A HETERODYNE DEVIATION METER

The instrument described here can be used to check the audio deviation of an fm transmitter, or to determine how far off frequency the transmitter carrier may be. It can also be used as a signal source to aid in setting a receiver on frequency, if a crystal of known accuracy is plugged into the oscillator.

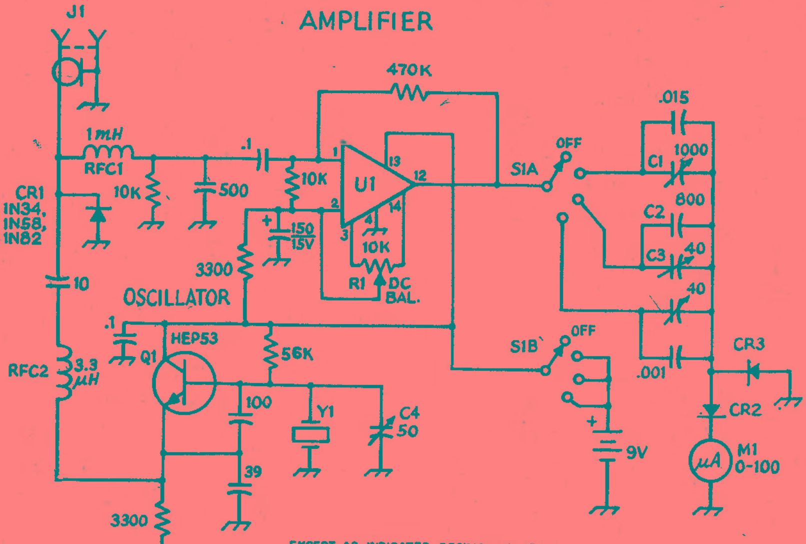
The Circuit

As shown in Fig. 17-57 a transistor oscillator is used to feed energy to a mixer diode, CR1. A small pickup antenna is connected to the diode also, thereby coupling a signal from a transmitter to the mixer. The output from the diode, in the audio range, is amplified by U1, a 2747 operational amplifier. The 2747 amplifies and clips the audio, providing a square wave of nearly constant amplitude at the output. This square wave is applied to a rectifier circuit through variable coupling capacitors and a selector switch. A meter is connected to the rectifier circuit to read the average current. Since the amplitude of the input is constant, a change in frequency will produce a change of average current. Three ranges are selected by S1, with individual trimmers being placed in the circuit for calibration.

Fig. 17-56 — The deviation meter is constructed in a Calectro aluminum box. A four-position switch is at the lower right. The crystal plugs in on the left, with the frequency adjusting trimmer just below. A short whip or pickup wire can be plugged into the phono connector that is mounted on the back wall of the box.

Construction

An aluminum box is used for the enclosure, 6-1/4 × 3-1/2 × 2 inches. A meter switch, variable capacitor, and crystal socket are all mounted on the top panel. A small pc board is fastened to the



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF) ;
OTHERS ARE IN PICOFARADS (pF OR µµF);
RESISTANCES ARE IN OHMS ;
k = 1000, M = 1000 000.

Fig. 17-57 — Circuit of the deviation meter. Connections shown are for a 2747 dual op amp. A 741 may be substituted with appropriate changes in pin numbers.

C1 — 360 to 1000 pF mica trimmer (J. W. Miller 160-A or equiv.).
C2, C3 — 3 to 30 pF mica trimmer (J. W. Miller 86 MA 2 or equiv.).
C4 — 50 pF miniature air variable (Hammarlund MAPC 50 or equiv.).
CR1 — Germanium diode, 1N34, 1N58, or 1N82 suitable.
CR2, CR3 — Silicon diode, 1N914 or equiv.
J1 — Coax connector, BNC or phono type suitable.
M1 — Microammeter, 0 to 1000 µA (Simpson Model 1212 Wide-Vue or equiv.).
Q1 — Motorola transistor.
R1 — 10,000-ohm miniature control, pc mount.
S1 — 2-pole, 4-position rotary switch, nonshorting.
U1 — Dual operational amplifier IC, Type 2747, one half not used.
Y1 — Crystal to produce harmonic on desired transmitter or receiver frequency. Fundamental range 6 to 20 MHz.

meter terminals as a convenient support. This board contains the IC and associated circuit components, as well as the rectifier diodes.

The oscillator is constructed on a separate pc board which mounts behind the crystal socket and variable capacitor. Metal spacers and 4-40 screws and nuts are used to fasten the oscillator board in place. A shield of pc board is placed between the oscillator and the amplifier to provide isolation. Power for the instrument is furnished by a 9-volt transistor radio battery that is held by a clip inside the box.

Testing and Use.

Before calibrating the meter, the dc balance should be adjusted. A voltmeter should be connected to the output of U1, (pin 12) and R1 adjusted until the potential at this pin in one half of the supply voltage.

A low-level audio signal can be used to test the amplifier and meter circuit. As little as 10 mV, applied to pin 1, will produce a square wave at the output of the amplifier. Three ranges are provided in this meter; 0 - 1000Hz, 0 - 10 kHz, and 0 - 20 kHz. Each position can be calibrated by adjustment of the associated trimmer capacitor. The amount of capacitance needed may vary with different diodes, so fixed ceramic capacitors may be placed in parallel with the trimmers to bring the adjustment within range. As the frequency of the input to U1 is varied, the meter reading should correspond to that frequency over most of its range. On the upper frequency range, 0 - 20 kHz, a multiplication factor must be applied to the reading on the meter.

In use, a short whip or piece of wire is connected to J1, and the meter placed near a transmitter. A crystal that will produce a harmonic on the correct frequency is plugged into the socket. The selector switch should be in the first (0 - 1000 Hz) position. When the transmitter is turned on, the meter will indicate the difference in frequency between the transmitter and the harmonic from the oscillator. The trimmer, C4, should be adjusted for a minimum reading. Any hum, noise, or power-supply whine will cause a residual reading that could mask true zero beat. Modulation can be applied to the transmitter and the deviation control adjusted for the amount desired as indicated on the meter. Note that there is a difference between the indications obtained from a sine wave and those from voice. Readings will be lower with voice, the amount being dependent on the meter that is used and upon the individual voice.

Fig. 17-58 — The dual op amp is located just below the center. Meter terminals are used as a convenient support for the amplifier pc board. The oscillator board is at the right, held in place by means of metal spacers.

Several transmitters can be netted to a system by setting the crystal in the device to the correct frequency at first, then adjust the frequency of each transmitter for an indication of zero beat.

Since there is some energy from the oscillator present at the input, J1, the same procedure can be used to align receivers to the correct frequency. When the deviation meter is acting as a signal source for checking either receivers or transmitters, the crystal should be checked for frequency drift several times during the test.

Chapter 18

Construction Practices and Data Tables

TOOLS AND MATERIALS

While an easier, and perhaps a better, job can be done with a greater variety of tools available, by taking a little thought and care it is possible to turn out a fine piece of equipment with only a few of the common hand tools. A list of tools which will be indispensable in the construction of radio equipment will be found on this page. With these tools it should be possible to perform any of the required operations in preparing panels and metal chassis for assembly and wiring. It is an excellent idea for the amateur who does constructional work to add to his supply of tools from time to time as finances permit.

RECOMMENDED TOOLS

Long-nose pliers, 6-inch and 4-inch
Diagonal cutters, 6-inch and 4-inch
Combination pliers, 6-inch
Screwdriver, 6- to 7-inch, 1/4-inch blade
Screwdriver, 4- to 5-inch, 1/8-inch blade
Phillips screwdriver, 6- to 7-inch
Phillips screwdriver, 3- to 4-inch
Long-shank screwdriver with holding clip on blade
Scratch awl or scriber for marking metal
Combination square, 12-inch, for layout work
Hand drill, 1/4-inch chuck or larger
Soldering pencil, 30-watt, 1/8-inch tip
Soldering iron, 200-watt, 5/8-inch tip
Hacksaw and 12-inch blades
Hand nibbling tool, for chassis-hole cutting
Hammer, ball-peen, 1-lb head
Heavy-duty jack knife
File set, flat, round, half-round, and triangular. Large and miniature types recommended
High-speed drill bits, No. 60 through 3/8-inch diameter
Set of "Spintite" socket wrenches for hex nuts
Crescent wrench, 6- and 10-inch
Machine-screw taps, 4-40 through 10-32 thread
Socket punches, 1/2", 5/8", 3/4", 1 1/8", 1 1/4", and 1 1/2"
Tapered reamer, T-handle, 1/2-inch maximum pitch
Bench vise, 4-inch jaws or larger
Medium-weight machine oil
Tin shears, 10-inch size
Motor-driven emery wheel for grinding
Solder, *rosin core only*
Contact cleaner, liquid or spray can
Duco cement or equivalent
Electrical tape, vinyl plastic

Radio-supply houses, mail-order retail stores and most hardware stores carry the various tools required when building or servicing amateur radio equipment. While power tools (electric drill or drill press, grinding wheel, etc.) are very useful and will save a lot of time, they are not essential.

Twist Drills

Twist drills are made of either high-speed steel or carbon steel. The latter type is more common and will usually be supplied unless specific request is made for high-speed drills. The carbon drill will suffice for most ordinary equipment construction work and costs less than the high-speed type.

While twist drills are available in a number of sizes, those listed in bold-faced type in Table 18-I will be most commonly used in construction of amateur equipment. It is usually desirable to purchase several of each of the commonly used sizes rather than a standard set, most of which will be used infrequently if at all.

Care of Tools

The proper care of tools is not alone a matter of pride to a good workman. He also realizes the energy which may be saved and the annoyance which may be avoided by the possession of a full kit of well-kept sharp-edged tools.

Drills should be sharpened at frequent intervals so that grinding is kept at a minimum each time. This makes it easier to maintain the rather critical surface angles required for best cutting with least wear. Occasional oilstoning of the cutting edges of a drill or reamer will extend the time between grindings.

The soldering iron can be kept in good condition by keeping the tip well tinned with solder and not allowing it to run at full voltage for long periods when it is not being used. After each period of use, the tip should be removed and cleaned of any scale which may have accumulated. An oxidized tip may be cleaned by dipping it in sal ammoniac while hot and then wiping it clean with a rag. If the tip becomes pitted it should be filed until smooth and bright, and then tinned immediately by dipping it in solder.

Useful Materials

Small stocks of various miscellaneous materials will be required in constructing radio apparatus, most of which are available from hardware or radio-supply stores. A representative list follows:

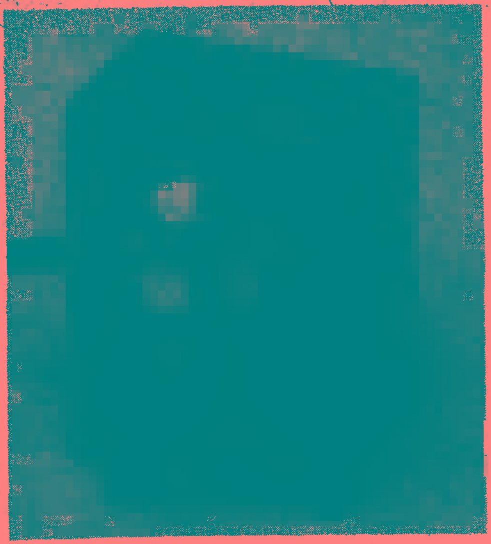


Fig. 1 — The SCR motor-speed control is housed in a small cabinet.

The working parts of the motor-speed control. The triac is centered on its aluminum heat sink, with the terminals of the speed-control resistor protruding from underneath. The rf-hash-suppression filter and components in tha gate-triggering circuit are mounted on a tie-point strip, being visible at the bottom of the enclosure as shown in this view. The triac is barely discernable at the right end of the fixed resistor. Terminals of the strip which are associated with the mounting feet are unused, and are bent down to prevent accidental shorts to other parts of the circuit.

Sheet aluminum, solid and perforated, 16 or 18 gauge, for brackets and shielding.
1/2 X 1/2-inch aluminum angle stock.
1/ 4-inch diameter round brass or aluminum rod for shaft extensions. Machine screws: Round-head and flat-head, with nuts to fit. Most useful sizes: 4-40, 6-32 and 8-32, in lengths from 1/4 inch to 1 1/2 inches. (Nickel-plated iron will be found satisfactory except in strong rf fields, where brass should be used.)
Bakelite, lucite and polystyrene scraps.
Soldering lugs, panel bearings, rubber grommets, terminal-lug wiring strips, varnished-cambric insulating tubing.
Shielded and unshielded wire.
Tinned bare wire, Nos. 22, 14 and 12.

Machine screws, nuts, washers, soldering lugs, etc., are most reasonably purchased in quantities of a gross. Many of the radio-supply stores sell small quantities and assortments that come in handy.

TRIAC MOTOR-SPEED CONTROL

Most electric hand drills operate at a single high speed; however, from time to time, the need arises to utilize low or medium speeds. Low speeds are useful when drilling in tight spaces or on exposed surfaces where it is important that the drill bit doesn't slip, and when drilling bakelite, Plexiglas and similar materials. Medium speeds are useful for drilling non-ferrous metals such as aluminum and brass. One way to accomplish these ends with a single-speed electric drill is to use a silicon bidirectional thyristor (Triac) speed control.

The circuit for the Triac speed control is shown in Fig. 1. This type of circuit provides some degree of regulation with varying loads.

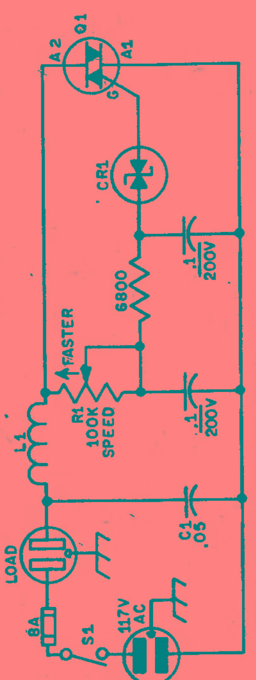


Fig. 1 — Schematic diagram of motor-speed control. Resistances are in ohms (k = 1000) and capacitances are in microfarads. Important note: The basing diagram for Q1 is correct as shown here. Some early literature accompanying the packaging of the HEP device appears to be in error.
C1 — .05-μF, 600-V paper.
CR1 — Diac (silicon bilateral trigger), 2-A, 300-mW (Motorola MPT28 or HEP311 or equiv.).
L1 — Approx. 70 μH; made with 18 ft. No. 18 enam. wire scramble-wound on body of C1, or on a 1-1/2-inch length of 1/2-inch dia. rod.
Q1 — Triac (silicon bidirectional thyristor), 8-A, 200-V (Motorola MAC2-4 or HEP340 or equiv.).
R1 — Linear-taper composition control, 2-W.
S1 — Spst toggle.

Construction

Because of the small complement of parts, the Triac speed control can be constructed inside a very small container. The model described was built in a 2-3/4 × 2-1/8 × 1-5/8-inch Minibox. Since the mounting stud and main body of the Triac are common with the anode, care should be used to mount the Triac clear from surrounding objects. In the unit shown, two soldering lugs were soldered together and the narrow ends connected to one side of the female output connector; the large ends were used as a fastening point for the Triac anode stud.

Operation

Although the circuit described is intended to be used to reduce the speed of electric hand drills that draw six amperes or less, it has many other applications. It can be used to regulate the temperature of a soldering iron, which is being used to wire a delicate circuit, or it may be used for dimming lamps or for controlling the cooking speed of a small hot plate. Note, however, if the circuit is used with a device drawing from three to six amperes for a continuous period of over ten minutes, it will be necessary to provide a heat sink (insulated from the chassis) for the Triac anode case.

CHASSIS WORKING

With a few essential tools and proper procedure, it will be found that building radio gear on a metal chassis is a relatively simple matter. Aluminum is to be preferred to steel, not only because it is a superior shielding material, but because it is much easier to work and provides good chassis contacts.

The placing of components on the chassis is shown quite clearly in the photographs in this *Handbook*. Aside from certain essential dimensions, which usually are given in the text, exact duplication is not necessary.

Much trouble and energy can be saved by spending sufficient time in planning the job. When all details are worked out beforehand the actual construction is greatly simplified.

Cover the top of the chassis with a piece of wrapping paper, or, preferably, cross-section paper, folding the edges down over the sides of the chassis and fastening with adhesive tape. Then assemble the parts to be mounted on top of the chassis and move them about until a satisfactory arrangement has been found, keeping in mind any parts which are to be mounted underneath, so that interferences in mounting may be avoided. Place capacitors and other parts with shafts extending through the panel first, and arrange them so that

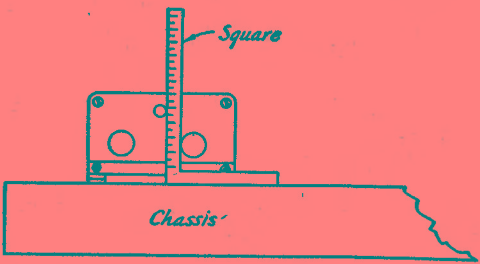


Fig. 18-3 — Method of measuring the heights of capacitor shafts. If the square is adjustable, the end of the scale should be set flush with the face of the head.

