


Fig. 1. Schematic of typical power transformer, showing voltages and EIA color-coding of windings.

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 located in one primary lead of the transformer.

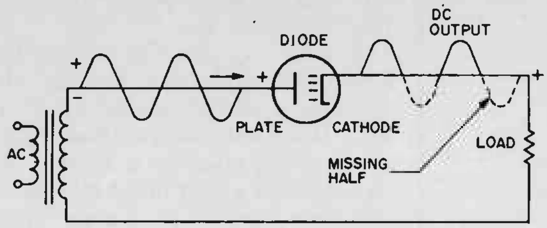


Fig. 2. Half-wave rectifier, showing how diode produces pulsating DC output by repelling electrons when plate is driven negative.

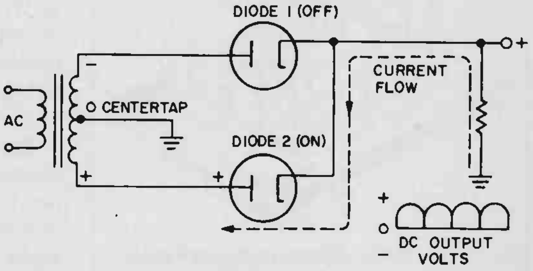


Fig. 3. Full-wave rectifier is a pair of diodes driven alternatively to take advantage of both halves of AC input voltage.

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 transfomer 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.

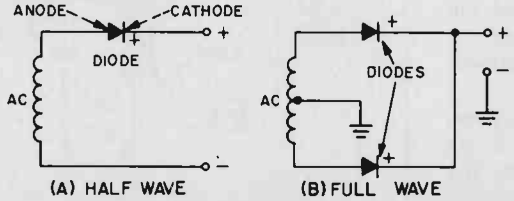


Fig. 4. Solid-state selenium or germanium diodes in similar half- and full-wave rectifier circuits are better than tubes since they don't need filaments or heaters for rectifying action.

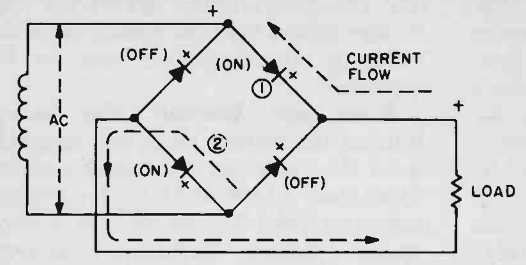


Fig. 5. Solid-state bridge rectifier provides full-wave rectification with center-tapped transformer by using four diodes.

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 centertapped 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

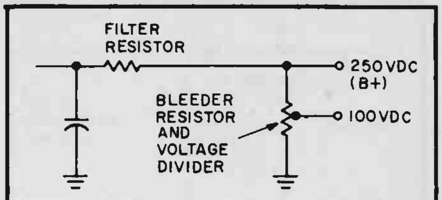


Fig. 7. Choke can be replaced by filter resistor. Also shown is bleeder resistor that serves both as output regulator as well as voltage divider.

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*.)

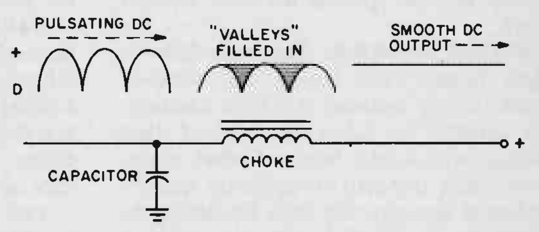
Note that a tap can be added to the bleeder to provide a second output voltage from the supply. Now the bleeder becomes a *voltage divider*. As such, it can supply the designer with multiple output voltages for operating various devices in a circuit.

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.



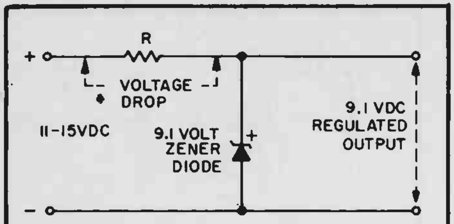


Fig. 8. For more efficient regulation than produced by bleeder resistor, zener diode shunted across DC output will hold voltage to specified limit.

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. ■

Understanding Superhets

☐ 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," at 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 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.

couldn't help but ruin the radio's selectivity. It loaded the tuning circuit, in-

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.

Superselectivity. 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.

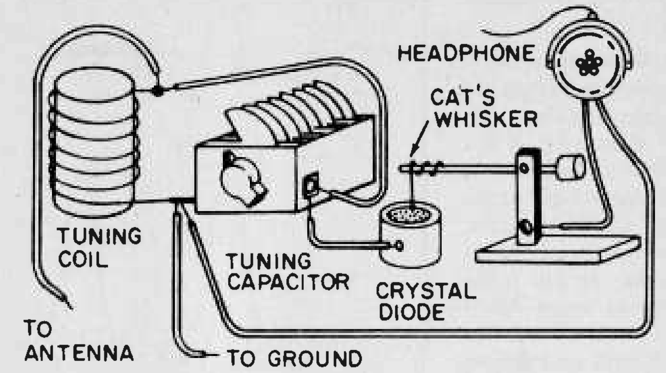
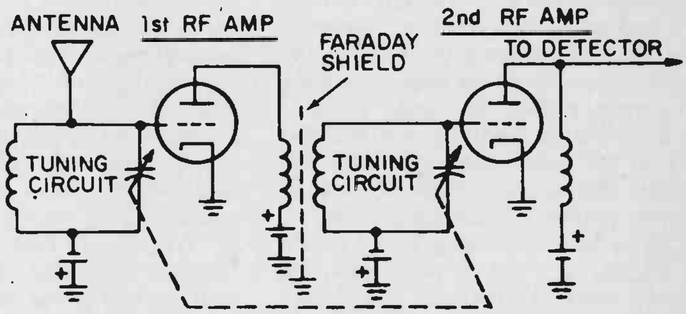


Fig. 1. Schematic representation of crystal radio shows how cat's whisker gently contacted diode surface in order to achieve demodulation of RF signal. Earliest semiconductor diodes made were miniature crystal diode/cat's whisker affairs encased in glass package.

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.



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 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 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.

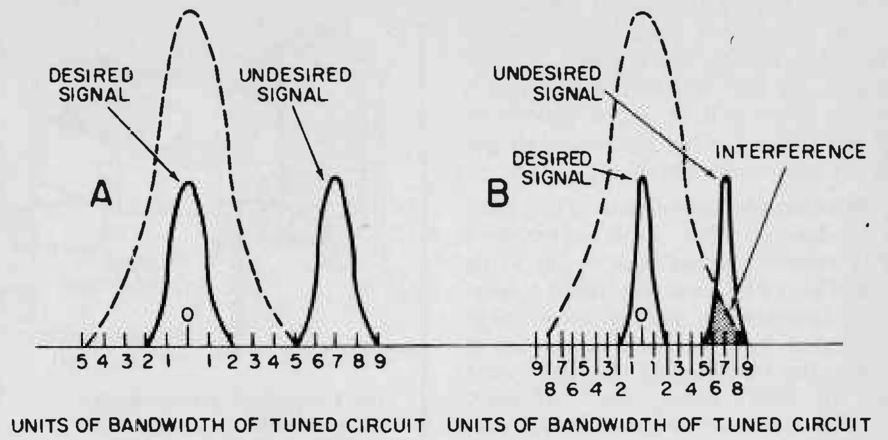


Fig. 3. Tuned-circuit bandwidth varies proportionally with frequency. Tuned circuit A, working at low frequency, rejects unwanted signal. Tuned circuit B, working at high frequency, can't completely reject undesired signal; interference results.

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,

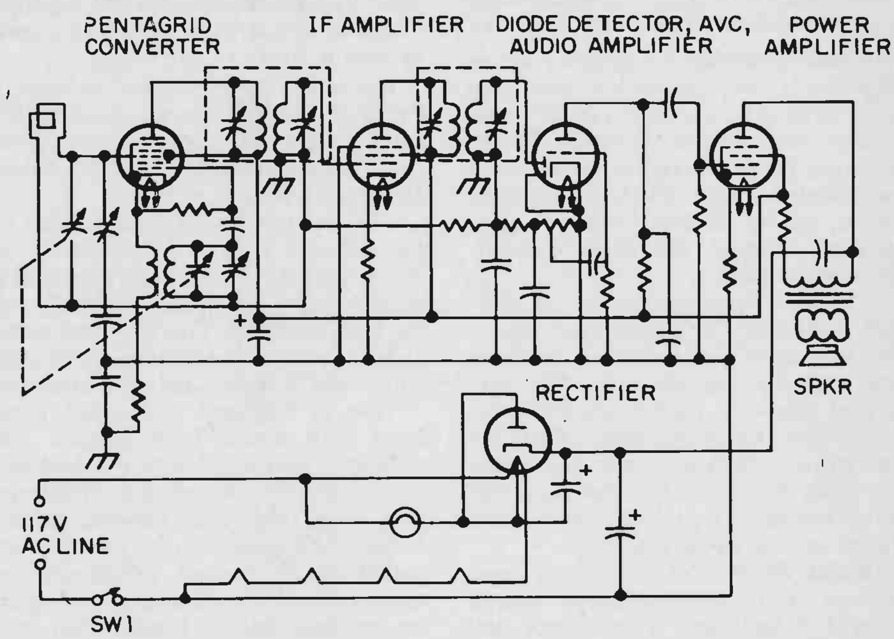


Fig. 4. Virtually all superhets sold commercially are five-tub rigs; most are also, in terms of design, electrically and mechanically equivalent.

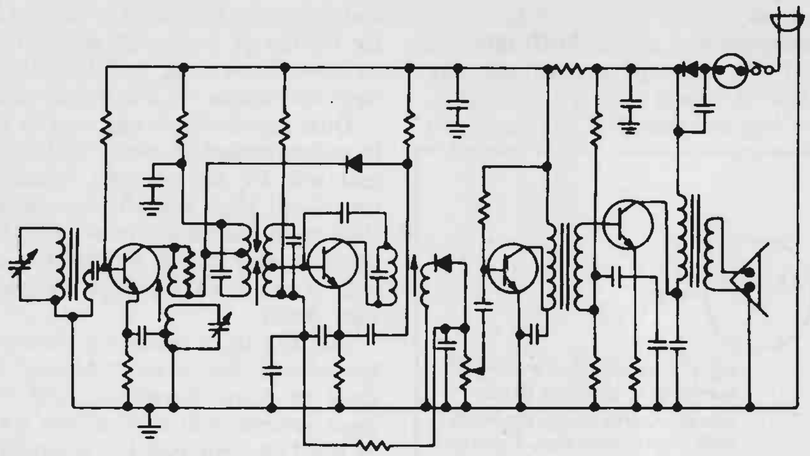


Fig. 5. Our schematic of a transistorized superheterodyne receiver is similar to the tubed superhet shown in Fig. 4. Biggest differences between the two are semiconductor diodes found in audio detector, AVC loop, and power rectifier stages.

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 pasess 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 positive-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.

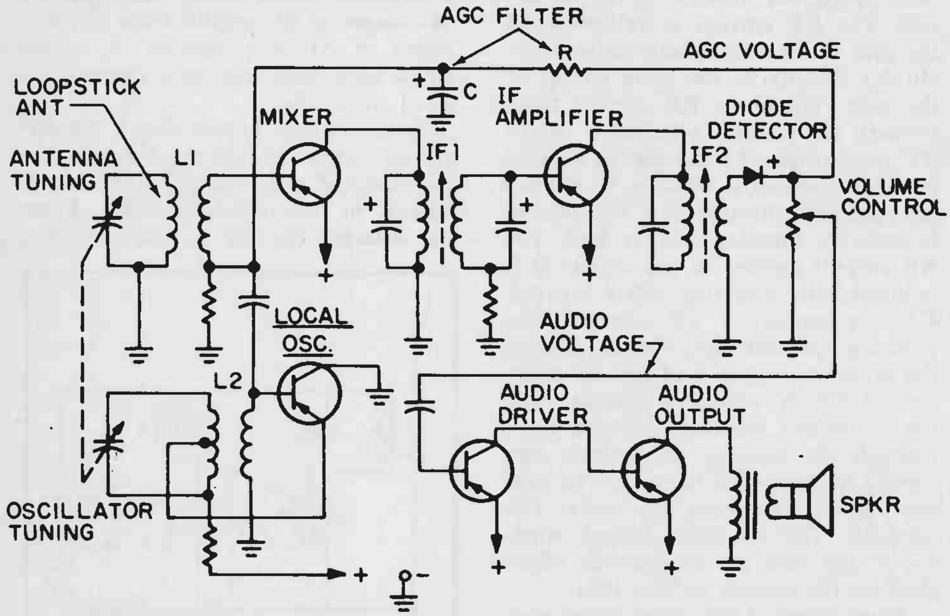


Fig. 6. Most superhets don't have separate local oscillator, mixer function; this schematic is more typical of BCB set. Communications-type receiver needs added usefulness of separate stages—it's easier to suppress images.

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 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 reject 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

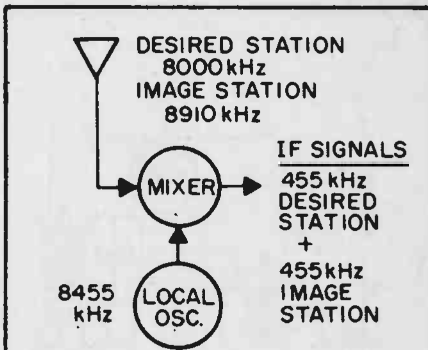


Fig. 7. Mixer is superhet's weakest link as signal handler. Too strong input signal can develop image frequency. Too much local oscillator signal pumped into mixer has same effect.

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.

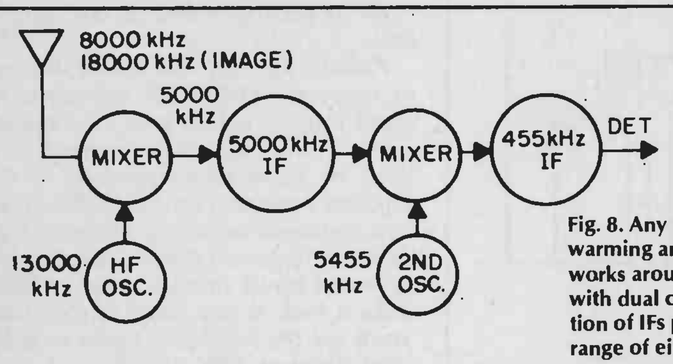


Fig. 8. Any superhet worthy of warming an amateur shack works around image problem with dual conversion. Combination of IFs puts image out of range of either stage.

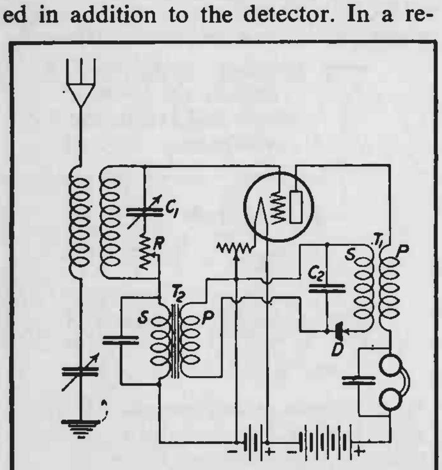
Dual conversion is *not* usually found in entertainment receivers–radio broadcast and TV for example, because it's too sharp! High selectivity could easily slice away sidebands in an FM stereo program and kill its multiplexed channel, or rob a TV image of its fine picture detail.

But, for all its faults, the basic superhet circuit we've been talking about must be doing something right. Every years 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? ■

Reflex Circuits Solved

□ One of the most interesting of the circuits used in the history of AM radio is the reflex circuit. Technical information about the different variations on this principle is difficult to obtain, but in this article a number of the most popular circuits have been brought together, and analyzed. Some of the circuits which will be discussed were used by deForest, Harkness, Erla, and other long vanished manufacturers of early receivers.

In most amplifier circuits a vacuum tube has only one duty to perform. When it is used as an audio frequency (AF) amplifier, it amplifies the audio frequencies after detection, and in a radio frequency (RF) amplifier it amplifies the radio frequencies before detection. Thus if 2 stages of RF amplification are desired, and 2 of AF amplification are desired, four tubes are needed in addition to the detector. In a reflex circuit with a crystal detector, all this is accomplished with 2 vacuum tubes, or if a tube detector is used, with 3 tubes.

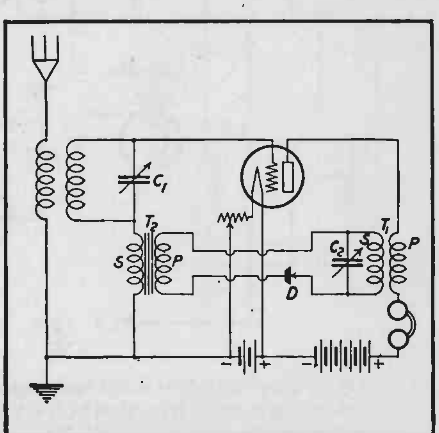


Circuit of the Acme Reflex receiver.

One Tube Circuits. Two different reflex circuits are shown using only 1 tube. In the Acme reflex circuit shown the RF current flows from the antenna through the primary of the antenna coil to ground. RF is induced into the secondary winding which has C1, a variable condenser, across it which tunes in the station we want to listen to. R is used to prevent oscillation in the circuit. The RF current is impressed on the grid of the tube which controls the current flowing in the plate circuit of the tube. When the RF current flows through the primary winding P of the RF transformer T1 current is induced into the secondary winding S. It does not proceed through the headphones because the impedance is too high. The RF current applied to the crystal D is rectified into pulsating direct current. C2 is a bypass for RF currents. The pulsating current then flows through the primary winding P of the AF transformer T2. A voltage is induced into the secondary winding S which flows through the antenna transformer secondary to the grid of the tube. The tube now greatly amplifies the audio frequencies. The AF flows through winding P and into the headphones which produce the sounds we can hear.

More Tubes. There were many variations of the one tube circuit such as that shown in the circuit diagram of the Harkness reflex receiver. There were also many reflex receivers built using three or four tubes. One of these was the Grimes Inverse Duplex set whose circuit is shown. There were problems associated with the reflex circuits such as uneven loading on the tubes, feedback due to magnetic coupling, and the amplification of power line noise and interference due to rotating machinery such as electric motors using brushes. The Grimes Inverse Duplex circuit is designed to overcome some of these problems. This circuit uses two tubes for amplification and one tube as a detector. These three tubes provide two stages of RF amplification and two stages of AF amplification. A crystal could have been used as a detector instead of a tube.

In the Grimes circuit shown the RF current flows through the tubes in the conventional way, through tubes 1, 2, and 3, in the following order. From the detector the AF is amplified first



Circuit of the Harkness Reflex set.

by tube 2, then tube 1, and then to the telephone receiver or headphones in the plate circuit of tube 1. In this circuit stability is increased, overloading of the tubes is reduced, and AF interference is reduced. The location of the by-pass capacitors allows the RF currents to return directly to the tube without going through the "B" battery or around the AF transformers. The set is simple to operate since there is one control for tuning, one for the vacuum tube filaments, and one for stability. Even though they were perfected, reflex circuits were abandoned in favor of neutrodyne and superhetrodyne receivers until the Great Depression of the 1930's forced set manufacturers to produce cheaper radio sets.

Multi-element Circuits. In an effort to cut the cost and the size of radio receivers multi-element tubes were developed. The circuit shown of the Kadette Jr., made by the International Kadette Radio Corp., of Ann Arbor, Michigan was one of the first AC-DC receivers made. In other words there was no power transformer and the tube filaments were connected in series

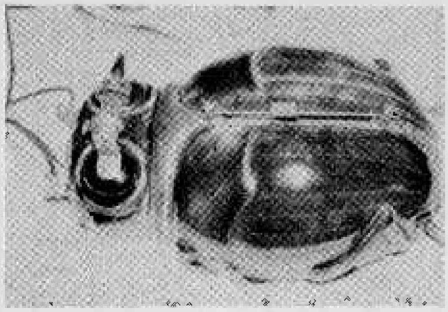


Photo by Frank Heathcote

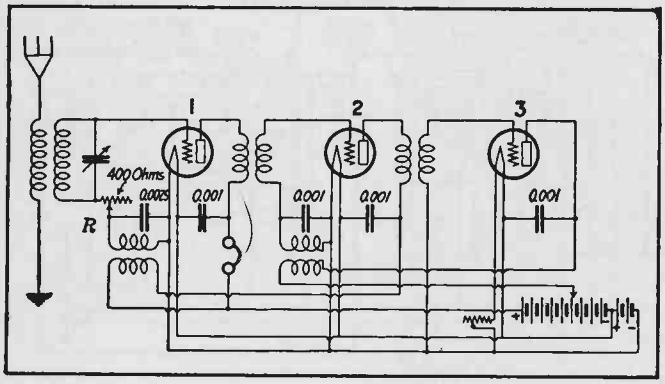
One of the most unique crystal radios made. It is in the shape of a large beetle, and you can see the way in which the detector, binding posts, etc. are mounted.

much like the Christmas tree lights of that day. The line voltage was rectified to supply the radio B voltages. It was advertised as a "Pocket Portable" and the first advertisement I ever saw for this radio showed a man putting the Kadette Jr. into his overcoat pocket. The radio used 2 dual purpose tubes, one a 6F7 with 1 cathode, 2 plates and 4 grids. The cathode was common to all the elements. Actually the glass envelope contains two tubes: a pentode and a triode with a common cathode. Reading from bottom to top the elements are: triode plate, triode control grid, cathode, pentode control grid, pentode screen grid, suppressor grid and plate.

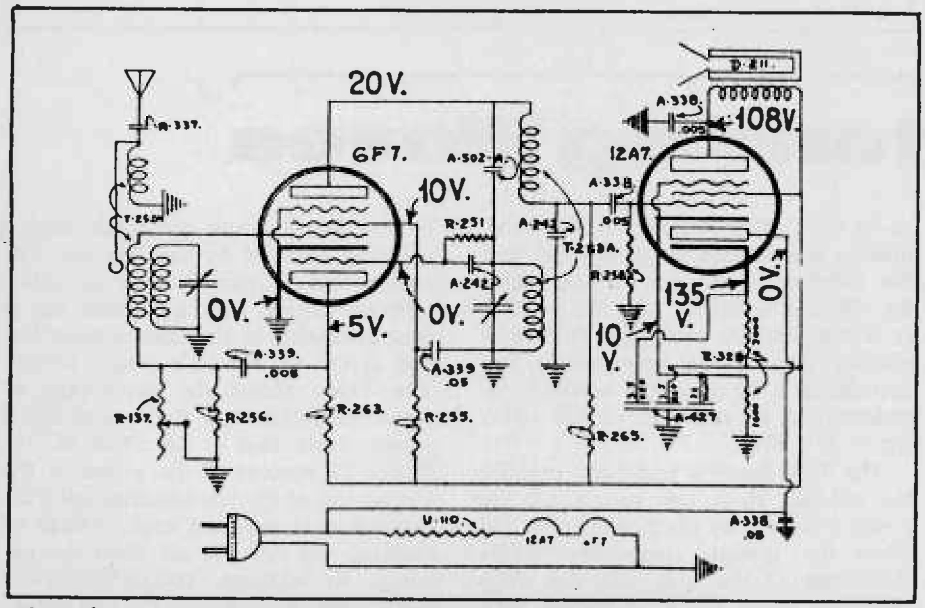
In this circuit the RF signal is fed to the pentode control grid by way of the antenna coil. Amplified it appears in the pentode plate circuit. The plate circuit contains a winding which links the pentode plate with the input of the audio output tube. At the same time the plate circuit is coupled to another tuned circuit through capacitor A-502-A. The RF signal finds it easy to pass through this capacitor to the grid leak capacitor part of the triode grid. This is the detector input circuit. The rectified signal then appears in the plate circuit of the triode and is fed to the control grid of the 6F7 pentode via the coupling capacitor A-339. The volume control, R137, is a variable resistor across the control grid to chassis.

The amplified AF signal again appears in the plate circuit of the pentode section, but in this case, its path is through the winding, through the capacitor A-338 and to the grid of the output tube control grid. The AF signal does not flow through capacitor A-502-A because it's impedance at AF is very much greater than that of the winding. Thus the 6F7 acts as an RF amplifier, detector, and as an AF amplifier. The 12A7 pentode section is the audio power amplifier, while the diode section rectifies the line voltage to supply the B voltages. This is in fact a TRF receiver with a grid leak detector, and one stage of AF amplification.

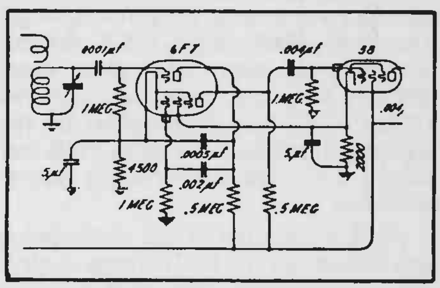
The "Mickey Mouse" Set. Another interesting receiver is the Emerson "Mickey Mouse," models 409, 410, 411, and 412. This receiver has a unique cabinet with a molded Mickey Mouse on the front of the cabinet. A 6F7 is used in circuit as a triode detector and a pentode AF amplifier. The AF signal appears at the plate of the triode and is then fed back to the pentode section through the .002 uF ca-



Circuit of the Grimes Inverse Duplex receiver, which uses three tubes to overcome problems of feedback, power line noise, and interference from electric motors.



The Kadette, Jr. was one of the first AC-DC receivers made. The tube filaments are in series.



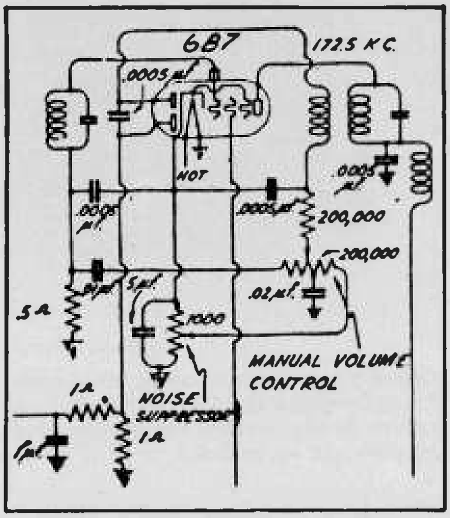
The Emerson "Mickey Mouse" receiver circuit, using a 6F7 as detector and AF amplifier tube simultaneously.

pacitor. It is amplified and fed back to the grid of the type 38 audio output tube through the .004 uF capacitor.

One more example of reflexing in a 6B7 shows how, in the Emerson model 678, 4 functions are accomplished in one tube. The circuit shown provides IF (intermediate frequency) amplification, detection, delayed AVC Automatic Volume Control) and AF amplification. The IF transformer feeds the IF signal into the pentode portion of the tube, and the amplified signal is transferred across the IF transformer to the upper diode plate. It is also fed to the lower diode plate via the .0005 uF capacitor. The AF signal is developed across the 200,000 ohm volume control potentiometer. The AF signal is then passed on to the control grid of the 6B7 pentode by way of the .01 uF capacitor and the IF transformer secondary. The amplified AF signal travels from the plate through the secondary of the IF transformer and then through the primary of the AF transformer. Note that in this circuit both the IF and AF signals are amplified by the same tube.

The final example of reflex action is in the Majestic chassis 500. The first IF tube, a 6F7S is used for both IF and AF amplification. You can trace the path of the signal into the first IF tube, into the 2nd IF transformer, and then into the control grid of the pentode. The amplified IF signal travels through the 3rd IF transformer and is detected in the diode section of the 6B7S. The AF signal is fed back to the control grid of the triode section of the 6F7S, and then to the grid of the audio output tube.

Further Reading. If you are interested in learning more about the way old radios work, it is best to start at the



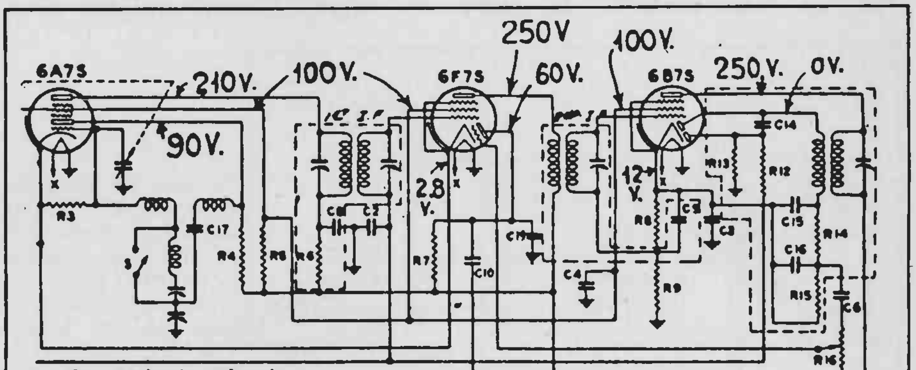
Partial circuit of the Emerson model 678.

beginning, with the first of the consumer receivers, the old crystal sets. There is a book titled *Vintage Crystal Sets*, by gordon Bussey, covering 1922 to 1927.

Mr. Bussey's aim in publishing this book was to create a reference book for the collector of crystal radio receivers. Even though many of its photos are of English made sets it will add to the knowledge of all radio collectors. There are over 50 photos of crystal radios plus many reprints of old advertisements for crystal sets. Some will remind you of similar sets made in the United States. There is also a long list of manufacturers of crystal radios with their trade names, some description of each set, and the price of the set when new.

This book may be purchased from Tudor Rees, 64 Broad Street, Staple Hill, Bristol, Great Britain BS16 5NL. The price is 3.00 English pounds which is around $6.00 in United States funds. This includes shipping by surface mail, which takes 4 to 6 weeks. You can purchase an International Money Order at the larger Post Offices. I consider the book a very good buy and recommend it to all antique radio collectors.

With this book, and the material contained in this article, you can get a good idea of the sort of equipment available in the early years of radio. Considering the technology, it produced fine results. ■



In the Majestic Chassis 500, the first IF tube, a 6F7S, is used for both IF and AF amplification.

CB Standing Waves

☐ Although most CBers are familiar with the term SWR, which means *standing wave ratio*, very few actually know how SWR affects a CB station's overall performance. In some cases SWR is absolutely meaningless to the CBer, having little or no effect on the station's signal. In other cases SWR can reduce a CB station's effective output to almost zero.

SWR is the *ratio* of the transmission line *impedance* to the antenna *impedance*, at resonance (the operating frequency). An SWR (ratio) is written "2:1", which can be described in words as "2 to 1." For example, if the transmission line impedance is 50 ohms and the antenna impedance is 100 ohms the SWR is equal to 100/50, or 2:1. It is not 50/100 or 0.5:1. Putting it another way, if the transmission line impedance is 50 ohms the antenna impedance can be either 25 or 100 ohms for a 2:1 SWR.

