Chapter 14

Direction Finding Antennas

The use of radio for direction-finding purposes (RDF) is almost as old as its application for communications. Radio amateurs have learned RDF techniques and found much satisfaction by participating in hidden-transmitter hunts. Other hams have discovered RDF through an interest in boating or aviation, where radio direction finding is used for navigation and emergency location systems.

In many countries of the world, the hunting of hidden amateur transmitters takes on the atmosphere of a sport, as participants wearing jogging togs or track suits dash toward the area where they believe the transmitter is located. The sport is variously known as *fox hunting*, *bunny hunting*, ARDF (Amateur Radio direction finding) or simply transmitter hunting. In North America, most hunting of hidden transmitters is conducted from automobiles, although hunts on foot are gaining popularity.

There are less pleasant RDF applications as well, such as tracking down noise sources or illegal operators from unidentified stations. Jammers of repeaters, traffic nets and other amateur operations can be located with RDF equipment. Or sometimes a stolen amateur rig will be operated by a person who is not familiar with Amateur Radio, and by being lured into making repeated transmissions, the operator unsuspectingly permits himself to be located with RDF equipment. The ability of certain RDF antennas to reject signals from selected directions has also been used to advantage in reducing noise and interference. Through APRS, radio navigation is becoming a popular application of RDF. The locating of downed aircraft is another, and one in which amateurs often lend their skills. Indeed, there are many useful applications for RDF.

Although sophisticated and complex equipment pushing the state of the art has been developed for use by governments and commercial enterprises, relatively simple equipment can be built at home to offer the Radio Amateur an opportunity to RDF. This chapter deals with antennas suitable for that purpose.

RDF by Triangulation

It is impossible, using amateur techniques, to pinpoint the whereabouts of a transmitter from a single receiving location. With a directional antenna you can determine the direction of a signal source, but not how far away it is. To find the distance, you can then travel in the determined direction until you discover the transmitter location. However, that technique can be time consuming and often does not work very well.

A preferred technique is to take at least one additional direction measurement from a second receiving location. Then use a map of the area and plot the bearing or direction measurements as straight lines from points on the map representing the two locations. The approximate location of the transmitter will be indicated by the point where the two bearing lines cross. Even better results can be obtained by taking direction measurements from three locations and using the mapping technique just described. Because absolutely precise bearing measurements are difficult to obtain in practice, the three lines will almost always cross to form a triangle on the map, rather than at a single point. The transmitter will usually be located inside the area represented by the triangle. Additional information on the technique of triangulation and much more on RDF techniques may be found in recent editions of *The ARRL Handbook*.

DIRECTION FINDING SYSTEMS

Required for any RDF system are a directive antenna and a device for detecting the radio signal. In amateur applications the signal detector is usually a transceiver and for convenience it will usually have a meter to indicate signal strength. Unmodified, commercially available portable or mobile receivers are generally quite satisfactory for signal detectors. At very close ranges a simple diode detector and dc microammeter may suffice for the detector.

On the other hand, antennas used for RDF techniques are not generally the types used for normal two-way communications. Directivity is a prime requirement, and here the word *directivity* takes on a somewhat different meaning than is commonly applied to other amateur antennas. Normally we associate directivity with gain, and we think of the ideal antenna pattern as one having a long, thin main lobe. Such a pattern may be of value for coarse measurements in RDF work, but precise bearing measurements are not possible. There is always a spread of a few (or perhaps many) degrees on the *nose* of the lobe, where a shift of antenna bearing produces no detectable change in signal strength. In RDF measure-ments, it is desirable to correlate an exact bearing or compass direction with the position of the antenna. In order to do this as accurately as possible, an antenna exhibiting a *null* in its pattern is used. A null can be very sharp in directivity, to within a half degree or less.

Loop Antennas

A simple antenna for HF RDF work is a small loop tuned to resonance with a capacitor. Several factors must be considered in the design of an RDF loop. The loop must be small in circumference compared with the wavelength. In a single-turn loop, the conductor should be less than 0.08 λ long. For 28 MHz, this represents a length of less than 34 inches (a diameter of approximately 10 inches). Maximum response from the loop antenna is in the plane of the loop, with nulls exhibited at right angles to that plane.

To obtain the most accurate bearings, the loop must be balanced electrostatically with respect to ground. Otherwise, the loop will exhibit two modes of operation. One is the mode of a true loop, while the other is that of an essentially nondirectional vertical antenna of small dimensions. This second mode is called the *antenna effect*. The voltages introduced by the two modes are seldom in phase and may add or subtract, depending upon the direction from which the wave is coming.

The theoretical true loop pattern is illustrated in **Fig 1A**. When properly balanced, the loop exhibits two nulls that are 180° apart. Thus, a single null reading with a small loop antenna will not indicate the exact direction toward the transmitter—only the line along which the transmitter lies. Ways to overcome this ambiguity are discussed later.

When the antenna effect is appreciable and the loop is tuned to resonance, the loop may exhibit little directivity, as shown in Fig 1B. However, by detuning the loop to shift the phasing, a pattern similar to 1C may be obtained. Although this pattern is not symmetrical, it does exhibit a null. Even so, the null may not be as sharp as that obtained with a loop that is well balanced, and it may not be at exact right angles to the plane of the loop.

By suitable detuning, the unidirectional cardioid pattern of Fig 1D may be approached. This adjustment is sometimes used in RDF work to obtain a unidirectional bearing, although there is no complete null in the pattern. A cardioid pattern can also be obtained with a small loop antenna by adding a *sensing element*. Sensing elements are discussed in a later section of this chapter.

An electrostatic balance can be obtained by shielding the loop, as **Fig 2** shows. The shield is represented by the broken lines in the drawing, and eliminates the antenna effect. The response of a well-constructed shielded loop is quite close to the ideal pattern of Fig 1A.

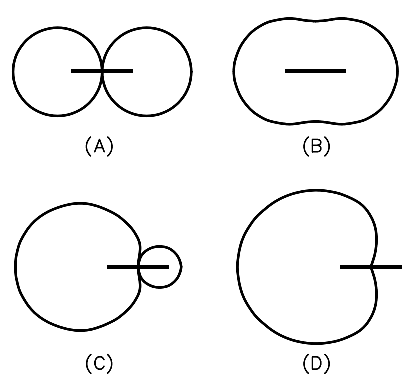


Fig 1—Small-loop field patterns with varying amounts of antenna effect—the undesired response of the loop acting merely as a mass of metal connected to the receiver antenna terminals. The straight lines show the plane of the loop.

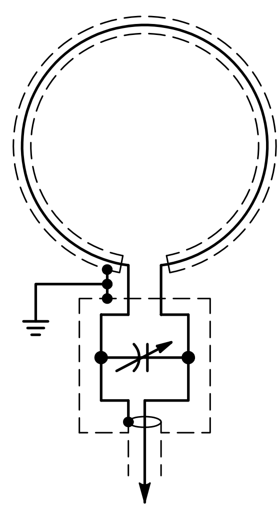


Fig 2—Shielded loop for direction finding. The ends of the shielding turn are not connected, to prevent shielding the loop from magnetic fields. The shield is effective against electric fields.

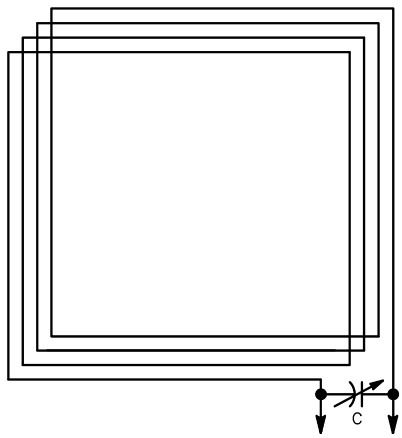


Fig 3—Small loop consisting of several turns of wire. The total conductor length is very much less than a wavelength. Maximum response is in the plane of the loop.

For the low-frequency amateur bands, single-turn loops of convenient physical size for portability are generally found to be unsatisfactory for RDF work. Therefore, multiturn loops are generally used instead. Such a loop is shown in **Fig 3**. This loop may also be shielded, and if the total conductor length remains below 0.08 λ, the directional pattern is that of Fig 1A. A sensing element may also be used with a multiturn loop.

Loop Circuits and Criteria

No single word describes a direction-finding loop of high performance better than *symmetry*. To obtain an undistorted response pattern from this type of antenna, you must build it in the most symmetrical manner possible. The next key word is *balance*. The better the electrical balance, the deeper the loop null and the sharper the maxima.

The physical size of the loop for 7 MHz and below is not of major consequence. A 4-foot diameter loop will exhibit the same electrical characteristics as one which is only an inch or two in diameter. The smaller the loop, however, the lower its efficiency. This is because its aperture samples a smaller section of the wave front. Thus, if you use loops that are very small in terms of a wavelength, you will need preamplifiers to compensate for the reduced efficiency.

An important point to keep in mind about a small loop antenna oriented in a vertical plane is that it is vertically polarized. It should be fed at the bottom for the best null response. Feeding it at one side, rather than at the bottom, will not alter the polarization and will only degrade performance. To obtain horizontal polarization from a small loop, it must be oriented in a horizontal plane, parallel to the earth. In this position the loop response is essentially omnidirectional.

The earliest loop antennas were of the *frame antenna* variety. These were unshielded antennas built on a wooden frame in a rectangular format. The loop conductor could be a single turn of wire (on the larger units) or several turns if the frame was small. Later, shielded versions of the frame antenna became popular, providing electrostatic shielding—an aid to noise reduction from such sources as precipitation static.

Ferrite Rod Antennas

With advances in technology, magnetic-core loop antennas came into use. Their advantage was reduced size, and this appealed especially to the designers of aircraft and portable radios. Most of these antennas contain ferrite bars or cylinders, which provide high inductance and Q with a relatively small number of coil turns.

Magnetic-core antennas consist essentially of turns of wire around a ferrite rod. They are also known as *loopstick* antennas. Probably the best-known example of this type of antenna is that used in small portable AM broadcast receivers. Because of their reduced-size advantage, ferrite-rod antennas are used almost exclusively for portable work at frequencies below 150 MHz.