TABLE 18-I

Numbered Drill Sizes

Num.	*Diameter (Mils)*	*Will Clear Screw*	*Drilled for Tapping from Steel or Brass**
1	228.0	—	—
2	221.0	12-24	—
3	213.0	—	14-24
4	209.0	12-20	—
5	205.0	—	—
6	204.0	—	—
7	201.0	—	—
8	199.0	—	—
9	196.0	—	—
10	193.5	10-32	—
11	191.0	10-24	—
12	189.0	—	—
13	185.0	—	—
14	182.0	—	—
15	180.0	—	—
16	177.0	—	12-24
17	173.0	—	—
18	169.5	8-32	—
19	166.0	—	12-20
20	161.0	—	—
21	159.0	—	10-32
22	157.0	—	—
23	154.0	—	—
24	152.0	—	—
25	149.5	—	10-24
26	147.0	—	—
27	144.0	—	—
28	140.0	6-32	—
29	136.0	—	8-32
30	128.5	—	—
31	120.0	—	—
32	116.0	—	—
33	113.0	4-40	—
34	111.0	—	—
35	110.0	—	6-32
36	106.5	—	—
37	104.0	—	—
38	101.5	—	—
39	099.5	3-48	—
40	098.0	—	—
41	096.0	—	—
42	093.5	—	4-40
43	089.0	2-56	—
44	086.0	—	—
45	082.0	—	3-48
46	081.0	—	—
47	078.5	—	—
48	076.0	—	—
49	073.0	—	2-56
50	070.0	—	—
51	067.0	—	—
52	063.5	—	—
53	059.5	—	—
54	055.0	—	—

***Use one size larger for tapping bakelite and phenolics.**

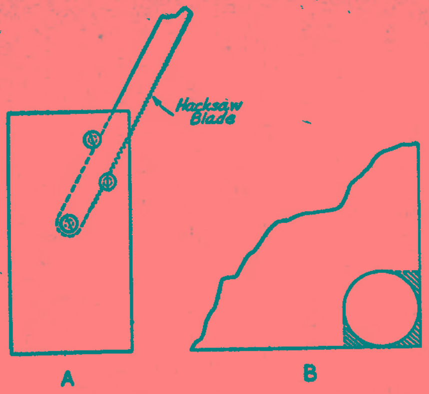


Fig. 18-4 — To cut rectangular holes in a chassis corner, holes may be filed out as shown in the shaded portion of B, making it possible to start the hack-saw blade along the cutting line. A shows how a single-ended handle may be constructed for a hack-saw blade.

the controls will form the desired pattern on the panel. Be sure to line up the shafts squarely with the chassis front. Locate any partition shields and panel brackets next, and then the tube sockets and any other parts, marking the mounting-hole centers of each accurately on the paper. Watch out for capacitors whose shafts are off center and do not line up with the mounting holes. Do not forget to mark the centers of socket holes and holes for leads under i-f transformers, etc., as well as holes for wiring leads. The small holes for socket-mounting screws are best located and center-punched, using the socket itself as a template, after the main center hole has been cut.

By means of the square, lines indicating accurately the centers of shafts should be extended to the front of the chassis and marked on the panel at the chassis line, the panel being fastened on temporarily. The hole centers may then be punched in the chassis with the center punch. After drilling, the parts which require mounting underneath may be located and the mounting holes drilled, marking sure by trial that no interferences exist with parts mounted on top. Mounting holes along the front edge of the chassis should be transferred to the panel, by once again fastening the panel to the chassis and marking it from the rear.

Next, mount on the chassis the capacitors and any other parts with shafts extending to the panel, and measure accurately the height of the center of each shaft above the chassis, as illustrated in Fig. 18-3. The horizontal displacement of shafts having already been marked on the chassis line on the panel, the vertical displacement can be measured from this line. The shaft centers may now be marked on the back of the panel, and the holes drilled. Holes for any other panel equipment coming above the chassis line may then be marked and drilled, and the remainder of the apparatus mounted. Holes for terminals etc., in the rear edge of the chassis should be marked and drilled at the same time that they are done for the top.

Drilling and Cutting Holes

When drilling holes in metal with a hand drill it is important that the centers first be located with a center punch, so that the drill point will not "walk" away from the center when starting the hole. When the drill starts to break through, special care must be used. Often it is an advantage to shift a two-speed drill to low gear at this point. Holes more than 1/4-inch in diameter should be started with a smaller drill and reamed out with the larger drill.

The check on the usual type of hand drill is limited to 1/4-inch drills. Although it is rather tedious, the 1/4-inch hole may be filed out to larger diameters with round files. Another method possible with limited tools is to drill a series of small holes with the hand drill along the inside of the circumference of the large hole, placing the holes as close together as possible. The center may then be knocked out with a cold chisel and the edges smoothed up with a file. Taper reamers which fit into the carpenter's brace will make the job easier. A large rat-tail file clamped in the brace makes a very good reamer for holes up to the diameter of the file.

For socket holes and other large holes in an aluminum chassis, socket-hole punches should be used. They require first drilling a guide hole to pass the bolt that is turned to squeeze the punch through the chassis. The threads of the bolt should be oiled occasionally.

Large holes in steel panels or chassis are best cut with an adjustable circle cutter. Occasional application of machine oil in the cutting groove will help. The cutter first should be tried out on a block of wood, to make sure that it is set for the right diameter.

The burrs or rough edges which usually result after drilling or cutting holes may be removed with a file, or sometimes more conveniently with a sharp knife or chisel. It is a good idea to keep an old wood chisel sharpened and available for this purpose.

Rectangular Holes

Square or rectangular holes may be cut out by making a row of small holes as previously described, but is more easily done by drilling a 1/2-inch hole inside each corner, as illustrated in Fig. 18-4, and using these holes for starting and turning the hack saw. The socket-hole punch and the square punches which are now available also may be of considerable assistance in cutting out large rectangular openings.

SEMICONDUCTOR HEAT SINKS

Homemade heat sinks can be fashioned from brass, copper or aluminum stock by employing ordinary workshop tools. The dimensions of the heat sink will depend upon the type of transistor used, and the amount of heat that must be conducted away from the body of the semiconductor.

Fig. 18-5 shows the order of progression for forming a large heat sink from aluminum or brass

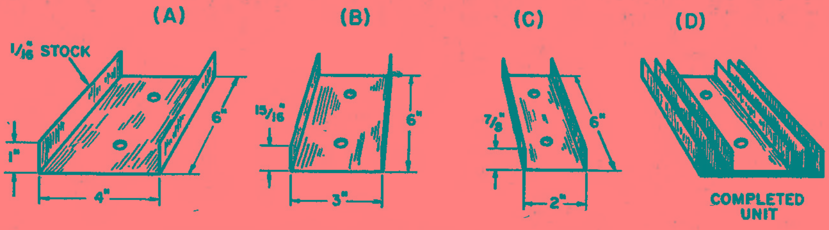


Fig. 18-5 — Details for forming channel type heat sinks.

channels of near-equal height and depth. The width is lessened in parts (B) and (C) so that each channel will fit into the preceding one as shown in the completed model at (D). The three pieces are bolted together with 8-32 screws and nuts. Dimensions given are for illustrative purposes only.

Heat sinks for smaller transistors can be fabricated as shown in Fig. 18-7. Select a drill bit that is one size smaller than the diameter of the transistor case and form the heat sink from 1/16 inch thick brass, copper or aluminum stock as shown in steps (A), (B), and (C). Form the stock around the drill bit by compressing it in a vise (A). The completed heat sink is press-fitted over the body of the semiconductor as illustrated at (D). The larger the area of the heat sink, the greater will be the amount of heat conducted away from the transistor body. In some applications, the heat sinks shown in Fig. 18-7 may be two or three inches in height (power transistor stages).

Another technique for making heat sinks for TO-5 type transistors (1) and larger models (1) is shown in Fig. 18-6. This style of heat sink will dissipate considerably more heat than will the type shown in Fig. 18-5. The main body of the sink is fashioned from a piece of 1/8-inch thick aluminum angle bracket – available from most hardware stores. A hole is bored in the angle stock to allow the transistor case to fit *snugly* into it. The transistor is held in place by a small metal plate whose center hole is slightly smaller in diameter than the case of the transistor. Details are given in Fig. 18-6.

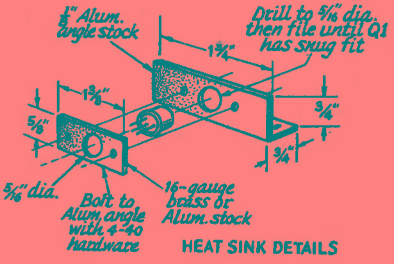
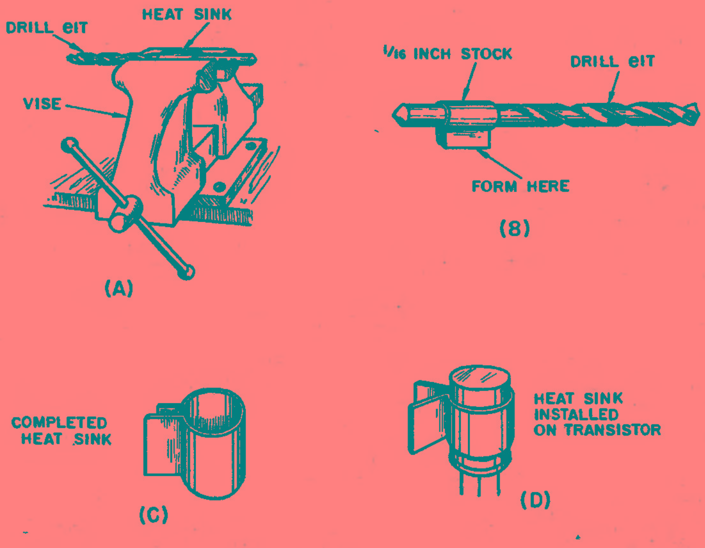


Fig. 18-6 — Layout and assembly details of another homemade heat sink. The completed assembly can be insulated from the main chassis of the transmitter by using insulating washers.

A thin coating of silicone grease, available from most electronics supply houses, can be applied between the case of the transistor and the part of the heat sink with which it comes in contact. The silicone grease will aid the transfer of heat from the transistor to the sink. This practice can be applied to all models shown here. In the example given in Fig. 18-5, the grease should be applied between the

Fig. 18-7 — Steps used in constructing heat sinks for small transistors.



three channels before they are bolted together, as well as between the transistor and the channel it contacts.

CONSTRUCTION NOTES

If a control shaft must be extended or insulated, a flexible shaft coupling with adequate insulation should be used. Satisfactory support for the shaft extension, as well as electrical contact for safety, can be provided by means of a metal panel bearing made for the purpose. These can be obtained singly for use with existing shafts, or they can be bought with a captive extension shaft included. In either case the panel bearing gives a "solid" feel to the control.

The use of fiber washers between ceramic insulation and metal brackets, screws or nuts will prevent the ceramic parts from breaking.

STANDARD METAL GAUGES

Gauge No.	*American or B&S*[1]	*U.S. Standard*[2]	*Birmingham or Stubs*[3]
1	.2893	.28125	.300
2	.2576	.265625	.284
3	.2294	.25	.259
4	.2043	.234375	.238
5	.1819	.21875	.220
6	.1620	.203125	.203
7	.1443	.1875	.180
8	.1285	.171875	.165
9	.1144	.15625	.148
10	.1019	.140625	.134
11	.09074	.125	.120
12	.08081	.109375	.109
13	.07196	.09375	.095
14	.06408	.078125	.083
15	.05707	.0703125	.072
16	.05082	.0625	.065
17	.04526	.05625	.058
18	.04030	.05	.049
19	.03589	.04375	.042
20	.03196	.0375	.035
21	.02846	.034375	.032
22	.02535	.03125	.028
23	.02257	.028125	.025
24	.02010	.025	.022
25	.01790	.021875	.020
26	.01594	.01875	.018
27	.01420	.0171875	.016
28	.01264	.015625	.014
29	.01126	.0140625	.013
30	.01003	.0125	.012
31	.008928	.0109375	.010
32	.007950	.01015625	.009
33	.007080	.009375	.008
34	.006350	.00859375	.007
35	.005615	.0078125	.005
36	.005000	.00703125	.004
37	.004453	.006640626	. . . .
38	.003965	.00625	. . . .
39	.003531	. . . .	. . . .
40	.003145	. . . .	. . . .

[1] Used for aluminum, copper, brass and non-ferrous alloy sheets, wire and rods.

[2] Used for iron, steel, nickel and ferrous alloy sheets, wire and rods.

[3] Used for seamless tubes; also by some manufacturers for copper and brass.

Cutting and Bending Sheet Metal

If a sheet of metal is too large to be cut conveniently with a hack saw, it may be marked with scratches as deep as possible along the line of the cut on both sides of the sheet and then clamped in a vise and worked back and forth until the sheet breaks at the line. Do not carry the bending too far until the break begins to weaken; otherwise the edge of the sheet may become bent. A pair of iron bars or pieces of heavy angle stock, as long or longer than the width of the sheet, to hold it in the vise, will make the job easier. "C" clamps may be used to keep the bars from spreading at the ends. The rough edges may be smoothed with a file or by placing a large piece of emery cloth or sandpaper on a flat surface and running the edge of the metal back and forth over the sheet. Bends may be made similarly.

Finishing Aluminum

Aluminum chassis, panels and parts may be given a sheen finish by treating them in a caustic bath. An enamelled or plastic container, such as a dishpan or infant's bathtub, should be used for the solution. Dissolve ordinary household lye in cold water in a proportion of 1/4 to 1/2 can of lye per gallon of water. The stronger solution will do the job more rapidly. Stir the solution with a stick of wood until the lye crystals are completely dissolved. Be very careful to avoid any skin contact with the solution. It is also harmful to clothing. Sufficient solution should be prepared to cover the piece completely. When the aluminum is immersed, a very pronounced bubbling takes place and ventilation should be provided to disperse the escaping gas. A half hour to two hours in the solution should be sufficient, depending upon the strength of the solution and the desired surface.

Remove the aluminum from the solution with sticks and rinse thoroughly in cold water while swabbing with a rag to remove the black deposit. When dry, finish by spraying on a light coat of clear lacquer.

Soldering

The secret of good soldering is to use the right amount of heat. Too little heat will produce a "cold-soldered joint"; too much may injure a component. The iron and the solder should be applied simultaneously to the joint. Keep the iron clean by brushing the hot tip with a paper towel. Always use rosin-core solder, never acid-core. Solders have different melting points, depending upon the ratio of tin to lead. A 50-50 solder melts at 425 degrees F, while 60-40 melts at 371 degrees F. When it is desirable to protect from excessive heat the components being soldered, the 60-40 solder is preferable to the 50-50. (A less-common solder, 63-37, melts at 361 degrees F.)

When soldering transistors, crystal diodes or small resistors, the lead should be gripped with a pair of pliers up close to the unit so that the heat will be conducted away. Overheating of a transistor or diode while soldering can cause permanent damage. Also, mechanical stress will have a similar effect, so that a small unit should be mounted so that there is no appreciable mechanical strain on the leads.

Trouble is sometimes experienced in soldering to the pins of coil forms or male cable plugs. It helps if the pins are first cleaned on the inside with a suitable twist drill and then tinned by flowing rosin-core solder into them. Immediately clear the surplus solder from each hot pin by a whipping motion or by blowing through the pin from the inside of the form or plug. Before inserting the wire in the pin, file the nickel plate from the tip. After soldering, round the solder tip off with a file.

When soldering to the pins of polystyrene coil forms, hold the pin to be soldered with a pair of heavy pliers, to form a "heat sink" and insure that the pin does not heat enough in the coil form to loosen and become misaligned.

Wiring

The wire used in connecting amateur equipment should be selected considering both the maximum current it will be called upon to handle and the voltage its insulation must stand without breakdown. Also, from the consideration to TVI, the power wiring of all transmitters should be done with wire that has a braided shielding cover. Receiver and audio circuits may also require the use of shielded wire at some points for stability, or the elimination of hum.

No. 20 stranded wire is commonly used for most receiver wiring (except for the high-frequency circuits) where the current does not exceed 2 or 3 amperes. For higher-current heater circuits, No. 18 is available. Wire with cellulose acetate insulation is good for voltages up to about 500. For higher voltages, themoplastic-insulated wire should be used. Inexpensive wire strippers that make the removal of insulation from hookup wire an easy job are available on the market.

When power leads have several branches in the chassis, it is convenient to use fiber-insulated multiple tie points as anchorages or junction points. Strips of this type are also useful as insulated supports for resistors, rf chokes and capacitors. High-voltage wiring should have exposed points held to a minimum; those which cannot be avoided should be made as inaccessible as possible to accidental contact or short-circuit.

Where shielded wire is called for and capacitance to ground is not a factor, Belden type 8885 shielded grid wire may be used. If capacitance must be minimized, it may be necessary to use a piece of car-radio low-capacitance lead-in wire, or coaxial cable.

For wiring high-frequency circuits, rigid wire is often used. Bare soft-drawn tinned wire, size 22 to 12 (depending on mechanical requirements) is suitable. Kinks can be removed by stretching a piece of 10 or 15 feet long and then cutting into short lengths that can be handled conveniently. Rf wiring should be run directly from point to point with a minimum of sharp bends and the wire kept well spaced from the chassis or other grounded metal surfaces. Where the wiring must pass through the chassis or a partition, a clearance hole should be cut and lined with a rubber grommet. In case insulation becomes necessary, varnished cambric tubing (spaghetti) can be slipped over the wire.

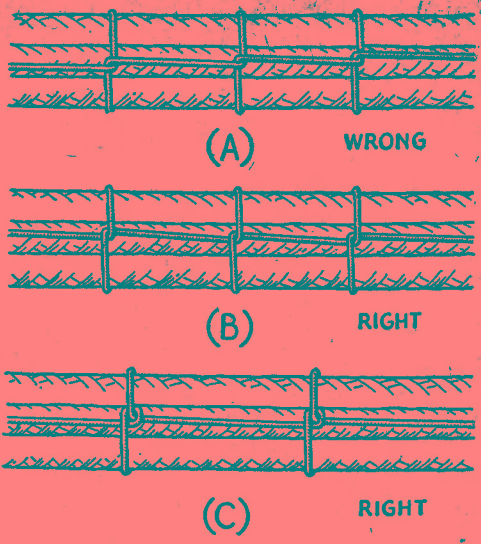


Fig. 18-8 — Methods of lacing cables. The method shown at C is more secure, but takes more time than the method of B. The letter is usually adequate for most amateur requiremants.