The SWR figure is important because the antenna does not accept all the power delivered by the transmission line when the antenna impedance differs from that of the line, and the SWR tells how much power is turned back by the line/antenna mismatch instead of being radiated by the antenna. The power that is turned back is called *reflected* power, and it is used up as heat dissipated in the transmission line and in the transmitter's output circuit. The Table shows the percentage of power reflected back for typical SWR values. Note that at an SWR of 3:1 there's 25 percent of the power at the output end of the transmission line (the antenna end) reflected back, instead of radiated out into the air from the antenna. In addition, there's always a natural loss of power in the line before the power gets to the antenna. Thus the SWR indicates a loss from the already-lowered (by line loss) output.

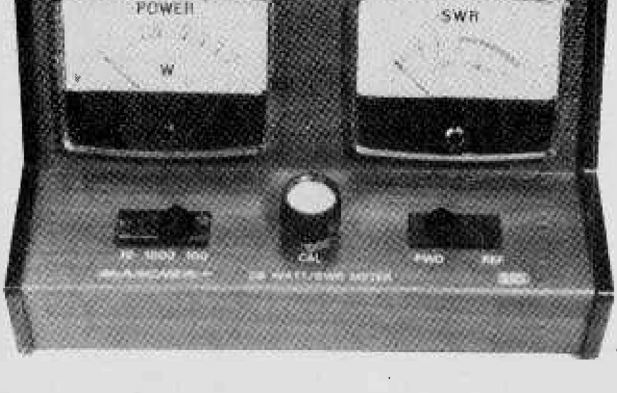
You will not be surprised to know that it's pretty difficult to measure the actual antenna impedance when the antenna is mounted on its mast or tower. Fortunately, when the reflected power flows back down the line the phase difference of current and voltage meeting the forward power sets up voltage and current *standing waves* on the line. By measuring the minimum and maximum values of these current or voltage standing waves we determine the ratio of forward-to-reflected power, which is the SWR of the antenna system. Since voltage is easier to measure than current the typical CB SWR meter indicates forward and reflected power through a voltage measurement, so the indicated SWR is actually *VSWR*—meaning SWR determind through a voltage measurement. All in-line CB SWR meters are really VSWR meters—the terms (*SWR* and *VSWR* being interchangeable.

Using the SWR Meter. In commercial installations, SWR is generally determined by measuring the forward and reverse power and then calculating the SWR. A much easier way to find the SWR is to use a meter that can be adjusted to indicate full scale on the forward power regardless of the actual level of the forward power. The reverse power is then indicated as a proportion of the full-scale reading. If the reverse power was 25 percent of the forward power the meter would always indicate the same reading regardless of the actual forward power as long as the meter was always calibrated to indicate full scale on the forward power. And this is the way most CB SWR meters work. They connect in series with the transmission line and sense the forward and reverse power. The user, by adjusting a *calibrate* control, sets the meter to indicate full scale on the forward power. When the meter is switched to read reverse power the scale calibration is directly in SWR; and some scales are calibrated to indicate both the SWR and the percent reflected power. Since the SWR meter senses *voltage* it absorbs very little, almost no RF energy. Thus it can be left permanently in the transmission line circuit, giving a continuous indication of the antenna system's SWR.

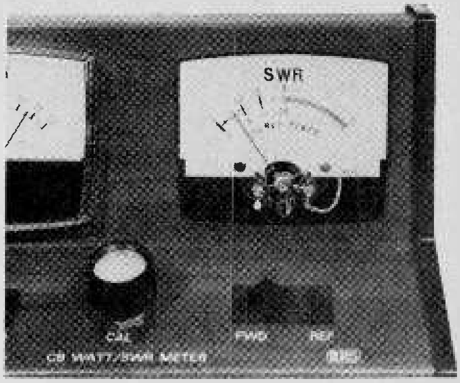
Some of the latest service shop SWR test meters have automatic full-scale calibration, so the meter reads out directly in SWR without the need to first calibrate the meter for the forward power.

How SWR Meters Work. Regardless of whether forward calibration is manual or automatic, SWR meters used for CB all use the same type of inductive forward-reverse power sensor shown in the schematic. Wires positioned on each side of a coaxial center conductor sense the forward and reverse RF energy in terms of standing wave ratio. The RF energy is rectified and filtered to a DC voltage which is proportional to the RF energy. The meter then uses the DC to indicate the SWR value.

In modern CB SWR meters it has become common practice to use a small printed circuit board for the RF sensor of SWR meters. The coax center conductor and the forward and reverse sensing wires are etched from copper on a printed circuit board, as shown in the photograph. Pictured here is a Radio Shack combination SWR and output power meter. The output power meter consists of the forward power sensor with an internal calibration control (not accessible to the user) and a scale calibrated in watts rather than SWR. A selector switch allows the CBer to set the scale calibration for 10, 100, or 1000 watts. Obviously, the 10 watt-scale is fine for CB, but since a power-SWR meter can be used for other services in addition to CB in the range of 3 to 30 MHz the additional calibrations (100 and 1000 watts) allow the meter to be used for these other applications without internal modification.



Radio Shack's combination power-SWR meter is in-line instrument capable of checking with transmitters up to 1000 watts (on amateur radio rigs).



Detailed view of SWR meter face shows relation between SWR and percent of power returned. Markings show 25% of power is lost at 3:1 SWR.

One photograph shows the RF forward-reverse power sensor. Flipping the unit over lets you see the attached coaxial connectors, which are shown in detail in the next photograph. When the whole thing is assembled all the CBer sees is a panel with RF connectors labeled *Antenna* and *Transmitter*. No damage will occur if the connections made to the antenna and the set are reversed. The meter will simply read backwards. That is, the forward power will be indicated when the meter is set for reverse power, and vice versa.

What Typical Values Mean. The closeup photograph of the SWR meter scale illustrates the typical *SWR/Percent Reverse Power* calibration common to most SWR meters used for CB. The top scale shows SWR values—note that there is no calibration above 3:1 because anything greater than 3:1 is simply not acceptable. If values near 3:1 are found the antenna system should be tuned or repaired, or an antenna matcher should be used.

The bottom scale represents *Percent Reverse Power*. It shows that an SWR of 3:1 means 25 percent of the power is reflected back from the antenna. An SWR of 1.5:1 means that only 4 percent of the power arriving at the antenna is reflected.

Useful CB Test Instrument. One of the latest CB service test instruments is the Sencore CB41 Automatic Performance Tester. It indicates power output. SWR. and percent modulation. Note that there is no forward power calibration control. This is because it is automatically calibrated when the *SWR Test Switch* is depressed. Since the meter is intended for use in service shops, its SWR scale is calibrated green, yellow and red to indicate good, passable and defective conditions, Of course it also has the usual SWR number markings.

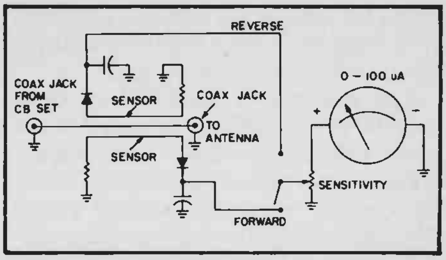
In addition to the normal reflected power loss one must remember that SWR increases all other antenna system losses. Further, the SWR reading is rarely accurate on long transmission lines because of the inevitable line losses. Starting with the SWR multiplier effect; if the normal line loss is say, 3 dB per 100 feet of coax transmission line, a moderately high SWR will add 1 dB additional loss. Further, the same loss is added to the return power loss so that an SWR meter working into 100 feet of cable sees a lower-than-actual return power, and therefore indicates a lower-than-actual reflected power. Normally the SWR indication is lower, to begin with, because of line loss.

To understand this, assume the SWR meter is connected at the input of about 100 feet of RG-58/U, which has a line loss of 3 dB per 100 feet. Also assume the SWR is 2:1, meaning 11 percent of the power is reflected back from the antenna. If we feed 4 watts into the line only 2 watts will get to the antenna end of the line because of the 3-dB loss .11 percent, or 0.2 watts, will be reflected by the antenna/line mismatch. But now, in traveling back down the line the 0.2 watt reflected power is also attenuated 3 dB so only 0.1 watt arrives at the meter. The meter sees only 2.5% reflected power—it knows nothing about line losses, so it indicates less than the actual 2:1 VSWR.

Comparison of SWR with Reflected Power (from antenna back)

SWR	Percent of power reflected
1:1*	0.00%
1.1:1	0.22%
1.2:1	0.82%
1.5:1	4.00%
2:1	11.40%
2.5:1	18.00%
3:1	25.00%

*Not attainable



Sensor picks up tiny bit of power via capacitance to drive SWR meter.

So you see, though an SWR meter is an important part of every CB installation, you still must keep in mind that it can be fooled, not only by normal line losses but by standing wave impedance variations (which we have not discussed). Nevertheless, and in spite of these errors the SWR meter is the CBer's most reliable, low-cost indicator of the condition of the antenna system, as well as of the match between the transmission line, and the antenna. ■

Prefixes and Exponents

☐ ANYONE WHO'S DIPPED his little toe into electronics is certain to have run across such terms as *micro*Farad, *milli*-Henry, and *milli*Ampere—not to mention *mega*Hertz *meg*Ohm, 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

ELECTRONIC PREFIXES AND THEIR MEANINGS

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

basic unit of *one-millionth* of a Farad —a *micro*Farad. 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 "10^3". (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 10^3", thus:

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

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	× 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 10^6. Thus, you should learn to mentally replace "meg-" with x 10^6, so that 6.8 megOhms becomes a 6.8 x 10^6 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 milli- can be replaced with "10^{-3}" (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^{-6}.

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:

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

The answer is 3.96 x 10^3 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 10^6 and 10^{-3}, 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 10^0 (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?

$$X_L = 2 \times \pi \times (1.5\times10^6) \times (22\times10^{-3})$$
$$= 207.24 \times 10^3 \text{ Ohms}$$
$$= 207.24 \text{ kilOhms}$$

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?

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

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

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

We wish this answer had come out with a "10^6", instead of a "10^8", because we can convert 10^6 Hertz directly to megaHertz. However, we can change the answer to 10^6, 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 $10^{-6} \times 10^{-6}$ Farad, or 10^{-12} Farad. This is more commonly known as the *picoFarad*. Similarly, a thousandth of a microAmpere is $10^{-3} \times 10^{-6}$ Ampere, or 10^{-9} 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 femtOhms! ■

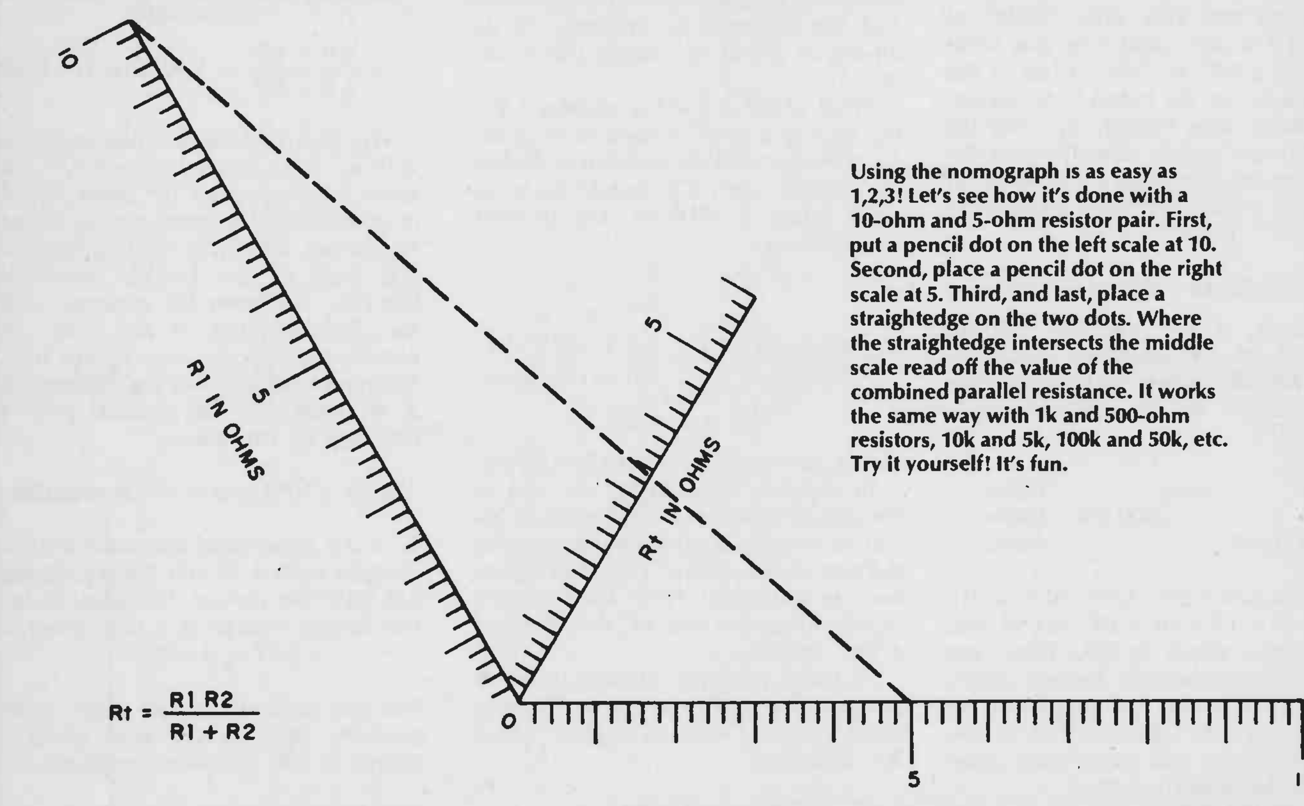
Resistance Nomograph

☐ 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



Using the nomograph is as easy as 1,2,3! Let's see how it's done with a 10-ohm and 5-ohm resistor pair. First, put a pencil dot on the left scale at 10. Second, place a pencil dot on the right scale at 5. Third, and last, place a straightedge on the two dots. Where the straightedge intersects the middle scale read off the value of the combined parallel resistance. It works the same way with 1k and 500-ohm resistors, 10k and 5k, 100k and 50k, etc. Try it yourself! It's fun.

$$Rt = \frac{R1\,R2}{R1 + R2}$$

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 equivalent 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 finalizing. 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. ■

Inductance and Capacitance

☐ The lowly resistor is the solid citizen of electronics. It can be relied upon to behave with the same, predictable performance, whether confronted with AC or DC. Unruffled by excursions into the higher frequencies, it continues to live by the guiding rule—Ohm's law—and declares that, no matter what, the current (I) it permits to flow shall depend solely on the applied voltage (E) divided by its own resistance (R).

However, the resistor's component cousins—the inductor and the capacitor—are by no means so stolid in the face of changing frequencies. The inductor, for example, grouchily shuts off more and more of the current flow as the applied frequency gets higher and higher, while the capacitor reacts to higher frequencies in just the opposite manner—it happily allows more and more current to flow as the frequency rises.

Fortunately, the reactionary behavior of these components is just as predictable as is the single-mindedness of their resistive cousin. If we study the strange conduct of these apparently erratic citizens, we not only discover the rules which govern their odd behavior, but also perceive that ultimately, they too, are faithful to Ohm's law—in their fashion—just as are all electronic components and circuits.

Reactionaries in the Lab. To begin our study, let's set up the lab experiment shown in Fig. 1.

Here, we have an audio oscillator set to produce an output of 60 Hz, and a power amplifier to amplify that signal to the 100-volt level. The power amplifier drives a load consisting of a large (25-watt) 390-ohm resistor connected in series with an ordinary 1½-volt (0.25-amp) flashlight bulb. An AC meter reads the output voltage from the power amplifier.

Turning on the equipment, we set the audio oscillator to 60 Hz, and gradually turn up the amplifier gain till 100 volts appears at the output. (Note: The ordinary hi-fi amplifier won't do this—you will need a public address amplifier with a high-voltage (70-volt, or 500-ohm) auxiliary output if you actually want to carry out this experiment.) At this point, the bulb will light to its normal brightness, indicating that the 100 volts is pushing about 0.25 ampere through the combined resistor/light-bulb circuit. Using Ohm's law, we can easily check this:

$$I = E/R$$
$$= 100 \text{ volts}/(390 \text{ ohms} + 6 \text{ ohms})$$
$$= 0.252 \text{ amperes}$$

Note that the light bulb's resistance, R, is

$$R = E/I$$
$$= 1\tfrac{1}{2} \text{ volts}/\tfrac{1}{4} \text{ ampere}$$
$$= 6 \text{ ohms}$$

Please also note that it's the 390-ohm resistor, not the bulb, which is the chief authority in establishing the current. The lamp current will change very little, whether the bulb is 6 ohms, 12 ohms, or zero ohms.

Next, let us vary the frequency of the audio oscillator; first, down to 30 Hz, and then, up to 120 Hz. We notice that the bulb stays at the same brightness, indicating that the 390-ohm resistor is behaving in its normal, stolid fashion—that is, it is steadfastly ignoring frequency changes, and permitting its current flow to be determined solely by Ohm's law. Even if the frequency were zero (which is another way of saying DC), the bulb's brightness would remain the same, if we applied 100 volts to it.

Enter the First Reactionary. Now, let's go to our parts supply bin, pick up a 1-henry inductor, and make a few preliminary measurements on it. Using an inductance bridge, we discover that its real value is 1.05 henry. We next connect it to an ordinary ohmmeter as shown in Fig. 2, which informs us that the inductor has a resistance of 45 ohms.

Now, let us replace the 390-ohm resistor of Fig. 1 with this 1-henry inductor as shown in Fig. 3, and predict what will happen when we turn on the equipment. Since the ohmmeter said "45 ohms" we can predict that the current will be

$$I = E/R$$
$$= 100 \text{ volts}/45 \text{ ohms} + 6 \text{ ohms}$$
$$= 1.96 \text{ amperes!}$$

With this large current—nearly 8 times normal—the light bulb should burn out almost instantly! However, when we apply 100 volts of 60 Hz to the inductor-plus-bulb, we are surprised to see that the bulb lights to normal brightness! This means that the inductor is behaving like a 390-ohm resistor, and is establishing a ¼-ampere flow of current—not the nearly-2 amperes calculated from the above ohmmeter measurement.

To compound the mystery, let us now vary the frequency of the oscillator: first, up to 120 Hz—and the bulb gets dimmer!—and then gingerly, down, just a little, to 50 Hz—and the bulb gets uncomfortably brighter. Here, in the lab, is the actual behavior forecast by theory—the inductor grouchily shuts down the current flow for high frequencies, causing the bulb to go dim at 120 Hz, but it is willing to let low frequencies through, thus allowing the bulb to get brighter for 50-Hz input.

A Little Compassion for the Reactionary. To understand this "reactionary" behavior, we must understand how an inductor "feels" about an alternating current. An inductor is, after all, an electromagnet. If a steady direct current flows through it, it fills the space in its vicinity with a magnetic field If we attempt to cut down the inductor's current, it reacts, quite understandably, by collapsing its magnetic field. But this collapsing field moves across the inductor winding in just the same way that a dynamo or generator field moves through the generator windings to make an output voltage. The inductor, then, reacts to any attempt to change its current by *acting as its own generator,* generating a new voltage of the correct polarity *to try to keep its own current from changing.* So, in its own way, the inductor is a solid, but *conservative* citizen—a citizen who tries to maintain the status quo.

Furthermore, the faster we try to change its current, the harder the inductor works to keep the current from changing. Therefore, the inductor sees a high frequency as an attempt at rapid changes—a threat to the status quo—so it works very hard to generate an opposing voltage (a 'counter-EMF' or 'counter-electro-motive-force') to keep its current from changing. This internally-generated voltage opposes the applied voltage more and more as the frequency rises; hence the actual current which flows drops lower and lower as the frequency rises. *This means that the apparent resistance of the inductor rises with frequency.* But this apparent resistance is not called *resistance*—since it is the inductor's reaction to the frequency applied to it, it is called *inductive reactance.*

A Resistance by Any Other Name. But whether you call it "apparent resistance" or "inductive reactance", it is still measured in ohms, and can be used as a part of the familiar Ohm's law formula. Where a simple resistive circuit answers to the expression

$$I = E/R$$

Fig. 1. Practical laboratory setup to demonstrate Ohm's law. Power amplifier must have a 70-volt output or a 500-ohm output transformer tap.

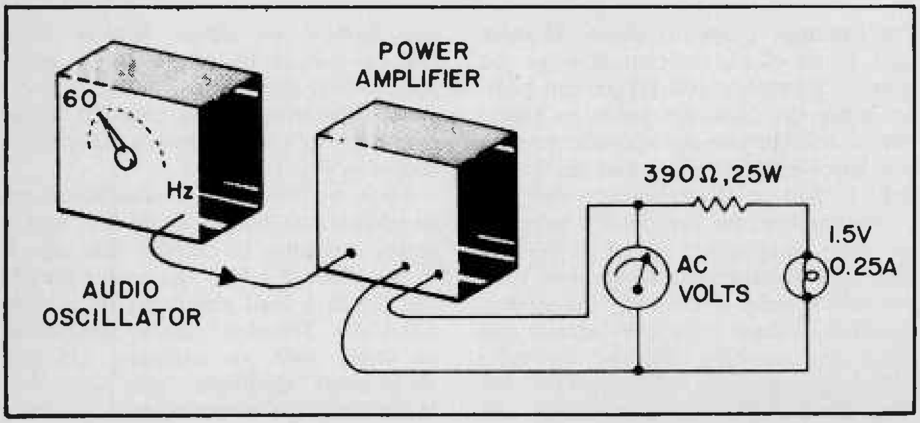
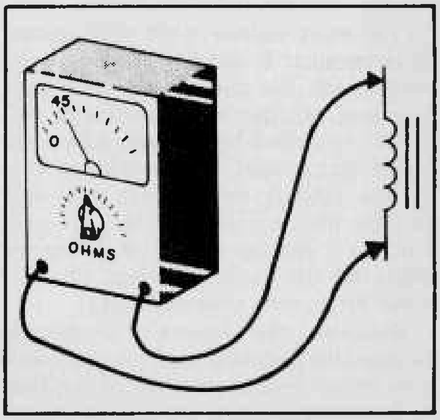


Fig. 2. Measuring the DC resistance of a one-henry inductor (choke coil) shows it has 45 ohms of resistance.



A similar circuit with resistor replaced by an inductor (coil) is described by the formula:

$$I = E/X,$$

where X is the symbol for reactance. But, since the amount of reactance (X) changes according to frequency, we must have a way to calculate its value at the frequency we are using. The following simple formula does that for us:

Inductive Reactance = 2 × π × frequency × inductance or, in the familiar algebraic shorthand,

$$X_L = 2\pi fL$$

where L is the inductance in henrys, and the subscript L following the X indicates we are talking about *inductive* reactance. Therefore, the current in an inductive circuit is:

$$I = E/X_L,$$
$$= E/2\pi fL$$

For Example. Let's take the 1.05-henry inductor and calculate its reactance at 60 Hz:

$$X = 2\pi fL,$$
$$= 2 \times \pi \times 60 \quad \times 1.05$$
$$= 395.8 \text{ ohms.}$$

which, as you can see, is very close to the 390 ohms of the resistive circuit of Fig. 1. This explains why the bulb lit to about the same brightness for the inductor as for the resistor.

When we cranked the audio oscillator up to 120 Hz, the inductive reactance became

$$X_L = 2\pi fL,$$
$$= 2 \times \pi \times 120 \quad \times 1.05$$
$$= 791.7 \text{ ohms.}$$

The new current becomes, ignoring, for the moment, the 6-ohm bulb:

$$I = E/X,$$
$$= 100 \text{ volts}/791.7 \text{ ohms},$$
$$= 0.125 \text{ ampere.}$$

which is about half the rated current of the bulb. Hence, it would be dim at this frequency. You can easily calculate that at 50 Hz, the X becomes 329.9 ohms and the current rises to the excessive value of .303 amperes; any further lowering of frequency could burn out the bulb!

Reactionary No. 2: The Capacitor. Returning to the parts-supply bin, we now take a large, *oil-filled* (—Don't try this with an electrolytic!) capacitor, and, measuring it on a capacitance bridge, find that its true value is 6.8 mfd. An ohmmeter placed across the capacitor's terminals registers an upward 'kick' of the needle as the ohmmeter's internal battery charges the capacitor, but the ohmmeter then settles down to indicate that, as far as *it* is concerned, the capacitor is—as it should be—an open circuit

We now replace the 390-ohm resistor of Fig. 1 with the 6.8 uF capacitor, as shown in Fig. 4.

Again set the oscillator to 60 Hz, and turn on the equipment. Since the capacitor is really an open circuit—according to the ohmmeter—one might expect no current flow at all. We are surprised, then, when the light bulb blithely ignores our oil-filled open circuit, and proceeds to glow as serenely and confidently as it did for the inductor and resistor! When we *drop* the frequency to 30 Hz, the bulb goes dim—when we gingerly raise the frequency to 70 Hz, the bulb gets brighter. This is just the opposite of the inductive effect, where the bulb got dimmer for higher frequencies.

Capacitive Reactance. We are obviously dealing with another type of reactance, this time arising from the presence of the capacitor in the circuit, and known as *capacitive reactance.* Its behavior in the face of changing frequency is exactly the opposite of that shown by inductive reactance. A capacitor's apparent resistance goes *down* as frequency goes up, and goes *up* as frequency goes down. This inverse relationship is seen in the expression for capacitive reactance, which is

$$X_C = \frac{1}{2\pi fC}$$

where X is *capacitive* reactance, and C is the capacity in *farads,* (not microfarads.)

Mathematically speaking, by placing f (frequency) in the *denominator* (bottom) of the fraction, we are saying that as f gets *larger*, the answer (X) gets *smaller*, which is exactly what we observed in the lab experiment above.

Just as in the inductive case, we can plug X right into the Ohm's law formula and have a way to calculate current or voltage for a capacitive circuit:

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

More Examples. As examples of how the above formulas can be used, let's calculate reactances and currents of our 6.8-uF capacitor at various frequencies at 60 hz,

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{2 \times \pi \times 60\text{Hz} \times 6.8\text{uF}}$$
$$= 390.1 \text{ ohms.}$$

(Note that 6.8 *micro*farads must be expressed as 6.8×10^{-6} farads, since the formula is always written for C in *farads.* Alternately, you could write 6.8 microfarads as 0.000 006 8 farads, but that's a little more awkward to handle.)

At 30 Hz, a *lower* frequency, the capacitive reactance *increases:*

$$X_C = \frac{1}{2 \times \pi \times 30 \text{ Hz } (6.8 \times 10^{-6}) \text{ farads}},$$
$$= 780.2 \text{ ohms,}$$

and at a *higher* frequency, say 70 Hz,

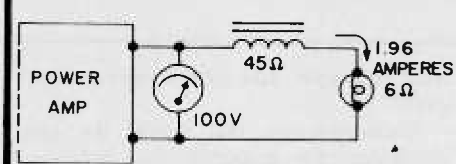


Fig. 3. Substituting the one-henry inductor in place of the 390-ohm resistor of Fig. 1 lowers the opposition of the circuit to AC, hence more current flows.

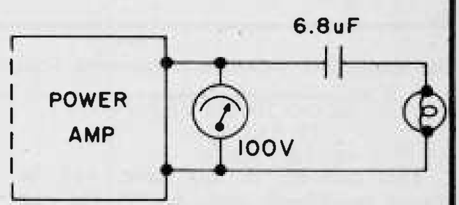


Fig. 4. A 6.8 uF capacitor substituted in the test circuit for the inductor. If the capacitor acted as an open (as it would for DC) no current would flow.

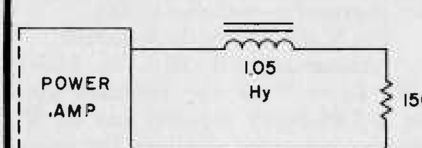


Fig. 5. Test circuit load is now combination of inductor (1.05 henry) and resistor (150 ohms). As the text explains, their combined reactance is computed by adding them at right angles!

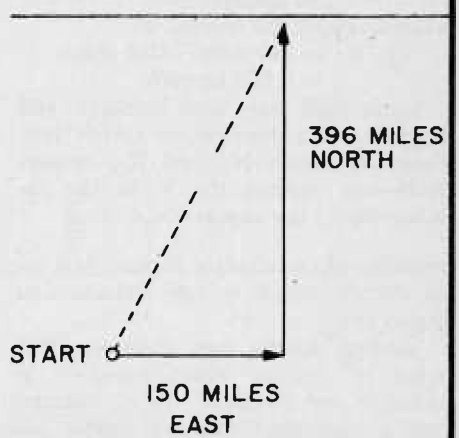


Fig. 6. Adding traveling distances in different directions yields resultant which is the diagonal (the shortest distance between the two points), also a right triangle. Back to the Pythagorean theorem!

Circuits which include capacitance and inductance as well as resistance are only slightly more complicated than circuits with just pure resistance. Once the AC frequency is known the reactance of inductors and capacitors is figured, added (subtracted) and inserted into the formula for impedance (see text above on this page).

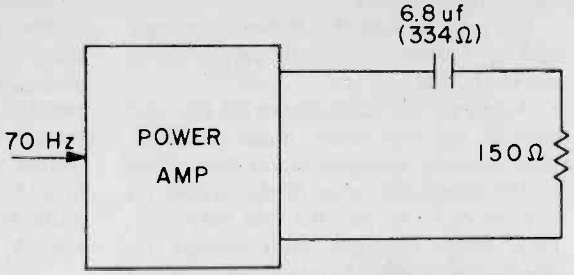


Fig. 7. The reactance of the capacitor at this frequency (70Hz) is 334 ohms. This may be combined with the pure resistance, 150 ohms, by using the formula discussed in the text.

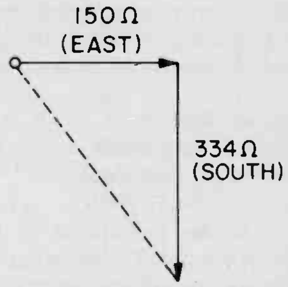


Fig. 8. This drawing shows how the two reactances are added, as also shown in Fig. 6 and, described in the text.

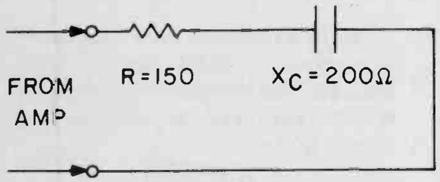


Fig. 9. Schematic showing reactance of capacitor. The two reactances add according to the formula, to yield a combined reactance (at the particular frequency used) of 250 ohms.

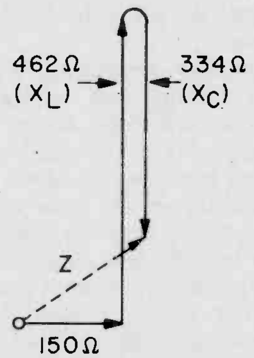


Fig. 11. The relative "directions" of capacitive and inductive reactances along with that of the pure resistance. Z (the diagonal) is the resultant of the 150-ohms resistance plus the difference between the two reactances.

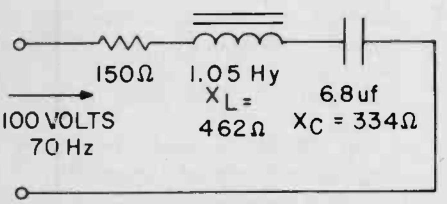


Fig. 10. Combining capacitive reactance and inductive reactance is also handled. Reactance of each at 70 Hz is computed, they are added together, and the difference is put into the formula with the pure resistance.