As implied in the earlier discussion of shielded loops in this chapter, the true loop antenna responds to the magnetic field of the radio wave, and not to the electrical field. The voltage delivered by the loop is proportional to the amount of magnetic flux passing through the coil, and to the number of turns in the coil. The action is much the same as in the secondary winding of a transformer. For a given size of loop, the output voltage can be increased by increasing the flux density, and this is done with a ferrite core of high permeability. A $^1/_2$-inch diameter, 7-inch rod of Q2 ferrite (m_i = 125) is suitable for a loop core from the broadcast band through 10 MHz. For increased output, the turns may be wound on two rods that are taped together, as shown in **Fig 4**. Loopstick antennas for con-

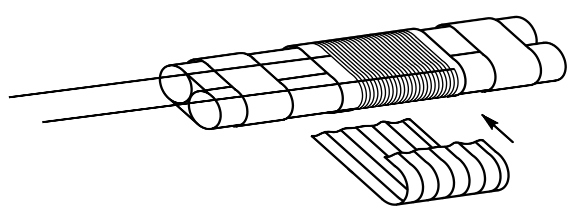


Fig 4—A ferrite-rod or loopstick antenna. Turns of wire may be wound on a single rod, or to increase the output from the loop, the core may be two rods taped together, as shown here. The type of core material must be selected for the intended frequency range of the loop. To avoid bulky windings, fine wire such as #28 or #30 is often used, with larger wire for the leads.

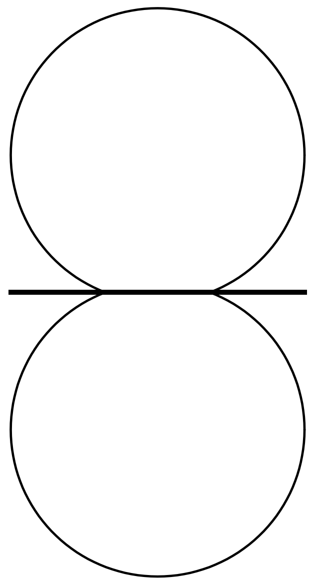


Fig 5—Field pattern for a ferrite rod antenna. The dark bar represents the rod on which the loop turns are wound.

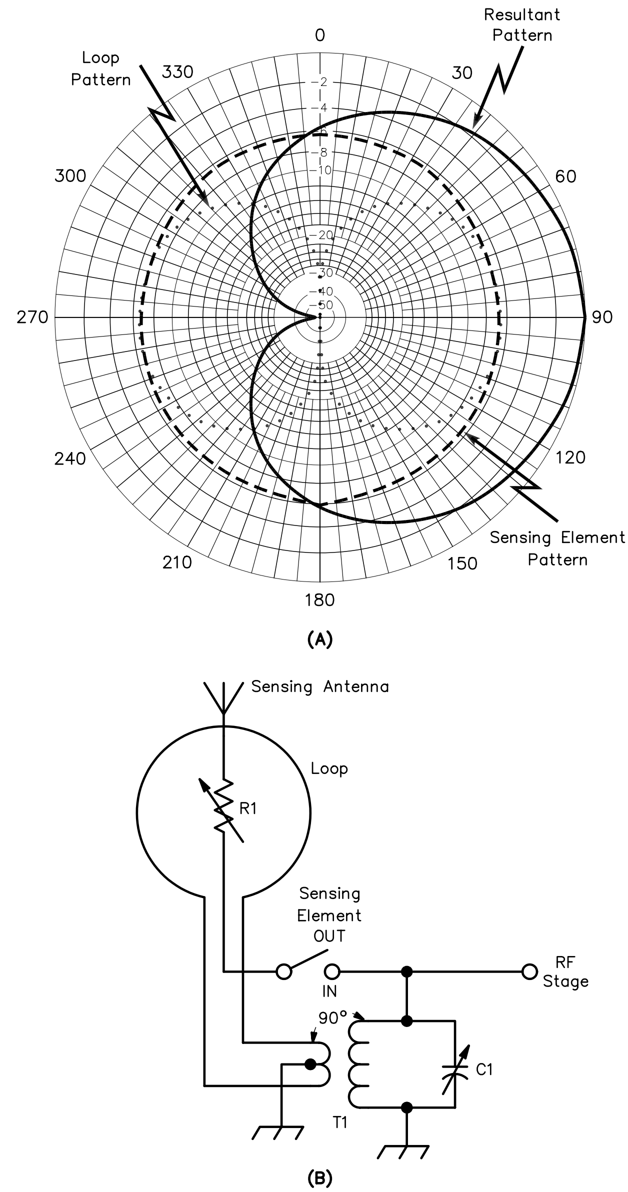


Fig 6—At A, the directivity pattern of a loop antenna with sensing element. At B is a circuit for combining the signals from the two elements. C1 is adjusted for resonance with T1 at the operating frequency.

struction are described later in this chapter.

Maximum response of the loopstick antenna is broadside to the axis of the rod as shown in **Fig 5**, whereas maximum response of the ordinary loop is in a direction at right angles to the plane of the loop. Otherwise, the performances of the ferrite-rod antenna and of the ordinary loop are similar. The loopstick may also be shielded to eliminate the antenna effect, such as with a U-shaped or C-shaped channel of aluminum or other form of *trough*. The length of the shield should equal or slightly exceed the length of the rod.

Sensing Antennas

Because there are two nulls that are 180° apart in the directional pattern of a loop or a loopstick, an ambiguity exists as to which one indicates the true direction of the station being tracked. For example, assume you take a bearing measurement and the result indicates the transmitter is somewhere on a line running approximately east and west from your position. With this single reading, you have no way of knowing for sure if the transmitter is east of you or west of you.

If more than one receiving station takes bearings on a single transmitter, or if a single receiving station takes bearings from more than one position on the transmitter, the ambiguity may be worked out by triangulation, as described earlier. However, it is sometimes desirable to have a pattern with only one null, so there is no question about whether the transmitter in the above example would be east or west from your position.

A loop or loopstick antenna may be made to have a single null if a second antenna element is added. The element is called a *sensing antenna*, because it gives an added sense of direction to the loop pattern. The second element must be omnidirectional, such as a short vertical. When the signals from the loop and the vertical element are combined with a 90° phase shift between the two, a cardioid pattern results. The development of the pattern is shown in **Fig 6A**.

Fig 6B shows a circuit for adding a sensing antenna to a loop or loopstick. R1 is an internal adjustment and is used to set the level of the signal from the sensing antenna. For the best null in the composite pattern, the signals from the loop and the sensing antenna must be of equal amplitude, so R1 is adjusted experimentally during setup. In practice, the null of the cardioid is not as sharp as that of the loop, so the usual measurement procedure is to first use the loop alone to obtain a precise bearing reading, and then to add the sensing antenna and take another reading to resolve the ambiguity. (The null of the cardioid is 90° away from the nulls of the loop.) For this reason, provisions are usually made for switching the sensing element in an out of operation.

PHASED ARRAYS

Phased arrays are also used in amateur RDF work. Two general classifications of phased arrays are end-fire and broadside configurations. Depending on the spacing and phasing of the elements, end-fire patterns may exhibit a null in one direction along the axis of the elements. At the same time, the response is maximum off the other end of the axis, in the opposite direction from the null. A familiar arrangement is two elements spaced $1/4$ λ apart and fed 90° out of phase. The resultant pattern is a *cardioid*, with the null in the direction of the leading element. Other arrangements of spacing and phasing for an end-fire array are also suitable for RDF work. One of the best known is the *Adcock array*, discussed in the next section.

Broadside arrays are inherently bidirectional, which means there are always at least two nulls in the pattern. Ambiguity therefore exists in the true direction of the transmitter, but depending on the application, this may be no handicap. Broadside arrays are seldom used for amateur RDF applications however.

The Adcock Antenna

Loops are adequate in RDF applications where only the ground wave is present. The performance of an RDF system for sky-wave reception can be improved by the use of an Adcock antenna, one of the most popular types of end-fire phased arrays. A basic version is shown in **Fig 7**.

This system was invented by F. Adcock and patented in 1919. The array consists of two vertical elements fed 180° apart, and mounted so the system may be rotated. Element spacing is not critical, and may be in the range from 0.1 to 0.75 λ. The two elements must be of identical lengths, but need not be self-resonant. Elements that are shorter than resonant are commonly used. Because neither the element spacing nor the length is critical in terms of wavelengths, an Adcock array may be operated over more than one amateur band.

The response of the Adcock array to vertically polarized waves is similar to a conventional loop, and the directive pattern is essentially the same. Response of the array to a horizontally polarized wave is considerably different from that of a loop, however. The currents induced in the horizontal members tend to balance out regardless of the orientation of the antenna. This effect has been verified in practice, where good nulls were obtained with an experimental Adcock under sky-wave conditions. The same circumstances produced poor nulls with small loops (both conventional and ferrite-loop models).

Generally speaking, the Adcock antenna has attractive properties for amateur RDF applications. Unfortunately, its portability leaves something to be desired, making it more suitable to fixed or semi-portable applications. While a metal support for the mast and boom could be used, wood, PVC or fiberglass are preferable because they are nonconductors and would therefore cause less pattern distortion.

Since the array is balanced, an antenna tuner is required to match the unbalanced input of a typical receiver. **Fig 8** shows a suitable link-coupled network. C2 and C3 are null-balancing capacitors. A low-power signal source is placed some distance from the Adcock

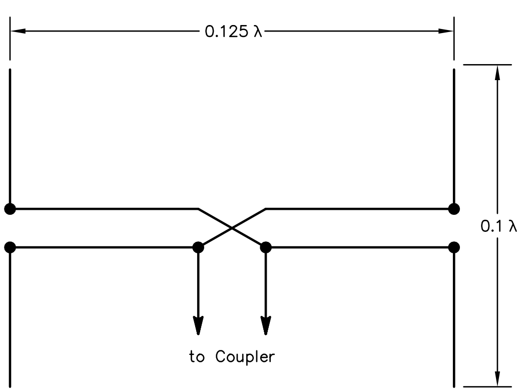


Fig 7—A simple Adcock antenna.

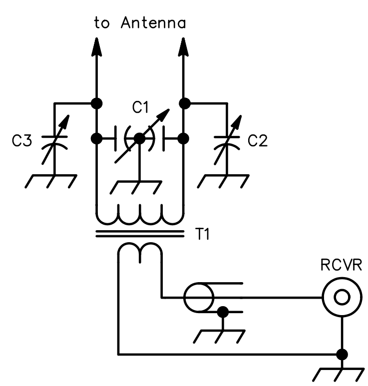


Fig 8—A suitable coupler for use with the Adcock antenna.