In transmitters where the peak voltage does not exceed 2500 volts, the shielded grid wire mentioned above should be satisfactory for power circuits. For higher voltages, Belden type 8656, Birnbach type 1820, or shielded ignition cable can be used. In the case of filament circuits carrying heavy current, it may be necessary to use No. 10 or 12 bare or enameled wire, slipped through spaghetti, and then covered with copper braid pulled tightly over the spaghetti. The chapter on TVI shows the manner in which shielded wire should be applied. If the shielding is simply slid back over the insulation and solder flowed into the end of the braid, the braid usually will stay in place without the necessity for cutting it back or binding it in place. The braid should be cleaned first so that solder will take with a minimun of heat.

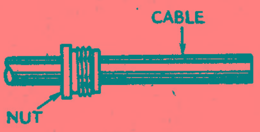
Rf wiring in transmitters usually follows the method described above for receivers with due respect to the voltages involved.

Where power or control leads run together for more than a few inches, they will present a better appearance when bound together in a single cable. The correct technique is illustrated in Fig. 18-8; both plastic and waxed-linen lacing cords are available. Plastic cable clamps are available to hold the laced cable.

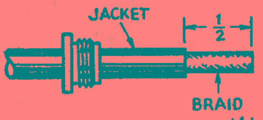
To give a "commercial look" to the wiring of any unit, run any cabled leads along the edge of the chassis. If this isn't possible, the cabled leads should then run parallel to an edge of the chassis. Further, the generous use of tie points (mounted parallel to an edge of the chassis), for the support of one or both ends of a resistor or fixed capacitor,

BNC Connectors

1.—Cut end of cable even.



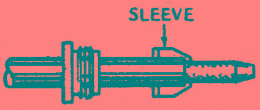
2.—Remove vinyl jacket ½"—*don't nick braid.*



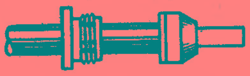
3.—Push braid back and remove ⅛" of insulation and conductor.

4.—Taper braid.

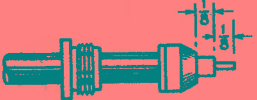
5.—Slide sleeve over tapered braid. Fit inner shoulder or sleeve squarely against end of jacket.



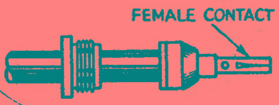
6.—With sleeve in place, comb out braid, fold back smooth as shown, and trim 3⁄32".



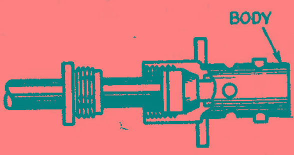
7.—Bare center conductor ⅛"—*don't nick conductor.*



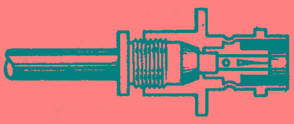
8.—Tin center conductor of cable. Slip female contact in place and solder. Remove excess solder. *Be sure cable dielectric is not heated excessively and swollen so as to prevent dielectric entering body.*



9.—Push into body as far as it will go. Slide nut into body and screw into place, with wrench, until it is moderately tight. Hold cable and shell rigidly and rotate nut.



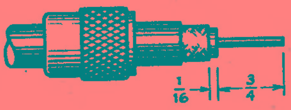
10.—This assembly procedure applies to BNC jacks. The assembly for plugs is the same except for the use of male contacts and a plug body.



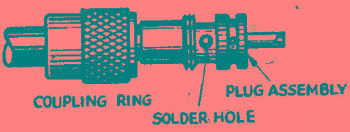
83-1SP Plug

1.—Cut end of cable even. Remove vinyl jacket 1⅛"—*don't nick braid.*

2.—Bare ¾" of center conductor—*don't nick conductor.* Trim braided shield 1⁄16" and tin. Slide coupling ring on cable.

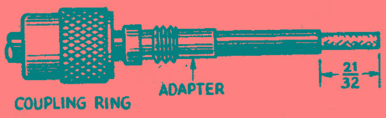


3.—Screw the plug assembly on cable. Solder plug assembly to braid through solder holes. Solder conductor to contact sleeve.

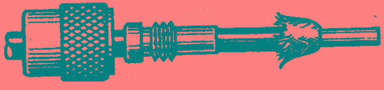


4.—Screw coupling ring on assembly.

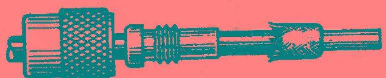
83-1SP Plug with Adapters



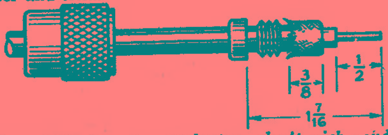
1.—Cut end of cable even. Remove vinyl jacket 21⁄32"—*don't nick braid.* Slide coupling ring and adapter on cable.



2.—Fan braid slightly and fold back over cable.



3.—Compress braid around cable. Position adapter to dimension shown. Press braid down over body of adapter to dimension shown. Press braid down over body of adapter and trim.



4.—Bare ½" of center conductor—*don't nick conductor.* Pre-tin exposed center conductor.

5, 6.—Same as 3 and 4 under 83-1SP Plug.

Fig. 18-9 — Cable-stripping dimensions and assembly instructions for several popular coaxial-cable plugs. This material courtesy Amphenol Connector Division, Amphenol-Borg Electronics Corp.

will add to the appearance of the finished unit. In a similar manner, "dress" the small components so that they are parallel to the panel or sides of the chassis.

Winding Coils

Close-wound coils are readily wound on the specified form by anchoring one end of a length of wire (in a vise or to a doorknob) and the other end to the coil form. Straighten any kinks in the wire and then pull to keep the wire under slight tension. Wind the coil to the required number of turns while walking toward the anchor, always maintaining a slight tension on the wire.

To space-wind the coil, wind the coil simultaneously with a suitable spacing medium (heavy thread, string or wire) in the manner described above. When the winding is complete, secure the end of the coil to the coil-form terminal and then carefully unwind the spacing material. If the coil is wound under suitable tension, the spacing material can be easily removed without disturbing the winding. Finish the space-wound coil by judicious applications of Duco cement, to hold the turns in place.

The "cold" end of a coil is the end at or close to chassis or ground potential. Coupling links should be wound on the cold end of a coil, to minimize capacitive coupling.

CIRCUIT-BOARD FABRICATION

Many modern-day builders prefer the neatness and miniaturization made possible by the use of etched or printed circuit boards. There are additional benefits to be realized from the use of circuit boards: Low lead inductances, excellent physical stability of the components and interconnecting leads, and good repeatability of the basic layout of a given project. The latter attribute makes the use of circuit boards ideal for group projects.

Methods

Perhaps the least complicated approach to circuit-board fabrication is the use of unclad perforated board into which a number of push-in terminals have been installed. The perforated board can be obtained with one of many hole patterns, dependent upon the needs of the builder. Perforated terminal boards are manufactured by such firms as Vector, Kepro, and Triad. Their products are available from the large mail-order houses.

Once the builder plots the layout of his circuit on paper, push-in terminals can be installed in the "perf" board to match the layout which was done on paper. The terminals serve as tie points and provide secure mounting-post anchors for the various components. Selected terminals can be wired together to provide ground and B-plus lines. Although this technique is the most basic of the methods, it is entirely practical.

An approach to etched-circuit board assembly can be realized by cutting strips of flashing copper, hobby copper, or brass shim stock into the desired shapes and lengths, then gluing them to a piece of unclad circuit board. Epoxy cement is useful for the latter. Alternatively, the strips can be held in place by means of brass eyelets which have been installed with a hand eyelet tool. If standard unclad circuit board is not handy, linoleum or Formica sheeting can be made to serve as a base for the circuit board. If this technique is used, the metal strips should be soldered together at each point where they join, assuring good electrical contact.

Etched-circuit boards provide the most professional end result of the three systems described here. They are the most stable, physically and electrically, and can be easily repeated from a single template. Etched-circuits can be formed on copper-clad perforated board, or on unpunched copper-clad board. There is no advantage in using the perforated board as a base unless push-in terminals are to be used.

Planning and Layout

The constructor should first plan the physical layout of the circuit by sketching a pictorial diagram on paper, drawing it to scale. Once this has been done, the interconnecting leads can be inked in to represent the copper strips that will remain on the etched board. The Vector Company sells layout paper for this purpose. It is marked with the same patterns that are used on their perforated boards.

After the basic etched-circuit design has been completed the designer should go over the proposed layout several times to insure against errors. When the foregoing has been done, the pattern can be painted on the copper surface of the board to be etched. Etch-resistant solutions are available from commercial suppliers and can be selected from their catalogs. Some builders prefer to use India ink for this purpose. Perhaps the most readily-available material for use in etch-resist applications is ordinary exterior enamel paint. The portions of the board to be retained are covered with a layer of paint, applied with an artist's brush, duplicating the pattern that was drawn on the layout paper. The job can be made a bit easier by tracing over the original layout with a ballpoint pen and carbon paper while the pattern is taped to the copper side of the unetched circuit board. The carbon paper is placed between the pattern and the circuit board. After the paint has been applied, it should be allowed to dry for at least 24 hours prior to the etching process. The Vector Company produces a rub-on transfer material that can also be used as etch-resist when laying out circuit-board patterns. Thin strips of ordinary masking tape, cut to size and firmly applied, serve nicely as etch-resist material too.

The Etching Process

Almost any strong acid bath will serve as an etchant, but the two chemical preparations recommended here are the safest to use. A bath can be prepared by mixing 1 part ammonium persulphate crystals with 2 parts clear water. A

Fig. 18-10 — A homemade stand for processing etched-circuit boards. The heat lamp maintains the etchant-bath temperature between 90 and 115 degrees, F. and is mounted on an adjustable arm. The tray for the beth is raised and lowered at one end by the ection of a motor-driven eccentric disk, providing the necessary agitation of the chemical solution. A darkroom thermometer monitors the temperature of the bath.

normal quantity of working solution for most amateur radio applications is composed of 1 cup of crystals and 2 cups of water. To this mixture add 1/4 teaspoon of mercuric chloride crystals. The latter serves as an activator for the bath. Ready-made etchant kits which use these chemicals are available from Vector. A two-bag kit is sold as item 2594 and costs just over $1. Complete kits which contain circuit boards, etchant powders, etch-resist transfers, layout paper, and plastic etchant bags are also available from Vector at moderate prices.

Another chemical bath that works satisfactorily for copper etching is made up from one part ferric chloride crystals and 2 parts water. No activator is required with this bath. Ready-made solutions (one-pint and one-gallon sizes) are available through some mail-order houses at low cost. They are manufactured by Kepro Co. and carry a stock number of E-1PT and E-1G, respectively. One pint costs less than a dollar.

Etchant solutions become exhausted after a certain amount of copper has been processed, therefore it is wise to keep a quantity of the bath on hand if frequent use is anticipated. With either chemical bath, the working solution should be maintained at a temperature between 90 and 115 degrees F. A heat lamp can be directed toward the bath during the etching period, its distance set to maintain the required temperature. A darkroom thermometer is handy for monitoring the temperature of the bath.

While the circuit board is immersed in the solution, it should be agitated continuously to permit uniform reaction to the chemicals. This action will also speed up the etching process somewhat. Normally, the circuit board should be placed in the bath with the copper side facing down, toward the bottom of the tray. The tray should be non-metallic, preferably a Pyrex dish or a photographic darkroom tray.

The photograph, Fig. 18-10, shows a homemade etching stand made up from a heat lamp, some lumber, and an 8 rpm motor. An eccentric disk has been mounted on the motor shaft and butts against the bottom of the etchant tray. As the motor turns, the eccentric disk raises and lowers one end of the try, thus providing continuous agitation of the solution. The heat lamp is mounted on an adjustable, slotted wooden arm. Its height above the solution tray is adjusted to provide the desired bath temperature. Because the etching process takes between 15 minutes and one hour —dependent upon the strength and temperature of the bath — such an accessory is convenient.

After the etching process is completed, the board is removed from the tray and washed thoroughly with fresh, clear water. The etch-resist material can then be rubbed off by applying a few brisk strokes with medium-grade steel wool. WARNING: *Always use rubber gloves when working with etchant powders and solutions. Should the acid bath come in contact with the body, immediately wash the affected area with clear water. Protect the eyes when using acid baths.*

COMPONENT VALUES

Values of composition resistors and small capacitors (mica and ceramic) are specified throughout this *Handbook* in terms of "preferred values." In the preferred-number system, all values represent (approximately) a constant-percentage increase over the next lower value. The base of the system is the number 10. Only two significant figures are used.

"Tolerance" means that a variation of plus or minus the percentage given is considered satisfactory. For example, the actual resistance of a "4700-ohm" 20-percent resistor can lie anywhere between 3700 and 5600 ohms, approximately. The permissible variation in the same resistance value with 5-percent tolerance would be in the range from 4500 to 4900 ohms, approximately.

In the component specifications in this *Handbook*, it is to be understood that when no tolerance is specified the *largest* tolerance available in that value will be satisfactory.

Values that do not fit into the preferred-number system (such as 500, 25,000) easily can be substituted. It is obvious, for example, that a 5000-ohm resistor falls well within the tolerance range of the 4700-ohm 20-percent resistor used in the example above. It would not, however, be usable if the tolerance were specified as 5 percent.

TABLE 18-II

Approximate Series-Resonance Frequencies of Disc Ceramic Bypass Capacitors

Capacitance	*Freq.*[1]	*Freq.*[2]
.01 µF	13 MHz	15 MHz
.0047	18	22
.002	31	38
.001	46	55
.0005	65	80
.0001	135	165

[1] Total lead length of 1 inch
[2] Total lead length of 1/2-inch

COLOR CODES

Standardized color codes are used to mark values on small components such as composition resistors and mica capacitors, and to identify leads from transformers, etc. The resistor-capacitor number color code is given in Table 18-III.

Fixed Capacitors

The methods of marking "postage-stamp" mica capacitors, molded paper capacitors and tubular ceramic capacitors are shown in Fig. 18-11.

Capacitors made to American War Standards or Joint Army-Navy specifications are marked with the 6-dot code shown at the top. Practically all surplus capacitors are in this category.

The 3-dot EIA code is used for capacitors having a rating of 500 volts and ±20 percent tolerance only; other ratings and tolerances are covered by the 6-dot EIA code.

Example: A capacitor with a 6-dot code has the following markings: Top row, left to right, black, yellow, violet; bottom row, right to left, brown, silver, red. Since the first color in the top row is black (significant figure zero) this is the AWS code and the capacitor has mica dielectric. The significant figures are 4 and 7, the decimal multiplier 10 (brown, at right of second row), so the capacitance is 470 pF. The tolerance is ±0%. The final color, the characteristic, deals with temperature coefficients and methods of testing (see Table 18-V).

A capacitor with a 3-dot code has the following colors, left to right: brown, black, red. The significant figures are 1, 0 (10) and the multiplier is 100. The capacitance is therefore 100 pF.

A capacitor with a 6-dot code has the following markings: Top row, left to right, brown, black, bisck; bottom row, right to left, black, gold, blue. Since the first color in the top row is neither black nor silver, this is the EIA code. The significant figures are 1, 0, 0 (100) and the decimal multiplier is 1 (black). The capacitance is therefore 100 pF. The gold dot shows that the tolerance is ±5% and the blue dot indicates 600-volt rating.

Ceramic Capacitors

Conventional markings for ceramic capacitors are shown in the lower drawing of Fig. 18-11. The colors have the meanings indicated in Table 18-III. In practice, dots may be used instead of the *narrow* bands indicated in Fig. 18-11.

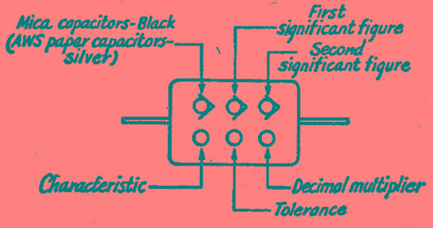
Example: A ceramic capacitor has the following markings: Broad band, violet; narrow bands or dots, green, brown, black, green. The significant figures are 5, 1 (51) and the decimal multiplier is 1, so the capacitance is 51 pF. The temperature coefficient is −750 parts per million per degree C., as given by the broad band, the capacitance tolerance is ±5%.

Fixed Composition Resistors

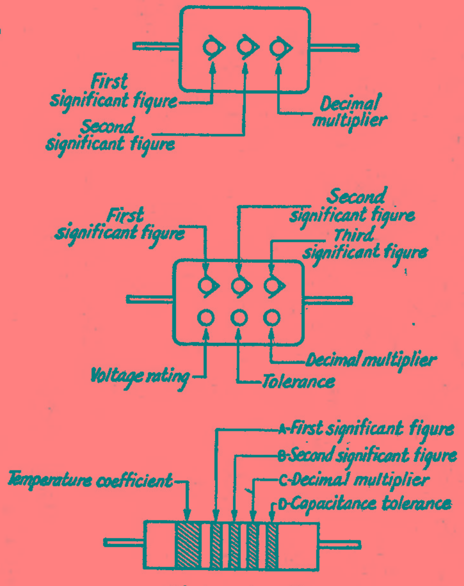
Composition resistors (including small wire-wound units molded in cases identical with the composition type) are color-coded as shown in Fig. 18-12. Colored bands are used on resistors having axial leads; on radial-lead resistors the colors are placed as shown in the drawing. When bands are used for color coding the body color has no significance.