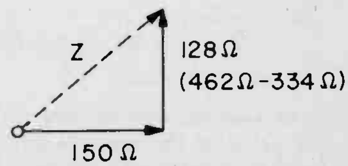


Fig. 12. Combining the reactances leaves a difference of 128 ohms and provides a directional diagram similar to that of Fig. 6. Such directional drawings are called "vector" diagrams.

the capacitive reactance becomes *less:*

$$X_C = \frac{1}{2 \times \pi \times 70\ \text{Hz}\ (6.8 \times 10^{-6})\ \text{farads}},$$

$$= 334.4\ \text{ohms}.$$

The current, in any case, can be found by Ohm's law. At 70 Hz, the current is

$I = E/X$,
$= 100$ volts/ 334.4 ohms,
$= 0.299$ ampere,

while at 30 Hz the current is:

$E/X = 100$ volts/780.2 ohms,
$= 0.128$ ampere.

So, in their way, both inductors and capacitors are obedient to Ohm's law. Their reactances—X_L and X_C, respectively—can replace the R in the familiar Ohm's law expression, $I = \frac{E}{R}$ enabling us to calculate current flow for ac circuits which include inductors or capacitors.

Adding Apples and Oranges. But, what of circuits which *combine* an inductor and a resistor? Or an inductor and a capacitor? Can we simply add the two 'ohms' together? Do resistance and reactance add like apples and apples?

Unfortunately, this is not the case. Consider, for example, the circuit of Fig. 5. Here, our 1.05-Henry inductor and a 150-ohm resistor are connected in series across the 100-volt, 60-Hz source. What is the current flow?

Obviously, we need an Ohm's-law-like expression—something like:

I = E, divided by the apparent "resistance" of R and L, combined.

We know from our previous work that a 1.05-henry inductor has an X inductive reactance of about 396 ohms. We wish that we could simply add the 396 ohms of reactance to the 150 ohms of resistance to get 546 ohms—but reactance and resistance simply don't add that way. *Instead, they add at right angles!* And how, you ask, does one *add* at *right angles?*

A Journey at Right Angles. To understand how resistance and reactance can add at right angles, consider another type of problem: If I travel 150 miles due east, and then 396 miles north, how far am I from my starting point? See Fig. 6.

You obviously cannot get the answer to this problem by adding 396 to 150, because you're certainly not 546 miles from home. But notice that the figure is a right triangle—a shape which that old Greek, Pythagoras, solved long ago. He said that if you *square* 150, and *square* 396, add the squares, and then take the square root, you will get the length of the longest side:

$$\sqrt{(150 \times 150) + (396 \times 396)},$$

$$\sqrt{179{,}316},$$

$$432.3\ \text{miles}.$$

This, then, is a way of adding two quantities that act at right angles to each other. Since inductive reactance is a kind of "north-bound resistance", operating at right angles to the "east-bound resistance" of an ordinary resistor, we combine the two by adding at right angles, just as the two right-angle distances were added in the above mileage problem. The effective resistance of the 396-ohm reactance and the 150-ohm resistor is therefore:

$\sqrt{(150 \times 150) + (396 \times 396)}$,
$= 432.4$ ohms.

What do we call this combination? It is obviously neither resistance nor reactance, but a combination of both. Since it represents a *general* way that a circuit can impede the flow of electrons, it is called *impedance*, and is represented by the symbol Z. The general formula for impedance is, therefore:

$$Z = \sqrt{R^2 + X^2}$$

Another Candidate for Ohm's Law. Impedance is measured in *ohms*, just as are reactance and resistance. If we know the impedance and voltage in a circuit, we can find the current by plugging Z into the familiar Ohm's Law expression:

$I = E/Z$,
$= E/\sqrt{R^2 + X^2}$.

Using this expression we can calculate the current in the example of Fig.5:

$I = E/Z$,
$= 10$ volts/423.4 ohms,
$= 0.326$ ampere.

Southbound Capacitors. The knowledge that inductive reactance adds at right angles to resistance leads immediately to the question, "What about *capacitive* reactance? Does it also act as a 'northbound' resistance?"

As you might except, two circuit elements as different as inductance and capacitance could never agree on the 'direction' of their reactances. If inductive reactance is 'northbound', the capacitor obstinately declares that *its* reactance is *'southbound'*, acting in direct opposition to the inductive direction, as shown in Figs. 7 and 8.

However, this makes no difference in the equation for impedance, which is still given by

$$Z = \sqrt{R^2 + X^2},$$

where X is, in this case, X_C, capacitive reactance.

As an example, let's calculate the impedance of the circuit of Fig 9.

$Z = \sqrt{R^2 + X^2}$
$= \sqrt{(150)^2 + (200)^2}$
$= \sqrt{62{,}500} = 250$ ohms

As a further calculation, let us determine the current which will flow if 50 volts is applied to the terminals at the left of Fig. 10:

$I = E/Z$,
$= 50/250$
$= 0.2$ ampere.

All Together, Now. The final question is this: If a circuit includes resistance, inductance and capacitance, all at once, what is its total impedance?

An example of such a series circuit is shown in Fig. 10.

Here, 100 volts at 70 Hz is applied across a series circuit of 150 ohms resistance, 1.05 henry inductance ($X_L =$ 462 ohms), and 6.8 uF capacitance ($X_C =$ 334 ohms).

As a first step in determining the total impedance, we can draw the 'directions' of the resistance and the two reactances, as shown in Fig. 11.

The first thing that strikes us about this figure is that the figure is that the effect of the 'northbound' (inductive) 462 ohms is partially cancelled by the 'southbound' (capacitive) 334 ohms. The *net reactance* of this circuit is therefore:

$X = X_L - X_C$,
$= 462$ ohms $- 334$ ohms,
$= 128$ ohms.

This combining of X_L and X_C by simple subtraction reduces the problem to a simpler one, resembling a problem we've already solved. This is graphically shown in Fig. 12.

Applying the formula for impedance

$Z = \sqrt{X^2 + R^2}$,
$= \sqrt{(128)^2 + (150)^2}$,
$= 197.2$ ohms.

The current flow is:

$I = E/Z$,
$= 100$ volts/197.2 ohms,
$= 0.51$ ampere.

North vs. South. In the above problem, we saw that the 'northbound' inductive reactance (462 ohms) was very nearly cancelled by the 'southbound' capacitive reactance (334 ohms). It's pretty obvious that by changing some values, or by changing the frequency, we could make *X_L exactly equal to X_C*, and they would cancel each other completely, leaving the circuit with no net reactance whatsoever—just 150 ohms of simple resistance. This condition, where $X_L = X_C$ exactly, is called *resonance*, and that's an interesting story, too. ■

The Way AVC Works

☐ 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 faraway 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.)

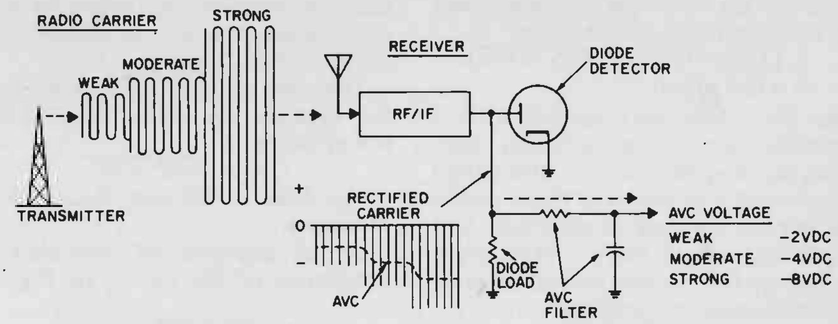


Fig. 1. Diode detector develops AVC voltage in typical tube-type receiver. For simplicity's sake, carrier is shown unmodulated but is assumed to originate in three fixed levels.

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 resistor 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 *u*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 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

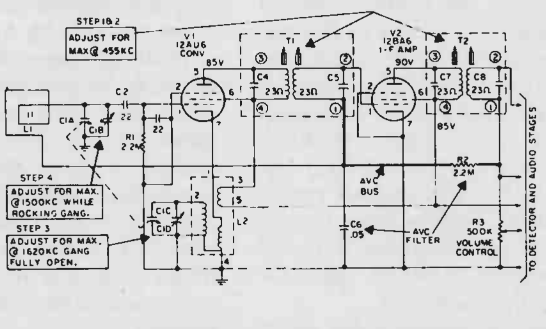


Fig. 3. Schematic of GE tube radio, showing AVC filter and bus. Since cathode of V2 is grounded, tube relies on AVC voltage on control grid (pin 1) for bias.

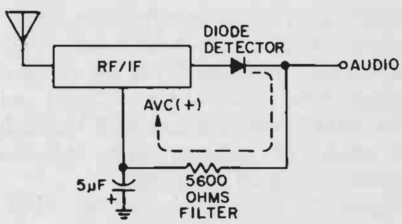


Fig. 4. As in tube sets, AVC in solid-state circuit is tapped from diode detector.

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.

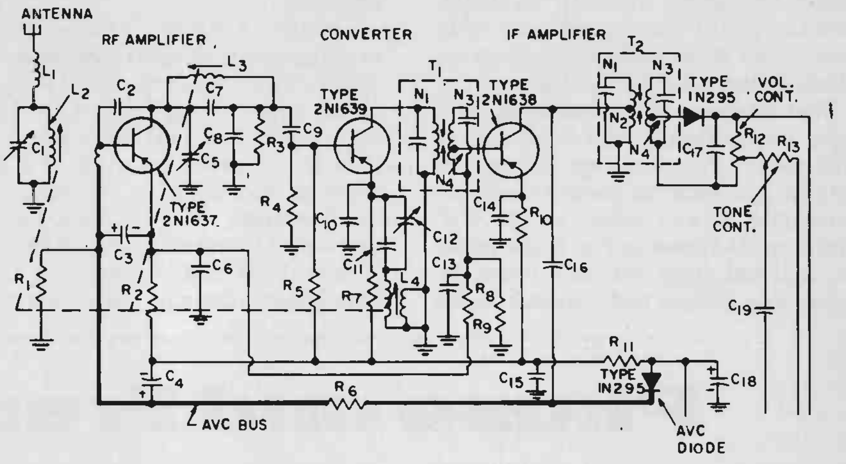


Fig. 5. Partial schematic of RCA car radio, showing separate AVC diode (lower right) and AVC bus. Since transistors here are pnp's, AVC voltage is positive rather than negative.

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 *D*AVC, for *d*elayed 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.

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.

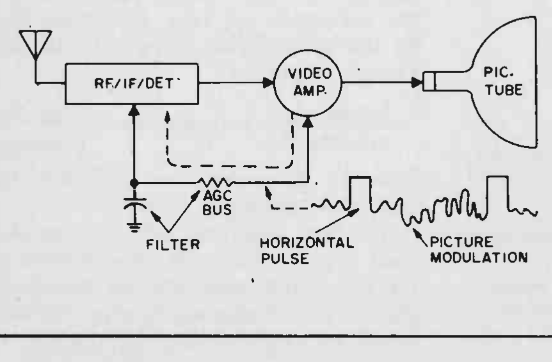


Fig. 6. In TV receiver, horizontal sync pulse must provide AGC voltage since video carrier itself isn't suitable. Note that basic idea is same as that used in AM and FM receivers.

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 *A*utomatic *G*ain *C*ontrol. Incidentally, 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. ■

Phase and Frequency

☐ THE INCREASING SOPHISTICATION of the home experimenter has resulted in his being required to make ever more demanding measuremnts. High on the list is the need to measure frequencies and phase shifts generated by experimental circuits. Short of buying one of the many frequency counters available, such measurements can be a problem. But they need not be a problem, because even the most modest experimenter probably has all of the equipment on his bench that is required to measure frequency quickly and accurately. All you need is an inexpensive oscilloscope and a frequency source such as an audio oscillator or a signal generator.

The simple equipment interconnections required are shown in the figure. Notice that all you have to do is connect the output of your frequency source to the vertical input of your oscilloscope, and the frequency that you wish to measure to the horizontal input. Then by making a few quick control adjustments you can determine the unknown frequency.

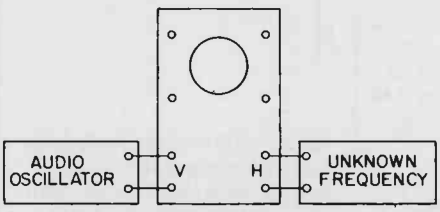
Frequency measurement with an oscilloscope is accomplished using Lissajous figures or patterns. Lissajous patterns are the displays that appear on an oscilloscope when voltages of different frequency, amplitude, and phase relationships are applied to its deflection plates. You have probably seen them in science fiction movies when "weird" patterns are used to indicate abnormal conditions aboard a spaceship.

Getting back to the test set-up, it is obvious that the signal applied to the vertical input will cause the CRT beam to move up and down at a rate determined by the frequency of the signal. The same action can be obtained in the horizontal direction by switching your oscilloscope sweep controls to the positions that bypass the normal sweep circuits and apply signals connected to the horizontal input directly to the horizontal channel amplifier. The result is that the CRT beam will be pulled up, down, right, and left all at the same time. The resulting display will literally resemble a tangled up ball of string unless the two signals are harmonically related to one another. When this condition exists, the display will become steady as a rock, and the unknown frequency car be determined by making a quick mental calculation.

The basis of using your oscilloscope to measure frequency is that you adjust the frequency controls of your frequency source to induce the steady display. Then by reading the frequency dial of your source one of the two frequencies is known and the other can quickly be determined. Simple?

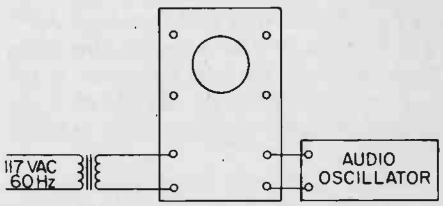
Here's How. Returning to the figure, you should now have your equipment connected as shown. Next, adjust the oscilloscope vertical and horizontal sensitivity controls to obtain a suitable deflection both vertically and horizontally. About 1-in. wide and 2-in. high is more than adequate. As mentioned before, at this point the display probably looks like a real mess. But that is normal.

Now adjust the frequency controls of your frequency source until the display stabilizes and resembles a pattern in the next figure. The accuracy of the final measurement will be a function of how stable you can make the display, so make certain that the display is as steady as you can get it. It might help to let your equipment warm-up for a while if drift is a problem, but don't forget that many frequencies are not too stable. We will tell you how to check the stability of your frequency source later. Also, though it is possible to obtain stable displays that have many loops in them, it is usually best to keep the number of loops in either direction below five if possible. This is simply because they are easier to count.



The frequency or phase measurement set up. Frequency less than 1 Hz is usually described in terms of phase angle. When the phase has shifted 360 degrees, it has changed in frequency by one Hertz.

Finally, referring to the examples shown in the last figure, count the number of times that the trace "touches" the left side of the display, and the number of times that the trace "touches" the top of the screen. Divide the number of "left-touches" by the number of "top-touches" and multiply the indication of your frequency dial by the result. This gives you the unknown frequency:



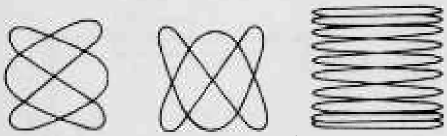
Audio oscillator calibration set up.

$$\frac{\text{left-touches}}{\text{top-touches}} \times \text{frequency} \doteq \text{Unknown Frequency}$$

Couldn't be easier, and you save the cost of a frequency counter.

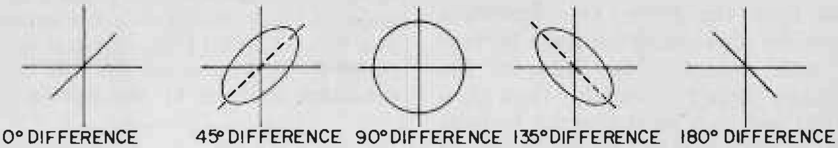
To firm it all up let's assume that your display looks like that shown in the last figure, and that the frequency dial of your frequency source indicates 3,345 Hz. First divide the number of "left-touches" (3) by the number of "top-touches" (4). The result is 0.750 if you hold the answer to a manageable and satisfactory three places. Next multiply the known frequency by 0.750 (0.750 X 3,345 = 2,509 Hz) to determine the unknown frequency. It's fast, easy, and as accurate as the degree to which you know the known frequency.

Since your frequency source probably makes you blush when anyone mentions calibration or accuracy, and who doesn't, let's cover how Lissajous patterns can be used to calibrate your frequency source. It is merely an extension of what you do to determine an unknown frequency, except now you "bor-



Various vertical to horizontal frequency ratios.

row" the known accuracy of your public utility line frequency. The 60-Hz power that you take from your wall socket is generally frequency controlled to within 0.1%. By using this known frequency, safely stepped down through a filament transformer, you can calibrate your signal generator frequency dial at any frequency that is a multiple

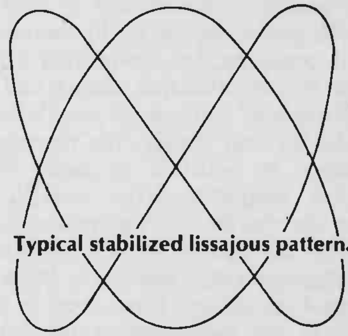


Major phase angle lissajous patterns.

of 60.

Connect the circuit shown. Then, beginning at 20 Hz, increase the frequency of your audio oscillator and observe how closely to the correct dial indication the scope display "locks in." After a while, say about 1800 Hz, you won't really be able to count the number of loops. But if you are careful you will be able to see the display stabilize, which indicates that you have reached the next multiple of 60.

Checking the stability of your frequency source is even easier. Simply adjust the frequency dial to obtain a stable display, and watch the display. After a reasonable warm-up time for the equipment, you should be able to obtain a display that seems to rotate very slowly, if at all. Of course, this will be a function of unit quality. But it will give you a feeling for how much drift can be expected from your fre-



Typical stabilized lissajous pattern.

quency source. Additional amounts can be attributed to the source of the unknown frequency.

The oscilloscope has always been the most useful tool available to the experimenter. Now you can use it to measure unknown frequencies, phase shifts, calibrate oscillators, check signal stability, and many other uses that will come to mind as you become familiar with Lissajous patterns. ■

Thermistors Are Hot Stuff

☐ A THERMISTOR is simply a thermal resistor or, more descriptively, a temperature sensitive resistor. Its composition is basically ceramic, made by sintering metallic oxides such as manganese, nickel, cobalt, copper and the like.

Now it is fairly common knowledge that resistors are temperature sensitive (the resistance changes with temperature), however, thermistors are many times more sensitive to temperature than are resistors. It is not uncommon to see a change in resistance of fifty times from 32 to 122° F (0 to 50° C) in a thermistor. The proportion of resistance change from 0° C to 50° C is called the *ratio* of the thermistor. For example, a thermistor having a resistance of 150,000 ohms at 0° C and a ratio of 15 would have a resistance of 10,000 ohms at 50° C. Thermistors are classified as having *negative temperature coefficients* since, as the temperature increases, the resistance decreases.

Thermistors are available in many configurations. Typical among these are beads, probes, rods, discs, glass coated beads and washers. Each of these configurations except the washer is usually formed with two leads that are used for electrical connection. The washer requires metal plates, pads or the like to butt against the opposite, electrically conductive, flat surfaces for electrical connection. Depending upon the manufacturer, most of these types can be used up to 300° C (572° F). However, some discs, washers and beads are limited to 150° C (302° F). In the higher temperature applications, the insulation should be of teflon or glass braid and the method of joining the circuit wires to the thermistor leads should be done by crimping with a suitable terminal.

To understand and apply thermistors, we must first look at the effect on the resistance of the thermistor as it is subjected to heat. The curve of Fig. 1 shows the nominal resistance versus temperature for a thermistor made by Fenwall, the QB42L1 (rod-type). Note the sharp decrease in resistance as the temperature increases from 0° C to 200° C.

So What? Up to this point we've talked a lot of theory but just how practical is this device? I'm glad I asked that question—let's look at some applications.

Suppose that we wanted to build a "thermometer" using a thermistor that corresponds to the nominal temperature-resistance curve of the QB42L1. Let's say that we wanted to cover the range of 32° F to 104° F and we plan to use the basic circuit of Fig. 2 where R1 is a potentiometer, R2 is the thermistor (QB42L1) and M1 is a milliammeter. We will adjust R1 for 10,000 ohms (and explain later why). The resistance of the circuit will be at it's minimum at 104° F. From the table we see that, at 104° F, R2 = 11,484 ohms; therefore, the total circuit resistance is 21,484 ohms. If V is nine volts, I = 9/21,484 = .42 mA. This means we can use a .5 mA meter. At 32° F, R2 is 56,500 ohms; total circuit resistance is 66,500 ohms, I = 9/66,500 = .13 mA.

From additional calculations the meter plate can be copied and re-labeled with the appropriate temperatures. The thermistor can be mounted quite a distance from the meter. One limitation is that the wire resistance must be very low with respect to the value of the minimum circuit resistance (less than 1/100) and it is good practice to twist long leads in a spiral fashion to avoid electrical pick-up in the leads.

That Series Resistor. In the thermometer circuit we used a 10,000-ohm series resistor. This resistor is used to limit the power applied to the thermistor and it concerns the self-heating effect or, as the specification sheets call it, the *dissipation constant* of the thermistor. As we said earlier, the thermistor resistance is sensitive to heat. Now visualize putting a large voltage, E, across the thermistor. The power dissipated by the thermistor is E^2/R where R is the thermistor resistance. So what happens? As current flows, heat is generated in the thermistor to the extent that the resistance of the thermistor begins to decrease. More power is dissipated in the thermistor because E^2/R is larger because R has become smaller. This continues until either the thermistor is damaged or the conduction of heat away from the thermistor is large enough to balance the heat generated by the current flow. In either case, the thermistor resistance cannot give a true indication of ambient temperature.

To minimize this effect we must consider the *dissipation constant* (d.c.) of the thermistor. The dissipation constant is the amount of power, in milliwatts (10^{-3} watts), that will raise the temperature of the thermistor 1° C above the ambient temperature. For example, if a thermistor whose d.c. is 0.1 milliwatt is placed in a 25° C ambient and then caused to dissipate 0.1 milliwatt by applying a voltage to the thermistor leads, the temperature of the thermistor would rise to 26° C. Typcial dissipation constants (in milliwatts) are as follows; bead 0.1, glass coated bead 1.7, disc 2.0, rod 4.0, washer 5.0.

Self-heating cannot be eliminated but it can be minimized to the extent that it is negligible. Without going into the detailed mathematics, the following procedure will allow you to limit the self-heating to an acceptable level. Use a resistor (or resistors) in series with the thermistor as shown in Fig. 2. The resistor value can be determined as follows: first determine the amount of error in degrees that is acceptable to the circuit; multiply the error by the dissipation constant to determine the maximum power dissipated by the thermistor. From Table 2, select the proper formula for R that appears in the same column as the maximum power that you calculated. (Note that you must select, or at least assume a value of voltage, V, for your circuit).

Table 2. This formula is used to determine the series resistor which limits the self heating effect. See text for more info.

Power (mW)	Resistance
½	$V^2 \times 1000/2$
1	$V^2 \times 1000/4$
2	$V^2 \times 1000/8$
3	$V^2 \times 1000/12$

Table 1. This data was used to generate the graph of Fig. 1. It describes the resistance of a Fenwall QB42L1 thermistor at various temperatures. In practice, this data can be generated at home by the experimenter.

temperature °F	°C	resistance Ohms
32	0	56,500
50	10	36,600
68	20	24,320
77	25	20,000
86	30	16,534
104	40	11,484
122	50	8,134
140	60	5,874
158	70	4,320
176	80	3,230
194	90	2,458
212	100	1,892
230	110	1,480
248	120	1,170
257	125	1,050
266	130	942
284	140	764
302	150	628
320	160	518
356	180	360
392	200	260

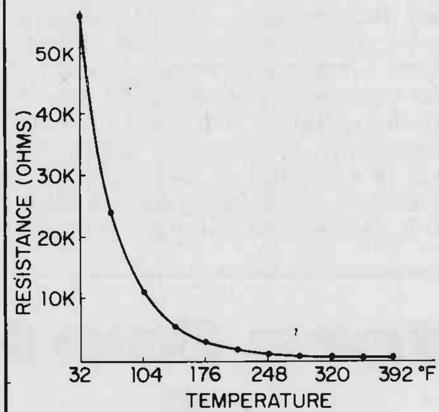


Fig. 1. Temperature-resistance graph.

Suppose you have a thermistor whose d.c. is 2 and you want to limit the error to 1° C. Let's say that the circuit voltage is 10 volts. Multiplying the maximum error (1° C) by the dissipation constant (2 milliwatts/°C) gives a maximum allowable power of 2 milliwatts. To limit the dissipation to 2 milliwatts we use the formula from Table 2 where, in the 2 milliwatt column, $R = V^2 \times 1000/8$ or $(10)^2 \times 1000/8 = 12{,}500$ ohms. Any R larger than 12,500 ohms will mean a smaller maximum dissipation and hence a smaller maximum error. Using a resistor of 12,500 ohms and a voltage of 10 volts will allow a maximum error of 1° C. This error will occur when the thermistor resistance is 12,500 ohms. As the thermistor resistance changes from 12,500 ohms (either increases or decreases), the self-heating and also the error becomes less.

The self-heating effect of the thermistors can be used to an advantage. A typical application is shown in Fig. 3 where V is the applied voltage, S1 is a switch, R1 is the thermistor and K1 is a relay. The thermistor is placed in series with the relay coil to provide a "delay on make." When S1 is first closed, the relay remains de-energized until the thermistor heats to the point where it's resistance is low enough to allow the current to reach the level of the pull-in current of the relay (note that the self-heating effect can be used with AC as well as DC).

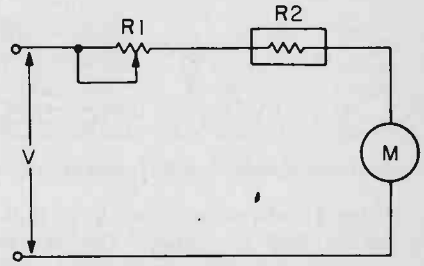


Fig. 2. Basic electronic thermometer

A more complex application of the self-heating effect is shown in Fig. 4 where it is required to regulate the voltage across lamp I1. The source voltage, V, varies 28 ± 4 volts and it is necessary to maintain a voltage of 2 to 3 volts across the lamp. Let me say at this point that using a thermistor in a self-heating mode is largely a trial and error situation. This is primarily because it is difficult to predict the amount of heat conducted away from the thermistor. Since this is not known, the thermistor temperature (and hence it's resistance) cannot be determined exactly. The more you learn about thermistors, the easier it becomes. Nevertheless, self-heating applications require a certain amount of "Kentucky Wind-

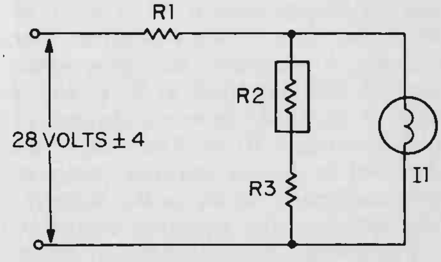


Fig. 3. Application of thermal delay.

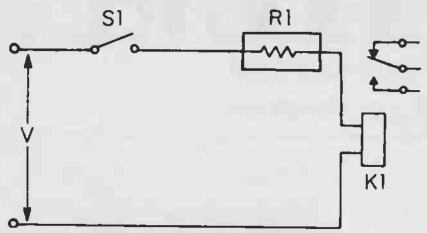


Fig. 4. Voltage stabilization using thermistor

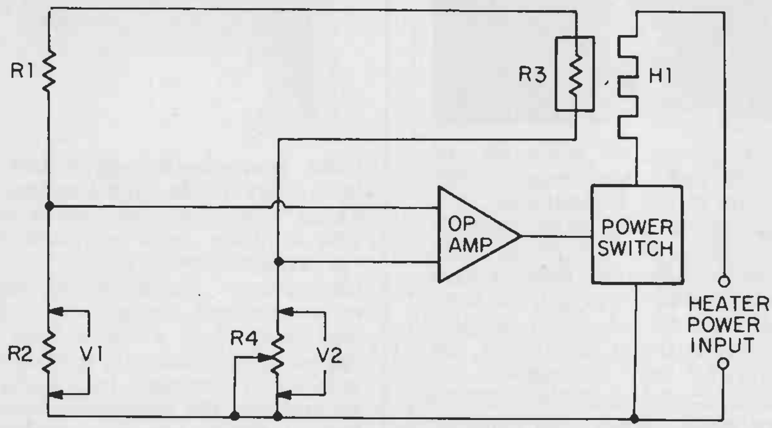
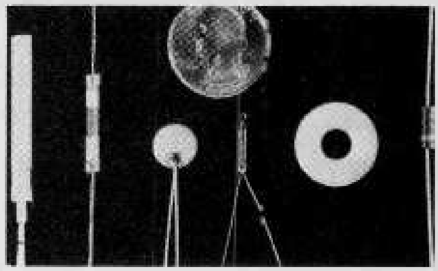


Fig. 5. Automatic temperature controller using thermistor and op amp.

age." After several attempts, using a Fenwall GB32J2 (Allied Electronics stock no. 791-0427) as R2, R1 = 345 ohms and R3 = 17.6 ohms, the voltage across the lamp is maintained at 2.65 ± .07 volts!

Other Applications. Thermistors have found extensive use in temperature controllers. A typical circuit is shown in Fig. 5 where R1, R2, thermistor R3 and R4 form a bridge network. R3 is located in close proximity to the heater, R4 is used to select the desired temperature; A1 is an op amp that senses the difference in voltage between V1 and V2. When V2 is smaller (R3 is large), the op amp turns on the power switch and the voltage is applied to the heater, H1. When V1 = V2 (R3 reaches temperature), the op amp stops energizing the power switch. The power switch can be a relay or a triac or a silicon controlled rectifier.

Be Practical. If you have a thermistor but do not have the resistance-temperature curve, the curve can be determined fairly easily. You will need a thermometer that covers the range of temperature over which you want to measure the thermistor, a method to heat the thermometer and thermistor simultaneously, a means of viewing the thermometer while, at the same time, you measure the resistance of the thermistor. You must arrange the thermometer to be very close to the thermistor and adjust the heat, in steps, so that at each step the temperature of the thermometer has stabilized after which the resistance of the thermistor is read and then the temperature and resistance readings are recorded. This step is repeated until the desired temperature range is completed. Usually only about four to seven readings are required to allow an accurate curve to be drawn.



The more common types of thermistor configurations are, from left to right, the probe, rod, disc, glass coated bead and washer.

If the thermistor is sealed (glass or epoxy covered), a simple method of heating is to immerse both the thermistor and the thermometer into a pan of water on top of a range; another method is to heat them inside a closed or semi-closed container such as an oven. In either case be sure not to let any part of the thermometer, or the thermistor, or the bare leads, touch the metal since this will probably draw off heat and cause an erroneous reading. Also, when reading the resistance, disconnect the meter immediately after the reading to avoid self-heating.