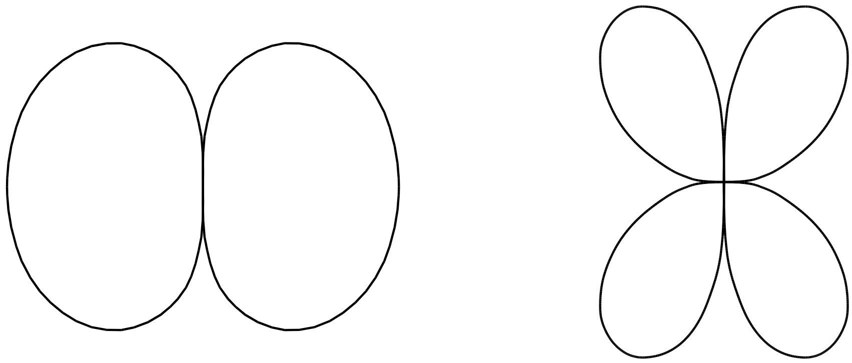


Fig 9—At A, the pattern of the Adcock array with an element spacing of 1/2 wavelength. In these plots the elements are aligned with the horizontal axis. As the element spacing is increased beyond 3/4 wavelength, additional nulls develop off the ends of the array, and at a spacing of 1 wavelength the pattern at B exists. This pattern is unsuitable for RDF work.

antenna and broadside to it. C2 and C3 are then adjusted until the deepest null is obtained. The tuner can be placed below the wiring-harness junction on the boom. Connection can be made by means of a short length of 300-Ω twin-lead.

The radiation pattern of the Adcock is shown in **Fig 9A**. The nulls are in directions broadside to the array, and become sharper with greater element spacings. However, with an element spacing greater than 0.75 λ, the pattern begins to take on additional nulls in the directions off the ends of the array axis. At a spacing of 1 λ the pattern is that of Fig 9B, and the array is unsuitable for RDF applications.

Short vertical monopoles are often used in what is sometimes called the *U-Adcock*, so named because the elements with their feeders take on the shape of the letter U. In this arrangement the elements are worked against the earth as a ground or counterpoise. If the array is used only for reception, earth losses are of no great consequence. Short, elevated vertical dipoles are also used in what is sometimes called the *H-Adcock*.

The Adcock array, with two nulls in its pattern, has the same ambiguity as the loop and the loopstick. Adding a sensing element to the Adcock array has not met with great success. Difficulties arise from mutual coupling between the array elements and the sensing element, among other things. Because Adcock arrays are used primarily for fixed-station applications, the ambiguity presents no serious problem. The fixed station is usually one of a group of stations in an RDF network.

LOOPS VERSUS PHASED ARRAYS

Although loops can be made smaller than suitable phased arrays for the same frequency of operation, the phased arrays are preferred by some for a variety of reasons. In general, sharper nulls can be obtained with phased arrays, but this is also a function of the care used in constructing and feeding the individual antennas, as well as of the size of the phased array in terms of wavelengths. The primary constructional consideration is the shielding and balancing of the feed line against unwanted signal pickup, and the balancing of the antenna for a symmetrical pattern.

Loops are not as useful for skywave RDF work because of random polarization of the received signal. Phased arrays are somewhat less sensitive to propagation effects, probably because they are larger for the same frequency of operation and therefore offer some space diversity. In general, loops and loopsticks are used for mobile and portable operation, while phased arrays are used for fixed-station operation. However, phased arrays are used successfully above 144 MHz for portable and mobile RDF work. Practical examples of both types of antennas are presented later in this chapter.

THE GONIOMETER

Most fixed RDF stations for government and commercial work use antenna arrays of stationary elements, rather than mechanically rotatable arrays. This has been true since the earliest days of radio. The early-day device that permits finding directions without moving the elements is called a *radiogoniometer*, or simply a *goniometer*. Various types of goniometers are still used today in many installations, and offer the amateur some possibilities.

The early style of goniometer is a special form of RF transformer, as shown in **Fig 10**. It consists of two fixed coils mounted at right angles to one another. Inside the fixed coils is a movable coil, not shown in Fig 10 to

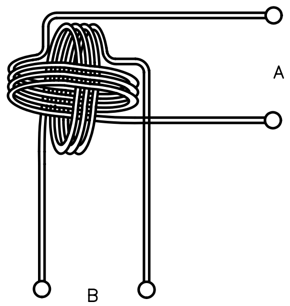


Fig 10—An early type of goniometer that is still used today in some RDF applications. This device is a special type of RF transformer that permits a movable coil in the center (not shown here) to be rotated and determine directions even though the elements are stationary.

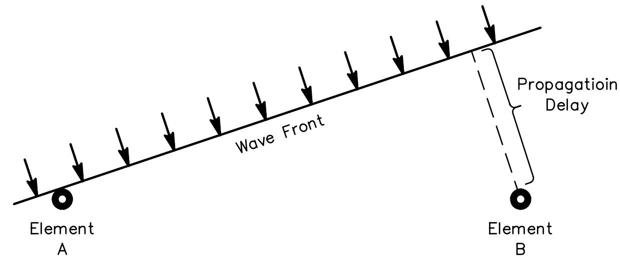


Fig 11—This diagram illustrates one technique used in electronic beam forming. By delaying the signal from element A by an amount equal to the propagation delay, the two signals may be summed precisely in phase, even though the signal is not in the broadside direction. Because this time delay is identical for all frequencies, the system is not frequency sensitive.

avoid cluttering the diagram. The pairs of connections marked A and B are connected respectively to two elements in an array, and the output to the detector or receiver is taken from the movable coil. As the inner coil is rotated, the coupling to one fixed coil increases while that to the other decreases. Both the amplitude and the phase of the signal coupled into the pickup winding are altered with rotation in a way that corresponds to actually rotating the array itself. Therefore, the rotation of the inner coil can be calibrated in degrees to correspond to bearing angles from the station location.

In the early days of radio, the type of goniometer just described saw frequent use with fixed Adcock arrays. A refinement of that system employed four Adcock elements, two arrays at right angles to each other. With a goniometer arrangement, RDF measurements could be taken in all compass directions, as opposed to none off the ends of a two-element fixed array. However, resolution of the 4-element system was not as good as with a single pair of elements, probably because of mutual coupling among the elements. To overcome this difficulty a few systems of eight elements were installed.

Various other types of goniometers have been developed over the years, such as commutator switching to various elements in the array. A later development is the diode switching of capacitors to provide a commutator effect. As mechanical action has gradually been replaced with electronics to "rotate" stationary elements, the word goniometer is used less frequently these days. However, it still appears in many engineering reference texts. The more complex electronic systems of today are called *beam-forming networks*.

Electronic Antenna Rotation

With an array of many fixed elements, beam rotation can be performed electronically by sampling and combining signals from various individual elements in the array. Contingent upon the total number of elements in the system and their physical arrangement, almost any desired antenna pattern can be formed by summing the sampled signals in appropriate amplitude and phase relationships. Delay networks are used for some of the elements before the summation is performed. In addition, attenuators may be used for some elements to develop patterns such as from an array with binomial current distribution.

One system using these techniques is the *Wullenweber* antenna, employed primarily in government and military installations. The Wullenweber consists of a very large number of elements arranged in a circle, usually outside of (or in front of) a circular reflecting screen. Depending on the installation, the circle may be anywhere from a few hundred feet to more than a quarter of a mile in diameter. Although the Wullenweber is not one that would be constructed by an amateur, some of the techniques it uses may certainly be applied to Amateur Radio.

For the moment, consider just two elements of a Wullenweber antenna, shown as A and B in **Fig 11**. Also shown is the wavefront of a radio signal arriving from a distant transmitter. As drawn, the wavefront strikes element A first, and must travel somewhat farther before it strikes element B. There is a finite time delay before the wavefront reaches element B.

The propagation delay may be measured by delaying the signal received at element A before summing it with that from element B. If the two signals are combined directly, the amplitude of the resultant signal will be maximum when the delay for element A exactly equals the propagation delay. This results in an in-phase condition at the summation point. Or if one of the signals is inverted and the two are summed, a null will exist when the element-A delay equals the propagation delay; the signals will combine in a 180° out-of-phase relationship. Either way, once the time delay is known, it may be converted to distance. Then the direction from which the wave is arriving may be determined by trigonometry.

By altering the delay in small increments, the peak of the antenna lobe (or the null) can be steered in azimuth. This is true without regard to the frequency of the incoming wave. Thus, as long as the delay is less than the period of one RF cycle, the system is not frequency sensitive, other than for the frequency range that may be covered satisfactorily by the array elements themselves. Surface acoustic wave (SAW) devices or lumped-constant networks can be used for delay lines in such systems if the system is used only for receiving. Rolls of coaxial cable of various lengths are used in installations for transmitting. In this case, the lines are considered for the time delay they provide, rather than as simple phasing lines. The difference is that a phasing line is ordinarily designed for a single frequency (or for an amateur band), while a delay line offers essentially the same time delay at all frequencies.

By combining signals from other Wullenweber elements appropriately, the broad beamwidth of the pattern from the two elements can be narrowed, and unwanted sidelobes can be suppressed. Then, by electronically switching the delays and attenuations to the various elements, the beam so formed can be rotated around the compass. The package of electronics designed to do this, including delay lines and electronically switched attenuators, is the beam-forming network. However, the Wullenweber system is not restricted to forming a single beam. With an isolation amplifier provided for each element of the array, several beam-forming networks can be operated independently. Imagine having an antenna system that offers a dipole pattern, a rhombic pattern, and a Yagi beam pattern, all simultaneously and without frequency sensitivity. One or more may be rotating while another is held in a particular direction. The Wullenweber was designed to fulfill this type of requirement.

One feature of the Wullenweber antenna is that it can operate 360° around the compass. In many government installations, there is no need for such coverage, as the areas of interest lie in an azimuth sector. In such cases an in-line array of elements with a backscreen or curtain reflector may be installed broadside to the center of the sector. By using the same techniques as the Wullenweber, the beams formed from this array may be slewed left and right across the sector. The maximum sector width available will depend on the installation, but beyond 70° to 80° the patterns begin to deteriorate to the point that they are unsatisfactory for precise RDF work.