Examples: A resistor of the type shown in the lower drawing of Fig. 18-12 has the following color bands: A, red; B, red; C, orange; D, no color. The significant figures are 2, 2 (22) and the decimal multiplier is 1000. The value of resistance is therefore 22,000 ohms and the tolerance is ±20%.

A resistor of the type shown in the upper drawing has the following colors: body (A), blue; end (B), gray; dot, red; end (D), gold. The significant figures are 6, 8 (68) and the decimal multiplier is 100, so the resistance is 6800 ohms. The tolerance is ± 5%.



AWS and JAN fixed capacitors



Fixed ceramic capacitors

Fig. 18-11 — Color coding of fixed mica, molded paper and tubular ceramic capacitors. The color code for mica and molded paper capacitors is given in Table 18-III. Table 18-IV gives the color code for tubular ceramic capacitors.

TABLE 18-III

Resistor-Capacitor Color Code

Color	Significant Figure	Decimal Multiplier	Tolerance (%)	Voltage Rating*
Black	0	1	–	–
Brown	1	10	1*	100
Red	2	100	2*	200
Orange	3	1,000	3*	300
Yellow	4	10,000	4*	400
Green	5	100,000	5*	500
Blue	6	1,000,000	6*	600
Violet	7	10,000,000	7*	700
Gray	8	100,000,000	8*	800
White	9	1,000,000,000	9*	900
Gold	–	0.1	5	1000
Silver	–	0.01	10	2000
No color	–		20	500

* Applies to capacitors only.

TABLE 18-IV

Color Code for Ceramic Capacitors

Color	Significant Figure	Decimal Multiplier	Capacitance Tolerance More than 10 pF (in %)	Capacitance Tolerance Less than 10 pF (in pF)	Temp. Coeff. ppm /deg. C.
Black	0	1	±20	2.0	0
Brown	1	10	± 1		– 30
Red	2	100	± 2		– 80
Orange	3	1000			–150
Yellow	4				–220
Green	5				–330
Blue	6		± 5	0.5	–470
Violet	7				–750
Gray	8	0.01		0.25	30
White	9	0.1	±10	1.0	500

TABLE 18-V

Capacitor Characteristic Code

Color Sixth Dot	Temperature Coefficient ppm/deg. C.	Capacitance Drift
Black	±1000	±5% +1 pF
Brown	±500	±3% +1 pF
Red	±200	±0.5%
Orange	±100	±0.3%
Yellow	–20 to +100	±0.1% +0.1 pF
Green	0 to +70	±0.05% +0.1 pF

I-f Transformers

Blue – plate lead.
Red – "B" + lead.
Green – grid (or diode) lead.
Black – grid (or diode) return.

NOTE: If the secondary of the i-f transformer is center-tapped, the second diode plate lead is green-and-black striped, and black is used for the center-tap lead.

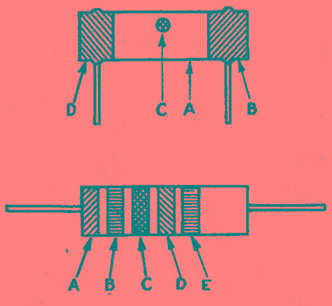
Audio Transformers

Blue – plate (finish) lead of primary.
Red – "B" + lead (this applies whether the primary is plain or center-tapped).
Brown – plate (start) lead on center-tapped primaries. (Blue may be used for this lead if polarity is not important.)
Green – grid (finish) lead to secondary.
Black – grid return (this applies whether the secondary is plain or center-tapped).
Yellow – grid (start) lead on center-tapped secondaries. (Green may be used for this lead if polarity is not important.)

NOTE: These markings apply also to line-to-grid and tube-to-line transformers.

Power Transformers

1) Primary Leads . . . . *Black*
   If tapped:
      Common . . . . *Black*
      Tap . . . . *Black and Yellow Striped*
      Finish . . . . *Black and Red Striped*
2) High-Voltage Place Winding . . . . *Red*
      Center-Tap . . . . *Red and Yellow Striped*
3) Rectifier Filament Winding . . . . *Yellow*
      Center-Tap . . . . . . *Yellow and Blue Striped*
4) Filament Winding No. 1 . . . . *Green*
      Center-Tap . . . . . *Green and Yellow Striped*
5) Filament Winding No. 2 . . . . *Brown*
      Center-Tap . . . . . *Brown and Yellow Striped*
6) Filament Winding No. 3 . . . . *Slate*
      Center-Tap . . . . . . *Slate and Yellow Striped*



Fixed composition resistors

Fig. 18-12 – Color coding of fixed composition resistors. The color code is given in Table 18-III. The colored areas have the following significance:
A – First significant figure of resistance in ohms.
B – Second significant figure.
C – Decimal multiplier.
D – Resistance tolerance in percent. If no color is shown the tolerance is ±20 percent.
E – Relative percent change in value per 1000 hours of operation; Brown, 1 percent; Red, 0.1 percent; Orange, .01 percent; Yellow, .001 percent.

TABLE 18-VI

Color Code for Hookup Wire

Wire Color	Type of Circuit
Black	Grounds, grounded elements, and returns
Brown	Heaters or filaments, off ground
Red	Power supply B plus
Orange	Screen grids and Base 2 of transistors
Yellow	Cathodes and transistor emitters
Green	Control grids, diode plates, and Base 1 of transistors
Blue	Plates and transistor collectors
Violet	Power supply, minus leads
Gray	Ac power line leads
White	Bias supply, B or C minus, agc

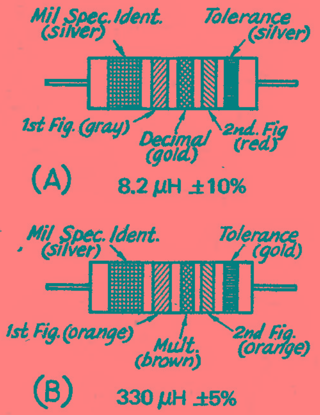
Wires with tracers are coded in the same manner as solid-color wires, allowing additional circuit identification over solid-color wiring. The body of the wire is white and the color band spirals around the wire lead. When more than one color band is used, the widest band represents the 1st color.

TABLE 18-VII

Metric Multiplier Prefixes

Multiples and submultiples of fundamental units (e.g., ampere, farad, gram, meter, watt)) may be indicated by the following prefixes.

Prefix	Abbreviation	Multiplier
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}



◀ Fig. 18-13 — Color coding for tubular ancapsulated rf chokes. At A, an exampla of tha coding for an 8.2-μH choke is given. At 8, the color bands for a 330-μH inductor are illustrated.

Color	Figure	Multiplier	Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1000	
Yellow	4		
Green	5		
Blue	6		
Violet	7		
Gray	8		
White	9		
None			20%
Silver			10%
Gold			5%

Multiplier is the factor by which the two color figures are multiplied to obtain the inductance value of the choke coil.

PILOT-LAMP DATA

Lamp No.	Bead Color	Base (Miniature)	Bulb Type	RATING Volts	Amp.
40	Brown	Screw	T-3 1/4	6–8	0.15
40A[1]	Brown	Bayonet	T-3 1/4	6–8	0.15
41	White	Screw	T-3 1/4	2.5	0.5
42	Green	Screw	T-3 1/4	3.2	**
43	White	Bayonet	T-3 1/4	2.5	0.5
44	Blue	Bayonet	T-3 1/4	6–8	0.25
45	*	Bayonet	T-3 1/4	3.2	**
46[2]	Blue	Screw	T-3 1/4	6–8	0.25
47[1]	Brown	Bayonet	T-3 1/4	6–9	0.15
48	Pink	Screw	T-3 1/4	2.0	0.06
49[3]	Pink	Bayonet	T-3 1/4	2.0	0.06
49A[3]	White	Bayonet	T-3 1/4	2.1	0.12
50	White	Screw	G-3 1/2	6–8	0.2
51[2]	White	Bayonet	G-3 1/2	6–8	0.2
53	—	Bayonet	G-3 1/2	14.4	0.12
55	White	Bayonet	G-4 1/2	6–8	0.4
292[5]	White	Screw	T-3 1/4	2.9	0.17
292A[5]	White	Bayonet	T-3 1/4	2.9	0.17
1455	Brown	Screw	G-5	18.0	0.25
1455A	Brown	Bayonet	G-5	18.0	0.25
1487	—	Screw	T-3 1/4	12–16	0.20
1488	—	Bayonet	T-3 1/4	14	0.15
1813	—	Bayonet	T-3 1/4	14.4	0.10
1815	—	Bayonet	T-3 1/4	12–16	0.20

[1] 40A and 47 are interchangeable.

[2] Have frosted bulbs.

[3] 49 and 49A are interchangeable.

[4] Replace with No. 48.

[5] Use in 2.5-volt sets where regular bulb burns out too frequently.

* White in G.E. and Sylvania; green in National Union, Raytheon and Tung-Sol.

** 0.35 in G.E. and Sylvania; 0.5 in National Union, Raytheon and Tung-Sol.

Finding Parts

No chapter on construction would be complete without information on where to buy parts. Amateurs, on a dwarfed scale, must function as purchasing agents in these perplexing times. A properly equipped buyer maintains as complete a catalog file as possible. Many of the companies listed in Chart I will provide free catalogs upon written request. Others may charge a small fee for catalogs. Mail ordering, especially for those distant from metropolitan areas, is today's means to the desired end when collecting component parts for an amateur project. Prices are, to some extent, competitive. A wise buyer will study the catalogs and select his merchandise accordingly.

Delays in shipment can be lessened by avoiding the use of personal checks when ordering. Bank or postal money orders are preferred by most distributors. Personal checks often take a week to clear, thereby causing frustrating delays in the order reaching you.

FRACTIONS OF AN INCH WITH METRIC EQUIVALENTS

Fractions of an inch	*Decimals of an inch*	*Millimeters*	*Fractions of an inch*	*Decimals of an inch*	*Millimeters*
1/64	0.0156	0.397	33/64	0.5156	13.097
1/32	0.0313	0.794	17/32	0.5313	13.494
3/64	0.0469	1.191	35/64	0.5469	13.891
1/16	0.0625	1.588	9/16	0.5625	14.288
5/64	0.0781	1.984	37/64	0.5781	14.684
3/32	0.0938	2.381	19/32	0.5938	15.081
7/64	0.1094	2.778	39/64	0.6094	15.478
1/8	0.1250	3.175	5/8	0.6250	15.875
9/64	0.1406	3.572	41/64	0.6406	16.272
5/32	0.1563	3.969	21/32	0.6563	16.669
11/64	0.1719	4.366	43/64	0.6719	17.066
3/16	0.1875	4.763	11/16	0.6875	17.463
13/64	0.2031	5.159	45/64	0.7031	17.859
7/32	0.2188	5.556	23/32	0.7188	18.256
15/64	0.2344	5.953	47/64	0.7344	18.653
1/4	0.2500	6.350	3/4	0.7500	19.050
17/64	0.2656	6.747	49/64	0.7656	19.447
9/32	0.2813	7.144	25/32	0.7813	19.844
19/64	0.2969	7.541	51/64	0.7969	20.241
5/16	0.3125	7.938	13/16	0.8125	20.638
21/64	0.3281	8.334	53/64	0.8281	21.034
11/32	0.3438	8.731	27/32	0.8438	21.431
23/64	0.3594	9.128	55/64	0.8594	21.828
3/8	0.3750	9.525	7/8	0.8750	22.225
25/64	0.3906	9.922	57/64	0.8906	22.622
13/32	0.4063	10.319	29/32	0.9063	23.019
27/64	0.4219	10.716	59/64	0.9219	23.416
7/16	0.4375	11.113	15/16	0.9375	23.813
29/64	0.4531	11.509	61/64	0.9531	24.209
15/32	0.4688	11.906	31/32	0.9688	24.606
31/64	0.4844	12.303	63/64	0.9844	25.003
1/2	0.5000	12.700	—	1.0000	25.400

Chart 1

L * $1 ** $10	Allied Electronics 2400 W. Washington Blvd. Chicago, IL 60612
H	All Star Products, Inc. PO Box 487 Defiance, OH 43512
L * free **	Amateur Electronic Supply 4828 W. Fond du Lac Ave. Milwaukee, WI 53216
B * free ** none	Amidon Associates 12033 Otsego Street N. Hollywood, CA 91607
L * free **	AM Tech PO Box 624 Marion, OH 52302
M, N * free **	Andy Electronics 6427 Springer Houston, TX 77017
M, N * sase ** none L	Associated Comtronics PO Box 200 Port Jefferson Station L.I., NY 11776
O * free ** none	Atlantic Surplus Sales 580 Third Avenue Brooklyn, NY 11215
B * free ** none	Barken Electronics 274 Mt. Pleasant Ave. Livingston, NJ 07039
A * free **	Barker & Williamson, Inc. Canal St. Bristol, PA 19007
L, M, N ** 50¢ * $5	Barry Electronics 512 Broadway New York, NY 10012
M, N * free ** $10	Budget Electronics 2704 West Nortb Avenue Chicago, IL 60647
L, M, N * free ** $5	Burstein-Applebee 3199 Mercier Street Kansas City, MO 64111
L,A * free **	Cambridge Tbermionic Corp. 445 Concord Ave. Cambridge, MA 02138
C, P * free ** none	Circuit Board Specialists 3011 Norwich Ave. Pueblo, CO 81008
A, E * free ** none	Circuit Specialists Co. PO Box 3047 Scottsdale, AZ 85257
J,M * free **	Theodore E. Dames Co. 308 Hickory St. Arlington, NJ 07032
I, M, N * free ** $3	Delta Electronics Co. PO Box 1 Lynn, MA 01903
L * free ** none	Dominion Radio & Elect. Co. 535 Yonge St. Toronto, Ontario, CANADA
L * free **	Electronics Distributors, Inc. 1960 Peck Street Muskegon, MI 49441
L * free ** $5	Electro-Sonic Supply 543 Yonge St. Toronto, Ontario, CANADA
A, C, E * free ** $5	Environmental Products Box 1014 Glenwood Springs, CO 81601
B, J * free ** none	E. S. Electronic Labs Box 434 Excelsior Springs, MO 64024
M, N * free **	Fair Radio Sales Box 1105 Lima, OH 45902
P * free **	Gregory Electronics Corp. 249 Rte. 46 Saddle Brook, NJ 07662
A,H,O * free ** none	HAL Devices Box 365 Urbana, IL 61801
L * free **	Ham Radio Center 8342 Olive Blvd. St. Louis, MO 63132
I K * free ** $10	Hammond Transformer 394 Edinburgh Rd. N. Guelph, Ontario, CANADA
	U.S. Distributor for Hammond: Genesee Radio Co. 2550 Delaware Ave. Buffalo, NY 14216
L * none **	Harrison Radio 20 Smith Street Farmingdale, L.I., NY 11735
M, N * free ** none	Hazelton Scientific Co. Box 163 Hazel Park, MI 48030
A * free **	Heath Co. Benton Harbor, MI 49022
L * none **	Henry Radio 11240 W. Olympic Blvd. Los Angeles, CA 92801
L * free **	Hobby Industries Box 864 Council Bluffs, IA 51501
D * free ** $5	International Crystal Co. 10 N. Lee Street Oklahoma City, OK 73102
D * free **	JAN Crystals 2400 Crystal Drive Ft. Myers, FL 33901
A, M, N * 25¢ ** $2	Jeff-Tronics 4252 Pearl Road Cleveland, OH 44109
C * free ** none	Kepro Circuit Systems; 3630 Scarlet Oak St. St. Louis, MO 63122
F * free ** $10	Kirk Electronics Division Electrotec Corp. 400 Town St. East Haddam, CT 06423
L * free ** none	Lafayette Radio Elect 111Jericho Tpk. Syosset, L.I., NY 11791 (Sae local phone directory)
M, N * free ** $5	John Meshna, Jr. Box 62 E. Lynn, MA 01904
J * free **	MFJ Enterprises PO Box 494 Mississippi State, MS 39762
A, G, H * free ** $5	James Millen Mfg. Co. 150 Exchange Street Malden, MA 02148
A, G, L * free **	J. W. Miller Company 19070 Reyes Avenue Compton, CA 90224
A, F, B * free ** none	N.E.E.E. P. O. Box 145 Wethersfield, CT 06109
N * free ** $5	Nurmi Electronic Supply 1727 Donna Rd. West Palm Beach, FL 33401
C	D.L. McClaren 19721 Maplewood Ave. Cleveland, OH 44135
F * free **	Payette Radio 730 ST-Jacques O. Montreal 101, Quebec, CANADA
A * free ** none	C. M. Peterson Co. Ltd. 575 Dundas St London, Ontario, CANADA
J * free **	Piezo Technology, Inc. Box 7877 Orlando, FL 32804
E, M * 15¢ ** none	Poly Paks Box 942 Lynnfield, MA 01940
M, N * free ** $2	Precision Systems PO Box 6, Murray Hill, NJ 07974
D * free ** none	Savoy Electronics, Inc Box 7127 Ft. Lauderdale, FL 33304
D * free ** none	Sentry Mfg. Co. Crystal Park Chickasha, OK 73108
F * free ** $10	Skylane Products 406 Bon Air Avenue Temple, Terrace, FL 33617
A, P * free ** none	Spectronics, Inc. 1009 Garfield Street Oak Park, IL 60304
J * free ** none	Spectrum International PO Box 1084 Concord, MA 01742
M, N * free ** $4	Star Tronics Box 17127 Portland, OR 97217
C	Charles R. Sempirek Route 3, Box 1 Bellaire, OH 43906
A * free ** none	Solid State Systems, Inc. 800 N. Providence Rd. Columbia, MO 65201
O	Teletype Corp., 5555 Touhy A. Skokie, IL 60076
K, A	Ten-Tec Inc. Highway 411, E. Sevierville, TN 37862
A, C, E * free ** none	Trigger Electronics 7361 North Ave. River Forest, IL 60305
O * sase ** none	Typetronics Box 8873 Ft. Lauderdale, FL 33310
E, M * free ** none	Weinschenker, K3DPJ Box 353 Irwin, PA 15642

Chart I Coding

A – New Components
B – Toroids and Ferrites
C – Etched-circuit board materials
D – Transmitting and receiving crystals
E – Solid-state devices
F – Antenna hardware
G – Dials and knobs
H – Variable capacitors
I – Transformers
J – I-f filters
K – Cabinet and boxes
L – All of above, general distributor
M – Surplus parts
N – Surplus assemblies
O – RTTY equipment and parts
P – Surplus fm gear and parts
* Catalog price
** Minimum billing

To the best of our knowledge, the suppliers shown in Chart I are willing to sell components to amateurs in small quantities by mail. This listing does not necessarily indicate that these firms have the approval of ARRL.