By using the ratio for a general evaluation, the resistance-temperature curves and the formulas for self-heating, the thermistor offers many applications in the areas of temperature measurement, temperature control, timing and control circuits.

This article is meant to be a first introduction to thermistors. For experimentation, one of the cheapest sources of thermistors is from junked pocket transistor radios. Most use thermistors to stabilize the class B push-pull audio output stage. Some even spell it out for you on the manufacturer's ident plate when they list the number of transistors, diodes, and thermistors. Good hunting and good luck! ■

Looking into Op Amps

☐ FEW LINEAR (non-digital) ICs have achieved the wide popularity of the op amp in hobbyists projects of every description. Combined with few other circuit components, the op amp circuit vastly outperforms the multiple transistor circuit of yesteryear. Because you will encounter the op amp time and time again in many circuit applications and may desire to work up your own op amp circuits, it is essential to become familiar with the device.

This will introduce you to the basics of op amp circuits and applications. Four simple rules of operation are logically applied to trace and deduce the operation of the basic linear op amp circuits. Test circuits are included for "hands on" familiarity. Only a few mathematical relationships are listed to effect a comparison of the several circuits.

Some Basics. As shown in Fig. 1a, the op amp has two input terminals and one output terminal. A plus sign at one input identifies the *non-inverting* or "follower" input. When this input goes positive (with respect to the other) the output voltage VOUT also goes positive, thus "following" the polarity of the input. The minus sign at the other input identifies the *inverting* input. When this input goes positive (with respect to the other), VOUT goes negative, thus "inverting" the polarity of the input. In technical terms, the input stage of the op amp is a balanced "differential input" amplifier and is one which responds to the *difference* between the voltages.

Output voltage VOUT equals VIN times AVOL (AVOL equals the open-loop

(Continued on page 74)

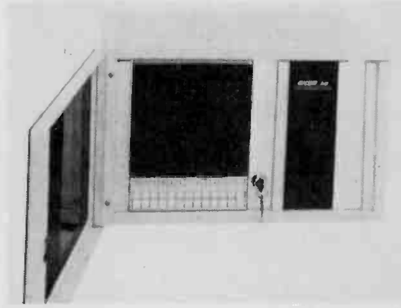
COMPUTER NEW PRODUCTS

Here in ELECTRONICS THEORY HANDBOOK you will find information on the newest hobby computers and accessories.

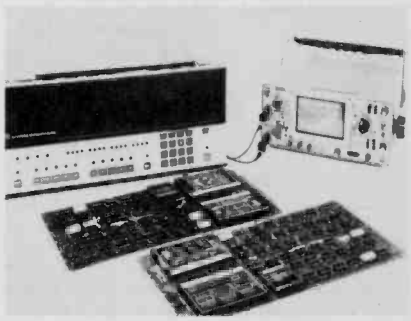
Hand-Held Terminal — National Semiconductor offers an inexpensive hand-held terminal, for use with the 8-bit "SC/MP" microprocessor kit, to eliminate the need for a costly teletype system. The SC/MP Keyboard Kit provides input/output capability through a calculator-type keyboard with a 6-digit hex display. It features a simple microprocessor control to allow the user to evaluate the SC/MP CPU, and direct object code program manipulation for development of a variety of application software. The keyboard package includes: manual, all required integrated circuits, resistors, keyboard display cable connector assembly, wire wrap connectors, precut wires, hand-held wire wrap tool. Heart of the keyboard kit is a ROM firmware package (512 bytes) which replaces the "Kit Bug" ROM originally supplied with the SC/MP kit. The keyboard is arranged as an 8 x 4 matrix array, but only 20 of the possible 32 keys are used. Functions of the used keys: 16 keys for hex command value 0 thru F; abort command; memory command; go command; terminate command; power on/off switch used for initializing SC/MP. Price: $95. National Semiconductor, 2900 Semiconductor Drive, Santa Clara, CA 95051. Circle number 46 on Reader Service Coupon for more information.

Home TV Game System—This Fairchild Video Entertainment System, designed to be a fully programmable home electronic game system, uses plug-in cartridges to provide an "unlimited number" of game and other format selections. Key to the system's versatility is the new Videocart cartridge which contains a semiconductor memory programmed to reproduce specific games, in full color, on a TV screen. Game selection is made through a keyboard console with mobile screen elements manipulated by means of dual controls. The game console incorporates a Fairchild F8 microprocessor and four solid-state, random-access memories. The console is connected to the TV set by means of a control box. In operation, the cartridge is inserted in the console and the player selects a game from the Videocart cartridge jacket and presses the appropriate key on the console. Time limits and speed-of-play can be varied. The game score and elapsed time are continuously displayed on the TV screen. Interruption of play is possible with a freeze switch, and sound effects are used to add "realism" to the games. Use with any color or black-and-white TV receiver. Priced at $169.95, plus $19.95 for each Videocart cartridge. Fairchild Camera and Instrument Corp., Consumer Products Group, 4001 Miranda Ave., Palo Alto, CA 94303. Circle number 61.

Low Cost Microcomputer System — E & L Instruments offers a Mini-Micro Designer microcomputer system in kit form for "people having minimal experience in digital techniques." The unit is based on Intel's 8080 microprocessor chip and combines ease of programming (direct input via built-in keyboard) with input/output buses via external card edge connections, or through a unique SK-10 interface/breadboarding socket. Internal status/date is shown by three sets of LED indicators. Included in the package is a memory card featuring 1K of read/write memory space. The system is easily expanded with many options, according to E & L. This unit is an outgrowth of E & L's major system, the Micro-Designer, and is supported by software that is easily understood by people having no previous background in microcomputers. Complete software takes the kit user from kit construction to system usage. Prices range from $125 for the simplest kit to $500 for a completely assembled and tested version with extra features. E & L Instruments Inc., 61 First Street, Derby, Conn. 06418. Circle number 54 on Reader Service Coupon.



Voice Response System—Micom Systems offers a new microcomputer controlled Voice Response System to provide multi-line voice response output "at exceptionally low cost" for any minicomputer. The Micom 310 requires no complicated hardware or software interfacing, and a Touch-Tone telephone can be used as a complete data terminal in computer inquiry-response applications. The natural sounding synthetic voice is based on analysis of real speech, either male or female. Both asynchronous and synchronous protocols may be used to communicate with the 310. Standard ASCII data characters are used to control all functions, including the interface to each Touch-Tone data set. Vocabulary may be stored in PROM or down-line loaded from the computer to provide virtually unlimited vocabulary and system flexibility, according to the company. The system may be local to host computer or may act as remote data/voice concentrator in a large data communications network. Redundant common logic and power supplies are provided for maximum reliability. Prices start at $500. Micom Systems, Inc., 9551 Irondale Ave., Chatsworth, CA 91311. Circle number 52 on Reader Service Coupon.



Analog Interface Systems—Computer Automation offers a series of 17 analog input/output systems for its LSI Family of minicomputers. The modular analog-to-digital (ADC) and digital-to-analog (DAC) converters provide complete low-cost data acquisition. The systems are class-
(Continued on page 102)

CB NEW PRODUCTS

Electronics Theory Handbook looks at some of the newest CB rigs, antennas and accessories for you to use in CB contacts this year!

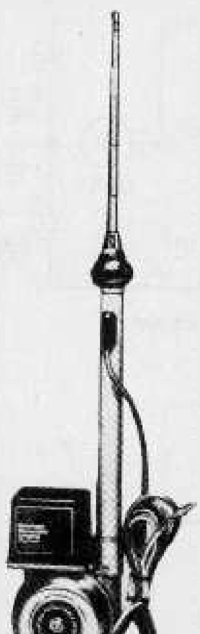
Low Pass Filter

To overcome the problem of CB rigs radiating harmonics of the same frequency assigned to one or more of the local TV channels, the Avanti AV-800 Low Pass Filter does the job of keeping channels 2 and 5 clean. Installed quickly in the coaxial line from the CB transceiver, the AV-800 has an impedance of 50 ohms, VSWR of 1.1:1, negligible line loss, and 3 dB cutoff frequency of 43 MHz. Attenuation on channel 2 (54 MHz) is 80 decibels. The unit has a capacity of 1000 watts making it useful for hams, too! Price is $24.95. For more info, write to Avanti Research & Development, Inc., 340 Stewart Avenue, Addison, IL 60101.

CIRCLE 49 ON READER SERVICE COUPON

Now You See It, Now You Don't

A new fully motorized retractable antenna for all 40 CB channels has been introduced by Sparkomatic. Priced to sell at $59.95. Sparkomatic's SA-301's many features include: its complete retractability into trunk or fender well which deters theft, vandalism, damage from car wash; its frequency dividing coupler providing optimum AM/FM/FM Stereo/CB operation. It eliminates the need for separate CB and radio antennas, and its high efficiency top loaded 4 section mobile antenna tunes easily by means of a threaded section at the tip of the antenna. The dash mounted switch gives fingertip control for extending or retracing the antenna, a built-in load prevents burn-out of power transistor, all internal elements are completely sealed against weather and corrosive road elements, and the unit comes complete with 17-ft. of RG-58/U coaxial cable, all mounting hardware and connectors and easy-to-follow installation instructions. For more information, write to Sparkomatic Corporation, Milford, PA 18337.



CIRCLE 55 ON READER SERVICE COUPON

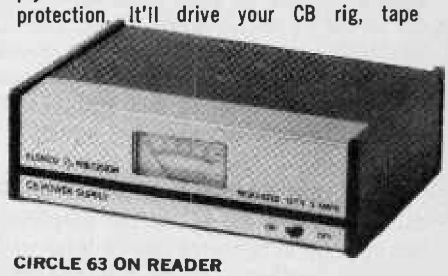
Noise-Cancelling Microphone

Can't get the message through because of the noise around you? Then you may need the Mura Model DX-119, designed for use in high ambient-noise areas where ordinarily voice transmission is marred. With the DX-119, truckers, cabdrivers and mobile CBers can get their message across in spite of annoying background noise. Also, the DX-119's noise-cancelling properties will be beneficial for public address use in factories or stores where noise levels are relatively high. Unlike most noise-cancelling microphones, the DX-119 utilizes two cartridges wired 180-degrees out of phase with each other for increased noise-cancelling effectiveness. The DX-119 can be wired for use with transceivers using either electronic or relay switching. The DX-119's high impact resistant case is designed to stand up to rough handling and normal abuse. The DX-119 comes complete with a 24-month warranty, 5-foot coiled cord and complete easy-to-read wiring instructions. It sells for $19.95. For additional information, write to Mura Corporation, Westbury, NY 11590.

CIRCLE 50 ON READER SERVICE COUPON

Indoor DC Power

Bring a mobile CB rig into the house for base operation or testing, and trouble begins—you don't have a 13.7 VDC power outlet. Don't despair! Elenco Precision Model XP-50 Deluxe regulated, metered power supply delivers 13.7 VDC at 3A with overload protection. It'll drive your CB rig, tape player, AM/FM car radio or other mobile equipment. No loss of RF output due to dropping DC voltage. Output DC current protection minimizes surge current that may cause damage. Sells for $35.95. Write to Elenco Electronics, Inc., Northbrook, IL 60062.



CIRCLE 63 ON READER SERVICE COUPON

Powered Antenna

New from Radio Shack is a motorized, retractable Citizens Band radio antenna that "disappears" as a deterrant to theft when not in use. The Archer Motorized CB Antenna extends to its full 33 inch length or retracts into the fender of your car at the flip of a switch. It can be easily wired to turn the CB radio on automatically when extended and off when retracted. The telescoping stainless steel antenna is powered by a rugged all-steel motor and drive system. No special tools are required for installation, and the antenna comes complete with a toggle switch for dash mounting, 18-foot coaxial cable and wiring harness and all mounting hardware. The Archer Motorized CB Antenna sells for $59.95. Available from Radio Shack stores and dealers ■

CIRCLE 32 ON READER SERVICE COUPON

Think of op amp as a high gain amplifier capable of boosting a minute signal many thousand times. With a little trick called inverse, or negative, feedback, you hook a resistor between the input and output which, in effect partially shorts out the gain to reduce it to your requirements.

Op Amps

(Continued from page 69)

voltage gain as listed on spec sheets). Input impedance (AC resistance) *Zi* and output impedance *Zoi* are shown in Fig. 1b. These are the primary characteristics of the op amp. If a perfect op am could be constructed, AVOL and *Zi* would be infinitely large and *Zoi* would be zero. Actually, for a general purpose 741 op amp, AVOL equals 200,000, *Zi* equals 2 megohms, and *Zoi* equals 75 ohms.

Important Concept. In linear applications such as an AC or DC amplifier, the op amp is operated closed-loop with negative feedback. To do this, the loop is "closed" by connecting a feedback circuit from the output terminal to the *inverting* input; this results in negative feedback. That porton of the output voltage fed back to the input tends to negate, or oppose, the applied input signal voltage. As will be shown later, the resulting closed-loop gain, AVCL, is very much smaller than the open-loop gain. Also, the closed-loop gain now depends on the particular feedback circuit itself and not on the actual value of the open-loop gain. This makes it possible to build amplifiers with precise closed-loop gains. Among other beneficial effects, negative feedback imparts high linearity and stability to the amplifier.

Rules Of Operation. A few basic facts of op amp operation will be stated as rules and applied to the operation of several circuits. The implications and meanings of these rules will become clear as you apply them to the circuits.

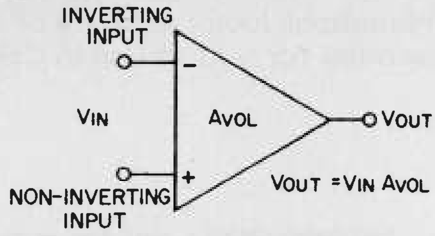
1. The *difference* in voltage between the + and − input terminals is always small and can be assumed to be zero. (This fact is a direct reuslt of very high AVOL.)

2. The current entering the + and − input terminals is small and can be assumed to be zero. (This rule is a direct result of a very high *Zi*.)

3. If the + input terminal is at ground voltage or zero, the − input terminal can be assumed to be virtually at ground voltage or zero. (This rule is also a direct result of high AVOL.)

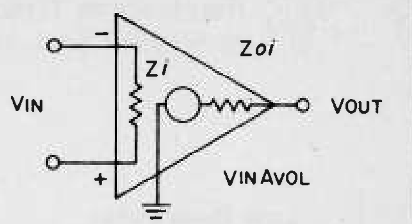
4. When an op amp is connected in a negative feedback configuration, a voltage change at the + input must result in an equal voltage change at the − input terminal. (This is a description of rule 1 in operation.)

Fig. 1A



CIRCUIT SYMBOL

Fig. 1B



CIRCUIT MODEL

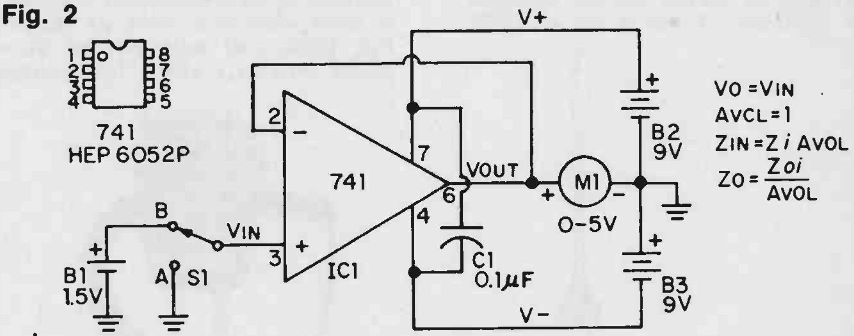
Setting Up. Breadboard the op amp circuit shown in Fig. 2. You can use perforated board and flea clips to assemble the circuit. Better still, use a breadboarding kit such as the Vector 38X solderless breadboard kit or similar. Use only the 741 or the HEP 6052P op amp for IC1. These are short-circuit proof and are internally frequency compensated to prevent oscillations. Switch S1 may be simulated by a clip lead.

Install disc capacitor C1 as close as possible to the IC. Use either a common tie point for all ground connections or a heavy ground bus. Keep the input lead wires well separated from the output lead wires. The prototype breadboard uses a 50 *u*A DC meter (Radio Shack 22-051) connected in series with a 100,000-ohm, 1% resistor for meter M1. Alternately, you can use your VOM (1000 ohms/volt or better) to measure output voltage. Use two fresh nine-volt transistor batteries for B2 and B3 and 1½ volts (an AA cell) for B1.

● **Unity Gain Follower.** Simplest of the op amp circuits, the unity-gain follower shown in Fig. 2 has a direct connection from output to the inverting input. This provides one-hundred percent negative feedback. With switch S1 at position A, the + input is grounded and meter M1 indicates zero. By rule 3, the − input is at virtual ground. Therefore, VOUT is also at virtual ground. With S1 set to position B, the meter now indicates the voltage of battery B1, near 1.5 volts. By rule 4, the 1.5 volt increase at the + input must be accompanied by a 1.5 volt increase at the − input. Hence, VOUT must rise to 1.5 volts.

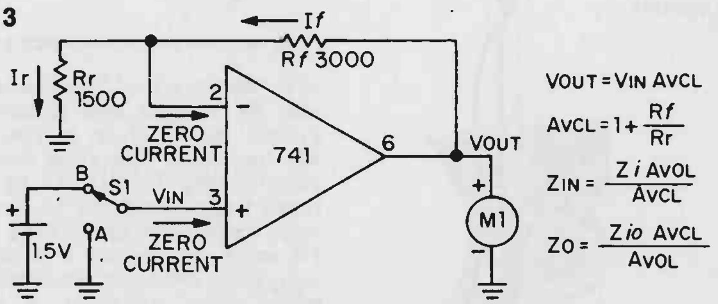
The resulting closed-loop gain, or AVCL, is unity (one unit out for one unit in). However, the high AVOL inside the IC itself is still present, enforcing close compliance with the several rules. As noted on Fig. 2, actual input and

Fig. 2



Unity-gain voltage follower.

Fig. 3



Non-inverting voltage amplifier.

output resistances ZIN and Zo are much improved due to feedback. The resultant input resistance now equals *Zi* times AVOL or 400,000 megohms for the 741 op amp! The resultant output resistance now equals *Zoi* divided by AVOL, or .0035 ohms! Consequently, the unity gain follower can duplicate the input voltage at its output without loading down the input voltage source due to the high input resistance and with high accuracy due to the low output resistance. Actually, input and output resistances are degraded somewhat by secondary factors. Nevertheless, this unity gain follower offers the highest input resistance and lowest output resistance of the several basic circuits.

● **Non-Inverting Voltage Amplifier.** Stable op amp voltage amplification is obtained by feeding back only a portion of the output voltage. Alter your breadboard circuit to include feedback voltage divider resistors R*f* *and* R*r* as shown in Fig. 3. With R*f* equal to 2R*r*, only one-third of the output voltage is fed back to the inverting input.

With S1 at position A, the + input is at ground voltage and the meter indicates zero. By rule 3, the — input is at virtual ground or zero. With zero voltage across R*r*, current I*r* is zero. In view of rule 2, I*f* always equals I*r* and is zero in this case. With zero current in R*f*, the — input and the output voltage must be equal and zero in this instance.

With S1 at position B, the + input is raised to 1.5 volts and the meter indicates 4.5 volts. By rule 4, the — input must rise to 1.5 volts matching that at the + input. The op amp does this by forcing a current into the feedback voltage divider as shown. With 1.5 volts across R*r*, current I*r* equals 1.5 volts divided by 1500 ohms, or 1 mA. Also, the voltage across R*f* equals 1 mA times 3000 ohms or 3 volts. Thus, VOUT equals 1.5 plus 3 or 4.5 volts.

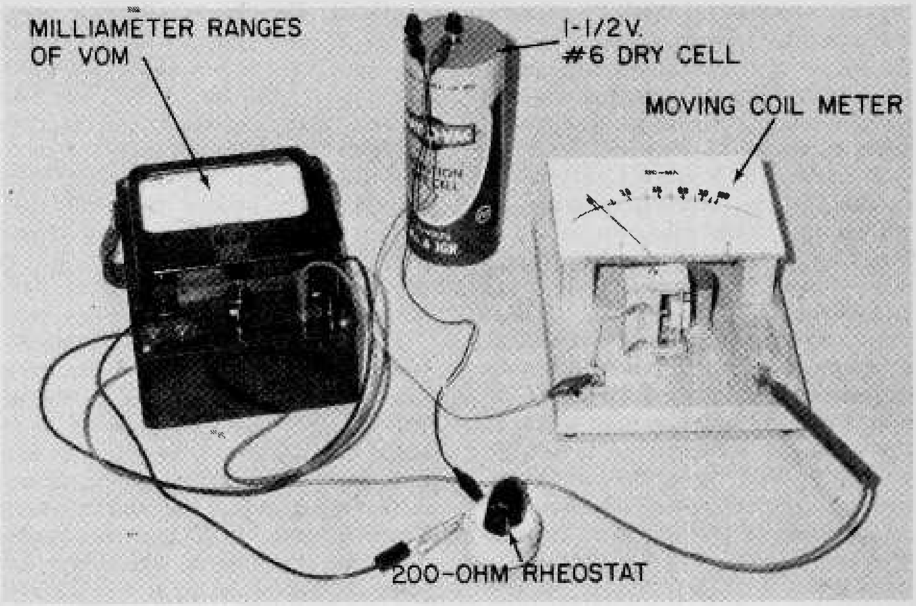
Closed-loop voltage gain AVCL equals 1 + (R*f*/R*r*) or 3 in this case. Compared with the unity gain circuit, actual output resistance Zo is three times greater and input resistance ZIN is one-third that of the unity gain circuit. This reflects the effect of feeding back 1/3 of the output voltage. To obtain a closed-loop gain of ten, resistor R*f* must equal 9R*r*, and so forth.

● **Inverting Voltage Amplifier.** Alter the breadboard circuit to that of Fig. 4 including reversal of the meter. With S1 at position A, the meter indicates zero. The proof of this result is identical to that of the non-inverting voltage amplifier with switch at position A. With S1 at position B, the meter indicates 3 volts (actually, minus 3 volts since the meter is now reversed).

In this case, the — input does not rise to 1.5 volts. By rule 3, with + input grounded, the — input must remain at virtual ground. Therefore, and quite importantly, the voltage across R*r* equals the input voltage, or 1.5 volts. Current I*r* equals 1.5 volts divided by 1500 ohms, or 1 mA, flowing in the direction shown. Since I*f* equals I*r*, the voltage across R*f* equals 1 mA times 3000 ohms, or 3 volts. With the — input at virtual ground, the output voltage must be minus 3 volts as indicated on the reversed meter.

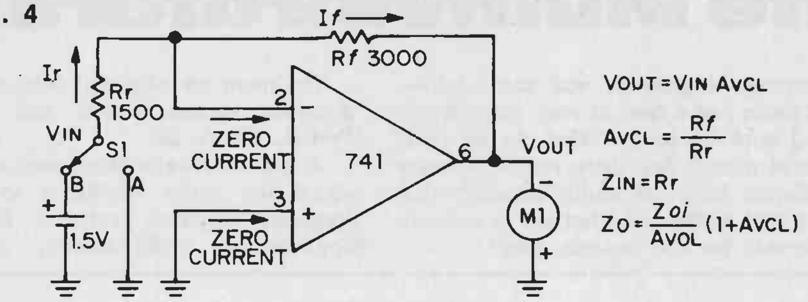
The closed loop voltage agin, AVCL, is simply R*f*/R*r*, or 2 in this case. Quite unlike the previous cases, actual input resistance ZIN equals R*r*, the input resistor. Compared with the unity gain non-inverting amplifier, actual output resistance Zo is greater by a factor of (1 + AVCL) or three times as much, still acceptably small at this (and even much higher) gain.

By connecting additional input resistors to the — input and upon apply-



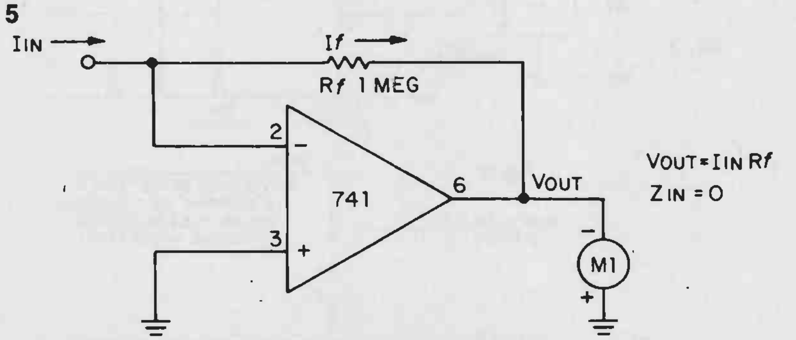
Circuit test and four simple rules of operation enhance understanding of op amps. You can construct an experimental test circuit on Vector's 38X Klip-Block board.

Fig. 4



Inverting voltage amplifier.

Fig. 5



Current to voltage converter.

ing several input voltages, the amplifier will sum the several input voltages at the output. For this reason, the amplifier is often termed a summing amplifier and the — input is termed the summing node or input.

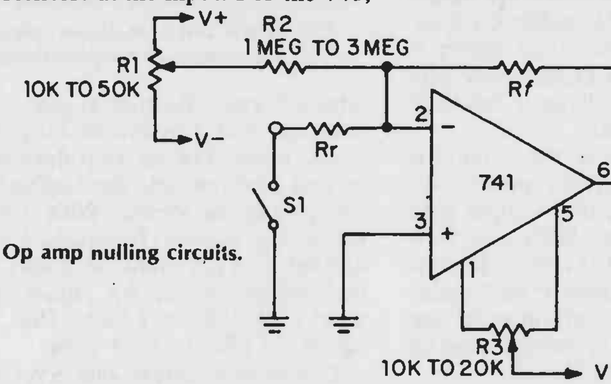
- **Current to Voltage Converter.** A variation of the inverting amplifier, the current to voltage converter shown in Fig. 5, omits input resistor R*r*. Because the — input must remain at virtual ground for linear operation, this circuit cannot accept an input voltage. Instead, it accepts an input *current* and is used to measure very small currents. If IIN were 1 *u*A, the output voltage would be 1 *u*A times 1 megohm, or 1 volt. By making R*f* very large, the circuit can measure extremely small currents. The input resistance of this circuit is zero. The output voltage, VOUT, equals IIN times R*f*.

If you breadboard this circuit, you may observe a small output voltage at zero input current. This output "offset" voltage is caused by the flow of a small bias current from output to input through the large feedback resistor, R*f*. Unless special op amps having very low bias currents are used, it is necessary to include a nulling circuit to reset the meter to zero.

- **Input Bias and Offset.** Although rule 2 assumed zero input currents, an op amp does require a small input current I*b* to bias the input stage into linear operation. For the 741, I*b* may range up to .5 *u*A. The difference between the input bias currents at the two inputs is the input offset bias current I*io*. This current is usually much smaller than I*b*. Both I*b* and I*io* cause an objectionable output offset voltage when R*f* is very large. To restore the output voltage to zero, add the nulling circuit potentiometer R1 and resistor R2 as shown in Fig. 5. With S1 open, adjust the control until meter indicates zero.

If R*r* is small, and upon closing S1, you may observe that the meter again loses its zero. This is caused by the input offset voltage V*io* resulting from slight mismatches of the input transistors. Input offset voltage V*io* is defined as that input voltage required to restore VOUT to zero. It is measured under open-loop conditions with very low value resistors at the input. For the 741, V*io* may range up to 6 millivolts. Conveniently, the 741 includes terminals allowing compensation for input offset voltage. Add potentiometer R3 and adjust the control with S1 closed, until the meter indicates zero. If both circuits are included, adjust the controls several times in succession.

Conclusion. Having become acquainted with the basic operation of the op amp, and with some knowledge of the six primary op amp specifications, you will now be able to experiment with op amp circuits with some degree of confidence rather than apprehension. With some appreciation of how and why the circuit functions as it does, how the performance of the several circuits compare with each other, and how negative feedback plays its part, you will find that op amp literature and circuits are more easily understood. ■



Op amp nulling circuits.

Solid State Multivibrators

☐ WHEN THE CONVERSATION turns from the Mets to multivibrators, you may hear all manner of strange words bandied about. Flip-flop, one-shot, astable, and bistable roll off the tongue of the all-knowing. And don't be too surprised if you hear the words free-running, single-step, and monostable—to name just a few—at your next electrified cocktail party. What do all these terms mean? Are there really so many different kinds of multivibrators? And, for that matter, of what use is a multivibrator for the experimenter?

The main job of a multivibrator is to generate square waves and pulses. Period. That's all!

A square wave is often used as a test signal for audio amplifiers to reveal frequency-response problems. In other applications, multivibrators generate

Fig. 1

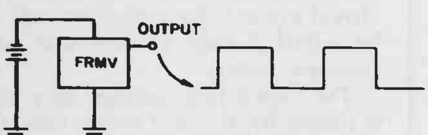


Fig. 2

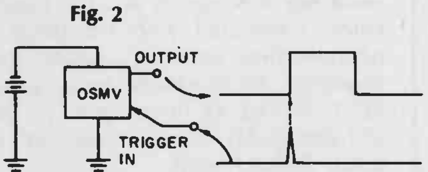


Fig. 3

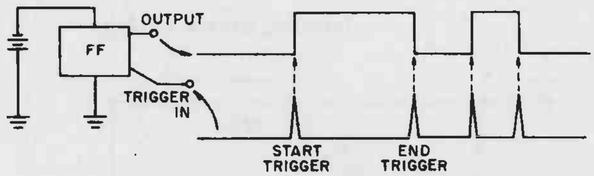
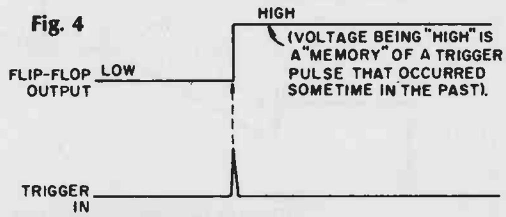


Fig. 4



short time constant pulses—only a few microseconds in duration. These mini pulses synchronize, or steady, the picture on our TV screens.

Longer pulses—those which are several seconds in duration—control the exposure time of photographic enlargers. Slow multivibrators can also drive the flashing warning lights seen by motorists as they approach roadside hazards. And, in the radio amateur's shack, faster multivibrators running at audio rates train the ham's eye and ear as he works with his code practice oscillator. Or, the same MV, as the multivibrator is also called, doubles duty as an audio signal source. The list could go on and on.

The uses of multivibrators grow daily, limited only by the ingenuity of those who understand their working principles.

The imposing list of names in the first paragraph creates the impression that there must be almost a dozen different types of multivibrators. Fortunately, this is not so! There are only three basic types. The long list of names merely shows the existence of more than one name for the same type of multivibrator.

The Circuit With an Alias. The three basic types of multivibrators are the *free-running* multivibrator, the *one-shot* multivibrator, and the *flip-flop*. With these three basic circuit types under your belt, you can whip up any of the jobs a multivibrator is capable of doing.