RDF SYSTEM CALIBRATION AND USE

Once an RDF system is initially assembled, it should be calibrated or checked out before actually being put into use. Of primary concern is the balance or symmetry of the antenna pattern. A lop-sided figure-8 pattern with a loop, for example, is undesirable; the nulls are not 180° apart, nor are they at exact right angles to the plane of the loop. If you didn't know this fact in actual RDF work, measurement accuracy would suffer.

Initial checkout can be performed with a low-powered transmitter at a distance of a few hundred feet. It should be within visual range and must be operating into a vertical antenna. (A quarter-wave vertical or a loaded whip is quite suitable.) The site must be reasonably clear of obstructions, especially steel and concrete or brick buildings, large metal objects, nearby power lines, and so on. If the system operates above 30 MHz, you should also avoid trees and large bushes. An open field makes an excellent site.

The procedure is to find the transmitter with the RDF equipment as if its position were not known, and compare the RDF null indication with the visual path to the transmitter. For antennas having more than one null, each null should be checked.

If imbalance is found in the antenna system, there are two options available. One is to correct the imbalance. Toward this end, pay particular attention to the feed line. Using a coaxial feeder for a balanced antenna invites an asymmetrical pattern, unless an effective balun is used. A balun is not necessary if the loop is shielded, but an asymmetrical pattern can result with misplacement of the break in the shield itself. The builder may also find that the presence of a sensing antenna upsets the balance slightly, due to mutual coupling. Experiment with its position with respect to the main antenna to correct the error. You will also note that the position of the null shifts by 90° as the sensing element is switched in and out, and the null is not as deep. This is of little concern, however, as the intent of the sensing antenna is only to resolve ambiguities. The sensing element should be switched out when accuracy is desired.

The second option is to accept the imbalance of the antenna and use some kind of indicator to show the true directions of the nulls. Small pointers, painted marks on the mast, or an optical sighting system might be used. Sometimes the end result of the calibration procedure will be a compromise between these two options, as a perfect electrical balance may be difficult or impossible to attain.

The discussion above is oriented toward calibrating portable RDF systems. The same general suggestions apply if the RDF array is fixed, such as an Adcock. However, it won't be possible to move it to an open field. Instead, the array must be calibrated in its intended operating position through the use of a portable or mobile transmitter. Because of nearby obstructions or reflecting objects, the null in the pattern may not appear to indicate the precise direction of the transmitter. Do not confuse this with imbalance in the RDF array. Check for imbalance by rotating the array 180° and comparing readings.

Once the balance is satisfactory, you should make a table of bearing errors noted in different compass directions. These error values should be applied as corrections when actual measurements are made. The mobile or por-

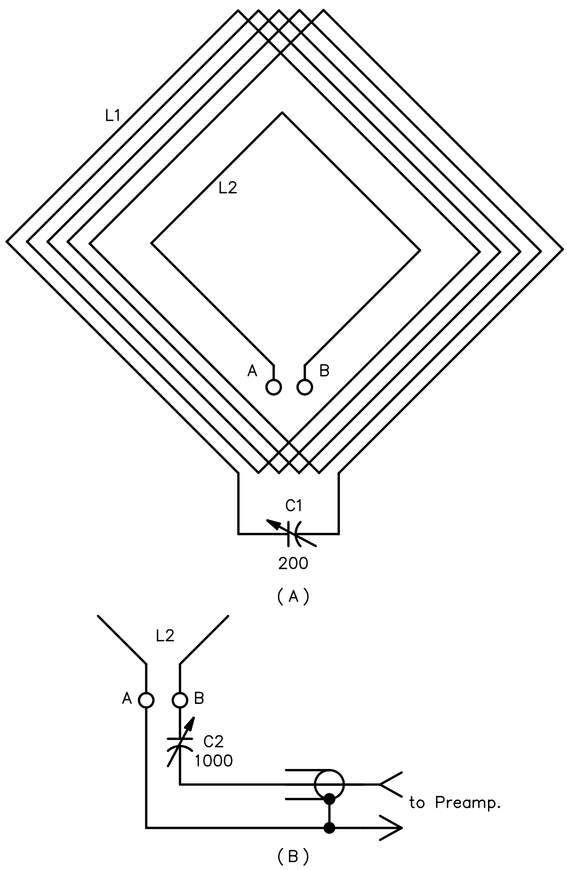


Fig 12—A multiturn frame antenna is shown at A. L2 is the coupling loop. The drawing at B shows how L2 is connected to a preamplifier.

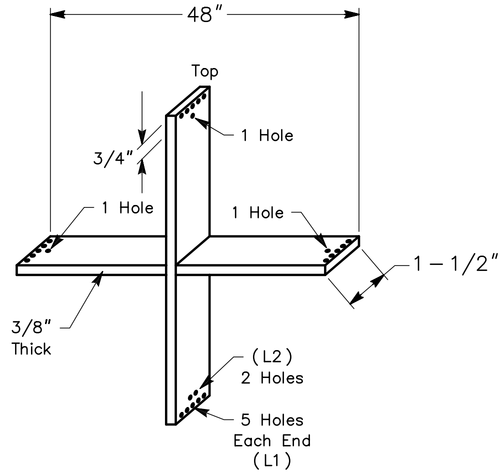


Fig 13—A wooden frame can be used to contain the wire of the loop shown in Fig 12.

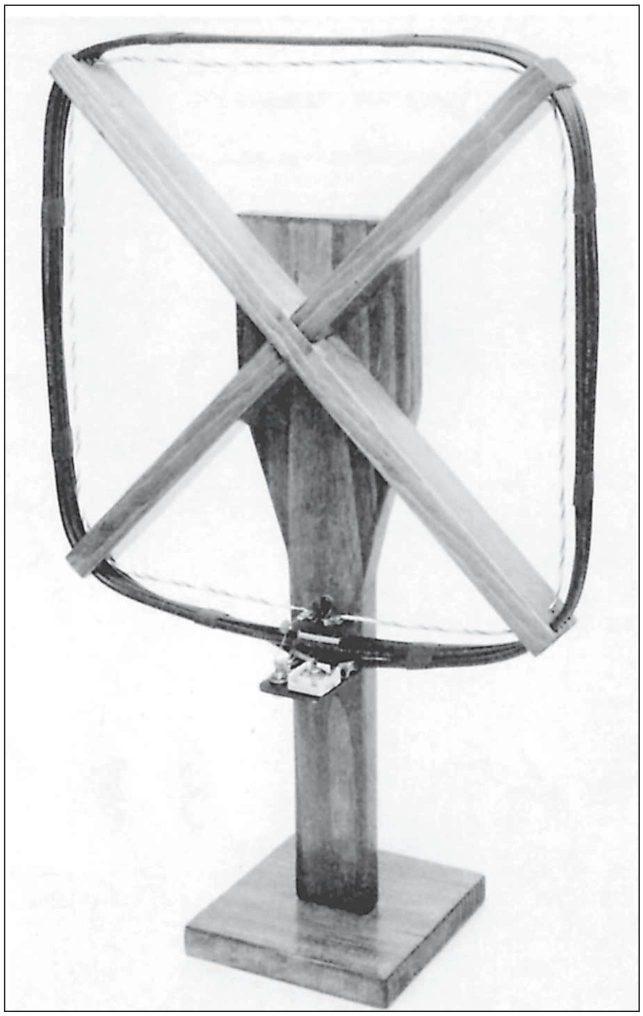


Fig 14—An assembled table-top version of the electrostatically shielded loop. RG-58 cable is used in its construction.

table transmitter should be at a distance of two or three miles for these measurements, and should be in as clear an area as possible during transmissions. The idea is to avoid conduction of the signal along power lines and other overhead wiring from the transmitter to the RDF site. Of course the position of the transmitter must be known accurately for each transmission.

FRAME LOOPS

It was mentioned earlier that the earliest style of receiving loops was the frame antenna. If carefully constructed, such an antenna performs well and can be built at low cost. **Fig 12** illustrates the details of a practical frame type of loop antenna. This antenna was designed by Doug DeMaw, W1FB, and described in *QST* for July 1977. (See the Bibliography at the end of this chapter.) The circuit in Fig 12A is a 5-turn system tuned to resonance by C1. If the layout is symmetrical, good balance should be obtained. L2 helps to achieve this objective by eliminating the need for direct coupling to the feed terminals of L1. If the loop feed were attached in parallel with C1, a common practice, the chance for imbalance would be considerable.

L2 can be situated just inside or slightly outside of L1; a 1-inch separation works nicely. The receiver or preamplifier can be connected to terminals A and B of L2, as shown in Fig 12B. C2 controls the amount of coupling between the loop and the preamplifier. The lighter the coupling, the higher is the loop Q, the narrower is the frequency response, and the greater is the gain requirement from the preamplifier. It should be noted that no attempt is being made to match the extremely low loop impedance to the preamplifier.

A supporting frame for the loop of Fig 12 can be constructed of wood, as shown in **Fig 13**. The dimensions given are for a 1.8-MHz frame antenna. For use on 75 or 40 meters, L1 of Fig 12A will require fewer turns, or the size of the wooden frame should be made somewhat smaller than that of Fig 13.

SHIELDED FRAME LOOPS

If electrostatic shielding is desired, the format shown in **Fig 14** can be adopted. In this example, the loop conductor and the single-turn coupling loop are made from RG-58 coaxial cable. The number of loop turns should be sufficient to resonate with the tuning capacitor at the operating frequency. Antenna resonance can be checked by first connecting C1 (Fig 12A) and setting it at midrange. Then connect a small 3-turn coil to the loop feed terminals, and couple to it with a dip meter. Just remember that the pickup coil will act to lower the frequency slightly from actual resonance.

In the antenna photographed for Fig 14, the 1-turn coupling loop was made of #22 plastic-insulated wire. However, electrostatic noise pickup occurs on such a coupling loop, noise of the same nature that the shield on the main loop prevents. This can be avoided by using RG-58 for the coupling loop. The shield of the coupling loop should be opened for about 1 inch at the top, and each end of the shield grounded to the shield of the main loop.