COPPER-WIRE TABLE

Wire Size A.W.G. (B&S)	Diam. in Mils[1]	Circular Mil Area	Turns per Linear Inch[2]			Cont.-duty current[3] single wire in open air	Cont.-duty current[3] wires or cables in conduits or bundles	Feet per Pound, Bare	Ohms per 1000 ft. 25° C.	Current Carrying Capacity[4] at 700 C.M. per Amp.	Diam. in mm.	Nearest British S.W.G. No.
			Enamel	S.C.E.	D.C.C.							
1	289.3	83690	—	—	—	—	—	3.947	.1264	119.6	7.348	1
2	257.6	66370	—	—	—	—	—	4.977	.1593	94.8	6.544	3
3	229.4	52640	—	—	—	—	—	6.276	.2009	75.2	5.827	4
4	204.3	41740	—	—	—	—	—	7.914	.2533	59.6	5.189	5
5	181.9	33100	—	—	—	—	—	9.980	.3195	47.3	4.621	7
6	162.0	26250	—	—	—	—	—	12.58	.4028	37.5	4.115	8
7	144.3	20820	—	—	—	—	—	15.87	.5080	29.7	3.665	9
8	128.5	16510	7.6	—	7.1	73	46	20.01	.6405	23.6	3.264	10
9	114.4	13090	8.6	—	7.8	—	—	25.23	.8077	18.7	2.906	11
10	101.9	10380	9.6	9.1	8.9	55	33	31.82	1.018	14.8	2.588	12
11	90.7	8234	10.7	—	9.8	—	—	40.12	1.284	11.8	2.305	13
12	80.8	6530	12.0	11.3	10.9	41	23	50.59	1.619	9.33	2.053	14
13	72.0	5178	13.5	—	12.8	—	—	63.80	2.042	7.40	1.828	15
14	64.1	4107	15.0	14.0	13.8	32	17	80.44	2.575	5.87	1.628	16
15	57.1	3257	16.8	—	14.7	—	—	101.4	3.247	4.65	1.450	17
16	50.8	2583	18.9	17.3	16.4	22	13	127.9	4.094	3.69	1.291	18
17	45.3	2048	21.2	—	18.1	—	—	161.3	5.163	2.93	1.150	18
18	40.3	1624	23.6	21.2	19.8	16	10	203.4	6.510	2.32	1.024	19
19	35.9	1288	26.4	—	21.8	—	—	256.5	8.210	1.84	.912	20
20	32.0	1022	29.4	25.8	23.8	11	7.5	323.4	10.35	1.46	.812	21
21	28.5	810	33.1	—	26.0	—	—	407.8	13.05	1.16	.723	22
22	25.3	642	37.0	31.3	30.0	—	5	514.2	16.46	.918	.644	23
23	22.6	510	41.3	—	37.6	—	—	648.4	20.76	.728	.573	24
24	20.1	404	46.3	37.6	35.6	—	—	817.7	26.17	.577	.511	25
25	17.9	320	51.7	—	38.6	—	—	1031	33.00	.458	.455	26
26	15.9	254	58.0	46.1	41.8	—	—	1300	41.62	.363	.405	27
27	14.2	202	64.9	—	45.0	—	—	1639	52.48	.288	.361	29
28	12.6	160	72.7	54.6	48.5	—	—	2067	66.17	.228	.321	30
29	11.3	127	81.6	—	51.8	—	—	2607	83.44	.181	.286	31
30	10.0	101	90.5	64.1	55.5	—	—	3287	105.2	.144	.255	33
31	8.9	80	101	—	59.2	—	—	4145	132.7	.114	.227	34
32	8.0	63	113	74.1	62.6	—	—	5227	167.3	.090	.202	36
33	7.1	50	127	—	66.3	—	—	6591	211.0	.072	.180	37
34	6.3	40	143	86.2	70.0	—	—	8310	266.0	.057	.160	38
35	5.6	32	158	—	73.5	—	—	10480	335	.045	.143	38-39
36	5.0	25	175	103.1	77.0	—	—	13210	423	.036	.127	39-40
37	4.5	20	198	—	80.3	—	—	16660	533	.028	.113	41
38	4.0	16	224	116.3	83.6	—	—	21010	673	.022	.101	42
39	3.5	12	248	—	86.6	—	—	26500	848	.018	.090	43
40	3.1	10	282	131.6	89.7	—	—	33410	1070	.014	.080	44

[1] A mil is .001 inch. [2] Figures given are approximate only; insulation thickness varies with manufacturer. [3] Max. wire temp. of 212° F and max. ambient temp. of 135° F. [4] 700 circular mils per ampere is a satisfactory design figure for small transformers, but values from 500 to 1000 c.m. are commonly used.

SEMICONDUCTOR DIODE COLOR CODE

The "1N" prefix is omitted. A double-width band, which also identifies the cathode terminal end of the diode, is usually used as the first band. (An alternative method uses equal band widths with the set clearly grouped toward the cathode end.) The code is read starting at the cathode end.

Diodes having two-digit numbers are coded with a black band followed by second and third bands. A suffix letter is indicated by a fourth band.

Diodes with three-digit numbers are coded with the sequence numbers in the first, second and third bands. Any suffix letter is indicated by a fourth band.

Diodes with four-digit numbers are coded by four bands followed by a black band. A suffix letter is indicated by a fifth band replacing the black band.

The color code (numbers) is the same as the resistor-capacitor code. The suffix-letter code is A—brown, B—red, C—orange, D—yellow, E—green, and F—blue.

Chapter 19

Wave Propagation

Though great advances have been made in recent years in understanding the many modes of propagation of radio waves, variables affecting communication over appreciable distances are very complex, and not entirely predictable. Amateur attempts to schedule operating time and frequencies for optimum results may not always succeed, but familiarity with the nature of radio propagation can certainly reduce the margin of failure and add greatly to one's enjoyment of the pursuit of any kind of DX.

The sun, ultimate source of life and energy on earth, dominates all radio communication beyond the local range. Conditions vary with such obvious sun-related earthly cycles as time of day and season of the year. Since these differ for appreciable changes in latitude and longitude, almost every communications circuit is unique in some respects. There are also short- and long-term solar cycles that influence propagation in less obvious ways. Furthermore, the state of the sun at a given moment is critical to long-distance communication, so it is understandable that propagation forecasting is still a rather inexact science.

With every part of the radio spectrum open to our use differing in its response to solar phenomena, amateurs have been, and still are, in a position to contribute to advancement of the art, both by accident and by careful investigation.

SOLAR PHENOMENA

Man's interest in the sun is older than recorded history. Sunspots were seen and discussed thousands of years ago, and they have been studied since Galileo observed them with the first telescope ever made. Records of sunspot observations translatable into modern terms go back nearly 300 years. Current observations are statistically "smoothed" to maintain a continuous record, in the form of the *Zurich Sunspot Number*, on which propagation predictions mentioned later are based.

A useful modern indication of overall solar activity is the *solar flux index*. Solar flux (noise) is measured on various frequencies in many places. A 2800-MHz measurement made several times daily in Ottawa is transmitted hourly by WWV. Because it is essentially current information, directly related to the sunspot number (see Fig. 19-1) and more immediately useful, it tends to displace the latter as a means of predicting propagation conditions.

SUNSPOT CYCLES

Even before their correlation with radio propagation variations was well-known, the periodic rise and fall of sunspot numbers had been studied for many years. These cycles average roughly 11 years in length, but have been as short as 9 and as long as 13 years. The highs and lows of the cycles also vary greatly. Cycle 19 peaked in 1958 with a sunspot number of over 200. Cycle 20, of nearer average intensity, reached 120 in 1969. By contrast, one of the lowest, Cycle 14, peaked at only 60 in 1907.[1] Several cycle lows have not reached zero levels on the Zurich scale for any appreciable period, while others have had several months of little or no activity.

Sunspot cycles should not be thought of as having sine-wave shape. There can be isolated highs during the normally low years. A remarkable example was a run of several days in October, 1974, only a few months from the approximate bottom of Cycle 20, when the solar flux reached 145, a level well above the highs of several cycles on record. Only 5 months later, several days of solar flux below 70 were recorded.

SOLAR RADIATION

Insofar as it affects most radio propagation, solar radiation is of two principal kinds: ultraviolet light and charged particles. The first travels at just under 300,000,000 meters (186,000 miles) per

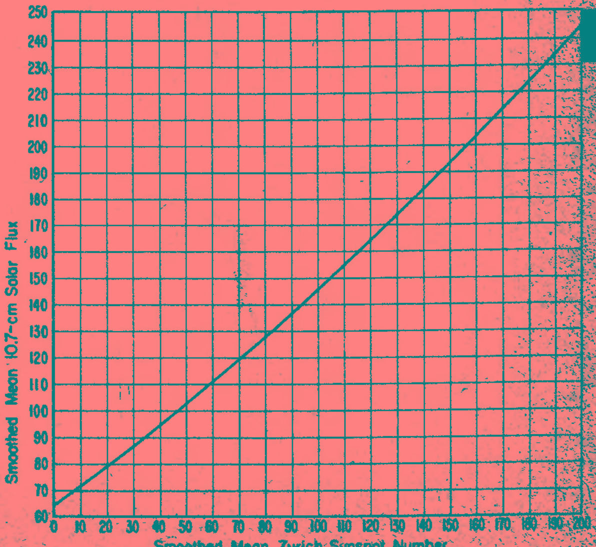


Fig. 19-1 — Relationship between smoothed mean Zurich sunspot number and the 2800-MHz solar flux. Highest solar flux recorded in 1974, Oct. 12, was 145, the equivalent of a sunspot number of 100. Lowest flux value in 1975 (early June) was 66, equating with a sunspot number very close to zero.

Fig. 19-2 — W1HDQ and W1SL look for sunspots with a simple projection system. The baffle at the top end of the small telescope provides a shaded area for viewing the sun's image (light circle) on the projection surface. Sunspots large enough to affect radio propagation are easily seen with this viewing system.

second, as does all electromagnetic radiation, so UV effects on wave propagation develop simultaneously with increases in observed solar noise, approximately 8 minutes after the actual solar event. Particle radiation moves more slowly, and by varying routes, so it may take up to 40 hours to affect radio propagation. Its principal effects are high absorption of radio energy and the production of auroras, both visual and the radio variety.

Variations in the level of solar radiation can be gradual, as with the passage of some sunspot groups and other long-lived activity centers across the solar disk, or sudden, as with solar flares. An important clew for anticipating variations in solar radiation levels and radio propagation changes resulting from them is the rotational period of the sun, approximately 27 days. Sudden events (flares) may be short-lived, but active areas capable of influencing radio propagation may recur at 4-week intervals for 4 or 5 solar rotations. Evidence of the "27-day cycle" is most marked during years of low solar activity.

Information on the condition of the sun, as it affects radio propagation, can be obtained in several ways. Projection of the sun's image as in Fig. 19-2 is particularly useful in the low years of the "11-year" cycle. At other times visible evidence of solar activity may be more difficult to sort out. Enough definition for our purposes is possible with the simplest telescopes. Low-cost instruments, 10 to 30-power, are adequate. A principal requirement is provision for mounting on a tripod having a pan-tilt head.[2]

Adjust the aiming to give a circular shadow of the scope body, then move the scope slowly until a bright spot appears on the projection surface. Put a baffle on the scope to enlarge the shaded area and adjust the focus to give a sharp-edged image of the solar disk. If there are any sunspots you will see them now. Draw a rough sketch of what you see, every time an observation is made, and keep it with your record of propagation observations.

Spots move across the image from left to right, as it is viewed with the sun at the observer's back. The line of movement is parallel to the solar equator. Not all activity capable of affecting propagation can be seen, but any spots seen have significance. Active areas may develop before spots are visible and may persist after spots associated with them are gone, but once identified by date they are likely to recur about 27 days later, emphasizing the worth of detailed records.

Variations in solar noise may be observed by aiming the antenna at the rising or setting sun. Sudden large increases may be heard regardless of the antenna position. Such bursts are often heard, but seldom recognized for what they are — warnings of imminent changes in propagation.

Vhf or uhf arrays capable of movement in elevation as well as azimuth are useful for solar noise monitoring. With a good system, the "quiet sun" can be "heard" at a low level.[3] Bursts that can be many dB higher indicate the start of a major event, such as a solar flare capable of producing an hf blackout and possibly vhf auroral propagation.

CHARACTERISTICS OF RADIO WAVES

All electromagnetic waves are moving fields of electric and magnetic force. Their lines of force are at right angles, and are mutually perpendicular to the direction of travel. They can have any position with respect to the earth. The plane containing the continuous lines of electric and magnetic force is called the *wave front*.

The medium in which electromagnetic waves travel has a marked influence on their speed of movement. In empty space the speed, as for light, is just under 300,000,000 meters per second. It is slightly less in air, and it varies with temperature and humidity to a degree, depending on the frequency. It is much less in dielectrics, where the speed is inversely proportional to the square root of the dielectric constant of the material.

Waves cannot penetrate a good conductor to any extent because the electric lines of force are practically short-circuited. Radio waves travel through dielectric materials with ease.

POLARIZATION

If the lines of force in the electric field are perpendicular to the surface of the earth the wave is said to be vertically polarized. If parallel with the earth, the polarization is said to be horizontal. It is possible to generate waves with rotating field lines. Known as circular polarization, this is useful in satellite communication, where polarization tends to be random. When the earth's surface is not available as a reference, polarization not of a rotating nature is described as linear or plane polarization, rather than vertical or horizontal, which become meaningless. Circular polarization is usable with plane-polarized antennas at the other end of the circuit, though with some small loss on most paths.

TYPES OF PROPAGATION

Depending on the means of propagation, radio waves can be classified as ionospheric, tropospheric, or ground waves. The ionospheric or sky wave is that main portion of the total radiation leaving the antenna at angles somewhat above the horizontal. Except for the reflecting qualities of the ionosphere, it would be lost in space. The tropospheric wave is that portion of the radiation kept close to the earth's surface as the result of bending in the lower atmosphere. The ground wave is that portion of the radiation directly affected by the surface of the earth. It has two components, an earth-guided surface wave, and the space wave, the latter itself being the resultant of two components, direct and ground-reflected. The terms "tropospheric wave" and "ground wave" are often used interchangeably, though this is not strictly correct.

THE IONOSPHERE

Long-distance communication and much over shorter distances, on frequencies below 30 MHz, is the result of bending of the wave in the ionosphere, a region between about 60 and 200 miles above the earth's surface where free ions and electrons exist in sufficient quantity to affect the direction of wave travel. Without the ionosphere, DX as we know it would be impossible.

Ionization of the upper atmosphere is attributed to ultraviolet radiation from the sun. The result is not a single region, but several layers of varying densities at various heights surrounding the earth. Each layer has a central region of relatively dense ionization that tapers off both above and below.

IONOSPHERIC LAYERS

The lowest useful region of the ionosphere is called the *E* layer. Its average height of maximum ionization is about 70 miles. The atmosphere here is still dense enough so that ions and electrons set free by solar radiation do not have to travel far before they meet and recombine to form neutral particles, so the layer can maintain its ability to bend radio waves only when continuously in sunlight. Ionization is thus greatest around local noon, and it practically disappears after sundown.

In the daylight hours there is a still lower area called the *D* region where ionization is proportional to the height of the sun. Wave energy in the two lowest frequency amateur bands, 1.8 and 3.5 MHz, is almost completely absorbed by this layer. Only the highest angle radiation passes through it and is reflected back to earth by the *E* layer. Communication on these bands in daylight is thus limited to short distances, as the lower angle radiation needed for longer distances travels farther in the *D* region and is absorbed.

The region of ionization mainly responsible for long-distance communication is called the *F* layer. At its altitude, about 175 miles at night, the air is so thin that recombination takes place very slowly. Ionization decreases slowly after sundown, reaching a minimum just before sunrise. The obvious effect of this change is the early disappearance of long-distance signals on the highest frequency that was usable that day, followed by loss of communication on progressively lower frequencies during the night. In the daytime the *F* layer splits into two parts, *F*1 and *F*2, having heights of about 140 and 200 miles, respectively. They merge again at sunset.

Scattered patches of relatively dense ionization develop seasonally at *E*-layer height. Such *sporadic E* is most prevalent in the equatorial regions, but it is common in the temperate latitudes in late spring and early summer, and to a lesser degree in early winter. Its effects become confused with those of other ionization on the lower amateur frequencies, but they stand out above 21 MHz, especially in the low-activity years of the solar cycle, when other forms of DX are not consistently available.