The free-running multivibrator is probably the type most familiar to the experimenter. It is very likely that the square wave generator or oscilloscope on his workbench has a free-running multivibrator buried somewhere in the instrument's circuit. The outstanding characteristic of the free-running multivibrator—and the one from which it earns its name—is that it runs freely. As long as a power supply is connected to it, the free-running MV enthusiastically pumps out a never-ending stream of square waves. This feature consistently earns the title of the Most Popular Circuit whenever John Q. Electronicsbuff needs square waves. See Fig. 1.

In contrast to the free-running MV, the one-shot multivibrator is a very reluctant beast. If fed DC from a power supply, it does not react by joyously bubbling forth a stream of square waves like its enthusiastic free-running cousin. Instead, it sits there, grumpily doing absolutely nothing.

And, it will continue to sit there unless kicked in the right place by an externally generated pulse, called a trigger pulse.

Under this urging, it reluctantly makes one and only one pulse, and then lapses back into its former sullen condition. Until, of course, it's kicked by another trigger. It derives its name—one shot—from the fact that it gives only one pulse in response to a trigger. See Fig. 2.

Flip Out Forget-me-not. The third type of multivibrator, the flip-flop, is a forgetful fellow. It, like the one-shot, gives no output pulse unless urged by a trigger pulse. But its response to a trigger is quite different. It starts out to produce a pulse, but forgets to end it, unless told to do so by another trigger pulse. Strangely enough, this forgetfulness can be turned into a memory. The

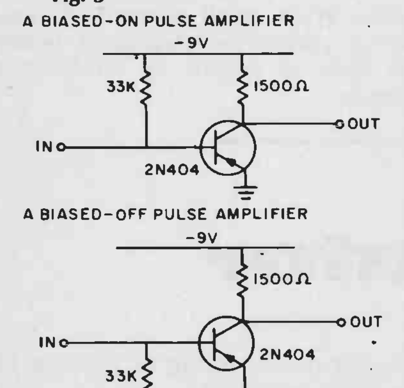
Fig. 5


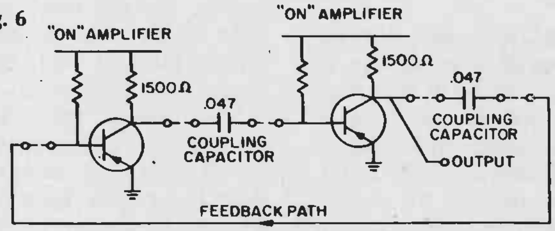
Fig. 6


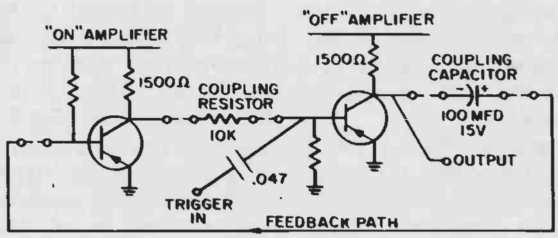
Fig. 7


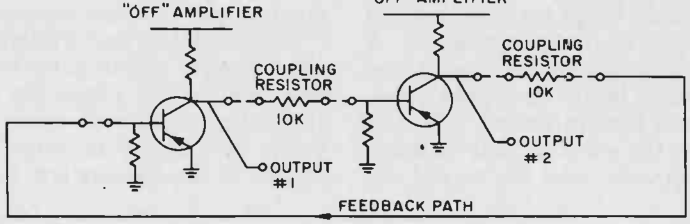
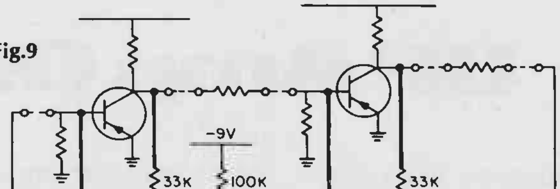
Fig. 8


Fig. 9


flip-flop is the heart of the register system of large computers. See Fig. 3.

How can this be? Because, as Fig. 4 shows, the flip-flop can remember forever (or, at least, until the power is turned off) that a trigger pulse has been applied to it. Using this single basic capability, the registers of giant computers can be constructed.

Some Basic Building Blocks. Circuit diagrams for these three basic multivibrators are surprisingly similar. They're all built from the same basic building blocks. These building blocks are shown in Fig. 5.

The free-running multivibrator combines these basic building blocks. The component values shown in Fig. 6 will make a free-running multivibrator which runs at 440 Hz. Musicologists know that frequency as A above middle C on the piano.

To double that frequency, cut the values of both coupling capacitors in half; to triple it, cut them to one third the value shown, and so on. To hear the square wave, place an ordinary 2,000-ohm headset across either 1,500-ohm collector load resistor. To see the square wave, connect an oscilloscope to the point marked "output."

The one-shot multivibrator is very similar. It is built from pieces stolen from the free-running multivibrator as shown in Fig. 7 by replacing one of the coupling capacitors with a coupling resistor, and one of the "on" amplifiers with an "off" amplifier.

The values shown produce a pulse two seconds long. To double the pulse length, double the capacitor's value; to triple it, triple the capacitor's value, and so on. To hear the pulse, place an ordinary 2,000-ohm headset across either 1,500-ohm resistor.

Momentarily touch the point marked "trigger in" to the the power supply. A click will be heard in the headphones as the one-shot begins its solitary pulse. Two seconds later, a second click will be heard as the one-shot ends its pulse. (The actual time may be longer, because large-value capacitors sometimes have twice the capacity on their case.)

To see the pulse, connect a voltmeter to the point marked "output." It will indicate –9 volts. Trigger the one-shot as above, by touching "trigger in" to the power supply. The voltmeter's needle will drop to zero volts, remain there for two seconds, and then pop up to 9 volts again.

To change the one-shot schematic to a flip-flop schematic; both pulse amplifiers must be of the biased-off type, and both coupling elements must be resistors. See Fig. 8. To see the action of this circuit, connect a voltmeter to output #1 or output #2—whichever of the two causes the voltmeter to register –9 volts. Leaving the voltmeter connected, short the output to ground. The voltmeter reading will drop to zero, of course, because there is a dead short right across its terminals. But, the surprising thing is that the reading will stay at zero after the short is removed.

Next, short the other output to ground. The voltmeter reading will rise to –9 volts, and stay there after the short is removed, showing that the flip-flop can remember an occurrence (like shorting one output) even after the occurrence is ended.

Kicked by a Trigger Pulse. Of course, shorting an output to stimulate the flip-flop into action is not the same as running it from a trigger. Triggering circuitry can be added to the basic flip-flop as shown in Fig. 9. Now, leaving the voltmeter connected to one output as above, you can trigger the flip-flop by momentarily connecting the point marked "trigger in" to ground. Each time a trigger is supplied, the output that was at zero volts will jump to –9 volts. A second trigger will cause the same output to revert to zero volts.

Since it takes two triggers to make one complete output pulse from a flip-flop, feeding 500 pulses per second to the trigger input will cause only 250 pulses per second to come from the output. If these pulses are, in turn, fed to another flip-flop, its output will provide only 125 pulses per second. This ability of flip-flops to act as a frequency divider finds very wide usage in applications ranging from computers to TV and electronic organs.

So much, then, for the three basic types of multivibrators. What about that long list of names we bandied about in the first paragraph? Where do they come in?

We can parcel out all those names among the three basic types. For example, the free-running multivibrator is known in formal electron-ese as an *astable* multivibrator. The prefix "a-" tells us that it lacks a stable condition, and hence runs endlessly as long as power is supplied. The one-shot MV also answers to the name *monostable* multivibrator, "mono" stable being the state in which it grumpily sits while awaiting a trigger.

And, the flip-flop is also a *bistable* multivibrator because it has two, or "bi-" stable states, and will sit happily forever with a given output either "high" (–9 volts in the above example) or "low" (zero volts).

Other Names, Yet. Other names for the flip-flop include *toggle*, from its action in response to two successive triggers; *binary*, from its ability to rest in either of two states, and *Eccles-Jordan*, after the two men who described the circuit many years ago.

The names *one-step* and *univibrator*, as well as *single-step*, *single-cycle*, and *monovibrator*, are all much less common names for the one-shot. Similarly, the free-runing multivibrator is rather infrequently referred to as an *unstable* multivibrator or an *Abraham-Bloch circuit*.

So, in spite of the abundance of names, there are only three basic types of multivibrators. Call the MV what you will, but the application of these three types reach through to almost every project the electronics hobbyist is likely to conjure up on his workbench. ■

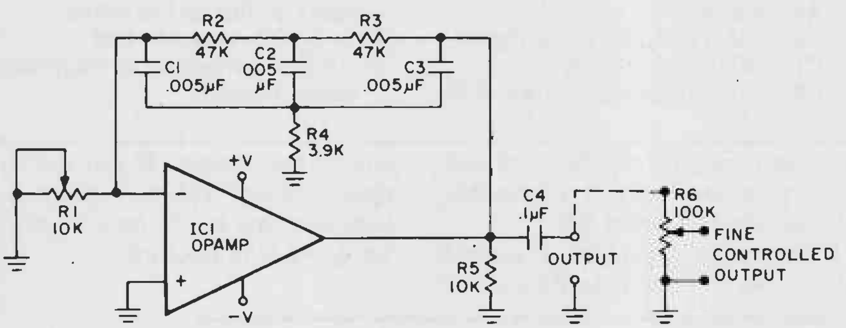
OP Amp Oscillator

☐ Every experimenter's spare parts box has the necessary components for our Notch Filter 1 kHz Oscillator. It's suitable for testing audio equipment, signal tracing or tape recorder bias adjustments. Integrated circuit IC1 can be just about any operational amplifier sold through "surplus dealers." The 1 kHz "notch filter" from the amplifier output to the inverting or negative (–) input determines the output frequency. Notch Filter Oscillator's non-inverting or positive (+) input is grounded.

The power supply is bi-polar; use any voltage up to ±15 VDC. While resistor R5 is not needed in many instances, its use insures your Notch

Filter Oscillator project's success. Potentiometer R1 sets the output level; its maximum value will approach the total power supply voltage. If fine output control is desired, add potentiometer R6.

When your Notch Filter Oscillator is connected to a DC circuit, connect a DC blocking capacitor in series with R6's wiper arm. If the oscillator is to drive circuits of less than 10K ohm impedance, substitute a 1-uF nonpolarized capacitor for C4, rated to the power supply's voltage. ■



PARTS LIST FOR NOTCH FILTER OSCILLATOR

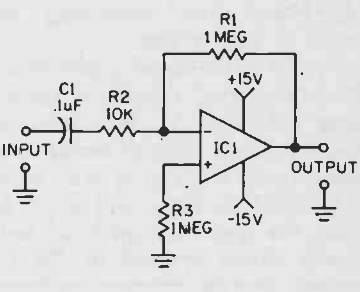
C1, C2, C3—0.005-uF, 75 VDC capacitor
C4—0.1-uF (see text) capacitor
IC1—741-type operational amplifier
R1—10,000 ohms pot
R2, R3—47,000-ohms, ½-watt resistor
R4—3,900-ohms, ½-watt resistor
R5—10,000-ohms, ½-watt resistor (see text)
R6—Potentiometer, 100,000-ohms, audio taper (see text)

Basic IC Amplifier

☐ This general purpose amplifier features a power gain of 100 (20dB) and can be used as a preamplifier for a microphone, receiver, signal tracer, etc. The IC is internally compensated, providing stable performance with a flat frequency response to about 10 kHz with a gradual roll-off to 20 kHz. The overall gain can be reduced to 10 by increasing the value of R2 to 100,000-ohms. IC1 is available in several different packages; use the one most convenient for your particular component layout. R3 connects to the non-inverting (+) input of the IC, R1 between the output and the inverting (−) input. No pin connections are given because the IC is available in many different configurations. ■

PARTS LIST FOR THE BASIC AMPLIFIER

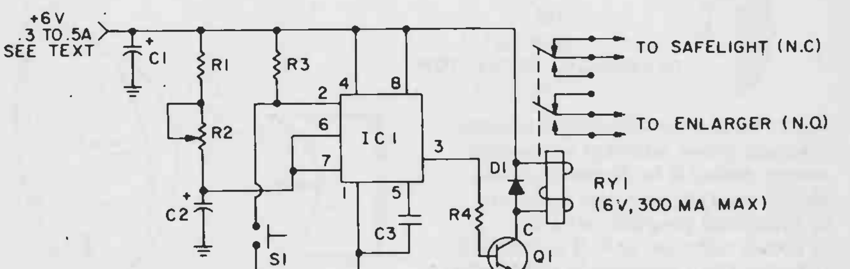
C1—0.1-uF Mylar capacitor, 25 VDC
IC1—Type 741 operational amplifier
R1, R3—1 megohm, ½-watt resistor
R2—10,000-ohm, ½-watt resistor, (see text)



IC Photo Timer

☐ You can spend $50 to $125 for a photo-enlarger timer but chances are you're not going to get more than a fancy version of this easy-to-build circuit. If you use a DPDT relay, as shown, your safelights can be wired to turn on when the enlarger turns off and vice versa.

If R2 is 1-megohm the timer's range is about 1 to 110 seconds. If R2 is 1.5-megohms the timer's range is approximately 1 to 165 seconds. The precise range will be determined primarily by C2's accuracy, so use a



reasonably good quality capacitor for C2, but don't get a precision or MIL-spec part; it's not necessary.

If you use a low current relay for RY1, say less than 100-mA at 6-VDC, you can eliminate Q1 and connect the relay directly from IC terminal 3 to ground. If you use a heavy-duty relay, as high as 300-mA at 6-volts, use Q1. The power input should be 6-volts (doesn't have to be regulated) at 300-mA, or 500-mA for a heavy-duty relay. We suggest any popular-brand low cost relay, such as P&B, Magnacraft or Calectro.

Potentiometer R2 should be linear taper. After the timer is assembled attach a large pointer knob to R1's shaft, and using an electric clock with a sweep second hand as a reference, calibrate timing control R2.

If the unit is assembled in a metal cabinet use a three-wire linecord to ground the cabinet. If you use an all plastic cabinet with no exposed metal hardware that can be touched you can use a two-wire linecord. ■

PARTS LIST FOR PHOTO TIMER

Resistors ½ watt, 10%, unless otherwise specified.
R1—10,000-ohms
R2—1.0- or 1.5-megohm linear taper potentiometer (see text)
R3—22,000-ohms
R4—560-ohms
Capacitors rated 6-VDC or higher
C1—100-uF electrolytic
C2—100-uF electrolytic (see text)
C3—0.01-uF capacitor
IC1—Integrated circuit timer type 555 (any package)
Q1—NPN transistor, Radio Shack 276-2030 or equiv.
D1—Silicon rectifier, 1N4003, equiv. or higher PIV rating.
RY1—6-VDC relay, see text
S1—N.O. push-button or momentary contact switch.

Next Horizon-Microwaves

☐ IN THE 30-ODD YEARS since World War II, the electromagnetic spectrum has been gobbled up faster than a bushel of bananas at a monkey Bar Mitzvah. The sad truth of the matter: the demand for frequencies has been growing faster than technology has been able to supply them.

Some parts of the radio spectrum are already overcrowded; others are rapidly becoming saturated to the point of bursting. To make matters worse, new communications techniques will mean that additional services will soon be clamoring for spectrum space as well.

Highway safety systems of the future, for example, will require frequencies for computerized traffic control, automatic guidance systems, visual and audible hazard warnings, and highway sign control. Picturephones, now being developed by Bell Laboratories, will also require spectrum space for their operation. And these are but two drops of the torrent expected to engulf the spectrum as we know it.

Expert Opinion. How will the problems created by frequency congestion be solved? Experts differ, and many solutions have been proposed. One report was prepared by some 200 of the nation's top telecommunications experts and took four years to complete. The 6-lb., 1200-page document, *Spectrum Engineering—The Key to Progress*, deals with the manner in which the spectrum is now being utilized, as well as the technical aspects of using it even more efficiently. The report also recommends increased research to find ways to better utilize those parts of the electromagnetic spectrum that are now largely unused. In particular, the sparsely used microwave portion of the spectrum, because of the vast amount of space available in that range, appears to be the last frontier in what is otherwise a morass of congestion.

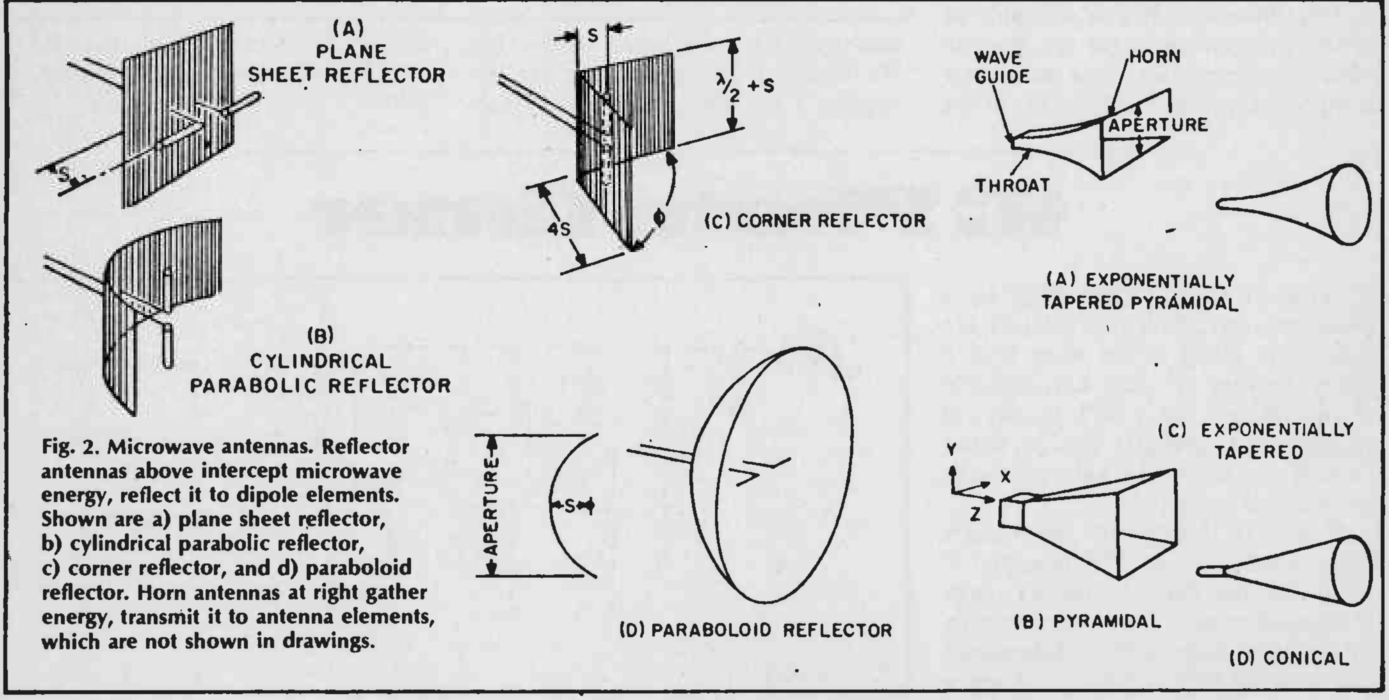


Fig. 2. Microwave antennas. Reflector antennas above intercept microwave energy, reflect it to dipole elements. Shown are a) plane sheet reflector, b) cylindrical parabolic reflector, c) corner reflector, and d) paraboloid reflector. Horn antennas at right gather energy, transmit it to antenna elements, which are not shown in drawings.

Frequency-wise, the microwave portion of the spectrum extends from 1000 MHz to the far infrared range of electromagnetic radiation, up to frequencies of 300,000 MHz! Imagine! Two hundred and ninety-nine thousand MHz of spectrum space! When we consider that the entire shortwave spectrum comprises a paltry 27 MHz, we realize what a bonanza the full use of the microwave region would be to communications.

Evidence indicates that in the years to come a great deal of research and development will be concentrated in this portion of the spectrum. If so, chances are that terms such as tropo scatter, magnetron, klystron, TWT, and waveguide will be as common as ionosphere, diode, and transmission line are to communications today.

Because microwaves truly represent the waves of the future, let's take a closer look at them so we can get a better understanding of their potential. Many telecommunications experts believe that microwaves will bring about a communications revolution before long. Here's why.

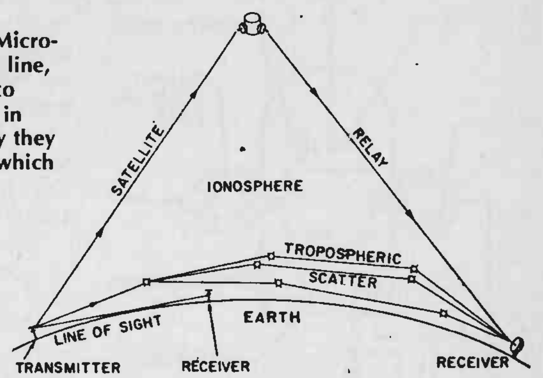
Microwaves have wavelengths that lie between those of radio waves and of ordinary light—30 centimeters to 1 millimeter. Because of this, they display characteristics that are common to both. Like radio waves, their generation stems from the use of low-frequency systems, and they can be modulated to carry intelligence, such as voice, Teletype, pictures, etc.

And like light, they travel in straight lines, are blocked by most solid objects, are affected by the weather, and can be focused and beamed in an optical system.

Tropo Scatter. Fig. 1 shows how microwaves are propagated. As anyone who has driven through a fog at night knows, the light from the headlights striking the fog is scattered and dissipated. Similarly, microwaves traveling through the Earth's lower atmosphere (the troposphere) are scattered. This scattering enables the transmission of some signals far beyond the Earth's horizon. Unlike shortwave signals, microwaves aren't affected by the ionosphere and pass completely through it. Tropospheric, or tropo, scatter is therefore the only means of transmitting over relatively long distances without the use of intermediate repeater stations.

A number of military scatter circuits are currently in operation, including one across the Pacific Ocean in island-hopping fashion, and one across the Arctic, linking our early warning radar stations. Significantly, the distance for a microwave scatter "hop" varies with the frequency. But at 1000 MHz, hops of several hundred miles are possible.

Fig. 1. Microwave propagation. Microwaves are propagated in straight line, from transmitter to receiver, or to satellite. They are also scattered in troposphere, which explains why they can be transmitted to locations which lie well beyond horizon.



Commercial microwave scatter links are also in operation. One such link provides 72 telephone circuits between Miami and the string of islands called the Bahamas.

Unfortunately, the energy transmitted by tropo scatter is extremely small. Because of this, high-power transmitters and high-gain antennas are required for successful communications.

Repeater Circuits. A second method of propagation is via line-of-sight transmission. In such circuits, the microwaves travel in essentially straight paths direct from the transmitting antenna to the receiving antenna. In general, the transmitting and receiving antennas are spaced about 30 miles apart.

Energy entering the receiving antenna is often amplified and retransmitted to another repeater, some 30 miles further away. In practice, the distance between transmitting and receiving antennas is slightly greater than true line-of-sight distance because some bending of the signal occurs as it passes through the lower atmosphere.

Numerous microwave networks, making extensive use of repeaters are in operation within the U.S. Many of these run from coast to coast.

Satellite Relays. In addition to tropo scatter and repeater circuits, another use of microwaves involves satellites to relay the signal to some distant point on Earth. All new-generation COMSAT communications satellites operate in the microwave portion of the spectrum, enabling the transmission of a great deal of information. Ground stations receiving this microwave energy require the use of elaborate antenna systems because the incoming signal is very weak.

Antennas. Since antenna elements are proportional to the wavelength of the radiated signal, microwave antennas lend themselves to designs that would be unwieldy at lower frequencies. A half-wave dipole operating the 6-MHz band, for example, is roughly 25 meters long. At 1000 MHz, a half-wave dipole antenna is 15 centimeters (about 6 in.) long. And at 10,000 MHz, an antenna element less than an inch long can be used.

As a result, a wide variety of exotic shapes and sizes of antennas have been developed; some of these are shown in Fig. 2. In general, all microwave antennas are designed to gather as much energy as possible. The reason is that some microwave signals, particularly those coming from satellites or over scatter circuits, are very weak.

Because of the large number of antenna elements that can be used for transmitting or receiving microwave signals, antenna gains of the order of 30 dB and more are possible. This enables the reception of very weak signals over vast distances. The Mariner 9 spacecraft, for example, transmitted television pictures over a distance of approximately 60 million miles!

Microwave Oscillators. Special tubes have been developed to produce microwave energy because ordinary vacuum tubes don't work effectively at frequencies in the microwave range. In a vacuum tube, electrons travel between

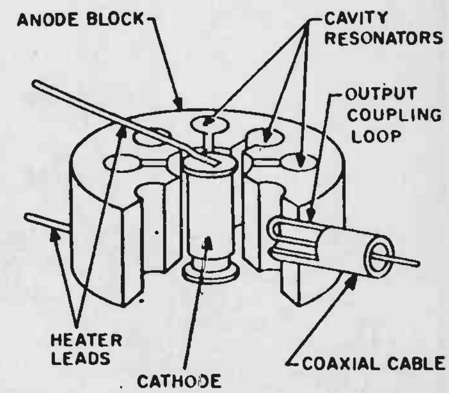


Fig. 3. Magnetron. Electrons from cathode move in circular orbits inside tube, generating microwaves in cavities. Tube is actually diode in structure, requires external magnet to provide magnetic field.

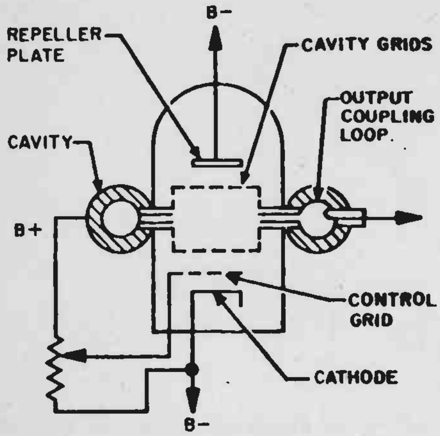


Fig. 4. Klystron. Electrons passing between electrodes are bunched at regular time intervals by changing voltages. Electron beam passes opening of cavity, produces microwave oscillation or amplification.

the electrodes. At microwave frequencies, the electrons oscillate so rapidly that they change directions before they've been able to pass from one electrode to another. As a result, the electrons literally get hung up within the tube.

Solving this problem introduces another: at microwave frequencies, capacitance between the electrodes tends to short out the elements in the tube. To cut the capacitance, the spacing between electrodes can be increased. But this makes the first problem of electrons not getting from one electrode to another even greater.

To overcome these stumbling blocks, tubes of a radically different design have been developed. Three of these, the magnetron, the klystron, and the travelling-wave tube (TWT) are shown in Figs. 3, 4, and 5.

The Magnetron. A resonant cavity is responsible for the magnetron's ability to produce microwave energy. Each cavity has a characteristic resonant frequency depending on the inductance of the walls of the cavity and the capacitance due to spacing between the walls. Thus, the cavity resembles a simple tank circuit that employs capacitances and inductances to form a resonant circuit at a particular frequency.

The magnetron of Fig. 3 has a series of cavities, and the entire tube is operated between the poles of a powerful electromagnet not shown here. The cathode emits electrons which travel in circular paths because of the influence of the magnetic field. The shape of the tube is such that the electrons graze the openings of the cavities, passing energy to them and setting them into oscillation.

Magnetrons can be made to deliver pulses of very high power, but they have two limitations. First, they require a heavy magnet to propel the electrons in circular orbits inside the tube. Second, the cavities are extremely small at higher frequencies, making manufacture difficult.

The Klyston. Illustrated in Fig. 4, the klystron doesn't require a magnet because electrons travel a straight line within its electrodes. Grid voltages are adjusted so that bursts of electrons flow past the cavity openings only at certain times. These bursts are synchronous with the resonant frequency of the cavity, and the electrons transfer their energy to the cavity, developing high power oscillations inside the cavity. The process has been compared with the periodic pushing of a swing to make it go higher.

Klystrons can operate at frequencies well above 100,000 MHz, but at these frequencies output power is very low.

The Traveling-Wave Tube. A very convenient device for space applications is the traveling-wave tube (TWT), which amplifies or generates microwave energy with very low noise and high sensitivity. Shown in Fig. 5, the tube consists of a narrow evacuated tube with a wire helix wound around it. A beam of electrons is sent along the inside of the tube while the signal to be amplified is fed into the helix.

By controlling the speed of the electron beam, the energy of the beam is passed to the signal in the helix, thus amplifying it. Similarly, by feeding pulses of energy into the helix, it will generate microwaves by amplifying the pulses.

The traveling-wave tube can be tuned over a wide range of microwave frequencies and is very sensitive. Its disadvantage is that it delivers much less power than magnetrons or klystrons.

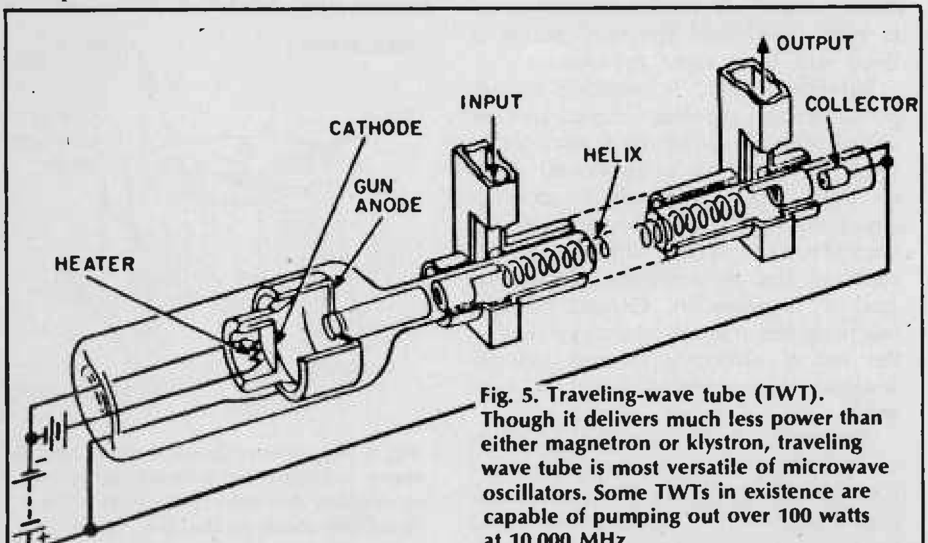


Fig. 5. Traveling-wave tube (TWT). Though it delivers much less power than either magnetron or klystron, traveling wave tube is most versatile of microwave oscillators. Some TWTs in existence are capable of pumping out over 100 watts at 10,000 MHz.

Waveguides and Cables. At microwave frequencies ordinary wire can't be used to transmit energy because the values of inductance and capacitance in the wire combine to block any current flow. To allow for transmission of microwave energy through transmitter and receiver circuits, new components had to be developed to carry the energy. Coaxial cable and waveguides were found to carry microwave energy efficiently.

Coax, as you may know, consists of a wire surrounded by a dielectric, or non-conducting material, such as polyethylene, surrounded by a cylindrical outer conductor. Microwave energy flows through the dielectric between the inner and outer conductors.