Larger single-turn frame loops can be fashioned from aluminum-jacketed Hardline, if that style of coax is available. In either case, the shield conductor must be opened at the electrical center of the loop, as shown in **Fig 15** at A and B. The design example is for 1.8-MHz operation.

To realize the best performance from an electrostatically shielded loop antenna, you must operate it near to and directly above an effective ground plane. An automobile roof (metal) qualifies nicely for small shielded loops. For fixed-station use, a chicken-wire ground screen can be placed below the antenna at a distance of 1 to 6 feet.

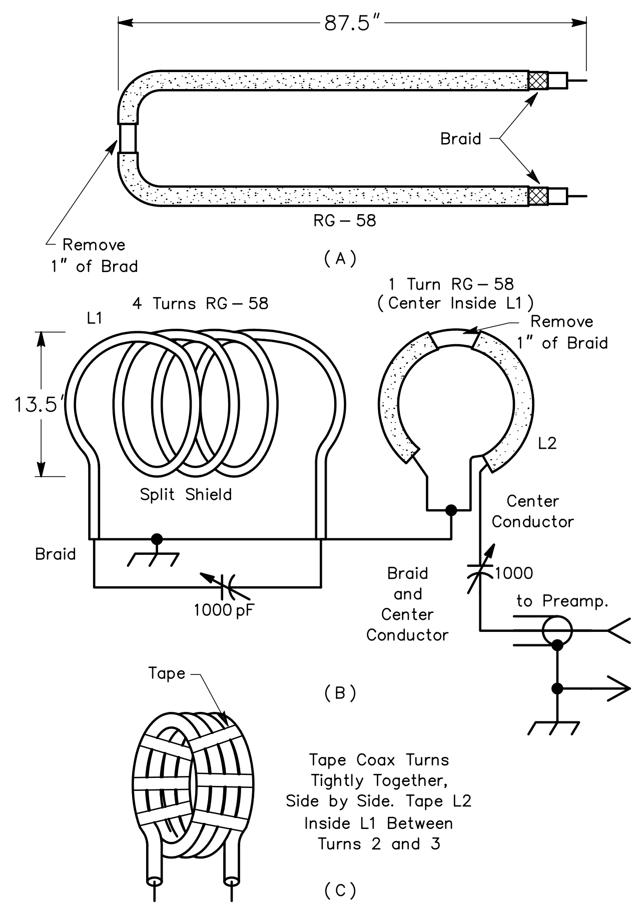


Fig 15—Components and assembly details of the shielded loop shown in Fig 14.

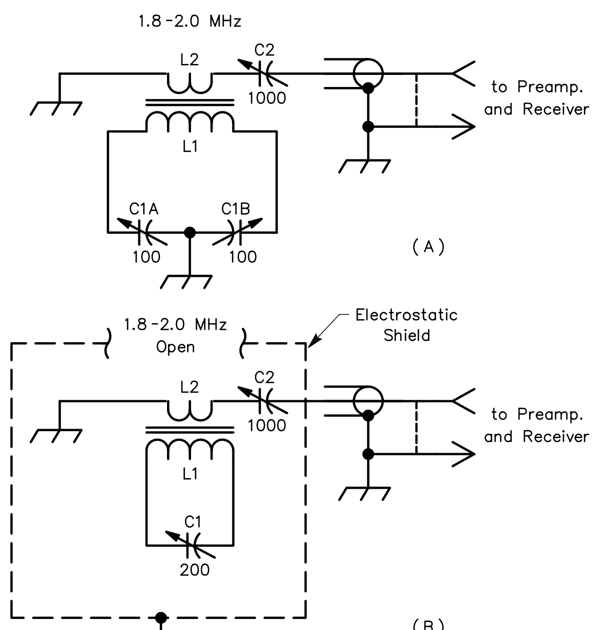


Fig 16—At A, the diagram of a ferrite loop. C1 is a dual-section air-variable capacitor. The circuit at B shows a rod loop contained in an electrostatic shield channel (see text). A suitable low-noise preamplifier is shown in Fig 19.

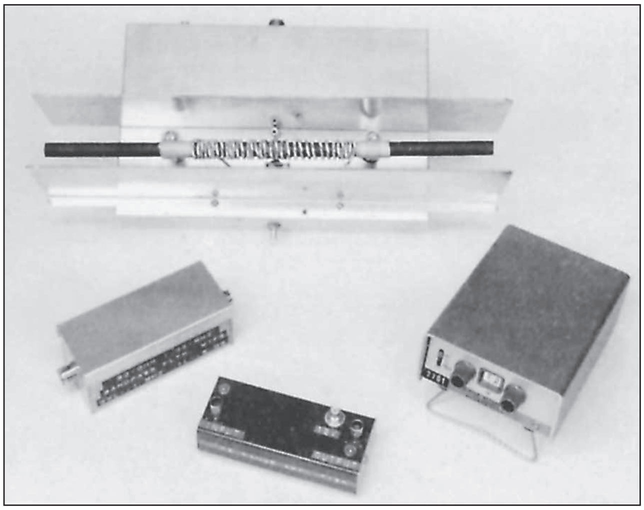


Fig 17—The assembly at the top of the picture is a shielded ferrite-rod loop for 160 meters. Two rods have been glued end to end (see text). The other units in the picture are a low-pass filter (lower left), broadband preamplifier (lower center) and a Tektronix step attenuator (lower right). These were part of the test setup used when the antenna was evaluated.

FERRITE-CORE LOOPS

Fig 16 contains a diagram for a rod loop (loopstick antenna). This antenna was also designed by Doug DeMaw, W1FB, and described in *QST* for July 1977. The winding (L1) has the appropriate number of turns to permit resonance with C1 at the operating frequency. L1 should be spread over approximately 1/3 of the core center. Litz wire will yield the best Q, but Formvar magnet wire can be used if desired. A layer of 3M Company glass tape (or Mylar tape) is recommended as a covering for the core before adding the wire. Masking tape can be used if nothing else is available.

L2 functions as a coupling link over the exact center of L1. C1 is a dual-section variable capacitor, although a differential capacitor might be better toward obtaining optimum balance. The loop Q is controlled by means of C2, which is a mica-compression trimmer.

Electrostatic shielding of rod loops can be effected by centering the rod in a U-shaped aluminum, brass or copper channel, extending slightly beyond the ends of the rod loop (1 inch is suitable). The open side (top) of the channel can't be closed, as that would constitute a shorted turn and render the antenna useless. This can be proved by shorting across the center of the channel with a screwdriver blade when the loop is tuned to an incoming signal. The shield-braid gap in the coaxial loop of Fig 15 is maintained for the same reason.

Fig 17 shows the shielded rod loop assembly. This antenna was developed experimentally for 160 meters and uses two 7-inch ferrite rods, glued together end-to-end with epoxy cement. The longer core resulted in improved sensitivity for weak-signal reception. The other items in the photograph were used during the evaluation tests and are not pertinent to this discussion. This loop and the frame loop discussed in the previous section have bidirectional nulls, as shown in Fig 1A.

Obtaining a Cardioid Pattern

Although the bidirectional pattern of loop antennas

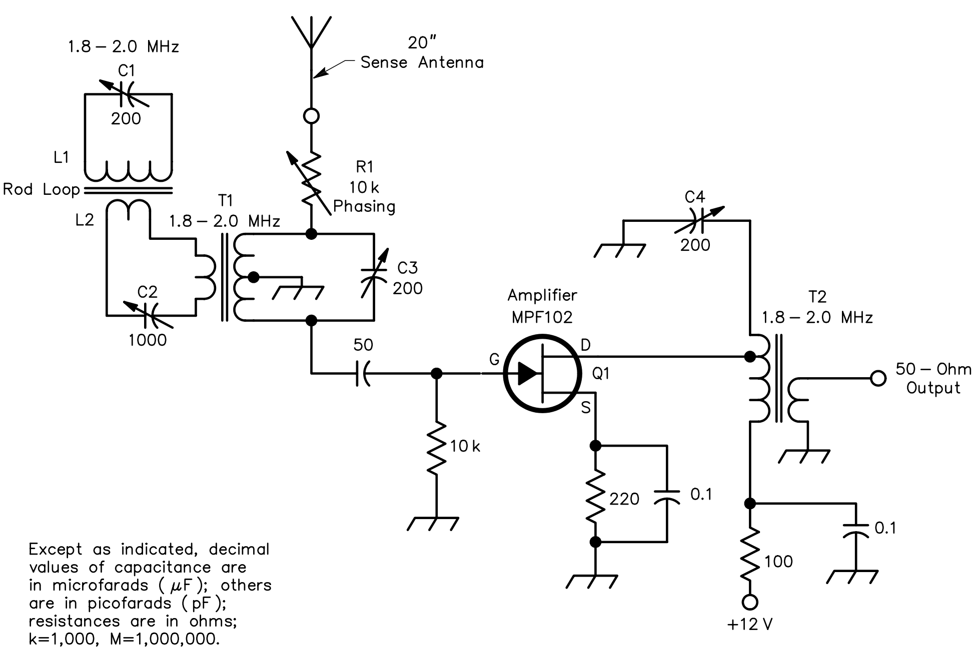


Fig 18—Schematic diagram of a rod-loop antenna with a cardioid response. The sensing antenna, phasing network and a preamplifier are shown also. The secondary of T1 and the primary of T2 are tuned to resonance at the operating frequency of the loop. T-68-2 to T-68-6 Amidon toroid cores are suitable for both transformers. Amidon also sells ferrite rods for this type of antenna.