Duration of openings decreases and the length of skip increases with progressively higher frequencies. Skip distance is commonly a few hundred miles on 21 or 28 MHz, but multiple hop propagation can extend the range to 2500 miles or more. June and July are the peak months in the northern hemisphere. E_s propagation is most common in midmorning and early evening, but may extend almost around the clock at times. The highest frequency for E_s is not known, but the number of opportunities for using the mode drops off rapidly between the amateur 50- and 144-MHz bands, whereas 28 and 50 MHz are quite similar.

The greater the intensity of ionization in a layer, the more the wave path is bent. The bending also depends on wavelength; the longer the wave the more its path is modified for a given degree of ionization. Thus, for a given level of solar radiation, ionospheric communication is available for a longer period of time on the lower-frequency amateur bands than on those near the upper limit of hf spectrum. The intensity and character of solar radiation are subject to many short-term and long-term variables, the former still predictable with only partial success.

ABSORPTION

In traveling through the ionosphere, a radio wave gives up some of its energy by setting the ionized particles in motion. When moving particles collide with others, this energy is lost. Such *absorption* is greater at lower frequencies. It also increases with the intensity of ionization, and with the density of the atmosphere. This leads to a propagation factor often not fully appreciated: *signal levels and quality tend to be best when the operating frequency is near the maximum that is reflected back to earth at the time.*

VIRTUAL HEIGHT

An ionospheric layer is a region of considerable depth, but for practical purposes it is convenient to think of it as having finite height, from which a simple reflection would give the same effects (observed from the ground) as result from the gradual bending that actually takes place. It is given several names, such as *group height*, *equivalent height*, and *virtual height*.

The virtual height of an ionospheric layer for various frequencies and vertical incidence is determined with a variable-frequency sounding device that directs pulses of energy vertically and measures the time required for the round-trip path shown at the left in Fig. 19-3. As the frequency rises, a point is reached where no energy is returned vertically. This is known as the *critical frequency*, for the layer under consideration. A representation of a typical *ionogram* is shown in Fig. 19-4.[4] In this sounding the virtual height for 3.5 to 4 MHz was 400 km. Because the ionogram is a graphical presentation of wave travel time, double-hop propagation appears as an 800-km return for the same frequency. The critical frequency was just over 5 MHz on this occasion. Such a clear *F*-layer ionogram is possible only under magnetically quiet conditions, and at night, when little or no *E*- and *D*-layer ionization is present.

EFFECTS OF THE EARTH'S MAGNETIC FIELD

The ionosphere has been discussed thus far in terms of simple bending, or refraction, a concept useful for some explanatory purposes. But an understanding of long-distance propagation must take the earth's magnetic field into account. Because of it, the ionosphere is a birefringent medium (doubly refracting) which breaks up plane-polarized waves into what are known as the *ordinary* and *extraordinary waves*, f_oF2 and f_xF2 in the ionogram. This helps to explain the dispersal of plane polarization encountered in most ionospheric communication.[5]

Sudden marked increases in solar radiation, such as with solar flares, trigger instantaneous effects in the *F*, *E*, and *D* regions; slightly delayed effects, mainly in the polar areas; and geomagnetic effects, delayed up to 40 hours.

Onset of the *D*-region absorption is usually sudden, lasting a few minutes to several hours, leading to use of the term SID (sudden ionospheric disturbance). Shortwave fadeouts (SWFs) and SIDs exhibit wide variations in intensity, duration, and number of events, all tending to be greater in periods of high solar activity. Though their effects on radio propagation are of great importance, solar flares and associated disturbances are among the least predictable of solar-induced communications variables.

RADIATION ANGLE AND SKIP DISTANCE

The lower the angle above the horizon at which a wave leaves the antenna, the less refraction in the ionosphere or troposphere is required to bring it back, or to maintain useful signal levels in the case of tropospheric bending. This results in the emphasis on low radiation angles in the pursuit of DX, on the hf or vhf bands. It is rarely possible to radiate energy on a line tangent to the earth's surface, but even when this is done some bending is still required for communication over appreciable distances, because of earth curvature.

Some of the effects of radiation angle are illustrated in Fig. 19-3. The high-angle wave at the left is bent only slightly in the ionosphere, and so goes through it. The wave at the somewhat lower

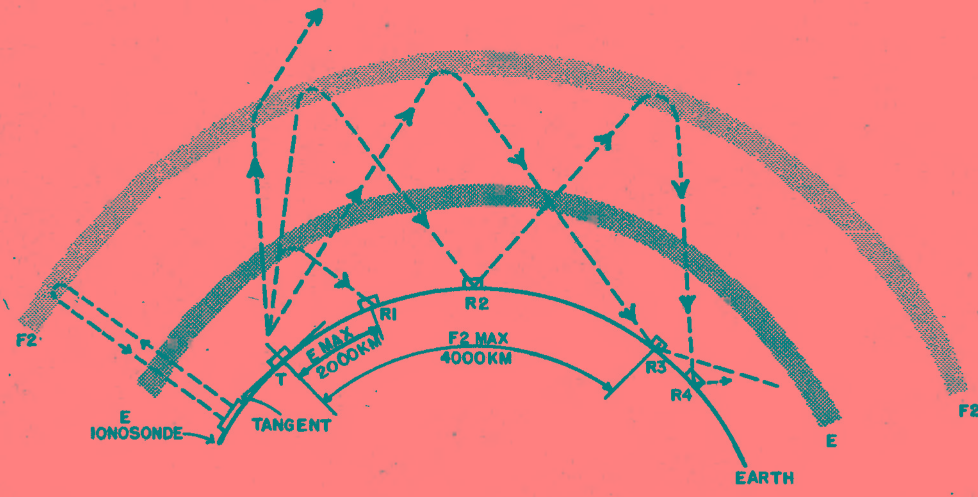


Fig. 19-3 — Three types of ionospheric propagation. Sounder, left, measures virtuel height and critical frequency of F_2 layer. Transmitter T is shown radiating at three different angles. Highest passes through the ionosphere after slight refraction. Lower-angle wave is returned to earth by the *E* layer, if frequency is low enough, at a maximum distance of 2000 kM. The *F*-layer reflection returns at a maximum distance of about 4000 kM, depending on the rediation angle. It is shown traversing a second path (double hop) from R2 to R4, the latter beyond single-hop ranga. The lowest-angle wave reaches the maximum practical single-hop distance at R3.

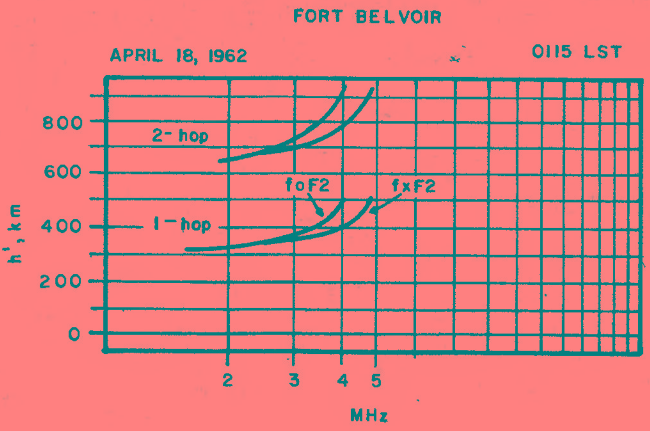


Fig. 19-4 — *F*-layer ionogram taken at night during magnetically quiet conditions. The traces show the breaking up into ordinary and extraordinary waves. Because it required twice the travel time, the double-hop return appears as having come from twice the height of the single-hop.

angle is just capable of being returned by the ionosphere. In daylight it might be returned via the *E* layer. Its area of return from the *F* layer, R2, is closer to the transmitting point, T, than is that of the lowest-angle wave. If R2 is at the shortest distance where returned energy is usable, the area between R1 and the outer reaches of the ground wave, near the transmitter, is called the *skip zone*. The distance between R2 and T is called the *skip distance*. The distances to both R1 and R2 depend on the ionization density, the radiation angle at T, and the frequency in use. The maximum distance for single-hop propagation via the *F* layer is about 2500 miles (4000 kilometers). The maximum *E*-layer single hop is about 1250 miles (2000 kilometers).

The maximum usable frequency (muf) for *F*-layer communication is about 3 times the critical frequency for vertical return, as at the left in Fig. 19-3. For *E*-layer propagation it is about 5 times.

MULTIPLE-HOP PROPAGATION

On its return to earth, the ionospherically propagated wave can be reflected back upward near R1 or R2, travel again to the ionosphere, and be refracted back to earth. This process can be repeated several times under ideal propagation conditions, leading even to communication over distances well beyond halfway around the world. Ordinarily ionospheric absorption and ground-reflection losses exact tolls in signal level and quality, so multiple-hop propagation usually yields lower signal levels and more distorted modulation than single-hop. This is not always the case, and under ideal conditions even long-way-around communication is possible with good signals. There is evidence to support the theory that signals for such communications, rather than hopping, may be ducted through the ionosphere for a good part of the distance.

FADING

Two or more parts of the wave may follow different paths, causing phase differences between wave components at the receiving end. Total field strength may be greater or smaller than that of one component. Fluctuating signal levels also result from the changing nature of the wave path, as in the case of moving air-mass boundaries, in tropospheric propagation on the higher frequencies. Changes in signal level, lumped under the term *fading*, arise from an almost infinite variety of phenomena; some natural, some man-made. Aircraft reflections are in the latter category.

Under some circumstances the wave path may vary with very small changes in frequency, so that modulation sidebands arrive at the receiver out of phase, causing distortion that may be mild or severe. Called *selective fading*, this problem increases with signal bandwidth. Double-sideband a-m signals suffer much more than single-sideband signals with suppressed carrier do.

THE SCATTER MODES

Much long-distance propagation can be described in terms of discrete reflection, through the analogy is never precise since true reflection would be possible only with perfect mirrors, and in a vacuum. All electromagnetic wave propagation is subject to scattering influences which alter idealized patterns to a great degree. The earth's atmosphere and ionospheric layers are scattering media, as are most objects that intervene in the wave path as it leaves the earth. Strong returns are thought of as reflections and weaker ones as scattering, but both influences prevail. Scatter modes have become useful tools in many kinds of communication.

FORWARD SCATTER

We describe a skip zone as if there were no signal heard between the end of useful ground-wave range and the points R1 or R2 of Fig. 19-3, but actually the transmitted signal can be detected over much of the skip zone, with sufficiently sensitive devices and methods. A small portion of the transmitted energy is scattered back to earth in several ways, depending on the frequency in use.

Tropospheric scatter extends the local communications range to an increasing degree with frequency, above about 20 MHz, becoming most useful in the vhf range. *Ionospheric scatter*, mostly from the height of the *E* region, is most marked at frequencies up to about 60 or 70 MHz. Vhf tropospheric scatter is usable within the limits of amateur power levels and antenna techniques, out to nearly 500 miles. Ionospheric forward scatter is discernible in the skip zone at distances up to 1200 miles or so.

A major component of ionospheric scatter is that contributed by short-lived columns of ionization formed around meteors entering the earth's atmosphere. This can be anything from very short bursts of little communications value to sustained periods of usable signal level, lasting up to a minute or more. Meteor scatter is most common in the early morning hours, and it can be an interesting adjunct to amateur communication at 21 MHz and higher, especially in periods of low solar activity. It is at its best during major meteor showers.[6]

BACKSCATTER

A complex form of scatter is readily observed when working near the maximum usable frequency for the *F* layer at the time. The transmitted wave is refracted back to earth at some distant point, which may be an ocean area or a land mass where there is no use of the frequency in question at the time. A small part of the energy is scattered back to the skip zone of the transmitter, via the ionospheric route.

Backscatter signals are generally rather weak, and subject to some distortion from multipath effects, but with optimum equipment they are usable at distances from just beyond the reliable local range out to several hundred miles. Under ideal conditions backscatter communication is possible over 3000 miles or more, though the term "sidescatter" is more descriptive of what probably happens on such long paths.

The scatter modes contribute to the usefulness of the higher parts of the DX spectrum, especially during periods of low solar activity when the normal ionospheric modes are less often available.

USING WWV BULLETINS

The National Bureau of Standards stations WWV and WWVH (see Chapter 17) transmit hourly propagation bulletins that are very useful for short-term communications planning. At 14 minutes after each hour (WWV only) information is given on expected propagation conditions, the current state of the geomagnetic field, and the solar flux index. At 18 minutes after each hour on WWV and at 46 after on WWVH, a summary for the previous day and a prediction for the current day are given. Detailed information on use of these bulletins appeared in *QST* for June, August, and September, 1975.[7]

PROPAGATION IN THE MF AND HF BANDS

The 1.8-MHz band offers reliable communication over distances up to about 25 miles during daylight. On winter nights ranges up to several thousand miles are possible.

The 3.5-MHz band is seldom usable beyond 200 miles in daylight, but long distances are not unusual at night, especially in years of low solar activity. Atmospheric noise tends to be high in the summer months on both 3.5 and 1.8 MHz.

The 7-MHz band has characteristics similar to 3.5 MHz, except that much greater distances are possible in daylight, and more often at night. In winter dawn and dusk periods it is possible to work the other side of the world, as signals follow the darkness path.

The 14-MHz band is the most widely used DX band. In the peak years of the solar cycle it is open to distant parts of the world almost continuously. During low solar activity it is open mainly in the daylight hours, and is especially good in the dawn and dusk periods. There is almost always a skip zone on this band.

The 21-MHz band shows highly variable propagation depending on the level of solar activity. During sunspot maxima it is useful for long-distance work almost around the clock. At intermediate levels it is mainly a daylight DX band. In the low years it is useful for transequatorial paths much of the year, but is open less often to the high latitudes. Sporadic-*E* skip is common in early summer and midwinter.

The 28-MHz band is excellent for DX communication in the peak solar-cycle years, but mostly in the daylight hours. The open time is shorter in the intermediate years, and is more confined to low-latitude and transequatorial paths as solar activity drops off. For about two years near the solar minimum, *F*-layer openings tend to be infrequent, and largely on north-south paths, with very long skip.

Sporadic-*E* propagation keeps things interesting in the period from late April through early August on this band, and on 21 MHz, providing single-hop communication out to 1300 miles or so, and multiple-hop to 2600 miles. Effects discussed in the following section on vhf propagation also show up in this band, though tropospheric bending is less than on 50 MHz.

THE WORLD ABOVE 50 MHZ

It was once thought that frequencies above 50 MHz would be useful only locally, but increased occupancy and improved techniques turned up many forms of long-distance vhf propagation. What follows supplements information given earlier in this chapter. First, let us consider the nature of our bands above 50 MHz.

50 to 54 MHz This borderline region has some of the characteristics of both higher and lower frequencies. Just about every form of wave propagation is found occasionally in the 50-MHz band, which has contributed greatly to its popularity. Its utility for service-area communication should not be overlooked. In the absence of any favorable condition, the well-equipped 50-MHz station should be able to work regularly over a radius of 75 to 100 miles or more, depending on terrain and antenna size and height.

Changing weather patterns extend coverage to 300 miles or more at times, mainly in the warmer months. Sporadic-*E* skip provides seasonal openings for work over 400 to 2500 miles, in seasons centered on the longest and shortest days of the year. Auroral effects afford vhf operators in the temperate latitudes an intriguing form of DX up to about 1300 miles. During the peak of "11-year" sunspot cycle 50-MHz DX of worldwide proportions may be workable by reflections of waves by the ionospheric F_2 layer. Various weak-signal scatter modes round out the 50-MHz propagation fare.

144 to 148 MHz Ionospheric effects are greatly reduced at 144 MHz. *F*-layer propagation is unknown. Sporadic-*E* skip is rare, and much more limited in duration and coverage than on 50 MHz. Auroral propagation is quite similar to that on 50 MHz, except that signals tend to be somewhat weaker and more distorted at 144. Tropospheric propagation improves with increasing frequency. It has been responsible for 144-MHz work over distances up to 2500 miles, and 500-mile contacts are fairly common in the warmer months. Reliable range on 144 is slightly less than on 50, under minimum conditions.

220 MHz and Higher Ionospheric propagation of the sorts discussed above is virtually unknown above about 200 MHz. Auroral communication is possible on 220 and 420 MHz, but probably not on higher frequencies, with amateur power levels. Tropospheric bending is very marked, and may be better on 432 than on 144 MHz, for example. Communication has been carried on over paths far beyond line of sight, on all amateur frequencies up through 10,000 MHz. Under minimum conditions, signal levels drop off slightly with each higher band.

PROPAGATION MODES

Known means by which vhf signals are propagated beyond the horizon are described below.

F_2-Layer Reflection Most communication on lower frequencies is by reflection of the wave in the *F* region, highest of the ionized layers. Its density varies with solar activity, the maximum usable frequency (muf) being highest in peak years of the sunspot cycle. Cycle 19 (in the recorded history of sunspot activity) hit an all-time high in the fall of 1958, which may never be equalled within the lifetime of some of us. Cycle 20 produced 50-MHz F_2 DX in 1968 to 1970, but less than Cycle 18 (1946 to 1949), and far less than Cycle 19.

The muf for F_2-layer propagation follows daily, monthly and seasonal cycles, all related to conditions on the sun, as with the hf bands. Frequent checks will show if the muf is rising or falling, and the times and directions for which it is highest. Two-way work has been done over about 1800 to 12,500 miles; even greater, if daylight routes around the earth the long way are included. The muf is believed to have reached about 70 MHz in 1958.

The TE Mode Also associated with high solar activity is a transequatorial mode, having an muf somewhat higher than the F_2. This is observed most often between points up to 2500 miles north and south of the *geomagnetic* equator, mainly in late afternoon or early evening.[3]

Sporadic-E Skip Patchy ionization of the *E* region of the ionosphere often propagates 28- and 50-MHz signals over 400 to 1300 miles or more. Often called "short skip," this is most common in May, June and July, with a shorter season around year end. Seasons are reversed in the southern hemisphere. *E* skip can occur at any time or season, but is most likely in mid-morning or early evening. Multiple-hop effects may extend the range to 2500 miles or more.