In contrast, waveguides are usually rectangular tubes which conduct the microwave energy within their walls. The tubes can be bent into many shapes without affecting their ability to carry microwave energy.

In both coaxial cable and waveguides, dimensions are highly critical and depend on the frequency to be transmitted. With both types of conductor, efficiency and power-handling capacity diminish with increasing frequency.

The Future. Of the 299,000 MHz available in the microwave region of the spectrum, only some 10% is now being used, and much of this is still experimental. Essentially, the problems are generating power at frequencies of 10,000 MHz and above, and of developing components that will operate at frequencies of 30 to 40 GHz and higher (1 GHz equals 1000 MHz).

A great deal of research is now going on in an effort to develop techniques and materials that will produce useful results at the mid- and upper-end of the microwave region. Experimentation involving solid-state devices is being successfully conducted in hundreds of laboratories. The general feeling is that technology will continue to expand the useful range of frequencies in this region of the spectrum.

Most of these studies are being financed by the government, and they are costly. But progress has been steady and hardly a week passes without some news of another breakthrough in this vast region of the spectrum, advancing the state of the art and pushing the frontiers of usable spectrum space ever higher. ■

Frequency Modulation

☐ If you're a regular reader of ELEMENTARY ELECTRONICS you probably know *modulation* puts information (words, music, or other desired information) on a radio frequency carrier wave. You also know that messages can be sent by making *changes* in something, such as changes in smoke—smoke signals; changes in drum beats—"talking" jungle drums; changes in the number of lanterns in a church steeple, —Paul Revere's friend; or by changing *amplitude* of a carrier wave—amplitude modulation. But amplitude changes are not the only way a radio (carrier) wave may be changed to send messages. You also know that messages can be sent by changing the carrier's *frequency*—frequency modulation, or its *phase*—phase modulation. This article tells us how these two modulation methods carry the message, and describe simple electronic hardware for the purpose.

Simple Changes for Simple Messages. The simplest possible AM signal consists of a sudden shift in the *amplitude* of the carrier, as shown in Fig. 1. Similarly, the very simplest FM signal is made by causing a sudden shift in the *frequency* of the carrier, as shown in Fig. 2.

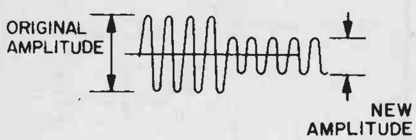


Fig. 1. Modulation of a radio frequency carrier wave by changing amplitude.

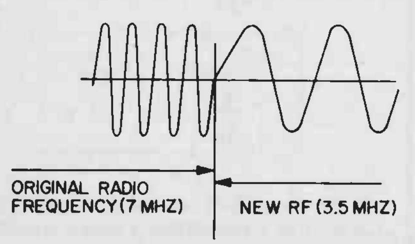


Fig. 2 Modulation of a radio frequency carrier wave by changing its frequency.

Practical AM communication systems for speech and music make the carrier amplitude shift smoothly up and down, so that the tips of the carrier wave conform to the shape of the audio waveform. This is shown in Fig. 3. By this means the modulated radio frequency carrier wave conveys the audio (information) to a distant receiver. If this audio waveform were supplied to a FM transmitter, there wouldn't be any amplitude changes. Instead, the *frequency* itself (the radio frequency carrier wave) is pulled smoothly back and forth, higher and lower, in accordance with the audio signal, as shown in Fig. 4.

The Walking Carrier. If the audio frequency were low enough—say, for example one hertz (cycle-per-second) we could actually "see" the carrier moving back and forth—walking up and down on the dial of the receiver (if we constantly retuned the dial pointer correctly). This is shown in Fig. 5. Notice in that drawing that the back-and-forth motion of the carrier reproduces the original audio waveform (which happens to be a sine wave in this simple example). It's a one hertz back-and-forth motion. If we increase the audio frequency to 3 Hz, the carrier will "walk" rapidly back and forth at a 3-Hz rate.

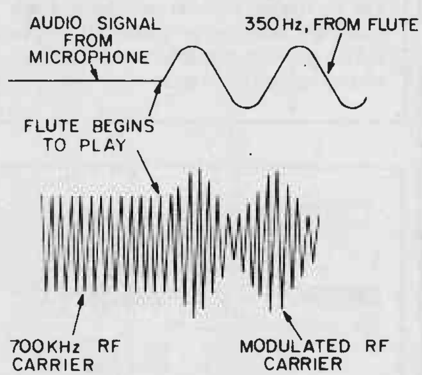


Fig. 3. Amplitude modulation by a musical note produces changes in the size of the carrier wave.

But seeing the carrier move back and forth on a hypothetical tuning dial won't let us hear sound. How can we take this back-and-forth carrier motion and convert it back to the original audio wave?

FM Detection Via an AM Detector. Surprisingly enough, there is a way to use an ordinary AM envelope detector (very similar to the rectifier of a power supply) to make this conversion. To understand how this is done, we must first understand that the frequency-selecting circuits of a receiver—the circuits that allow us to listen to one station and exclude all others—normally give a sloping shape to the "window" through which the desired station is allowed to pass as shown in Fig. 6.

We all know from experience in tuning ordinary AM receivers that if we don't tune right on the station, the signal will sound weaker than it should.

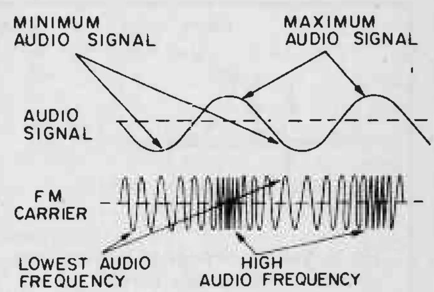


Fig. 4. Modulation of carrier wave by audio.

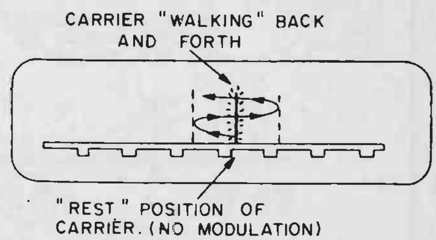


Fig. 5. Modulation of carrier wave changes its frequency so that it could, theoretically, be received by rapid retuning of a standard (AM) set's dial.

This happens because the sloping edges of the frequency-selective window start chopping off (attenuating) the signal, as shown in Fig. 7.

But, what if the desired signal is an *FM* signal—walking back and forth on the dial—and we *deliberately* mistune so that the center of the "walk" is half-way down the slope? As you can see in Fig. 8, the back-and-forth carrier motion causes the signal to become alternately strong and weak—which is *amplitude* modulation! And, since the strengthening and weakening takes place at the audio rate, the slope of the frequency-selective circuit has converted the FM wave to an AM wave which may be detected with a simple AM detector! See Fig. 9. This is called *slope* detection, or side-tuning detection. It is *not* the most commonly-used FM-detection scheme, but its method forms the basis for more sophisticated FM-detecting techniques. If you understand slope detection, you will easily grasp the more elaborate arrangements found in textbooks and receiver schematic diagrams.

Making FM. Figure 10 shows a practical schematic diagram for an oscillator. If we were to build this oscillator and apply the correct voltages, it would generate a carrier which could be received on a nearby receiver. Its carrier would appear on the receiver dial at a place determined by the values we choose for inductor L and capacitor C.

If we vary either L or C, the carrier will shift to a new location on the dial. In the diagram, C is shown to be a variable capacitor. Shifting the value of C by turning the variable-capacitor knob will cause the carrier to appear at a new location on the receiver dial.

If we could attach a microphone's diaphragm to the variable-capacitor knob, as shown semi-schematically in Fig. 11, the sound waves striking the diaphragm would rock the capacitor back and forth rapidly, causing the received carrier to "walk" back and forth on the receiver dial—in short, the oscillator will be frequency-modulated.

Of course, no one makes an FM transmitter in such a crude mechanical fashion. In the first place, the amount of walk—the distance the carrier could deviate from its rest frequency—would be very small. In addition, the higher-pitched audio sounds couldn't possibly rock the capacitor, so no high notes would get through—the result would be very lo-fi.

There are a great many practical ways to build an FM transmitter, and a great many books which tell about them. One very simple, practical system uses *variable-capacity diodes*—a type of diode which actually can act as a capacitor whose value can be varied by applying a varying voltage to it. The system is shown in Fig. 12.

The two diode symbols with variable capacitor symbols to indicate variability, are the variable-capacity diodes, also known as *varactors*. Their value varies according to the audio voltage fed to them. They produce the same effect as rocking a variable-capacitor knob with a microphone diaphragm, only they can respond to higher sounds, and can also walk (deviate) the carrier much farther.

Modulation Without Limit. In AM there is a limit to the loudness of the sound which an amplitude-modulated carrier can handle. We call this limit "100 per cent" modulation, and show its wave form in A of Fig. 13. A louder signal would cause *overmodulation,* and would look like B in Fig. 13, where the received signal can be seen to be distorted. Is there a corresponding limit for an FM wave? Where does "100% modulation" occur in FM?

There is no such limit on FM. We can "walk" (deviate) the carrier farther and farther from its rest position. The farther we deviate, the more the signal become immune to interferences from lightning disturbances, automobile ignition systems, and the like. However, the farther we deviate the carrier, the more channel space is gobbled up by the signal. The practical limit on FM, then, is set by how much channel space we are willing to trade in return for freedom from interference. A present-day FM broadcast station takes up many times the channel space of a standard AM broadcast station, and it is correspondingly more free of noise and interference.

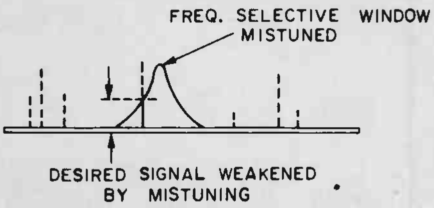


Fig. 6. Tuning circuits of AM receiver permit reception of a narrow set of frequencies and exclude those on side.

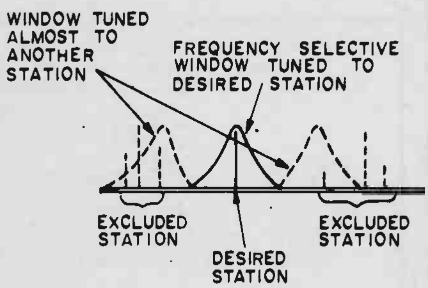


Fig. 7. If tuning circuits are tuned off to one side, the strength of the signal received is impaired.

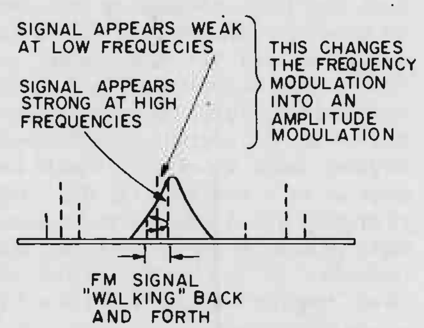


Fig. 8. Tuning circuits of standard AM receivers have sloping-shaped response which permits reception of frequency-changing carrier waves.

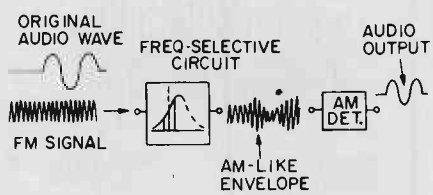


Fig. 9. Careful tuning of selective circuits combined with AM slope detector permits reception of FM signals.

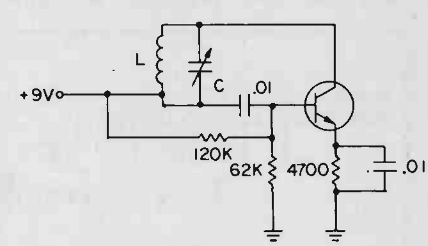


Fig. 10. Diagram of simple transmitter.

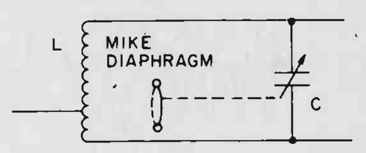


Fig. 11. Simplified scheme for varying the capacity in a transmitter's tuned circuit to change its frequency in accordance with sound waves.

FM—Another View. In Figure 5 we visualized FM resulting from a 1-Hz "audio" signal as a carrier shifting slowly back and forth around its rest (unmodulated) position. This is easily visualized for a 1-Hz signal, but what happens when we apply a flute sound at 700-Hz to an FM transmitter? We can, if we wish, think of a carrier buzzing rapidly back and forth at a 700-Hz rate. But this is rather awkward, and we find ourselves asking if there's *another* way to visualize this signal. For example, does an FM signal have sidebands? Can we visualize FM as a *non-moving, non-walking* carrier surrounded by sidebands, just like AM?

Surprising as the idea may seem, it is true. We can visualize FM *either* as a carrier swinging back and forth at, say, a 700-Hz rate, *or* we can visualize it as a completely non-moving carrier, fixed at one frequency, but surrounded by sidebands.

Which picture is right? Either one, depending on what aspect of FM we are trying to understand. After all, *none* of these pictures of sidebands, carriers, and waveforms actually exist. They are merely ways to help us visualize what's happening to the electrons scurrying around in our circuits.

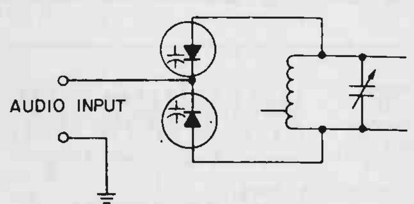


Fig. 12. Simplified schematic showing scheme for varying the frequency of carrier wave. Audio voltage applied to the two varactor diodes changes value of capacitance in tuning circuit.

Sidebands and FM. Let us ask our flutist to play his 700-Hz tone into the microphone of an *FM* transmitter, while we watch what happens on our imaginary receiver dial which lights up wherever there's a carrier or sideband. Before the flutist begins to play, we see the carrier sitting at its rest frequency (Fig. 14A), and as he begins to play—softly—we note that a side frequency appears on each side of the carrier, 700 Hz away—just as in AM (See Fig. 14B).

However, we note in B of Fig. 14 that the lower sideband is *inverted*—dangling below the base line. This signifies that its phase is inverted from the "normal" side frequency of an AM signal.

We can also see in B of Fig. 14 that the line representing the carrier becomes *shorter* as the flute begins to play, indicating that the carrier loses some of its strength (amplitude) as the sidebands *gain* amplitude. You might expect this, since the *total* amplitude doesn't change in FM—remember Fig. 4—so as one part (the sidebands) gets larger, the other part (the carrier) must get smaller.

More Sidebands to Come! But that's not the whole story, yet. If we ask the flutist to play a little louder, we find that—as we might expect—the carrier line gets even shorter and the two side frequencies appear, at 2 x 700 = 1400 Hz away from the carrier! See Fig. 15. As the flutist plays louder, the carrier gets even smaller, the side frequencies get even larger, and—another surprise—a *third* set of side frequencies appears at 3 x 700 = 2100 Hz from the carrier! And, again, the lower side frequency of the pair is inverted. See Fig. 16.

How long can this go on, with sidebands multiplying like rabbits, and the carrier shrinking toward extinction? In our example, it's limited only by how loudly the flutist can play—and, of course, we can add an amplifier to his flute and go on almost without limit, if we don't mind gobbling up channel space. As the flutist plays louder and louder, we will get side frequencies at 4 x 700 = 2800 Hz, 5 x 700 = 3500 Hz, 6 x 700 = 4200 Hz, 7 x 700 = 4900 Hz, and so on. What's more, the *odd* multiples—*3* x 700, *5* x 700, *7* x 700, and so on—will have one of the pair upside down—dangling below the base line.

And the carrier? It can actually shrink to zero, and reappear *beneath* the baseline, indicating it has reversed its phase.

Do all the sidebands go on growing, without limit? Fortunately, no. By the time the carrier has shrunk to about half

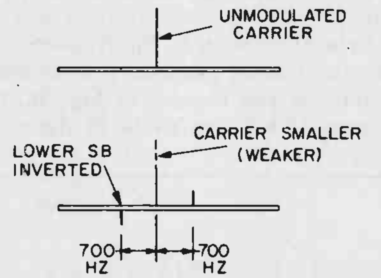


Fig. 14. Spectrum display of FM (or on radio tuning dial) shows single carrier frequency when no audio modulation is present (A). When a 700-Hz audio tone modulates the carrier wave (B) it takes power from the carrier to produce sidebands 700 Hz on either side.

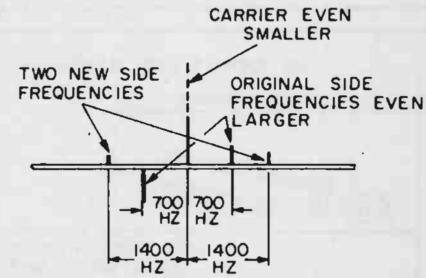


Fig. 15. Modulation by a louder audio tone produces a second set of sidebands — further power will be drawn away from the main carrier wave.

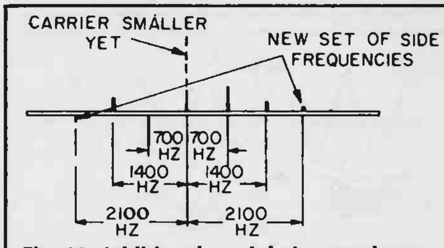


Fig. 16. Additional modulation produces yet another set of sidebands, reducing amplitude of carrier even further.

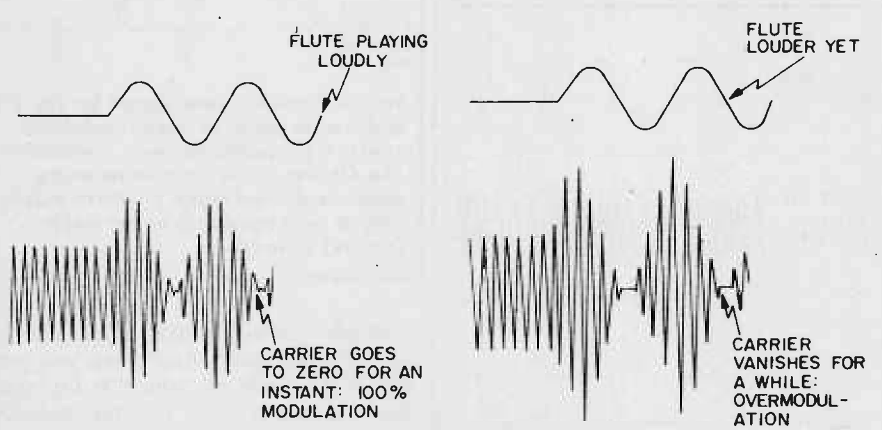


Fig. 13. When audio signal is sufficiently loud it modulates the carrier wave 100 percent (A). When audio signal is too loud it produces distortion of the carrier wave through overmodulation (B).

its unmodulated size, the two sidebands closest to it stop growing and start shrinking. And, when the flute is so loud that the carrier has reversed and is dangling well below the baseline, the *next* set of sidebands—the ones 1400 Hz from the carrier—start shrinking. And shortly thereafter, the ones at 2100 Hz start shrinking. Sound complicated? Maybe a picture will help. Fig. 17 is a graph of the behavior of the carrier and two sets of sidebands, showing what happens as the flute plays louder and louder.

By tracing out the carrier line on the graph, you can see it shrink, vanish, invert, grow, shrink again, and vanish again, re-invert, and so on. Similarly, you can see the first two sets of sidebands (700 Hz and 1400 Hz) going through the same sort of changes. For comparison, we have also sketched the graph for an AM case in Fig. 18, which shows the single set of sidebands growing to the 100 percent modulation point, which is the AM limit.

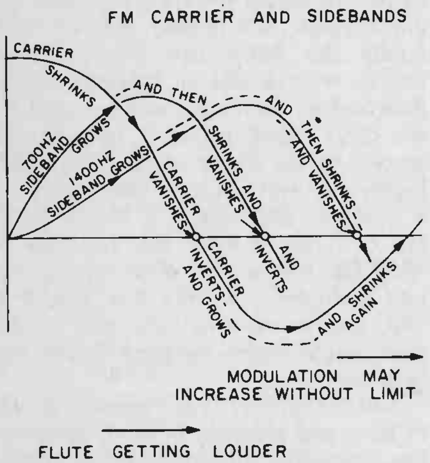


Fig. 17. Graphical representation showing progressively louder modulation taking more power from the carrier and putting it into the sidebands.

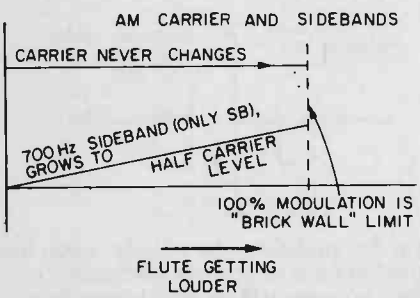


Fig. 18. Each AM sideband can become only half as big as the carrier, no more.

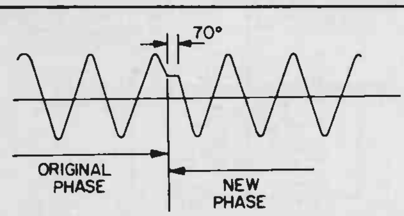


Fig. 19. Phase modulation introduces momentary delay (shown here) or advance, in phase of carrier. Actual audio wave would produce thousands of advances and delays each second.

Advantages of FM. There is no question that FM is a more complex way of sending a message—at least so far as sidebands are concerned. But in return for this complexity, we obtain a signal which is more immune to such disturbances as lightning, electric motor sparking, and so on. In addition, two FM stations on the same frequency will not interfere with each other, because the FM receiver will receive only the stronger of the two—never both. This is a decided advantage, particularly for car radios.

Phase Modulation. In addition to *amplitude* and *frequency* modulation there are other methods of modulation. One of these, which is similar in many respects to FM, is *phase* modulation. This actually is a specialized form of FM, in which the changes in the frequency of the carrier wave occur briefly, as *phase delays* and *phase advances,* as shown in Figs. 19 and 20, respectively. These actually are the same as the frequency of the carrier being changed, momentarily.

Here, as you can see in Fig. 20, the distance Q between peaks at the point of phase advance is *smaller,* indicating that, *for an instant, the frequency became higher.*

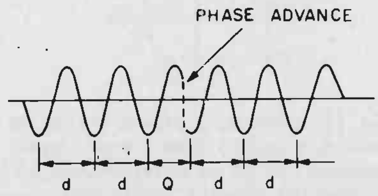


Fig. 20. Phase modulation produces delays alternately with advances in the phase of the carrier.

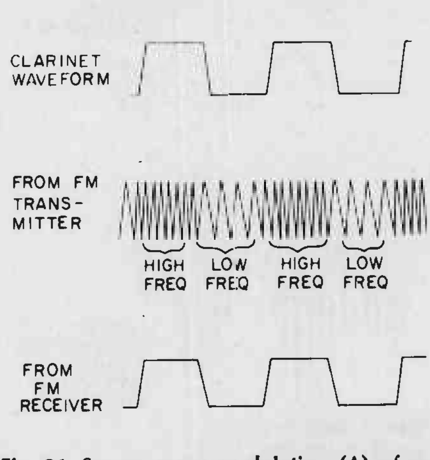


Fig. 21. Square wave modulation (A) of an FM carrier produces two frequencies (B) of carrier wave. FM receiver detector produces square waves (C) from the modulated carrier.

There are, then, two directions of phase change—one, a *delay,* which causes a *momentary lower frequency,* and the other, an *advance,* which causes a *momentary higher frequency.*

If a square wave, Fig. 21A, was fed to an FM transmitter it would modulate the carrier wave as shown in B of Fig. 21, and the output of the FM receiver would change only momentarily, and the output of an FM receiver converting this carrier to audio would resemble the waveform of Fig. 22C. However, by changing the detection system of the FM receiver to that of a phase-detecting system we could extract audio waveforms from the phase-modulated carrier identical with the original audio square wave. In other words, if we feed audio to an FM transmitter through an appropriate RC network, we have a *PM* transmitter, and if we receive this PM signal on an FM receiver to which we have added an *inverse* RC network, we have a PM receiver.

There are other methods of modulation more exotic than phase modulation, but they are not in widespread use at the hobby level at this time. The next time you tune in an FM station, you should have a better appreciation of the bouncing carriers and flickering

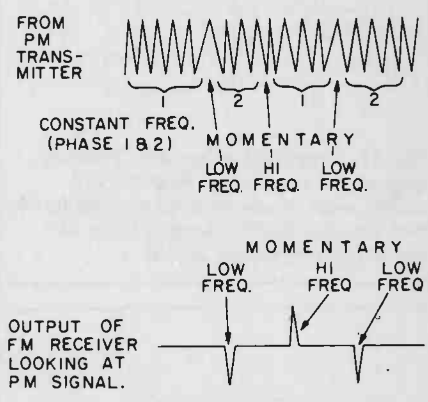


Fig. 22. Applying same square (as Fig. 21) audio wave signal to phase-modulated carrier wave produces phase modulation (A). Output of FM detector receiving phase-modulated signal produces output only at each transistion of the audio (square) wave (B).

multiple sidebands that bring you the speech and music. And when you press the PTT switch on your CB rig, you'll have a better feel for the pulsating waveforms which dance from transmitter to receiver. When you flip the channels of your TV set . . . would you believe, it's not *single*-sideband, but *one-and-a-third* sidebands? And that's an interesting story, too, but a story for another day. ■

Action's Outside the Carrier

☐ ALL COMMUNICATION is by means of *change*, or *modulation* of some kind, whether it's electronic communication, smoke signals, or the lanterns in the Old North Church in Boston which sent Paul Revere on his famous midnight ride 200 years ago. There are three basic ways a carrier can be changed, or *modulated*, to convey information from a radio transmitter to a radio receiver. These three ways are AM, FM, and PM (Amplitude Modulation, Frequency Modulation, and Phase Modulation). For a close look at how AM works, see the sketches of waveforms and discussion in the January/February 1976 issue of ELEMENTARY ELECTRONICS. That article also explains how the detector converts the amplitude modulated radio frequency (RF) carrier wave back into audible sound signals (audio).

But examining waveforms is not the only way to gain an understanding of AM. If we look, instead, at what happens at the dial of the receiver as the carrier is modulated, we get another view of AM—one that will help us to a better grasp of the inner workings of not only AM, but FM and PM as well.

A Dial's-Eye view of AM. Imagine a radio receiver with a dial which lights up at any point where a signal appears. By moving the tuning indicator to one of the lit points, the operator could hear in his loudspeaker the speech or music being transmitted at that frequency. Such an imaginary dial would appear as in Fig. 1.

The lights indicating the presence of a signal appear in the figure as vertical lines, with strong signals appearing as tall lines and weaker signals as short lines.

Imagine further that we can use a magnifying glass to closely inspect the area around one of the bright lines, and at the same time can set the tuning indicator to that bright line, so we can hear in the loudspeaker any signal being sent (Fig. 2).

The magnifying glass shows us a single bright line indicating a carrier at 840 KHz, while the loudspeaker gives us only a low-level hiss, indicating that an unmodulated carrier is present, but no information is being sent. (To continue our Paul Revere analogy, we could say that the steeple is present, but no lanterns have been hung.)

Now, let us ask a flutist to step before the microphone and play a 700-Hz tone. Immediately, of course, the flute's tone is heard in the receiver's loudspeaker. But the most surprising thing happens at the receiver dial: Here, (see Fig. 3), two *new* frequencies appear—small bright lines on either side of the carrier. Looking closely, we see that each of the new frequencies is spaced exactly 700 Hz from the carrier—one above, at 840,700 Hz, and the other below, at 839,300 Hz. These two new frequencies are called *side frequencies,* and are the lanterns in the steeple—the indication of information being sent.

If we ask the flutist to play more loudly, we find that the side frequencies grow taller, until, at 100% modulation each one is exactly half the height of the carrier. (See Fig. 4).

Now, let us suppose that another flutist joins the first, and this second musician plays a tone at 1100 Hz (in this case blowing slightly louder than the first flutist). We now find a second group of side frequencies spaced 1100 Hz each side of the carrier (Figure 5).

With the two flutists playing, we have the beginning of a *band* of side frequencies on each side of the carrier. The higher frequency is the *upper side band,* and the lower frequency is the *lower side band.*

If the two flutists are now joined in the studio by a rock group (or a symphony orchestra), the many instruments, playing many different frequencies simultaneously, will cause many side frequencies to appear, and the sidebands will be composed of a very complicated group of side frequencies, constantly changing as the musicians play. Figure 6 can be thought of as a snapshot of the sidebands for a very brief period in time. This is called a *spectrum display,* and the group of frequencies shown is called the spectrum of the signal.

In this spectrum display, we observe that the upper and lower sidebands extend equally far from the carrier—about 5,000 Hz in the figure—and that they are always exact mirror images of each other. As the sound striking the microphone changes, the the sidebands change in a mirror-image manner. A snapshot (spectrum display) taken a few seconds later might look like Fig. 7.

Is This Sideband Necessary? The fact that the two sidebands are mirror images of each other makes us wonder if they are both necessary. It's just as though Paul Revere's friend had hung a complicated set of lanterns on the *right* side of the steeple, and then had hung an identical set on the *left.* The second set would have been unnecessary because the first set would have given him the message, and Paul would have been on horseback and gone long before the second set could be lit!

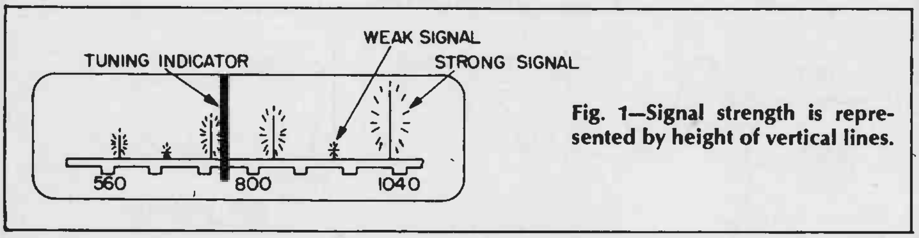


Fig. 1—Signal strength is represented by height of vertical lines.

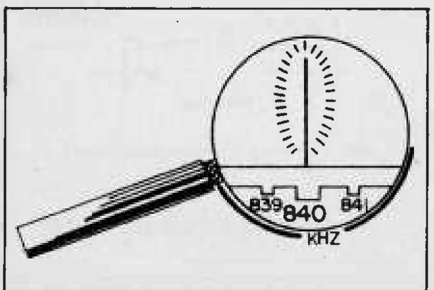


Fig. 2—Non-modulation of signal concentrates signal strength at the carrier frequency.

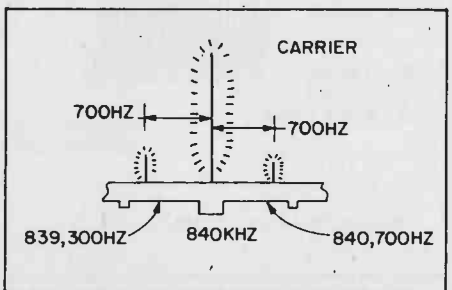


Fig. 3—Modulating the carrier with a 700-Hz audio tone generates weaker signals 700 Hz above and below carrier.