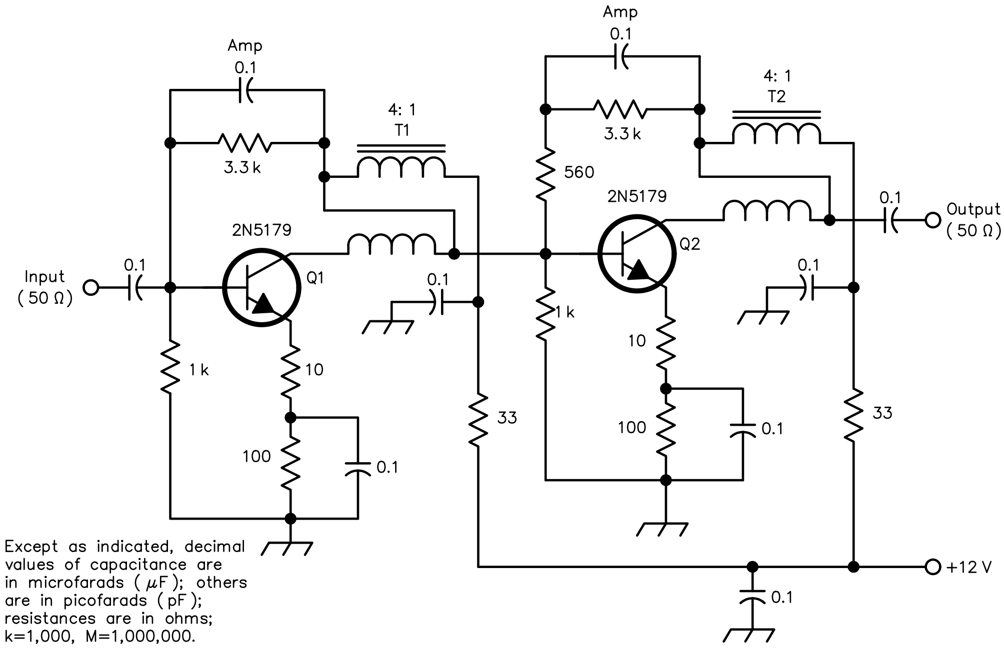


Fig 19—Schematic diagram of a two-stage broadband amplifier patterned after a design by Wes Hayward, W7ZOI. T1 and T2 have a 4:1 impedance ratio and are wound on FT-50-61 toroid cores (Amidon) which have a μ_i of 125. They contain 12 turns of #24 enamel wire, bifilar wound. The capacitors are disc ceramic. This amplifier should be built on double-sided circuit board for best stability.

can be used effectively in tracking down signal sources by means of triangulation, an essentially unidirectional loop response will help to reduce the time spent finding the fox. Adding a sensing antenna to the loop is simple to do, and it will provide the desired cardioid response. The theoretical pattern for this combination is shown in Fig 1D.

Fig 18 shows how a sensing element can be added to a loop or loopstick antenna. The link from the loop is connected by coaxial cable to the primary of T1, which is a tuned toroidal transformer with a split secondary winding. C3 is adjusted for peak signal response at the frequency of interest (as is C4), then R1 is adjusted for minimum back response of the loop. It will be necessary to readjust C3 and R1 several times to compensate for the interaction of these controls. The adjustments are repeated until no further null depth can be obtained. Tests at ARRL Headquarters showed that null depths as great as 40 dB could be obtained with the circuit of Fig 18 on 75 meters. A near-field weak-signal source was used during the tests.

The greater the null depth, the lower the signal output from the system, so plan to include a preamplifier with 25 to 40 dB of gain. Q1 shown in Fig 18 will deliver approximately 15 dB of gain. The circuit of **Fig 19** can be used following T2 to obtain an additional 24 dB of gain. In the interest of maintaining a good noise figure, even at 1.8 MHz, Q1 should be a low-noise device. A 2N4416, an MPF102, or a 40673 MOSFET would be satisfactory. The sensing antenna can be mounted 6 to 15 inches from the loop. The vertical whip need not be more than 12 to 20 inches long. Some experimenting may be necessary in order to obtain the best results. Optimization will also change with the operating frequency of the antenna.

A SHIELDED LOOP WITH SENSING ANTENNA FOR 28 MHz

Fig 20 shows the construction and mounting of a simple shielded 10-meter loop. The loop was designed by Loren Norberg, W9PYG, and described in *QST* for April 1954. (See the Bibliography at the end of this chapter.) It is made from an 18-inch length of RG-11 coax (either solid or foam dielectric) secured to an aluminum box of any convenient size, with two coaxial cable hoods (Amphenol 83-1HP). The outer shield must be broken at the exact center. C1 is a 25-pF variable capacitor, and is connected in parallel with a 33-pF fixed mica padder capacitor, C3. C1 must be tuned to the desired frequency while the loop is connected to the receiver in the same way as it will be used for RDF. C2 is a small differential capacitor used to provide electrical symmetry. The lead-in to the receiver is 67 inches of RG-59 (82 inches if the cable has a foamed dielectric).

The loop can be mounted on the roof of the car with a rubber suction cup. The builder might also fabricate some kind of bracket assembly to mount the loop temporarily in the window opening of the automobile, allowing for loop rotation. Reasonably true bearings may be obtained through the windshield when the car is pointed in the direction of the hidden transmitter. More accurate bearings may be obtained with the loop held out the window and the signal coming toward that side of the car.

Sometimes the car broadcast antenna may interfere with accurate bearings. Disconnecting the antenna from the broadcast receiver may eliminate this trouble.

Sensing Antenna

A sensing antenna can be added to Norberg's loop above to determine which of the two directions indicated by the loop is the correct one. Add a phono jack to the top of the aluminum case shown in Fig 20. The insulated center terminal of the jack should be connected to the side of the tuning capacitors that is common to the center conductor of the RG-59 coax feed line. The jack then takes a short vertical antenna rod of the diameter to fit the jack, or a piece of #12 or #14 solid wire may be soldered to the center pin of a phono plug for insertion in the jack. The sensing antenna can be plugged in as needed. Starting with a length of about four times the loop diameter, the length of the sensing antenna should be pruned until the pattern is similar to that of Fig 1D.

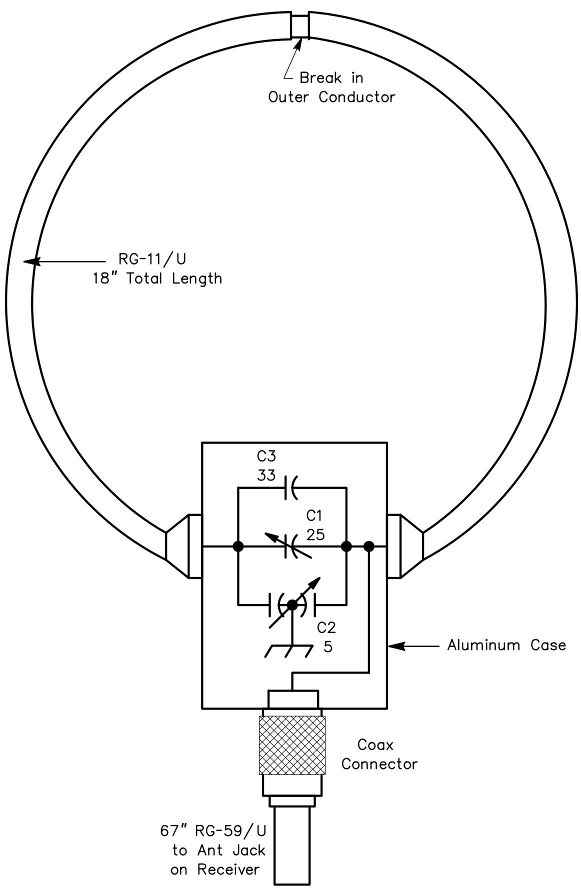


Fig 20—Sketch showing the constructional details of the 28-MHz RDF loop. The outer braid of the coax loop is broken at the center of the loop. The gap is covered with waterproof tape, and the entire assembly is given a coat of acrylic spray.

THE SNOOP LOOP—FOR CLOSE-RANGE HF RDF

Picture yourself on a hunt for a hidden 28-MHz transmitter. The night is dark, very dark. After you take off at the start of the hunt, heading in the right direction, the signal gets stronger and stronger. Your excitement increases with each additional S unit on the meter. You follow your loop closely, and it is working perfectly. You're getting out of town and into the countryside. The roads are unfamiliar. Now the null is beginning to swing rather rapidly, showing that you are getting close.

Suddenly the null shifts to give a direction at right angles to the car. With your flashlight you look carefully across the deep ditch beside the road and into the dark field where you know the transmitter is hidden. There are no roads into the field as far as you can see in either direction. You dare not waste miles driving up and down the road looking for an entrance, for each tenth of a mile counts. But what to do?—Your HF transceiver is mounted in your car and requires power from your car battery.

In a brief moment your decision is made. You park

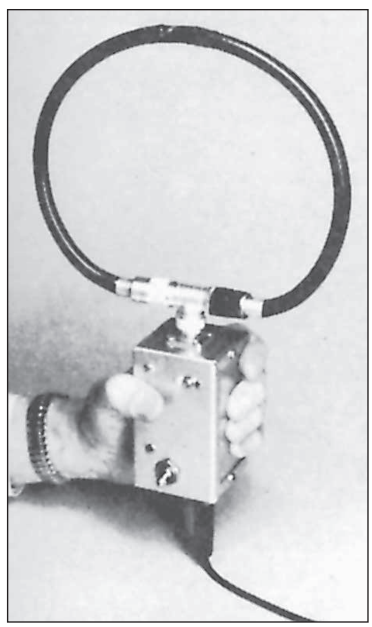


Fig 21—The box containing the detector and amplifier is also the "handle" for the Snoop Loop. The loop is mounted with a coax T as a support, a convenience but not an essential part of the loop assembly. The loop tuning capacitor is screwdriver adjusted. The on-off switch and the meter sensitivity control may be mounted on the bottom.

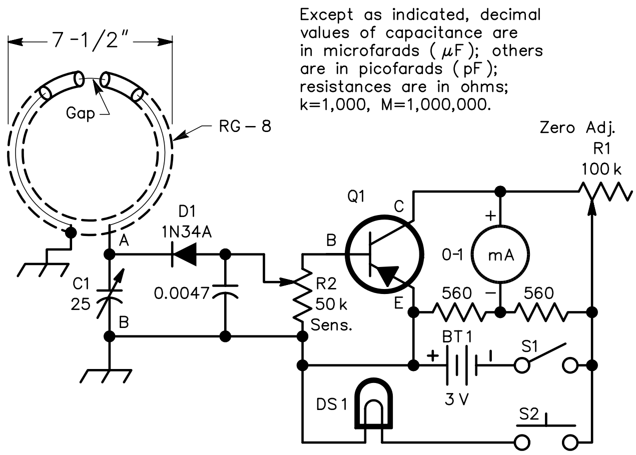


Fig 22—The Snoop Loop circuit for 28-MHz operation. The loop is a single turn of RG-8 inner conductor, the outer conductor being used as a shield. Note the gap in the shielding; about a 1-inch section of the outer conductor should be cut out. Refer to Fig 23 for alternative connection at points A and B for other frequencies of operation.