E_s propagation has been observed in the 144-MHz band, and on TV channels up to about 200 MHz. Minimum skip distance is greater, and duration of openings much shorter, on 144 MHz than on 50. Reception of strong E_s signals from under 300 miles on 50 MHz indicates some possibility of skip propagation on 144, probably to 800 miles or more.

Aurora Effect High-frequency communication may be wiped out or seriously impaired by absorption in the ionosphere, during disturbances associated with high solar activity and variations in the earth's magnetic field. If this occurs at night in clear weather, there may be a visible aurora, but the condition also develops in daylight, usually in late afternoon. Weak wavery signals in the 3.5-MHz and 7-MHz bands are good indicators.

Vhf waves can be returned to earth from the auroral region, but the varying intensity of the aurora and its porosity as a propagation medium impart a multipath distortion to the signal, which garbles or even destroys any modulation. Distortion increases with signal frequency and varies, often quite quickly, with the nature of the aurora. Single-sideband is preferred to modes requiring more bandwidth. The most effective mode is cw, which may be the only reliable communications method at 144 MHz and higher, during most auroras.

Propagation is generally from the north, but probing with a directional array is recommended. Maximum range is about 1300 miles, though 50-MHz signals are heard occasionally over greater distances, usually with little or no auroral distortion.

How often auroral communication is possible is related to the *geomagnetic* latitude of participating stations, auroras being most frequent in northeastern USA and adjacent areas of Canada. They are rare below about latitude 32 in the Southeast and about latitude 38 to 40 in the Southwest. The highest frequency for auroral returns depends on equipment and antennas, but auroral communication has been achieved up to at least 432 MHz.

Tropospheric Bending An easily-anticipated extension of normal vhf coverage results from abrupt changes in the refractive index of the atmosphere, at boundaries between air masses of differing temperature and humidity characteristics. Such warm-dry over cool-moist boundaries often lie along the southern and western edges of stable slow-moving areas of fair weather and high barometric pressure. Troposheric bending can increase signal levels from within the normal working range, or bring in more distant stations, not normally heard.

A condition known as *ducting* or *trapping* may simulate propagation within a waveguide, causing vhf waves to follow earth curvature for hundreds or even thousands of miles. Ducting incidence increases with frequency. It is rare on 50 MHz, fairly common on 144, and more so on higher frequencies. It occurs most often in temperate or low latitudes. It was the medium for the W6NLZ-KH6UK work on 144, 220 and 432 MHz, over a 2540-mile path. Gulf-Coast states see it often, the Atlantic Seaboard, Great Lakes and Mississippi Valley areas occasionally, usually in September and October.

Many local conditions contribute to tropospheric bending. Convection in coastal areas in warm weather; rapid cooling of the earth after a hot day, with upper air cooling more slowly; warming of air aloft with the summer sunrise; subsidence of cool moist air into valleys on calm summer evenings – these familiar situations create upper-air conditions which can extend normal vhf coverage.

The alert vhf enthusiast soon learns to correlate various weather signs and propagation patterns. Temperature and barometric-pressure trends, changing cloud formations, wind direction, visibility and other natural indicators can give him clues as to what is in store in the way of tropospheric propagation.

The 50-MHz band is more responsive to weather effects than 28, and 144 MHz is much more active than 50. This trend continues into the microwave region, as evidenced by tropospheric records on all our bands, up to and including work over a 275-mile path on 10,000 MHz.

The Scatter Modes Though they provide signal levels too low for routine communication, several scatter modes attract the advanced vhf operator.

Tropospheric scatter offers marginal communication up to 500 miles or so, almost regardless of conditions and frequency, when optimum equipment and methods are used.

Ionospheric scatter is useful mainly on 50 MHz, where it usually is a composite of meteor bursts and a weak residual scatter signal. The latter may be heard only when optimum conditions prevail. The best distances are 600 to 1200 miles.

Back scatter, common on lower frequencies, is observed on 50 MHz during ionospheric propagation, mainly of the F_2 variety. Conditions for 50-MHz backscatter are similar to those for the hf bands, detailed earlier in this chapter.

Scatter from meteor trails in the *E* region can cause signal enhancement, or isolated bursts of signal from a station not otherwise heard. Strength and duration of meteor bursts decrease with increasing signal frequency, but the mode is popular for marginal communication in the 50- and 144-MHz bands. It has been used on 220 MHz, and, more marginally, on 432 MHz.

Random meteor bursts can be heard by cooperating vhf stations at any time or season, but early-morning hours are preferred. Major meteor showers (August Perseids and December Geminids) provide frequent bursts. Some other showers have various periods, and may show phenomenal burst counts in peak years.[6] Distances are similar to other *E*-layer communication.

All scatter communication requires good equipment and optimum operating methods. The narrow-band modes are superior to wide-band systems.

Communication Via the Moon Though amateurs first bounced signals off the moon in the early 1950s, real communication via the earth-moon-earth (eme) route is a fairly recent accomplishment. Requirements are maximum legal power, optimum receiving equipment, very large high-gain antennas, and precise aiming. Sophisticated tracking systems, narrow bandwidth (with attendant requirements for receiver and transmitter stability) and visual signal-resolution methods are desirable. Lunar work has been done on all amateur frequencies from 50 to 2400 MHz, over distances limited only by the ability of the stations to "see" the moon simultaneously.

For more detailed vhf propagation information and references, see *The Radio Amateur's VHF Manual*, Chapter 2.

Propagation References

[1] Tilton, "The DXers Crystal Ball," *QST*, June, August, and September, 1975.

[2] Projection of the sun and interpretation of results are discussed in Reference 1, and in *QST* for December, 1974, p. 83, and January, 1975, p. 84. A black-box viewing device (Tomcik, K4HYF) for sun projection is shown in July, 1964, *QST*. (Photocopy from ARRL, 75 cents and stamped envelope.)

[3] Bray and Kirchner, "Antenna Patterns from the Sun," *QST*, July, 1960. Wilson, "432-MHz Solar Patrol," *QST*, August, 1967.

[4] Davies, "Ionospheric Radio Propagation," NBS Monograph 80, U.S. Government Printing Office, Washington, DC 20402, $2.75. p. 117. Available from *Ham Radio*, Greenville, NH, $4.00.

[5] See Reference 4, p. 45.

[6] Bain, "VHF Propagation by Meteor Trail Ionization," *QST*, May, 1974. Table of major meteor showers, "Radio Amateurs VHF Manual," Ch. 2.

Chapter 20

Transmission Lines

The place where rf power is generated is very frequently not the place where it is to be utilized. A transmitter and its antenna are a good example: The antenna, to radiate well, should be high above the ground and should be kept clear of trees, buildings and other objects that might absorb energy, but the transmitter itself is most conveniently installed indoors where it is readily accessible.

The means by which power is transported from point to point is the rf transmission line. At radio frequencies a transmission line exhibits entirely different characterisitcs than it does at commercial power frequencies. This is because the speed at which electrical energy travels, while tremendously high as compared with mechanical motion, is not infinite. The peculiarities of rf transmission lines result from the fact that a time interval comparable with an rf cycle must elapse before energy leaving one point in the circuit can reach another just a short distance away.

OPERATING PRINCIPLES

If a source of emf – a battery, for example – is connected to the ends of a pair of insulated parallel wires that extend outward for an infinite distance, electric currents will immediately become detectable in the wires near the battery terminals. The electric field of the battery will cause free electrons in the wire connected to the positive terminal to be attracted to the battery, and an equal number of free electrons in the wire connected to the negative terminal will be repelled from the battery. These currents do not flow instantaneously throughout the length of the wires; the electric field that causes the electron movement cannot travel faster than the speed of light, so a measurable interval of time elapses before the currents become evident even a relatively short distance away.

For example, the currents would not become detectable 300 meters (nearly 1000 feet) from the battery until at least a microsecond (one millionth of a second) after the connection was made. By ordinary standards this is a very short length of time, but in terms of radio frequency it represents the time one complete cycle of a 1000-kilohertz current – a frequency considerably lower than those with which amateurs communicate.

The current flows to charge the capacitance between the two wires. However, the conductors of this "linear" capacitor also have appreciable inductance. The line may be thought of as being composed of a whole series of small inductances and capacitances connected as shown in Fig. 20-1, where each coil is the inductance of a very short section of one wire and each capacitor is the capacitance between two such short sections.

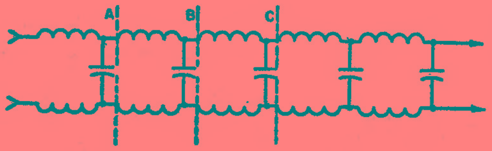


Fig. 20-1 – Equivalent of a transmission line in lumped circuit constants.

Characteristic Impedance

An infinitely long chain of coils and capacitors connected as in Fig. 20-1, where the small inductances and capacitances all have the same values, respectively, has an important property. To an electrical impulse applied at one end, the combination appears to have an impedance – called the characteristic impedance or surge impedance – approximately equal to $\sqrt{L/C}$ where L and C are the inductance and capacitance per unit length. This impedance is purely resistive.

In defining the characteristic impedance as $\sqrt{L/C}$, it is assumed that the conductors have no inherent resistance – that is, there is no I^2R loss in them – and that there is no power loss in the dielectric surrounding the conductors. There is thus no power loss in or from the line no matter how great its length. This may not seem consistent with calling the characteristic impedance a pure resistance, which implies that the power supplied is all dissipated in the line. But in an infinitely long line the effect, so far as the source of power is concerned, is exactly the same as though the power were dissipated in a resistance, because the power leaves the source and travels outward forever along the line.

The characteristic impedance determines the amount of current that can flow when a given voltage is applied to an infinitely long line, in exactly the same way that a definite value of actual resistance limits current flow when a voltage is applied.

The inductance and capacitance per unit length of line depend upon the size of the conductors and the spacing between them. The closer the two conductors and the greater their diameter, the higher the capacitance and the lower the inductance. A line with large conductors closely spaced will have low impedance, while one with small conductors widely spaced will have relatively high impedance.

"Matched" Lines

Actual transmission lines do not extend to infinity but have a definite length and are connected to, or terminate in, a load at the "output" end, or end to which the power is delivered. If the load is a pure resistance of a value equal to the characteristic impedance of the line, the line is said to be matched. To current traveling along the line such a load just looks like still more transmission line of the same characteristic impedance.

In other words, a short line terminated in a purely resistive load equal to the characteristic impedance of the line acts just as though it were infinitely long. In a matched transmission line, power travels outward along the line from the source until it reaches the load, where it is completely absorbed.

RF on Lines

The principles discussed above, although based on direct-current flow from a battery, also hold when an rf voltage is applied to the line. The difference is that the alternating voltage causes the amplitude of the current at the input terminals of the line to vary with the voltage, and the direction of current flow also periodically reverses when the polarity of the applied voltage reverses. The current at a given instant at any point along the line is the result of a voltage that was applied at some *earlier* instant at the input terminals. Since the distance traveled by the electromagnetic fields in the time of one cycle is equal to one wavelength, the instantaneous amplitude of the current is different at all points in a one-wavelength section of line. In fact, the current flows in opposite directions in the same wire in successive half-wavelength sections. However, at any given point along the line the current goes through similar variations with time that the current at the input terminals did.

Thus the current (and voltage) travels along the wire as a series of waves having a length equal to the speed of travel divided by the frequency of the ac voltage. On an infinitely long line, or one properly matched by its load, an ammeter inserted anywhere in the line will show the same current, because the ammeter averages out the variations in current during a cycle. It is only when the line is not properly matched that the wave motion becomes apparent through observations made with ordinary instruments.

STANDING WAVES

In the infinitely long line (or its matched counterpart) the impedance is the same at any point on the line because the ratio of voltage to current is always the same. However, the impedance at the end of the line in Fig. 20-2 is zero – or at least extremely small – because the line is short-circuited at the end. The outgoing power, on meeting the short-circuit, reverses its direction of flow and goes back along the transmission line toward the input end. There is a large current in the short-circuit, but substantially no voltage across the line at this point. We now have a voltage and current representing the power going outward (incident power) toward the short-circuit, and a second voltage and current representing the reflected power traveling back toward the source.

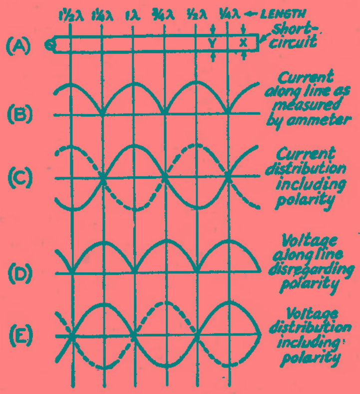


Fig. 20-2 – Standing waves of voltage and current along a short-circuited transmission line.

The reflected current travels at the same speed as the outgoing current, so its instantaneous value will be different at every point along the line, in the distance represented by the time of one cycle. At some points along the line the phase of the incident and reflected currents will be such that the currents cancel each other while at others the amplitude will be doubled. At in-between points the amplitude is between these two extremes. The points at which the currents are in and out of phase depend only on the *time* required for them to travel and so depend only on the *distance* along the line from the point of reflection.

In the short-circuit at the end of the line the two current components are in phase and the total current is large. At a distance of one-half wavelength back along the line from the short-circuit the outgoing and reflected components will again be in phase and the resultant current will again have its maximum value. This is also true at any point that is a multiple of a half wavelength from the short-circuited end of the line.

The outgoing and reflected currents will cancel at a point one-quarter wavelength, along the line, from the short-circuit. At this point, then, the current will be zero. It will also be zero at all points that are an *odd* multiple of one-quarter wavelength from the short-circuit.

If the current along the line is measured at successive points with an ammeter, it will be found to vary about as shown in Fig. 20-2B. The same result would be obtained by measuring the current in either wire, since the ammeter cannot measure phase. However, if the phase could be checked, it would be found that in each successive half-wavelength section of the line the currents at any given instant are flowing in opposite directions, as indicated by the solid line in Fig. 20-2C. Furthermore, the current in the second wire is flowing in the opposite direction to the current in the adjacent section of the first wire. This is indicated by the broken curve in Fig. 20-2C. The variations in current intensity along the transmission line are referred to as **standing waves.** The point of maximum line current is called a **current loop** or **current antinode** and the point of minimum line current is called a **current node.**

Voltage Relationships

Since the end of the line is short-circuited, the voltage at that point has to be zero. This can only be so if the voltage in the outgoing wave is met, at the end of the line, by a reflected voltage of equal amplitude and opposite polarity. In other words, the phase of the voltage wave is *reversed* when reflection takes place from the short-circuit. This reversal is equivalent to an extra half cycle or half wavelength of travel. As a result, the outgoing and returning voltages are in phase a quarter wavelength from the end of the line, and again out of phase a half wavelength from the end. The standing waves of voltage, shown at D in Fig. 20-2, are therefore displaced by one-quarter wavelength from the standing waves of current. The drawing at E shows the voltage on both wires when phase is taken into account. The polarity of the voltage on each wire reverses in each half wavelength section of transmission line. A voltage maximum is called a **voltage loop** or **antinode** and a **voltage minimum** is called a **voltage node.**

Open-Circuited Line

If the end of the line is open-circuited instead of short-circuited, there can be no current at the end of the line but a large voltage can exist. Again the incident power is reflected back toward the source. The incident and reflected components of current must be equal and opposite in phase at the open circuit in order for the total current at the end of the line to be zero. The incident and reflected components of voltage are in phase and add together. The result is again that there are standing waves, but the conditions are reversed as compared with a short-circuited line. Fig. 20-3 shows the open-circuited line case.

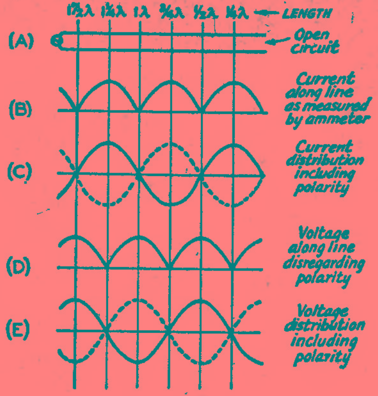


Fig. 20-3 — Standing waves of current and voltage along an open-circuited transmission line.

Lines Terminated in Resistive Load

Fig. 20-4 shows a line terminated in a resistive load. In this case at least part of the incident power is absorbed in the load, and so is not available to be reflected back toward the source. Because only part of the power is reflected, the reflected components of voltage and current do not have the same magnitude as the incident components. Therefore neither voltage nor current cancel completely at any point along the line. However, the *speed* at which the incident and reflected components travel is not affected by their amplitude, so the phase relationships are similar to those in open- or short-circuited lines.

It was pointed out earlier that if the load resistance, Z_R, is equal to the characteristic impedance, Z_0, of the line all the power is absorbed in the load. In such a case there is no reflected power and therefore no standing waves of current and voltage. This is a special case that represents the change-over point between "short-circuited" and "open-circuited" lines. If Z_R is less than Z_0, the current is largest at the load, while if Z_R is greater than Z_0 the voltage is largest at the load. The two conditions are shown at B and C, respectively, in Fig. 20-4.

The resistive termination is an important practical case. The termination is seldom an actual resistor, the most common terminations being resonant circuits or resonant antenna systems, both of which have essentially resistive impedances. If the load is reactive as well as resistive, the operation of the line resembles that shown in Fig.