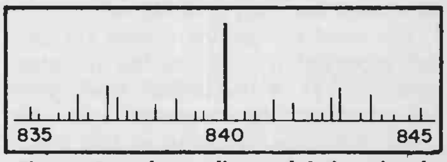


Fig. 6—Complex audio modulating signals generate complex sideband frequencies.

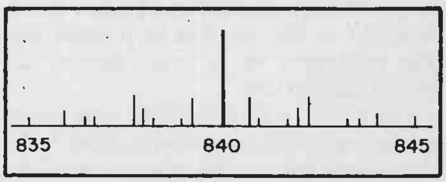


Fig. 7—A different set of audio signals generates a different set of sideband frequencies.

In the same way, we can get the message through by using only a single sideband, instead of the mirror-image pair. Such a system is called a *single-sideband system,* and is abbreviated SSB. SSB offers many advantages over conventional AM systems, especially for voice communication.

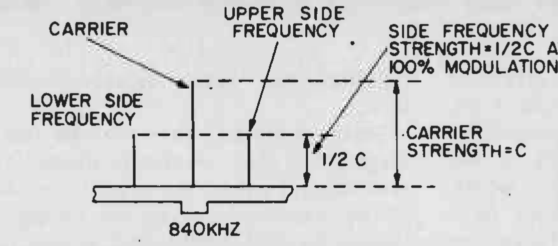


Fig. 4—Strength of upper and lower sideband frequencies is proportional to modulation.

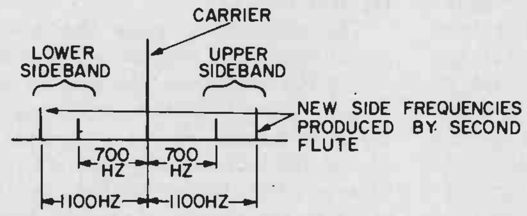


Fig. 5—Second audio modulating signal generates second set of sidebands.

Eliminating the Carrier. If only one sideband is needed to get the message through, we can also ask whether the carrier itself is absolutely necessary. Can we get the message through without the carrier?

The answer is, definitely yes! With proper modulation methods, we can eliminate the carrier completely, and still send the message. To continue our Paul Revere analogy, we are saying that it is only the lanterns that are essential to the message; the steeple could be eliminated if we could find a way to hold the lanterns in place.

Figure 8 shows the result of eliminating the carrier, but keeping *both* sidebands.

This is called a *suppressed carrier system.* The most striking result of suppressing the carrier is seen in the waveform displays of Fig. 8. First we see that, in the absence of an audio signal, there is no carrier (Fig. 8). Second, we note that the envelope representing the original audio signal is somehow tangled up inside the waveform, in such a way that it can't be extracted by a simple "power-supply"–kind of detector (envelope detector) described in the Jan.-Feb. 1976 article on modulation.

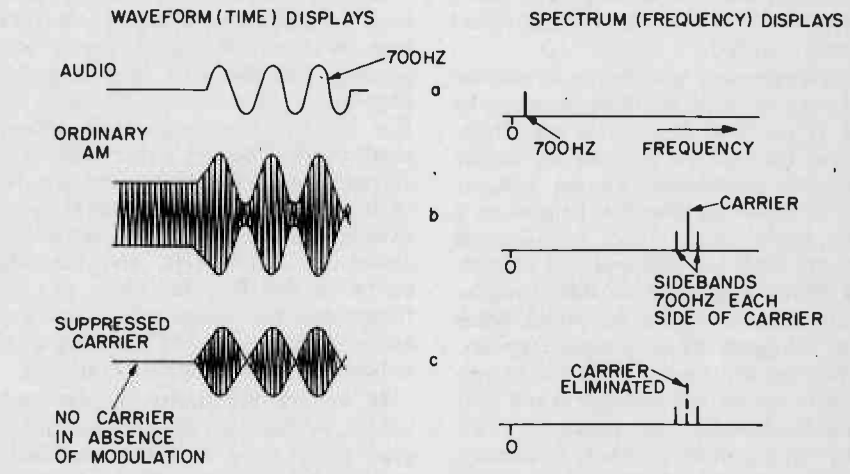


Fig. 8—Elimination of the carrier leaves the sidebands, which include the audio information. Carrier is reinserted at the receiver.

The result of eliminating the carrier looks so unusual that we wish we could put it back. So that's exactly what we do. At the receiver, we insert an artificial carrier, carefully adjusted to the right frequency and strength, which restores the waveform to its more familiar appearance, (Fig. 8), and allows us to detect it with a conventional detector.

But, you might ask, why go through all the motions of first removing the carrier, and then putting it back? What advantage does this gain for us?

The most compelling reason for carrier suppression is the saving in transmitter power. A transmitter could pour 10,000 watts into its carrier, and only a few millionths of a watt of this would arrive at the receiver. It makes much more sense to eliminate the huge transmitter wattage, and instead build a small oscillator at the receiver to provide the few millionths of a watt needed to imitate the carrier.

The power saving becomes even more interesting when we observe how little of the total transmitter power goes into the sidebands. At 100% modulation, a transmitter with 100 watts in the carrier

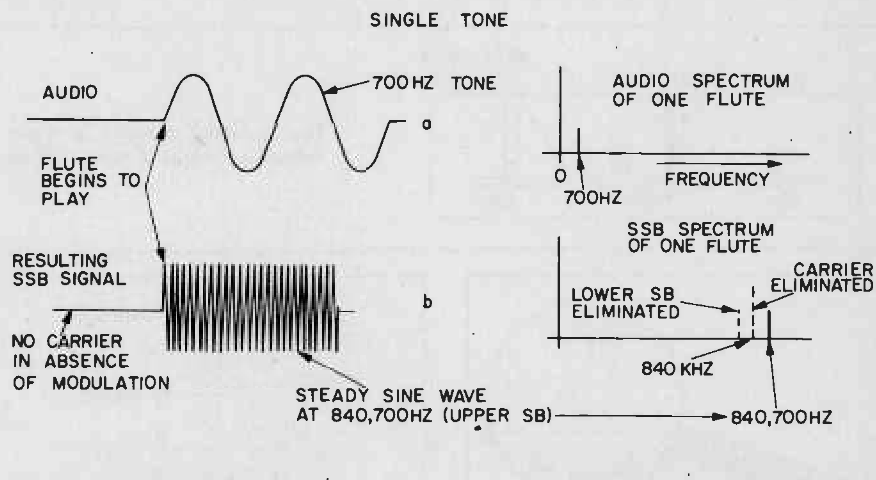


Fig. 10—At onset of 700 Hz audio modulation the carrier sideband appears. With no modulation, no sidebands are present.

will have only 25 watts* in each sideband for a total of 50 watts in the pair. So, only one-third of the transmitter's 150 watts of total power is in the information-bearing sidebands.

Single-Sideband—Sending Only the Necessities. If each sideband of a 100-watt transmitter provides only 25 watts, then eliminating the carrier cuts the total power from 100 + 25 + 25 =

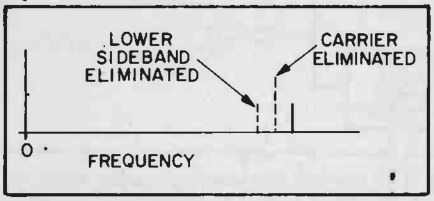


Fig. 9—Spectrum display of a transmitted signal modulated by a 700-Hz tone—lower sideband suppressed.

150 watts, down to 25 + 25 = 50 watts. But, as we pointed out earlier, each of these two sidebands is a mirror image of the other; one of them can be eliminated without hurting the message a bit! Figure 8 shows the spectrum display of an SSB transmitter modulated by a 700-Hz tone. The dotted lines show where the suppressed carrier and the eliminated lower side band would have been.

Dropping one of the unnecessary sidebands reduces the required power down to 25 watts, with only a small decrease in the ability of the signal to get through. Or, if we wish, we can design the transmitter to pour all its available power into that one sideband, with a consequent increase in our ability to get the message through—and without changing the transmitter's size, weight, or power! The only price we pay is the requirement that we insert an artificial carrier at the receiver, to allow us to detect the information in the sideband sent.

SSB Waveforms—A Surprising Story. Now, with SSB concepts firmly in hand, if we look back to the world of waveforms we shall find a most surprising and interesting story.

Figure 9 tells this story. In Figure 10a, we see our familiar 700-Hz flute tone, and on the right of Figure 10b we see the SSB spectrum resulting from

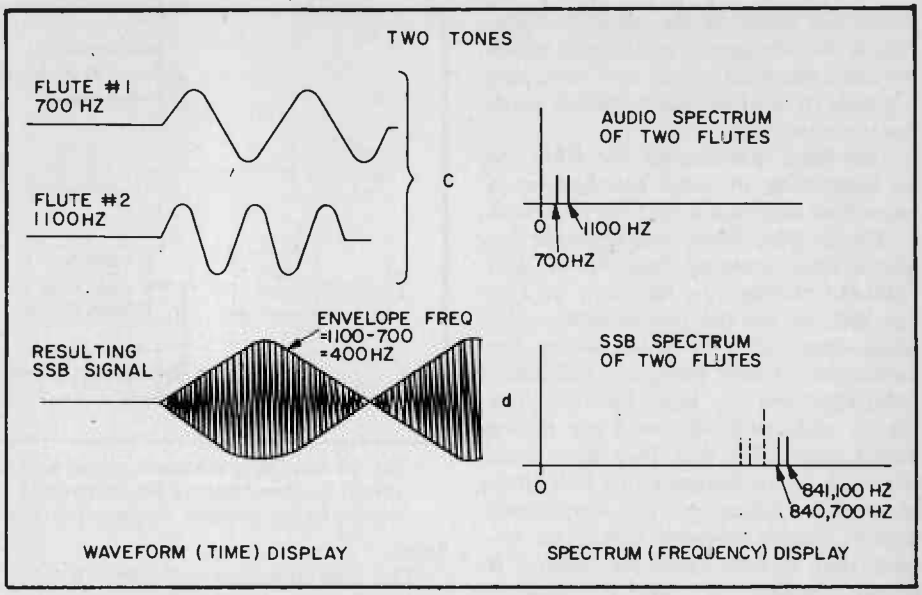


Fig. 11—With two modulating audio signals we have two sidebands generated.

modulating an SSB transmitter with this tone. But on the left of Figure 10b we get our first surprise. True, we would expect no carrier, before the tone begins—we've seen this before, in Fig. 8. (the suppressed carrier case). But when our flutist begins to play, we get a single, steady sine wave from the transmitter—with no evidence of modulation of any kind! Can this be a signal? It looks just like a carrier!

Can't Tell the Lanterns from the Steeple without a Program! The steady sine wave of Figure 10b is indeed a signal; not a carrier. In the first place, it will get bigger (more amplitude) if the flutist plays louder, and will get smaller if he plays more softly. It is, therefore, amplitude modulated—for SSB is just a form of AM. But the *pitch* of the flute—the 700 Hz—is *not* packaged neatly in an envelope, as it was in Figure 8b (standard AM) and in Figure 8c (suppressed carrier). The only clue to its 700-Hz pitch is the fact that this single carrier-like frequency is *700 Hz from where the carrier would have been* if we had sent it!

You can see, then, that re-inserting the carrier at precisely the right frequency is essential to recovering the proper pitch. If the carrier was supposed to be 840,000 Hz, and it is instead re-inserted at 840,030 Hz—only 30 Hz high—then the flute tone will come out of the speaker 30 Hz low, at 670 Hz instead of 700 Hz. Conversely, a reinserted carrier at 839,970 Hz—30 Hz low—will obtain for us a higher pitch:—730 Hz. Therefore, we must know precisely where the carrier should have been if we are to re-create the exact sound which struck the microphone. This is the additional complexity that we endure to obtain the advantages of SSB.

Tuning by Ear. In a practical situation, the speech and music errors introduced by even a slight carrier error are so obvious that it's easy for a listener to simply readjust the inserted carrier frequency until the reproduction "sounds right." This is possible because, as soon as more than a single, simple tone is transmitted, our ears quickly

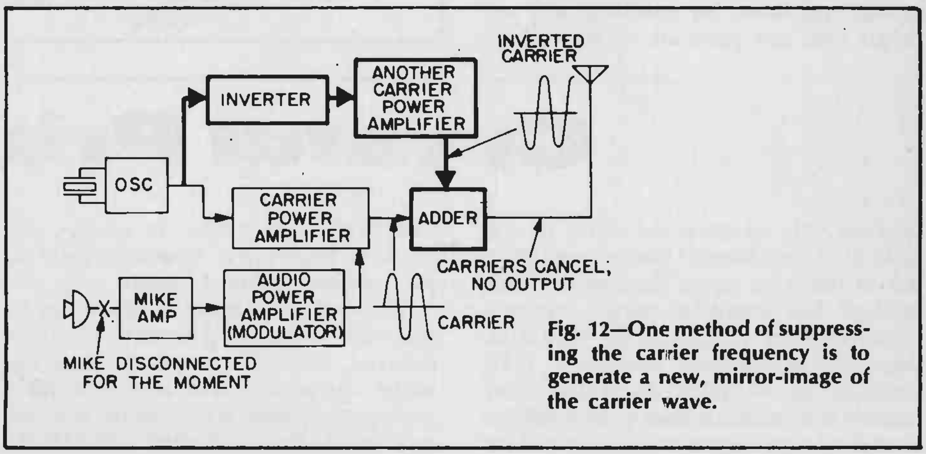


Fig. 12—One method of suppressing the carrier frequency is to generate a new, mirror-image of the carrier wave.

* In case you're wondering how, in Fig. 8, we could say the sidebands at 100% modulation are *half* the carrier, while here we're saying they're *one-quarter,* remember that Fig. 8 shows relative *voltages*. Since power is proportional to the *square* of the voltage, and since *one-half* squared is *one-quarter,* then each sideband's *power* at 100% modulation is *one-quarter* of the carrier power.

detect the errors in the complex waveforms, such as speech and music, which we have encountered all our lives, and a simple twist of the knob quickly clarifies the reception.

Two-tone Waveforms for SSB. As an illustration of what can happen if more than one tone is sent via SSB, look at Figure 10c. Here, our flute-playing pair is again intoning their 700-Hz and 1100-Hz pitches. On the right of Figure 10d, we see the *two* resulting sidebands—one, 700 Hz from where the carrier would have been, and the other, 1100 Hz from the same location. The carrier and lower sideband are shown dotted, indicating that they have been removed. If we compare this SSB spectrum with Figure 8c, (the suppressed-carrier, *double*-sideband case), we observe that, in *both* cases, *the receiver is simply looking at two frequencies.* Therefore, the waveforms should be very much the same in the two cases, even though one arises from a *single* flute tone, and the other, from *two* flute's tones. In the earlier figure, (suppressed carrier), the two frequencies were 2 x 700 = 1400 Hz apart, and the resulting waveform had peaks at a 1400 Hz rate. In our present figure, (10d), the two frequencies are 1100 − 700 = 400 Hz apart, so the peaks occur at a 400 Hz rate. Note that this frequency—400 Hz—never occurred at the microphone; it is the *difference* between the two tones generated by the flutists. But the most important fact is that the waveform of a *single* flute modulating a *double*-sideband transmitter is the same as *two* flutes modulating a *single*-sideband transmitter.

Hardware for SSB. Since SSB is merely a very sophisticated version of ordinary AM, you might expect that you could generate a SSB signal by some kind of change to the basic AM system. In fact, a three-step change to that figure will give an understanding of how SSB is generated. In the first step, (Fig. 11), we have added another carrier power amplifier, an inverter, and an adder (the new parts are shown in bold lines).

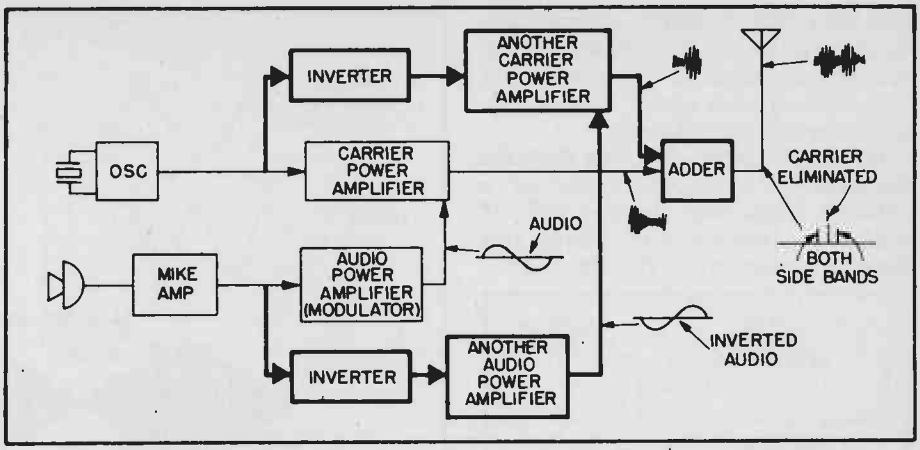


Fig. 13—Inverting the audio signal and using it to control the inverted carrier wave results in strengthening the uninverted carrier. Resulting unequal carriers no longer cancel, hence produce sidebands at antenna.

The new amplifier provides an "upside-down" carrier which, when added to the original carrier, cancels it—provided the gains of the carrier power amplifiers are the same. The result is no carrier output at all—the carrier has been suppressed. In Figure 12 we show the second step of the change.

Here, the *audio* signal is inverted and passed through another audio power amplifier. This inverted audio signal is used to control the output of the new inverted-carrier amplifier. Since the audio supplied to the inverted-carrier amplifier is "upside-down," it will *weaken* the output of the amplifier at the same instant that the "right-side-up" audio is *strengthening* the output of the "right-side-up" carrier. The two carriers are therefore unequal, so they can no longer cancel each other; hence, an output will appear at the antenna. This output is the *double*-sideband, suppressed-carrier signal of Figure 10c.

SSB by Sideband Filtering. The third step of our three-step change consists of merely adding a filter to eliminate one of the sidebands—either one. In Fig. 13, we have chosen to eliminate the *lower* sideband.

The signal from the antenna is now a single-sideband signal, and will have the waveforms and display of Figure 10.

Other Roads to SSB, This SSB system was chosen as an easy-to-understand system which can be developed directly from a standard AM transmitter. It is not the most practical configuration, but, understanding it, you will easily understand the more practical systems. ■

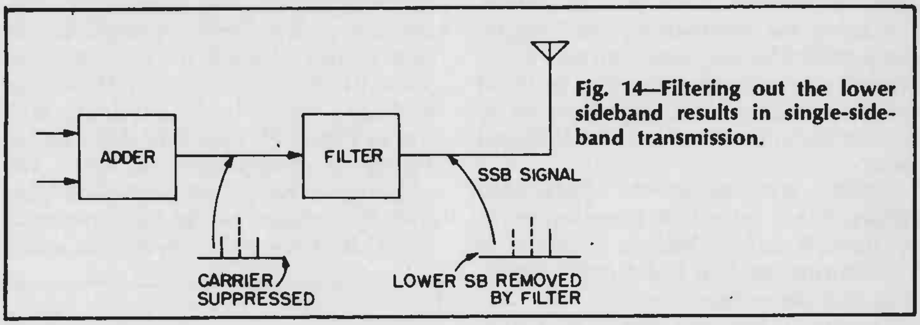


Fig. 14—Filtering out the lower sideband results in single-sideband transmission.

Crystal Primer

☐ 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 plenitude, 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 (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 crystals 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

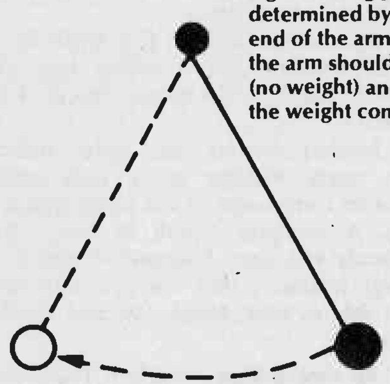


Fig. 1. A long pendulum swings at a rate determined by its length and weight at the end of the arm. To experiment at home, the arm should be made of light thread (no weight) and a small heavy mass (all the weight concentrated at one point).

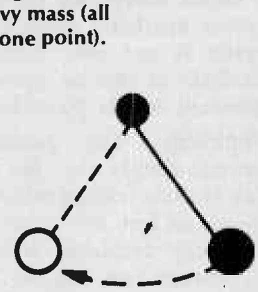


Fig. 2. A short pendulum swings at a faster rate no matter what the weight is. The heavier the weight, the longer the pendulum will swing at the faster rate.

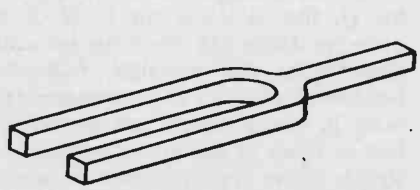


Fig. 3. The geometry of the tuning fork produces a continuous pure tone for a long time when struck gently. It is favored by piano tuners as a convenient way to carry a source of accurately-known tone or pitch.

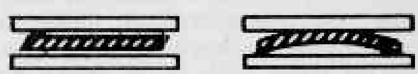


Fig. 4. Depending on how the crystal is cut or sliced from the mother crystal, some crystals warp or bend as in A and others shear as shown in B. Each of the many cuts have special characteristics.

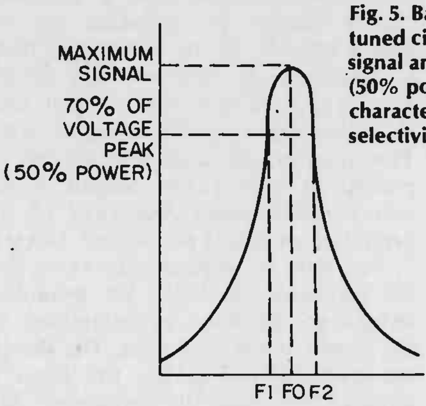


Fig. 5. Bandwidth characteristic of a typical tuned circuit shows the peak or maximum signal amplitude and the 70% voltage peak (50% power) points. This is the characteristic that determines overall selectivity.

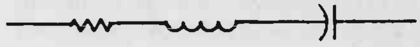


Fig. 6. Diagram is a typical equivalent circuit for a crystal. As resistance is lowered to near zero; crystal efficiency increases. In use, the crystal holder and external circuit add some capacitance across the entire circuit.

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 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.

Pieozelectricity. 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 multipication factor, and others even more confusingly 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 Fo/Q, where *Fo* 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 (*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 L-C 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.

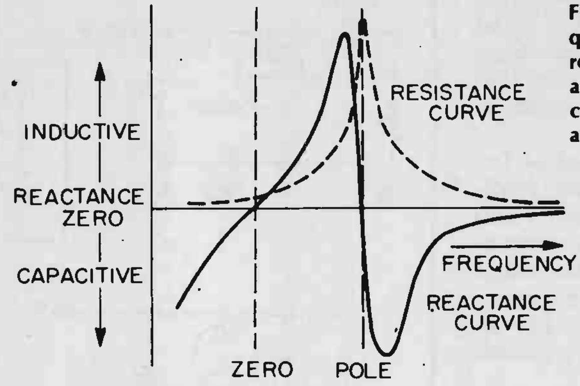


Fig. 7. Some characteristics of a quartz crystal. When slightly off resonant frequency (at the pole) a crystal exhibits inductive or capacitive reactance—just like an LC circuit.

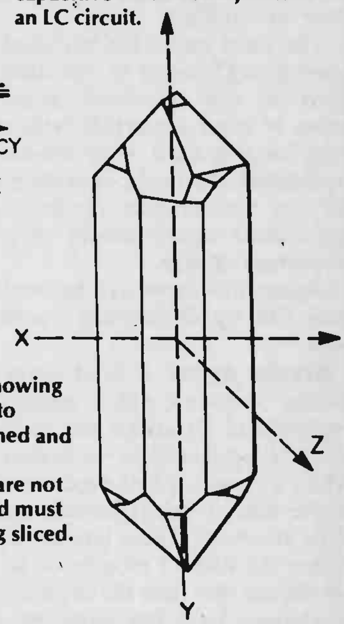


Fig. 8. A view of a mother crystal showing X, Y, and Z axes. Crystal is sliced into blanks, ground to frequency, polished and plated (on facing sides) to make permanent electrodes. All crystals are not made perfect by Mother Nature and must be examined optically before being sliced.

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 frequently 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 ±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 ±0.005% or greater, the crystal must be ground for a single specific oscillator. If ±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.

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.

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 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 fre-

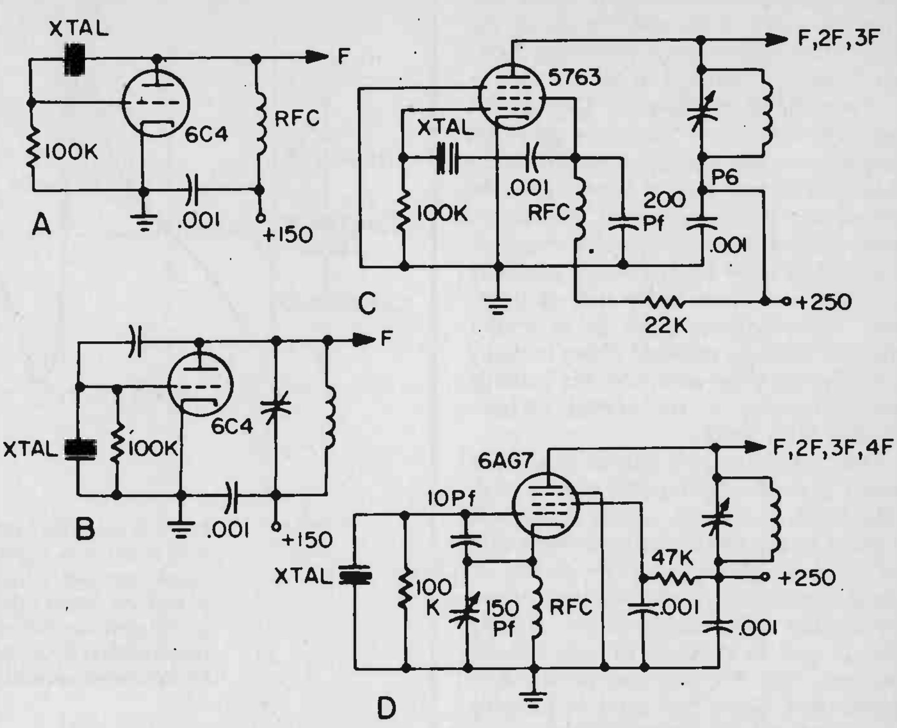
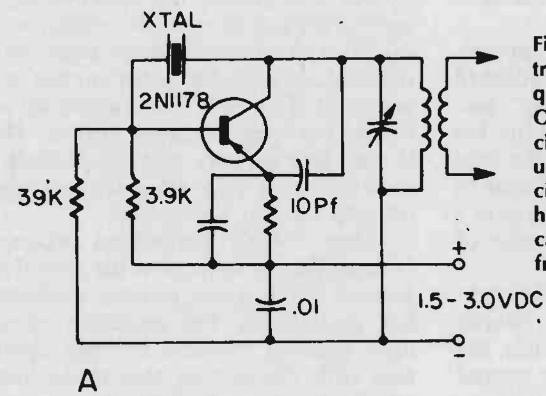


Fig. 9. The simplest crystal oscillator circuit (A) has no tuned circuits. To change frequency it is only necessary to change crystals, although a small variable capacitor across the crystal will cause some small frequency change. Miller oscillator (B) is nearly as simple as Pierce type shown in (A). 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.



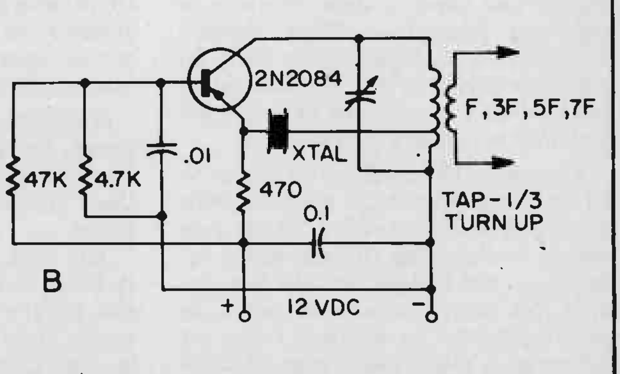


Fig. 10. Fundamental frequency transistorized oscillator (A) is quite similar to that in Fig. 9A. One difference is that tuned circuit in output replaces RFC unit. The overtone (harmonic) circuit (B) uses crystal for odd harmonic feedback. Either circuit can be used for fundamental frequency operation—just tune.

quency (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 frequency 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.

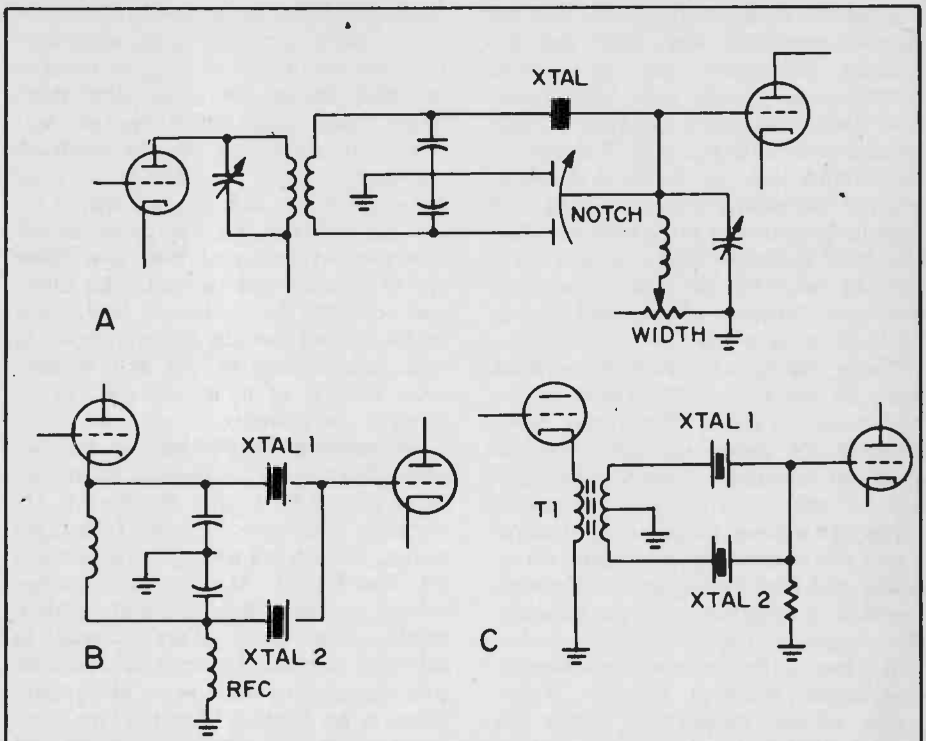


Fig. 11. Crystal filter used in the IF amplifier of a receiver sharpens the selectivity. Circuit in A uses special variable capacitor to adjust notch frequency. Potentiometer varies width (selectivity) of notch. Adding resistance lowers Q of crystal circuit which, increases bandwidth. Two-crystal circuits (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.