BT1—Two penlight cells.
C1—25-pF midget air padder.
D1—Small-signal germanium diode such as 1N34A or equiv.
DS1—Optional 2-cell penlight lamp for meter illumination, such as no. 222.
Q1—PNP transistor such as ECG102 or equiv.
R1—100-kΩ potentiometer, linear taper. May be PC-mount style.
R2—50-kΩ potentiometer, linear taper.
S1—SPST toggle.
S2—Optional momentary push for illuminating meter.

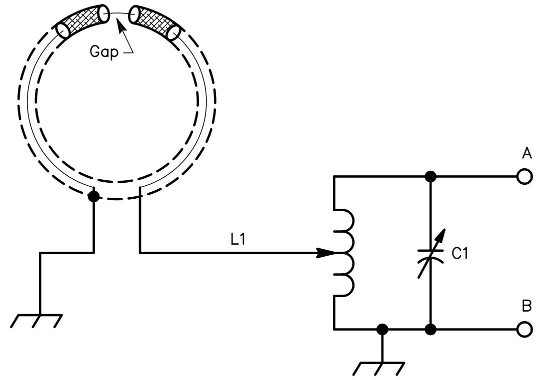


Fig 23—Input circuit for lower frequency bands. Points A and B are connected to corresponding points in the circuit of Fig 22, substituting for the loop and C1 in that circuit. L1-C1 should resonate within the desired amateur band, but the L/C ratio is not critical. After construction is completed, adjust the position of the tap on L1 for maximum signal strength. Instead of connecting the RDF loop directly to the tap on L1, a length of low impedance line may be used between the loop and the tuned circuit, L1-C1.

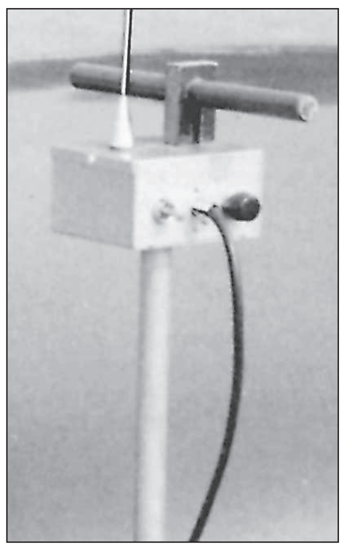


Fig 24—Unidirectional 3.5-MHz RDF using ferrite-core loop with sensing antenna. Adjustable components of the circuit are mounted in the aluminum chassis supported by a short length of tubing.

beside the road, take your flashlight, and plunge into the veldt in the direction your loop null clearly indicated. But after taking a few steps, you're up to your armpits in brush and can't see anything forward or backward. You stumble on in hopes of running into the hidden transmitter—you're probably not more than a few hundred feet from it. But away from your car and radio equipment, it's like the proverbial hunt for the needle in the haystack. What you really need is a portable setup for hunting at close range, and you may prefer something that is inexpensive. The Snoop Loop was designed for just these requirements by Claude Maer, Jr, WØIC, and was described in *QST* for February 1957. (See the Bibliography at the end of this chapter.)

The Snoop Loop is pictured in **Fig 21**. The loop itself is made from a length of RG-8 coax, with the shield broken at the top. A coax T connector is used for convenience and ease of mounting. One end of the coax loop is connected to a male plug in the conventional way, but the center conductor of the other end is shorted to the shield so the male connector at that end has no connection to the center prong. This results in an unbalanced circuit, but seems to give good bidirectional null readings, as well as an easily detectable maximum reading when the grounded end of the loop is pointed in the direction of the transmitter. Careful tuning with C1 will improve this maximum reading. Don't forget to remove one inch of shielding from the top of the loop. You won't get much signal unless you do.

The detector and amplifier circuit for the Snoop Loop

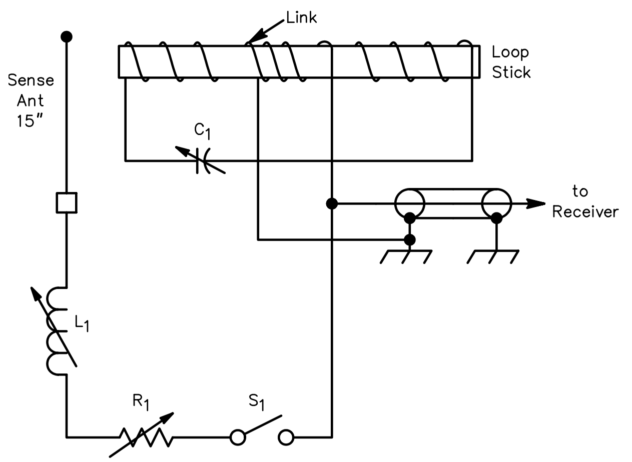


Fig 25—Circuit of the 3.5-MHz direction finder loop.
C1—140 pF variable (125-pF ceramic trimmer in parallel with 15-pF ceramic fixed.
L1—Approximately 140 µH adjustable (Miller No. 4512 or equivalent.
R1—1-kΩ carbon potentiometer.
S1—SPST toggle.
Loopstick—Approximately 15 µH (Miller 705-A, with original winding removed and wound with 20 turns of #22 enamel). Link is two turns at center. Winding ends secured with Scotch electrical tape. This type of ferrite rod may also be found in surplus transistor AM radios.

is shown in **Fig 22**. The model photographed does not include the meter, as it was built for use only with high-impedance headphones. The components are housed in an aluminum box. Almost any size box of sufficient size to contain the meter can be used. At very close ranges, reduction of sensitivity with R2 will prevent pegging the meter.

The Snoop Loop is not limited to the 10-meter band or to a built-in loop. **Fig 23** shows an alternative circuit for other bands and for plugging in a separate loop connected by a low-impedance transmission line. Select coil and capacitor combinations that will tune to the desired frequencies. Plug-in coils could be used. It is a good idea to have the RF end of the unit fairly well shielded, to eliminate signal pickup except through the loop. This little unit should certainly help you on those dark nights in the country. (Tip to the hidden-transmitter operator—if you want to foul up some of your pals using these loops, just hide near the antenna of a 50-kW broadcast transmitter!)

A LOOPSTICK FOR 3.5 MHz

Figs 24 through 26 show an RDF loop suitable for the 3.5-MHz band. It uses a construction technique that has had considerable application in low-frequency marine direction finders. The loop is a coil wound on a ferrite rod from a broadcast-antenna loopstick. The loop was designed by John Isaacs, W6PZV, and described in *QST* for June 1958. Because you can make a coil with high Q using a ferrite core, the sensitivity of such a loop is comparable to a conventional loop that is a foot or so in diameter. The output of the vertical-rod sensing antenna, when properly combined with that of the loop, gives the system the cardioid pattern shown in Fig 1D.

To make the loop, remove the original winding on the ferrite core and wind a new coil, as shown in **Fig 25**. Other types of cores than the one specified may be substituted; use the largest coil available and adjust the winding so that the circuit resonates in the 3.5-MHz band within the range of C1. The tuning range of the loop may be checked with a dip meter.

The sensing system consists of a 15-inch whip and an adjustable inductor that resonates the whip as a quarter-wave antenna. It also contains a potentiometer to control the output of the antenna. S1 is used to switch the sensing antenna in and out of the circuit.

The whip, the loopstick, the inductance L1, the capacitor C1, the potentiometer R1, and the switch S1 are all mounted on a 4 × 5 × 3-inch box chassis, as shown in **Fig 26**. The loopstick may be mounted and protected inside a piece of 1/2-inch PVC pipe. A section of 1/2-inch electrical conduit is attached to the bottom of the chassis box and this supports the instrument.

To produce an output having only one null there must a 90° phase difference between the outputs of the loop and sensing antennas, and the signal strength from each must be the same. The phase shift is obtained by tuning the sensing antenna slightly off frequency, using the slug in L1. Since the sensitivity of the whip antenna is greater than that of the loop, its output is reduced by adjusting R1.

Adjustment

To adjust the system, enlist the aid of a friend with a mobile transmitter and find a clear spot where the transmitter and RDF receiver can be separated by several hundred feet. Use as little power as possible at the transmitter. (Make very sure you don't transmit into the loop if you are using a transceiver as a detector.) With the test transmitter operating on the proper frequency, disconnect the sensing antenna with S1, and peak the loopstick using C1, while watching the S meter on the transceiver. Once the loopstick is peaked, no further adjustment of C1 will be necessary. Next, connect the sensing antenna and turn R1 to minimum resistance. Then vary the adjustable slug of L1 until a maximum reading of the S meter is again obtained. It may be necessary to turn the unit a bit during this adjustment to obtain a higher reading than with the loopstick alone. The last turn of the slug is quite critical, and some hand-capacitance effect may be noted.

Now turn the instrument so that one side (not an end) of the loopstick is pointed toward the test transmitter. Turn R1 a complete revolution and if the proper side was chosen a definite null should be observed on the S meter for one particular position of R1. If not, turn the RDF 180° and try again. This time leave R1 at the setting producing

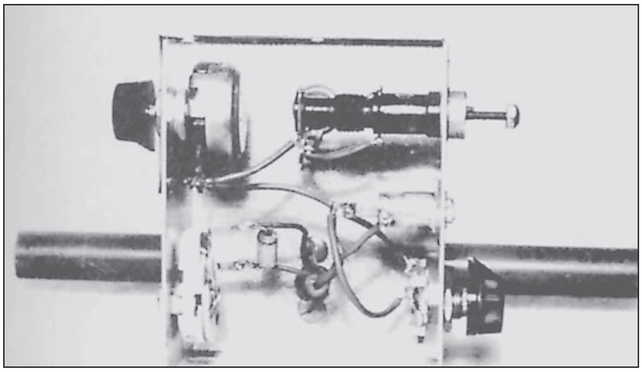


Fig 26—Components of the 3.5-MHz RDF are mounted on the top and sides of a channel-lock type box. In this view R1 is on the left wall at the upper left and C1 is at the lower left. L1, S1 and the output connector are on the right wall. The loopstick and whip mount on the outside.