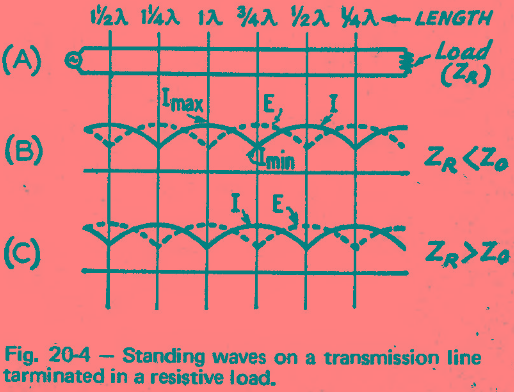


Fig. 20-4 — Standing waves on a transmission line terminated in a resistive load.

20-4, but the presence of reactance in the load causes two modifications: The loops and nulls are shifted toward or away from the load; and the amount of power reflected back toward the source is increased, as compared with the amount reflected by a purely resistive load of the same total impedance. Both effects become more pronounced as the ratio of reactance to resistance in the load is made larger.

Standing-Wave Ratio

The ratio of maximum current to minimum current along a line, Fig. 20-5, is called the standing-wave ratio. The same ratio holds for maximum voltage and minimum voltage. It is a measure of the mismatch between the load and the line, and is equal to 1 when the line is perfectly matched. (In that case the "maximum" and "minimum" are the same, since the current and voltage do not vary along the line.) When the line is terminated in a purely resistive load, the standing-wave ratio is

$$SWR = \frac{Z_R}{Z_0} \text{ or } \frac{Z_0}{Z_R} \qquad \text{(20-A)}$$

where SWR = Stand-wave ratio
Z_R = Impedance of load (pure resistance)
Z_0 = Characteristic impedance of line

Example: A line having a characteristic impedance of 300 ohms is terminated in a resistive load of 25 ohms. The SWR is

$$SWR = \frac{Z_0}{Z_R} = \frac{300}{25} = 12 \text{ to } 1$$

It is customary to put the larger of the two quantities, Z_R or Z_0, in the numerator of the fraction so that the SWR will be expressed by a number larger than 1.

It is easier to measure the standing-wave ratio than some of the other quantities (such as the impedance of an antenna) that enter into transmission-line computations. Consequently, the SWR is a convenient basis for work with lines. The higher the SWR the greater the mismatch between line and load. In practical lines, the power loss in the line itself increases with the SWR as shown later.

INPUT IMPEDANCE

The input impedance of a transmission line is the impedance seen looking into the sending-end or input terminals; it is the impedance into which the source of power must work when the line is connected. If the load is perfectly matched to the line the line appears to be infinitely long, as stated earlier, and the input impedance is simply the characteristic impedance of the line itself. However, if there are standing waves this is no longer true; the input impedance may have a wide range of values.

This can be understood by referring to Figs. 20-2, 20-3, or 20-4. If the line length is such that standing waves cause the voltage at the input terminals to be high and the current low, then the input impedance is higher than the Z_0 of the line, since impedance is simply the ratio of voltage to current. Conversely, low voltage and high current at the input terminals mean that the input impedance is lower than the line Z_0. Comparison of the three drawings also shows that the range of input impedance values that may be encountered is greater when the far end of the line is open- or short-circuited than it is when the line has a resistive load. In other words, the higher the SWR the greater the range of input impedance values when the line length is varied.

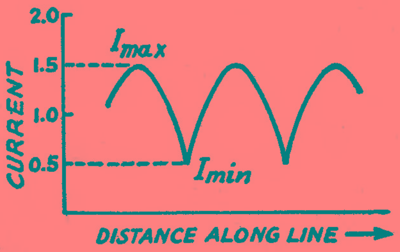


Fig. 20-5 — Measurement of standing-wave ratio. In this drawing, I_{max} is 1.5 and I_{min} is 0.5, so the SWR = I_{max}/I_{min} = 1.5/0.5 = 3 to 1.

In addition to the variation in the absolute value of the input impedance with line length, the presence of standing waves also causes the input impedance to contain both reactance and resistance, even though the load itself may be a pure resistance. The only exceptions to this occur at the exact current loops or nodes, at which points the input impedance is a pure resistance. These are the only points at which the outgoing and reflected voltages and currents are exactly in phase: At all other distances along the line the current either leads or lags the voltage and the effect is exactly the same as though a capacitance or inductance were part of the input impedance.

The input impedance can be represented either by a resistance and a capacitance or by a resistance and an inductance. Whether the impedance is inductive or capacitive depends on the characteristics of the load and the length of the line. It is possible to represent the input impedance by an equivalent circuit having resistance and reactance either in series or parallel, so long as the total impedance and phase angle are the same in either case.

The magnitude and character of the input impedance are quite important, since they determine the method by which the power source must be coupled to the line. The calculation of input impedance is rather complicated and its measurement is not feasible without special equipment. Fortunately, in amateur work it is unnecessary either to calculate or measure it. The proper coupling can be achieved by relatively simple methods described later in this chapter.

Lines Without Load

The input impedance of a short-circuited or open-circuited line not an extact multiple of one-quarter wavelength long is practically a pure reactance. This is because there is very little power lost in the line. Such lines are frequently used as "linear" inductances and capacitances.

If a shorted line is less than a quarter-wave long, as at *X* in Fig. 20-2, it will have inductive reactance. The reactance increases with the line length up to the quarter-wave point. Beyond that, as at *Y*, the reactance is capacitive, high near the quarter-wave point and becoming lower as the half-wave point is approached. It then alternates between inductive and capacitive in successive quarter-wave sections. Just the reverse is true of the open-circuited line.

At exact multiples of a quarter wavelength the impedance is purely resistive. It is apparent, from examination of B and D in Fig. 20-2, that at points that are a multiple of a half wavelength – i.e., 1/2, 1, 1 1/2 wavelengths, etc. – from the short-circuited end of the line that the current and voltage have the same values that they do at the short circuit. In other words, if the line were an exact multiple of a half wavelength long the generator or source of power would "look into" a short circuit. On the other hand, at points that are an odd multiple of a quarter wavelength – i.e., 1/4, 3/4, 1 1/4, etc. – from the short circuit the voltage is maximum and the current is zero. Since $Z = E/I$, the impedance at these points is theoretically infinite. (Actually it is very high, but not infinite.) This is because the current does not actually go to zero when there are losses in the line. Losses are always present, but usually are small.)

Impedance Transformation

The fact that the input impedance of a line depends on the SWR and line length can be used to advantage when it is necessary to transform a given impedance into another value.

Study of Fig. 20-4 will show that, just as in the open- and short-circuited cases, if the line is one-half wavelength long the voltage and current are exactly the same at the input terminals as they are at the load. This is also true of lengths that are integral multiples of a half wavelength. It is also true for all values of SWR. Hence the input impedance of any line, no matter what its Z_0, that is a multiple of a half wavelength long is exactly the same as the load impedance. Such a line can be used to transfer the impedance to a new location without changing its value.

When the line is a quarter wavelength long, or an odd multiple of a quarter wavelength, the load impedance is "inverted." That is, if the current is low and the voltage is high at the load, the input impedance will be such as to require high current and low voltage. The relationship between the load impedance and input impedance is given by

$$Z_S = \frac{Z_0^2}{Z_R} \qquad \text{(20-B)}$$

where Z_S = Impedance looking into line (line length and odd multiple of one-quarter wavelength
Z_R = Impedance of load (pure resistance)
Z_0 = Characteristic impedance of line

Example: A quarter-wavelength line having a characteristic impedance of 500 ohms is terminated in a resistive load of 75 ohms. The impedance looking into the input or sending end of the line is

$$Z_S = \frac{Z_0^2}{Z_R} = \frac{(500)^2}{75} = \frac{250{,}000}{75} = 3333 \text{ ohms}$$

If the formula above is rearranged, we have

$$Z_0 = \sqrt{Z_S Z_R} \qquad \text{(20-C)}$$

This means that if we have two values of impedance that we wish to "match," we can do so if we connect them together by a quarter-wave transmission line having a characteristic impedance equal to the square root of their product. A quarter-wave line, in other words, has the characteristics of a transformer.

Resonant and Nonresonant Lines

The input impedance of a line operating with a high SWR is critically dependent on the line length, and resistive only when the length is some integral multiple of one-quarter wavelength. Lines cut to such a length and operated with a high SWR are called "tuned" or "resonant" lines. On the other hand, if the SWR is low the input impedance is close to the Z_0 of the line and does not vary a great deal with the line length. Such lines are called "flat,“ or "untuned," or "nonresonant."

There is no sharp line of demarcation between tuned and untuned lines. If the SWR is below 1.5 to 1 the line is essentially flat, and the same input coupling method will work with all line lengths. If the SWR is above 3 or 4 to 1, the type of coupling system, and its adjustment, will depend on the line length and such lines fall into the "tuned" category.

It is usually advantageous to make the SWR as low as possible. A resonant line becomes necessary only when a considerable mismatch between the load and the line has to be tolerated. The most important practical example of this is when a single antenna is operated on several harmonically related frequencies, in which case the antenna impedance will have widely different values on different harmonics.

RADIATION

Whenever a wire carries alternating current the electromagnetic fields travel away into space with the velocity of light. At power-line frequencies the field that "grows" when the current is increasing has plenty of time to return or "collapse" about the conductor when the current is decreasing, because the alternations are so slow. But at radio frequencies fields that travel only a relatively short distance do not have time to get back to the conductor before the next cycle commences. The consequence is that some of the electromagnetic energy is prevented from being restored to the conductor; in other words, energy is radiated into space in the form of electromagnetic waves.

The lines previously considered have consisted of two parallel conductors of the same diameter. Provided there is nothing in the system to destroy symmetry, at every point along the line the current in one conductor has the same intensity as the current in the other conductor at that point, but the currents flow in opposite directions. This was shown in Figs. 20-2C and 20-3C. It means that the fields set up about the two wires have the same intensity, but *opposite directions.* The consequence is that the total field set up about such a transmission line is zero; the two fields "cancel out." Hence no energy is radiated.

Practically, the fields do not quite cancel out because for them to do so the two conductors would have to occupy the same space, whereas they are actually slightly separated. However, the cancellation is substantially complete if the distance between the conductors is very small compared to the wavelength. Transmission line radiation will be negligible if the distance between the conductors is .01 wavelength or less, provided the currents in the two wires are balanced.

The amount of radiation also is proportional to the current flowing in the line. Because of the way in which the current varies along the line when there are standing waves, the effective current, for purposes of radiation, becomes greater as the SWR is increased. For this reason the radiation is least when the line is flat. However, if the conductor spacing is small and the currents are balanced, the radiation from a line with even a high SWR is inconsequential. A small unbalance in the line currents is far more serious – and is just as serious when the line is flat as when the SWR is high.

PRACTICAL LINE CHARACTERISTICS

The foregoing discussion of transmission lines has been based on a line consisting of two parallel conductors. The parallel-conductor line is but one of two general types, the other being the coaxial or concentric line. The coaxial line consists of a conductor placed in the center of a tube. The inside surface of the tube and the outside surface of the smaller inner conductor form the two conducting surfaces of the line.

In the coaxial line the fields are entirely inside the tube, because the tube acts as a shield to prevent them for appearing outside. This reduces radiation to the vanishing point. So far as the electrical behavior of coaxial lines is concerned, all that has previously been said about the operation of parallel-conductor lines applies. There are, however, practical differences in the construction and use of parallel and coaxial lines.

PARALLEL-CONDUCTOR LINES

A type of parallel-conductor line sometimes used in amateur installations is one in which two wires (ordinarily No. 12 or No. 14) are supported a fixed distance apart by means of insulating rods called "spacers." The spacings used vary from two to six inches, the smaller spacings being necessary at frequencies of the order of 28 MHz and higher so that radiation will be minimized. The construction is shown in Fig. 20-6. Such a line is said to be air insulated. The characteristic impedance of such "open-wire" lines is between 400 and 600 ohms, depending on the wire size and spacing.

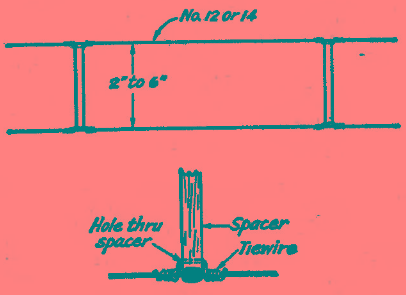


Fig. 20-6 — Typical construction of open-wire line. The line conductor fits in a groove in the end of the spacer, and is held in place by a tie-wire anchored in a hole near the groove.

Parallel-conductor lines also are occasionally constructed of metal tubing of a diameter of 1/4 to 1/2 inch. This reduces the characteristic impedance of the line. Such lines are mostly used as quarter-wave transformers, when different values of impedance are to be matched.

Prefabricated parallel-conductor line with air insulation, developed for television reception, can be used in transmitting applications. This line consists of two conductors separated one-half to one inch by molded-on spacers. The characterstic impedance is 300 to 450 ohms, depending on the wire size and spacing.

A convenient type of manufactured line is one in which the parallel conductors are imbedded in low-loss insulating material (polyethylene). It is commonly used as a TV lead-in and has a characteristic impedance of about 300 ohms. It is sold under various names, the most common of which is "Twin-Lead." This type of line has the advantages of light weight, close and uniform conductor spacing, flexibility and neat appearance. However, the losses in the solid dielectric are higher than in air, and dirt or moisture on the line tends to change the characteristic impedance. Moisture effects can be reduced by coating the line with silicone grease. A special form of 300-ohm Twin-Lead for transmitting uses a polyethylene tube with the conductors molded diametrically

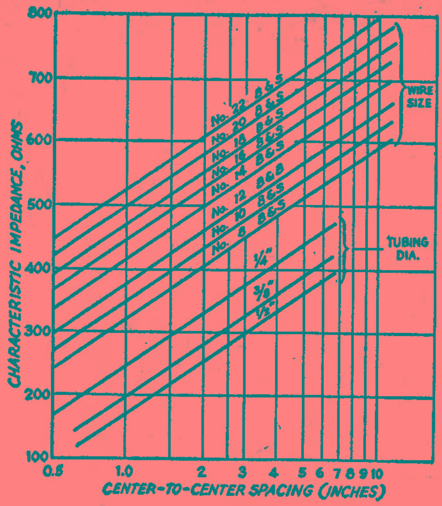


Fig. 20-7 — Chart showing the characteristic impedance of spaced-conductor parallel transmission lines with air dielectric. Tubing sizes given are for outside diameters.

opposite; the longer dielectric path in such line reduces moisture troubles.

In addition to 300-ohm line, Twin-Lead is obtainable with a characteristic impedance of 75 ohms for transmitting purposes. Light-weight 75- and 150-ohm Twin-Lead also is available.

Characteristic Impedance

The characteristic impedance of an air-insulated parallel-conductor line is given by:

$$Z_0 = 276 \log \frac{b}{a} \qquad \text{(20-D)}$$

where Z_0 = Characteristic impedance
b = Center-to-center distance between conductors
a = Radius of conductor (in same units as b)

It does not matter what units are used for a and b so long as they are the *same* units. Both quantities may be measured in centimeters, inches, etc. Since it is necessary to have a table of common logarithms to solve practical problems, the solution is given in graphical form in Fig. 20-7 for a number of common conductor sizes.

In solid-dielectric parallel-conductor lines such as Twin-Lead the characteristic impedance cannot be calculated readily, because part of the electric field is in air as well as in the dielectric.

Unbalance in Parallel-Conductor Lines

When installing parallel-conductor lines care should be taken to avoid introducing electrical unbalance into the system. If for some reason the current in one conductor is higher than in the other, or if the currents in the two wires are not exactly out of phase with each other, the electromagnetic fields will not cancel completely and a considerable amount of power may be radiated by the line.

Maintaining good line balance requires, first of all, a balanced load at its end. For this reason the antenna should be fed, whenever possible, at a point where each conductor "sees" exactly the same thing. Usually this means that the antenna system should be fed at its electrical center. However, even though the antenna appears to be symmetrical physically, it can be unbalanced electrically if the part connected to one of the line conductors is coupled to something (such as house wiring or a metal pole or roof) that is not duplicated on the other part of the antenna. Every effort should be made to keep the antenna as far as possible from other wiring or sizable metallic objects. The transmission line itself will cause some unbalance if it is not brought away from the antenna at right angles to it for a distance of at least a quarter wavelength.

In installing the line conductors take care to see that they are kept away from metal. The minimum separation between either conductor and all other wiring should be at least four or five times the conductor spacing. The shunt capacitance introduced by close proximity to metallic objects can drain off enough current (to ground) to unbalance the line currents, resulting in increased radiation. A shunt capacitance of this sort also constitutes a reactive load on the line, causing an impedance "bump" that will prevent making the line actually flat.

COAXIAL LINES

The most common form of coaxial line consists of either a solid or stranded-wire inner conductor surrounded by polyethylene dielectric. Copper braid is woven over the dielectric to form the outer conductor, and a waterproof vinyl covering is placed on top of the braid. This cable is made in a number of different diameters. It is moderately flexible, and so is convenient to install. This solid coaxial cable is commonly available in impedances approximating 50 and 70 ohms.

Air-insulated coaxial lines have lower losses than the solid-dielectric type, but are rarely used in amateur work because they are expensive and difficult to install as compared with the flexible cable. The common type of air-insulated coaxial line uses a sold-wire conductor inside a copper tube, with the wire held in the center of the tube by means of insulating "beads" placed at regular intervals.

Characteristic Impedance

The characteristic impedance of an air-insulated coaxial line is given by the formula

$$Z_0 = 138 \log \frac{b}{a} \qquad \text{(20-E)}$$

where Z_0 = Characteristic impedance
b = Inside diameter of outer conductor
a = Outside diameter of inner conductor (in same units as b)