More popular for general usage today is the band-pass filter, shown in Figs. 11B and 11C.

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. ■

Inside Microwave Ovens

☐ 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 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 × 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, 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.

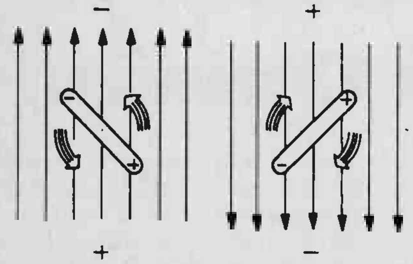


Fig. 1

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. Conduction 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 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,

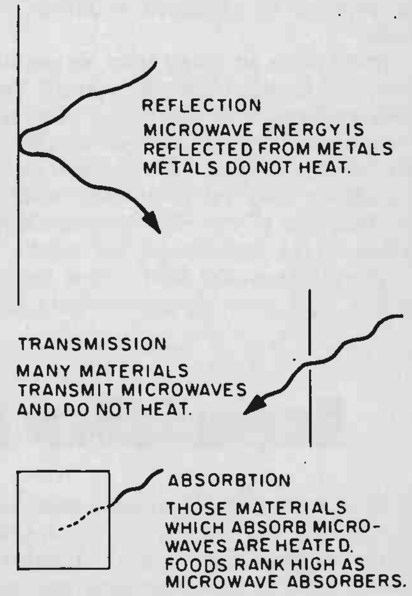


Fig. 2

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).

$Q = 0.75$ lbs. x 0.9 x (160°F.– 70°F.)

$Q = 0.75 \times 0.9 \times 90$

$Q = 60.75$ 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

$$T = \frac{Q}{57} \doteq 63 \text{ seconds}$$

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

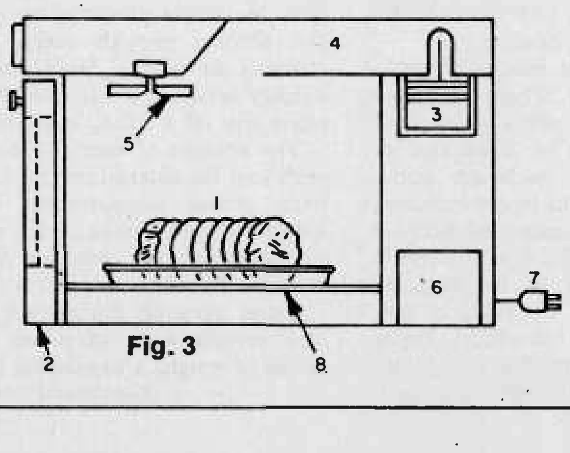


Fig. 3

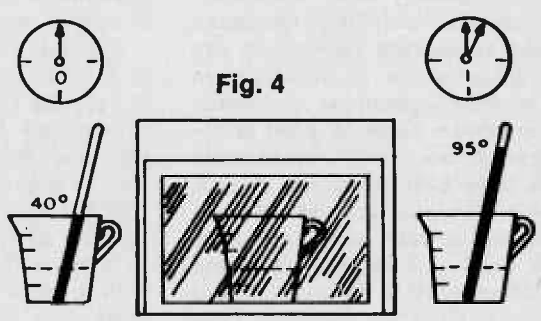
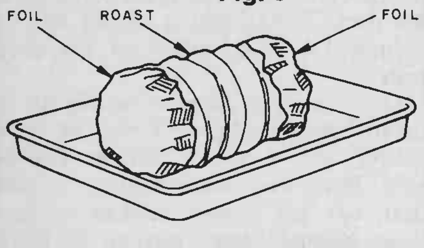


Fig. 4

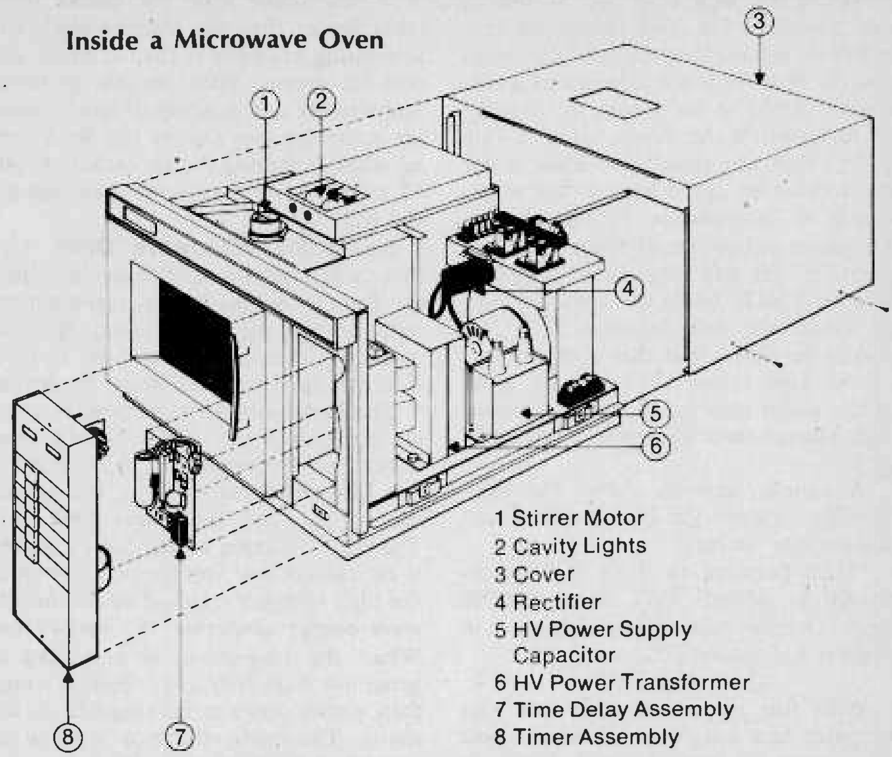
between food sugars and amino acids; the reaction proceeds slowly at low temperatures and is accelerated by increasing the temperature. In microwave cooking the surface temperature of foods rarely exceeds 212°F., the boiling point of water, and is usually much lower. Because of this, most foods cooked 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

Fig. 5



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 presear 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.

Inside a Microwave Oven



If you have seen the inside of one microwave oven you've seen them all. Basically, tracing from the line cord in, there's the rectifier, high-voltage transformer, and magnetron (hidden behind the oven's cavity). Necessary extras are stirrer assembly, oven lights and timer.

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.

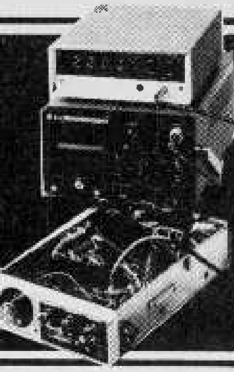
Dinner Is in the Bag. One of the principal advantages of microwave cooking is that it often can be accomplished in the serving dish or in the package in which the food was purchased. With the exception of metals, all packaging materials are transparent to microwave energy. The list includes oven-proof 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 caution. 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.

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 aborbed by the container.

Some ceramic dinnerware may absorb several watts of power for each ounce of weight. Considering the weight
(Continued on page 102)

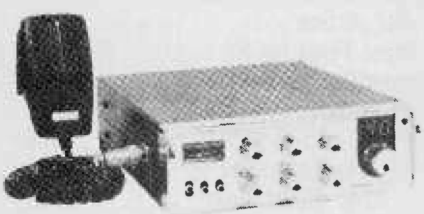
CB XCVR CHECKOUT



- Boman CB-950
- Cobra 77X
- General Electric 3-5871
- Kris XL-50
- Panasonic RJ-3050
- President Grant
- Royce 1-682

☐ To aid in the process of establishing an effective Citizens Band radio station, ELECTRONIC THEORY HANDBOOK presents these technical evaluations of some of the latest of the 40-channel CB transceivers. These units are not prototypes, but are "stock standard," the same as the transceivers that you can buy over the counter. If you don't find the particular unit you are interested in reported on here, check the newsstands for the 1977 edition of CB BUYERS GUIDE, or the latest edition of ELEMENTARY ELECTRONICS, where the newest CB products are continuously reviewed.

• BOMAN CB-950
$389.95 (Boman Astrosonix)
General Description: A 40-channel AM/LSB/USB transceiver for mobile, PA operation. Fine tuning ± 1.5 kHz is provided. Power supply 12 to 13.8 VDC with negative or positive ground. Overall dimensions are 2½-in. h x 7½-in. w x 11-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch/PA, Clarifier, AM/LSB/USB, SWR Meter Calibrate, LED Dimmer, Meter Function, Noise Blanker, RF Gain Sensitivity. Standard accessories are microphone, mobile mount, DC power cable.



CIRCLE 45 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity .... 0.5 μV
Adjacent Channel Rejection .... 73 dB
AGC Action .... 7 dB
Input Level for S9 .... 60 μV

Transmitter Section Test:
RF Output .... 3.5 watts
Modulation to 85% .... yes
Relative Sensitivity for 85% Modulation .... —32 dB
Modulation Limited to 100% ...... yes

Editorial Remarks: The Boman CB-950 has a relative reading S-meter, double conversion receiver, jacks for external and PA speakers, LED digital indicator with continuously variable dimmer, and S/RF output meter. ■

• COBRA 77X
$149.95 (Dynascan Corp.)
General Description: A 40-channel AM transceiver for mobile, PA operation. Power supply 12 to 13.8 VDC with negative or positive ground. Overall dimensions are 2¼-in. h x 5⅞-in. w x 8½-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch, Dynamike (microphone gain), PA/CB, ANL. Standard accessories are microphone, mobile mount, DC power cable.

CIRCLE 48 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity .... 0.5 μV
Adjacent Channel Rejection ...... 64 dB
AGC Action .... 10 dB
Input Level for S9 .... 100 μV

Transmitter Section Test:
AM RF Output .... 3.7 watts
Modulation to 85% .... yes
Relative Sensitivity for 85% Modulation .... —26 dB maximum
Modulation Limited to 100% .... no

Editorial Remarks: The Cobra 77X has an S-meter that reads 6 dB per S-unit, double conversion receiver, external and PA speaker jacks, and S/RF output meter. ■

• GENERAL ELECTRIC 3-5871
$249.95 (General Electric)
General Description: A 40-channel AM transceiver for mobile, PA, fixed operation. Delta tuning ± 1.5 kHz provided. Power supply 12 to 13.8 VDC with negative or positive ground and 120 VAC. Overall dimensions are 4-in. h x 11-7/16-in. w x 9-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch, RF Gain, Tone, Delta Tune, CB/PA, ANL. Standard accessories are microphone, mobile bracket, DC power cable, AC power cable.

CIRCLE 51 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity .... 0.4 μV
Adjacent Channel Rejection ...... 66 dB
AGC Action .... 9 dB
Input Level for S9 .... 76 μV

Transmitter Section Test:
AM RF Output .... 3.7 watts
Modulation to 85% .... yes
Relative Sensitivity for 85% Modulation .... —31 dB
Modulation Limited to 100% .... yes

Editorial Remarks: The General Electric 3-5871 has a relative reading S-meter, double conversion receiver, external and PA speaker jacks, LED digital channel indicator, and S/RF output meter. ■

• KRIS XL-50
$259.95 (Kris, Inc.)
General Description: A 40-channel AM transceiver for mobile, PA operation. Delta tuning ±1.5 kHz provided. Power supply 12 to 13.8 VDC with negative or positive ground. Overall dimensions are 3-in. h x 8.9-in. w x 9.5-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch, RF Gain, Tone, Delta Tune, Meter Lamp Dimmer, Noise Blanker, CB/PA, Intercom Function, Internal/External Speaker (feeds CB through PA speaker), LED Dimmer. Standard accessories are microphone, mobile mount, DC power cable.

CIRCLE 59 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity ....0.3 µV
Adjacent Channel Rejection ......55 dB
AGC Action ....2 dB
Input Level for S9 ....20 µV
Transmitter Section Test:
RF Output ....3.7 watts
Modulation to 85% ....yes
Relative Sensitivity for
85% Modulation ....—28 dB
Modulation Limited to 100% ....yes
Editorial Remarks: The Kris XL-50 has an S-meter that reads 3 dB per S-unit, double conversion receiver, external and PA speaker jacks, LED digital channel indicator, S-meter, RF output meter, modulation meter, and jack for external S-meter. ■

• PANASONIC RJ-3050
$129.95 (Panasonic)
General Description: A 40-channel AM transceiver for mobile operation. Power supply 12 to 13.8 VDC with negative or positive ground. Overall dimensions are 2⅜-in. h x 6¾-in. w x 10-in. d. Front panel controls for Channel Selector, Volume, Squelch. Standard accessories are microphone, mobile mount, DC power cable.

CIRCLE 58 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity ....3.0 µV
Adjacent Channel Rejection ....67 dB
AGC Action ....9 dB
Input Level for S9 ....30 µV
Transmitter Section Test:
AM RF Output ....3.4 watts
Modulation to 85% ....no
Relative Sensitivity for 85%
Modulation ....—29 dB
Modulation Limited to 100% ....yes
Editorial Remarks: The Panasonic RJ-3050 has a relative reading S-meter, double conversion receiver, external speaker jack, LED digital channel indicator, and S/RF output meter. ■

• PRESIDENT GRANT
$339.95 (President Electronics, Inc.)
General Description: A 40-channel AM/SSB transceiver for mobile, PA operation. Fine tuning ±1.25 kHz provided. Power supply 12 to 13.8 VDC with negative or positive ground. Overall dimensions are 2⅜-in. h x 7⅞-in. w x 10½-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch, Clarifier, Microphone Gain, Panel Light Dimmer, AM/LSB/USB, PA/CB, Noise Blanker, Local/Distance Sensitivity. Standard accessories are microphone, mobile mount, DC power cable.

CIRCLE 53 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensitivity ....0.4 µV
Adjacent Channel Rejection ......60 dB
AGC Action ....7 dB
SSB Opposite Sideband
Rejection ....60+ dB
Input Level for S9 ....100 µV
Transmitter Section Test:
RF Output ....3.6 watts AM,
12 watts PEP SSB
Modulation to 85% ....yes
Relative Sensitivity for
85% Modulation....—20 to —40 dB
Modulation Limited to 100% ....yes
Editorial Remarks: The President Grant has a relative reading S-meter, double conversion receiver, external and PA speaker jacks, LED digital channel indicator, and S/RF output meter. ■

• ROYCE 1-682
$219.95 (Royce Electronics Corp.)
General Description: A 40-channel AM transceiver for mobile, PA operation. Variable tuning ± 1.5 kHz provided. Power supply 12 VDC with negative and positive ground. Overall dimensions are 2-13/32-in. h x 7⅞-in. w x 8-13/16-in. d. Front panel controls and switches for Channel Selector, Volume, Squelch, Fine Tuning, RF Gain, PA/CB, ANL, and Channel Indicator Dimming. Standard Accessories are microphone, mobile mount, DC cable.

CIRCLE 47 ON READER SERVICE COUPON

Receiver Section Test:
Input Sensiitvity ....0.5 µV
Adjacent Channel Rejection ......62 dB
AGC Action ....13 dB
Input Level for S9 ....26 µV
Transmitter Section Test:
RF Output ....3.6 watts
Modulation to 85% ....yes
Relative Sensitivity for
85% Modulation ....—30 dB
Modulation Limited to 100% ....yes
Editorial Remarks: The Royce 1-682 has a relative reading S-meter, double conversion receiver, external and PA speaker jacks, S/RF output meter, submaster volume control built into microphone case, and LED digital channel indicators. ■

LITERATURE LIBRARY

301. Get acquainted with the new *EICO* products, designed for the professional technician and electronics hobbyist. Included in brochure are 7 IC project kits, *EICO's* "Foneaids," security products and many varied kits.

302. *International crystal* has illustrated folders containing product information on radio communications kits for experimenters (PC boards; crystals; transistor RF mixers & amplifiers; etc.).

303. *Regency* has a new low cost/high performance UHF/FM repeater. Also in the low price is their 10-channel monitoradio scanner that offers 5-band performance.

304. *Dynascan's* new *B & K* catalog features test eequipment for industrial labs, schools, and TV servicing.

305. Before you build from scratch, check the *Fair Radio Sales* latest catalog for surplus gear.

306. Get *Antenna Specialists'* catalog of latest mobile antennas, test equipment, wattmeters, accessories.

307. Want a deluxe CB base station? Then get the specs on *Tram's* super CB rigs.

308. Compact is the word for *Xcelite's* 9 different sets of midget screwdrivers and nutdrivers with "piggyback" handle to increase length and torque. A handy show case serves as a bench stand also.

310. *Turner* has two booklets on their Signal Kicker antennas. They give specifications and prices on their variety of CB base and mobile line. Construction details help in your choice.

311. *Midland Communications'* line of base, mobile and hand-held CB equipment, marine transceivers, scanning monitors, plus a sampling of accessories are covered in a colorful 18-page brochure.

312. *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 pilotlight socket or $699.95 for a stereo AM/FM receiver, you'll find it here.

313. Get all the facts on *Progressive Edu-Kits* Home Radio Course. Build 20 radios and electronic circuits; parts, tools, and instructions included.

316. Get the *Hustler* brochure illustrating their complete line of CB and monitor radio antennas.

317. *Teaberry's* new brochure presents their complete lines of CB and marine transceivers and scanners for monitoring police, fire and other public service frequencies.

318. CBers, *GC Electronics'* 16-page catalog offers the latest in CB accessories. There are base and mobile mikes and antennas; phone plugs; adaptors and connectors; antenna switchers and matchers; TVI filters; automotive noise suppressor kits; SWR power and FS meters; etc.

319. *Browning's* mobiles and its famous Golden Eagle base station, are illustrated in detail in the new 1977 catalog. It has full-color photos and specification data on Golden Eagle, LTD and SST models, and on "Brownie," a dramatic new minimobile.

320. *Edmund Scientific's* new catalog contains over 4500 products that embrace many sciences and fields.

321. *Cornell Electronics'* "Imperial Thrift Tag Sale" Catalog features TV and radio tubes. You can also find almost anything in electronics.

322. *Radio Shack's 1977* 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.

323. Get *Lafayette Radio's* "new look" 1977 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.

327. *Avanti's* new brochure compares the quality difference between an Avanti Racer 27 base loaded mobile antenna and a typical imported base loaded antenna.

328. A new free catalog is available from *McGee Radio*. It contains electronic product bargains.

329. Semiconductor Supermart is a new 1977 catalog listing project builders' parts, popular CB gear, and test equipment. It features semiconductors—all from *Circuit Specialists*.

330. There are nearly 400 electronics kits in *Heath's* new catalog. Virtually every do-it-yourself interest is included—TV, radios, stereo and 4-channel, hi-fi, etc.

331. *E. F. Johnson* offers their CB 2-way radio catalog to help you when you make the American vacation scene. A selection guide to the features of the various messenger models will aid you as you go through the book.

332. If you want courses in assembling your own TV kits, *National Schools* has 10 from which to choose. There is a plan for GIs.

333. 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.

334. *Sprague Products* has L.E.D. readouts for those who want to build electronic clocks, calculators, etc. Parts lists and helpful schematics are included.

335. The latest edition of the *TAB BOOKS* catalog describes over 450 books on CB, electronics, broadcasting, do-it-yourself, hobby, radio, TV, hi-fi, and CB and TV servicing.

337. *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.

338. "Break Break," a booklet which came into existence at the request of hundreds of CBers, contains real life stories of incidents taking place on America's highways and byways. Compiled by the *Shakespeare Company*, it is available on a first come, first serve basis.

342. *Royce Electronics* has a new 1977 full line product catalog. The 40-page, full-color catalog contains their entire new line of 40-channel AM and SSB CB transceivers, hand-helds, marine communications equipment, and antennas and accessories.

344. 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.

345. 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.

350. 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.

352. Send for the free descriptive bulletin from *Finney* Co. It tells all about their new auto FM radio signal booster (eliminates signal fading).

353. *MFJ* offers a free catalog of amateur radio equipment—CW and SSB audio filters, electronic components, etc. Other lit. is free.

354. A government FCC License can help you qualify for a career in electronics. Send for information from *Cleveland Institute of Electronics.*

355. New for CBers from *Anixter-Mark* is a colorful 4-page brochure detailing their line of base station and mobile antennas, including 6 models of the famous Mark Heliwhip.

356. Send for *Continental Specialties* new breadboarding prototest devices. They vary in prices from a mini-budget kit at $19.95. Featured is the new logic monitor, giving information on what it does, how it works, and how to use it.

357. *Dage Scientific Instruments* offers a 16-page booklet on how to build an electronic thermometer with control. Included is an introductory course on thermocouples, schematics and many applications.

358. *PixTronics* announces its new Model 200 Super Sensitive Electronic Darkroom Exposure Meter, used to determine the correct exposures of all black-and-white and color negatives. Useable with any enlarger.

359. *Electronics Book Club* has literature on how to get up to 3 electronics books (retailing at $58.70) for only 99 cents each . . . plus a sample Club News package.

360. *Cornell-Dubilier* has a 4-color, 4-page, brochure on its Ham II, CD-44, and Big Talk rotor communication systems. Exploded half tones detail interior rotor construction, and tables list specs.

ELECTRONICS THEORY HANDBOOK — **1977 Ed.**
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301	302	303	304	305	306	307	308	310	311	312	313
316	317	318	319	320	321	322	323	327	328	329	330
331	332	333	334	335	337	338	342	344	345	350	352
353	354	355	356	357	358	359	360				

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ADDRESS ____________________

CITY ____________ STATE ________ ZIP ________

Ovens

(Continued from page 98)

of such containers, the total power absorbed can be considerable.

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. ■

Computer New Products

(Continued from page 70)

ed in three basic groups: ADC's with 8, 16 and 32 differential, or 16, 32 and 64 single-ended analog input channels; DAC's with 2 analog output channels; ADC/DAC combination with 8 differential or 16 single-ended input channels and 2 output channels. Each system is packaged on a single half-card for significant space and cost savings, and the systems will operate from the standard chassis power supply so no separate power supply is needed. The top-of-the-line, 12-bit ADC can process up to 64 channels of analog data at a throughput rate of 35,000 channels/sec or 28.5 microseconds / conversion. Standard features include programmable real-time clock, acquisition of data on external event, sequential mode operation, input analog multiplexer, sample and hold amplifier, input protection against improper operation. Single unit price: $2,275. ADC prices range downward to $1,575 for an 8-channel differential input device. ADC/DAC combination products, also modular, start at $950 and are expandable up to 16 analog input channels. Standard on all products: two 12-bit digital-to-analog converters, input buffer registers, power amplifier output for driving up to 50 feet of cable, Z-axis control. Computer Automation, Inc., 18651 Von Karman, Irvine, CA 92713. Circle number 57 on Reader Service Coupon. ■

Ask Hank, He Knows!

(Continued from page 12)

friend's car, it works fine with his CB rig—and my rig, too! What's wrong?

O. P., Hollywood, FL

Your problem may be a plastic gutter mount that's a perfect insulator offering no ground circuit for the antenna's metalic clamp. If you need a quick disconnect, go for a magnetic mount.

Static Charge

Can you suggest a simple static electricity experiment I can use.

—P. H., Jackson, TN

Cut or tear paper to ¼-in. squares approximately. Then, rub a plastic comb with a wool cloth. The comb should attract the paper bits—if the humidity is low enough.

Junk is Good

Everyone is trying to rip me off. I want to rebuild a heater fan motor in my old car and the best I can get is a new heater assembly for 60 dollars. What can I do?

—D. M., Boise, ID

Do what I do, visit your local auto junk yard with a set of tools. For a few bucks, the owner will let you salvage the part you want. Should the part be defective, the chances are the owner will let you do it again without additional cost. Heater motors usually are factory sealed units that cannot be repaired.

Likes to Snooze

My phone rings when I want to sleep. What's an easy way to turn it off without getting in trouble with the phone company?

—E. L., Fort Worth, TX

Well, if you have a wall plug and jack combination, simply disconnect the phone. Another way is to open the 2-in. square junction box (that's where the cable from the telephone connects) and separate the yellow and green wires that go to the phone. Leave the green where it is (so you'll be able to get a dial tone) and connect the yellow to an unwired or vacant terminal in the junction box. (Now the phone won't ring). Connect an external snap or slide switch via a two-wire cable across the yellow and green wires in the junction box. When the switch is closed, the bell circuit will ring during incoming calls. With the switch off, the bell circuit will not ring, however you will be able to make calls.

Needs 5 Volts DC

My minicomputer came complete except for a 5-volt DC supply. Can you give me the plans for one? Please keep it simple and cheap. My dad's wallet is operating on it's last slow-blow fuse.

—J. P., Salt Lake City, UT

I suggest you visit your local Radio Shack and pick up the parts and printed circuit board for their 5-volt DC regulated supply kit, catalog number 277-102. It's rated at 1 ampere and also has a 60-Hz output, should you need it.

Testing

How can I check my calculator before I start using it to be sure it is working?

—D. Y., Hobbs, NM

Turn it on, place it in the F (floating decimal) mode and enter 1.1111111. Hit the X (multiplication) key and the = (equal) key. Your answer should be 1.2345678. This does not check out all functions in the calculator, but it does tell you that most of the circuitry is working and the batteries are operative. Incidentally, run down batteries are the major cause of incorrect calculator answers.

△ Jim Nickel, 1012 South 111 St., West Allis, WI 53214 needs the schematic diagram for the Hallicrafter S-38C receiver.

△ An odd one—schematic diagram for a 3-channel psychedelic light control kit manufactured by Bowman Leisure Industries, Model PCC-3LF. Write to Kyle McKown, Box 18, Arnoldsburg, WV 25234.

△ Al G. Spence has looked a long time for a service manual for a Knight KG-2000 oscilloscope. Write to Al at 629 Henderson Ave., Staten Island, NY 10310.

△ B. R. Barnum, 1456 C Street, Eureka, CA 95501 would like info on Sebcom 2-station, single-channel wireless intercom. Anybody?

△ Jacques Blanchet, 35 St. Georges, Levis, Que., Canada G6V 3PO needs diagrams and manuals on: Marconi MK1, No. 9 transceiver, and Research Enterprise RH-1, No. 32.

△ Sony TC-500 tape transport repair manual is needed by Robert H. Stirling, Champlain Drive, Old Lyme, CT 06371.

△ Walter L. Damkoehler needs the schematic diagram for a Lincoln SW-34 receiver. Write to Walter, W4EBO, at 515 Grand Avenue, Gadsden, AL 35901.

△ Sean Welsh, 234 Wincott Dr., Weston, Ont., Canada M9R 2R4 is rebuilding the Canadian General Electric Model C7T2 VHF TV set made in 1957. Sean needs schematic diagram and tube placement diagram.

△ Dan Smith, 2027 West F St., Napa, CA 94558 needs every bit of info he can get on the following: Johnson Viking Challenger Amateur transmitter, Supreme Model 546 oscilloscope, and Precision Model E-200-C signal generator.

△ William Burchett, Star Route, Ulysses, KY 41264 wants to restore an Echophone Model EC-1A radio. Send schematic diagram and other info.

△ Got a copy of the Hallicrafters SX99 operator's manual? Please send it or Xerox to Stanley Mason, 12 Reservoir Rd., Melville, NY 11746. ■

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ELECTRONIC THEORY HANDBOOK—PUBLISHED ANNUALLY. The rate per word for Classified Ads is $1.00 each insertion, minimum ad $15.00 payable in advance. Capitalized words 40¢ per word additional. To be included in next issue, write to R. S. Wayner, DAVIS PUBLICATIONS, INC., 220 Park Ave. So., NY 10003.

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HOMEWORK! BIG MONEY addressing, mailing envelopes. Exciting offer 10¢. Linco Services, 3636 Peterson, Chicago 60659.

1000% PROFIT Bronzing Baby Shoes. Free Literature. NBC, Box 1904-DG, Sebring, FL 33870.

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CB Q and A

Before starting this special CB Theory Quiz make sure you have carefully read the "Cram Course on CB Theory" beginning on page XX of this issue of ELECTRONICS THEORY HANDBOOK. The quiz is designed to be a quick, enjoyable way to check your knowledge of that important subject, CB theory. Score 22 or more correct answers and you're a CB expert and ready to hold your own on the airwaves. If you get 18 to 21 right, stay on the air, but put those one minute silent periods to good use by digging into that CB theory until you're up to snuff. Less than 18 correct and you'd better pull the plug until you've mastered the basics and are qualified to crank up the rig again.

1. There are presently two distinct and separate types of transmission systems in use: ______ and ______.

2. In the process of combining the audio modulation and RF carrier, new frequencies called ______ are generated.

3. Single sideband, or SSB as it is termed, utilizes the principle that only ______ is required for transmitting intelligence.

4. If all CB stations were SSB the present 23 channels could provide ___ communications channels.

5. The IF amplifier provides most of the receiver's ______ and all ______.

6. The RF amplifier amplifies the ______ to a ______.

7. The important justification for a double conversion IF strip is for the ______ of ______.

8. Double conversion means ______ IF frequencies.

9. AM is easily obtained in an SSB transceiver by simply ______ the carrier.

10. The best servicing advice concerning modern solid-state transceivers, whether AM or SSB, is ______.

11. The least expensive form of frequency control in transceivers of substantially less than full-23 coverage (say, 6 channels) is the ______ oscillator.

12. Frequencies assigned to the Citizens Band are among the ______ in the whole radio spectrum.

13. On the Citizens Band most noise is primarily ______ noise.

14. The simplest form of noise limiter is the so-called ______ or ______ type.

15. Ultimate noise suppression is obtained from a ______ circuit.

16. The permissible limit of modulation for an AM or SSB transmitter is ______ percent.

17. While talk power devices are very effective for AM transmitters they can often result in the ______ of an SSB transmitter.

18. If your CB transceiver doesn't have a negative power wire, it means the ground connection is made through the ______.

19. Don't depend on the antenna system coaxial cable ______ to provide the ground connection.

20. For safety's sake, antenna masts should always be ______.

21. The ______ is the best and possibly the only device available to the CBer which indicates directly whether the power coming from the transmitter is reaching the antenna.

22. To check SWR you need only install an SWR meter or "bridge" between the ______ and the ______.

23. If there is substantial change in SWR readings when a ¼-wavelength section of coaxial cable is installed between an SWR meter and the transmission line, the antenna is ______.

24. The CB Matcher (at least those presently available) makes the overall antenna system load appear as ___ ohms.

25. All CB rigs will work if you talk into the mike, but the clarity of the modulation will be determined by the ______ built into the transceiver.

Answers to CB Theory Quiz

1. *AM and SSB*
2. *sidebands*
3. *one sideband*
4. *46*
5. *gain and all selectivity*
6. *weak received signal to a usable level*
7. *reduction of image interference*
8. *two*
9. *re-introducing*
10. *don't touch!*
11. *crystal controlled*
12. *noisiest*
13. *impulse*
14. *floating series or parallel*
15. *„noise suppressor"*
16. *100*
17. *destruction*
18. *transceiver's cabinet*
19. *shield*
20. *grounded*
21. *SWR meter*
22. *transmitter output and the transmission line*
23. *not 50 ohms*
24. *overall microphone gain*


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