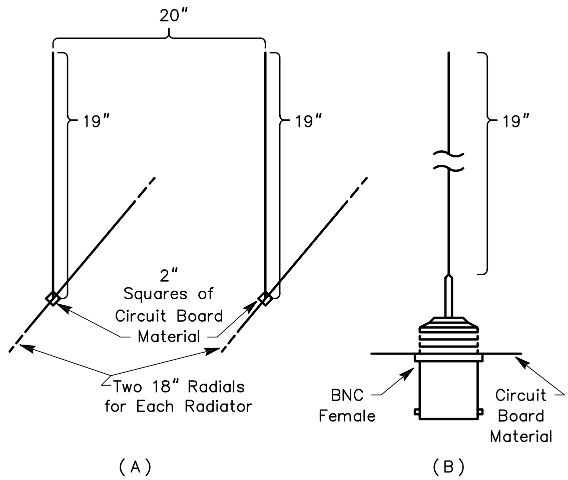


Fig 27—At A is a simple configuration that can produce a cardioid pattern. At B is a convenient way of fabricating a sturdy mount for the radiator using BNC connectors.

the minimum reading. Now adjust L1 very slowly until the S-meter reading is reduced still further. Repeat this several times, first R1, and then L1, until the best minimum is obtained.

Finally, as a check, have the test transmitter move around the RDF and follow it by turning the RDF. If the tuning has been done properly the null will always be broadside to the loopstick. Make a note of the proper side of the RDF for the null, and the job is finished.

A 144-MHZ CARIOID-PATTERN RDF ANTENNA

Although there may be any number of different VHF antennas that can produce a cardioid pattern, a simple design is depicted in **Fig 27**. Two 1/4-wavelength vertical elements are spaced one 1/4-λ apart and are fed 90° out of phase. Each radiator is shown with two radials approximately 5% shorter than the radiators. This array was designed by Pete O'Dell, KB1N, and described in *QST* for March 1981.

Computer modeling showed that slight alterations in the size, spacing and phasing of the elements strongly impact the pattern. The results suggest that this system is a little touchy and that the most significant change comes at the null. Very slight alterations in the dimensions caused the notch to become much more shallow and, hence, less usable for RDF. Early experience in building a working model bore this out.

This means that if you build this antenna, you will find it advantageous to spend a few minutes to tune it carefully for the deepest null. If it is built using the techniques presented here, then this should prove to be a small task, well worth the extra effort. Tuning is accomplished by adjusting the length of the vertical radiators, the spacing between them and, if necessary, the lengths of the phasing harness that connects them. Tune for the deepest null on your S meter when using a signal source such as a moderately strong repeater.

This should be done outside, away from buildings and large metal objects. Initial indoor tuning on this project was tried in the kitchen, which revealed that reflections off the appliances were producing spurious readings. Beware too of distant water towers, radio towers, and large office or apartment buildings. They can reflect the signal and give false indications.

Construction is simple and straightforward. Fig 27B shows a female BNC connector (RadioShack 278-105) that has been mounted on a small piece of PC-board material. The BNC connector is held upside down, and the vertical radiator is soldered to the center solder lug. A 12-inch piece of brass tubing provides a snug fit over the solder lug. A second piece of tubing, slightly smaller in diameter, is telescoped inside the first. The outer tubing is crimped slightly at the top after the inner tubing is installed. This provides positive contact between the two tubes. For 146 MHz the length of the radiators is calculated to be about 19 inches. You should be able to find small brass tubing at a hobby store. If none is available in your area, consider brazing rods. These are often available in hardware sections of discount stores. It will probably be necessary to solder a short piece to the top since these come in 18-inch sections. Also, tuning will not be quite as convenient. Two 18-inch radials are added to each element by soldering them to the board. Two 36-inch pieces of heavy brazing rod were used in this project.

The Phasing Harness

As shown in **Fig 28**, a T connector is used with two different lengths of coaxial line to form the phasing harness. This method of feeding the antenna is superior over

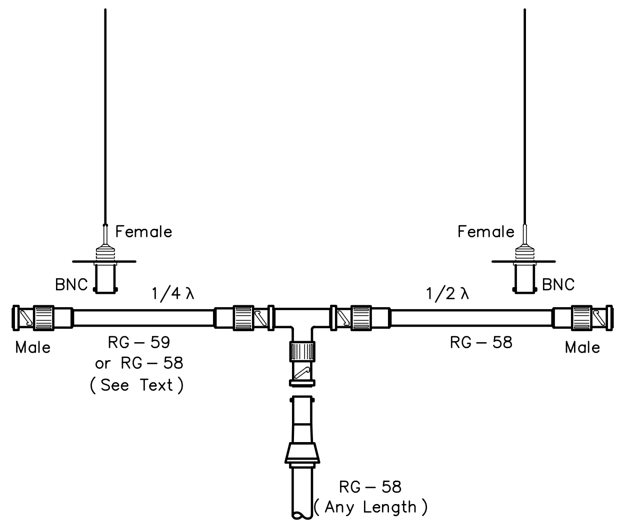


Fig 28—The phasing harness for the phased 144-MHz RDF array. The phasing sections must be measured from the center of the T connector to the point that the vertical radiator emerges from the shielded portion of the upside-down BNC female. Don't forget to take the length of the connectors into account when constructing the harness. If care is taken and coax with solid polyethylene dielectric is used, you should not have to prune the phasing line. With this phasing system, the null will be in a direction that runs along the boom, on the side of the 1/4-wavelength section.

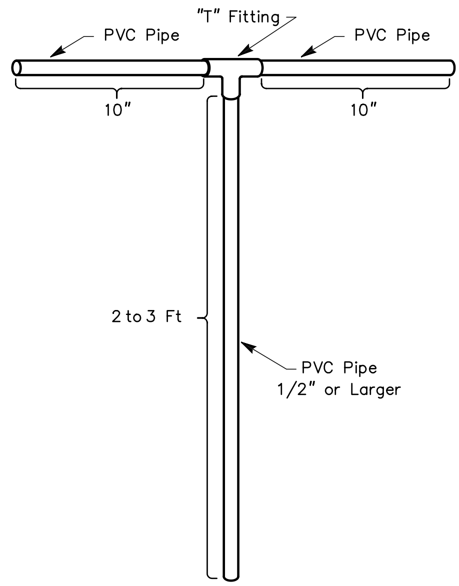


Fig 29—A simple mechanical support for the DF antenna, made of PVC pipe and fittings.

other simple systems to obtain equal currents in the two radiators. Unequal currents tend to reduce the depth of the null in the pattern, all other factors being equal.

The 1/2-wavelength section can be made from either RG-58 or RG-59, because it should act as a 1:1 transformer. With no radials or with two radials perpendicular to the vertical element, it was found that a 1/4-wavelength section made of RG-59 75-Ω coax produced a deeper notch than a 1/4-wavelength section made of RG-58 50-Ω line. However, with the two radials bent downward somewhat, the RG-58 section seemed to outperform the RG-59. Because of minor differences in assembly techniques from one antenna to another, it will probably be worth your time and effort to try both types of coax and determine what works best for your antenna. You may also want to try bending the radials down at slightly different angles for the best null performance.

The most important thing about the coax for the harness is that it be of the highest quality (well-shielded and with a polyethylene dielectric). The reason for avoiding foam dielectric is that the velocity factor can vary from one roll to the next—some say that it varies from one foot to the next. Of course, it can be used if you have test equipment available that will allow you to determine its electrical length. Assuming that you do not want to or cannot go to that trouble, stay with coax having a solid polyethylene dielectric. Avoid coax that is designed for the CB market or do-it-yourself cable-TV market. (A good choice is Belden 8240 for the RG-58 or Belden 8241 for the RG-59.)

Both RG-58 and RG-59 with polyethylene dielectric have a velocity factor of 0.66. Therefore, for 146 MHz a quarter wavelength of transmission line will be 20.2 inches × 0.66 = 13.3 inches. A half-wavelength section will be twice this length or 26.7 inches. One thing you must take into account is that the transmission line is the total length of the cable *and the connectors*. Depending on the type of construction and the type of connectors that you choose, the actual length of the coax by itself will vary somewhat. You will have to determine that for yourself.

Y connectors that mate with RCA phono plugs are widely available and the phono plugs are easy to work with. Avoid the temptation, however, to substitute these for the T and BNC connectors. Phono plugs and a Y connector were tried. The results with that system were not satisfactory. The performance seemed to change from day to day and the notch was never as deep as it should have been. Although they are more difficult to find, BNC T connectors will provide superior performance and are well worth the extra cost. If you must make substitutions, it would be preferable to use UHF connectors (type PL-259).

Fig 29 shows a simple support for the antenna. PVC tubing is used throughout. Additionally, you will need a T fitting, two end caps, and possibly some cement. (By not cementing the PVC fittings together, you will have the option of disassembly for transportation.) Cut the PVC for the dimensions shown, using a saw or a tubing cutter.

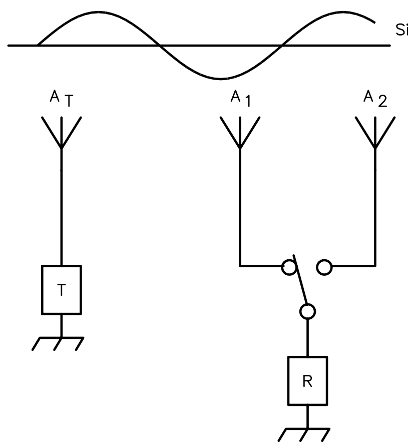


Fig 30—At the left, A_T represents the antenna of the hidden transmitter, T. At the right, rapid switching between antennas A_1 and A_2 at the receiver samples the phase at each antenna, creating a pseudo-Doppler effect. An FM detector detects this as phase modulation.

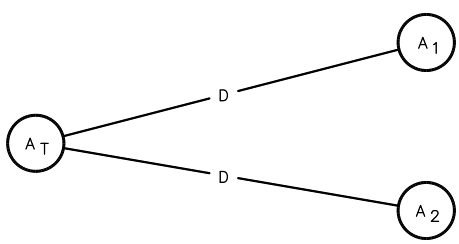


Fig 31—If both receiving antennas are an equal distance (D) from the transmitting antenna, there will be no difference in the phase angles of the signals in the receiving antennas. Therefore, the detector will not detect any phase modulation, and the audio tone will disappear from the output of the detector.

A tubing cutter is preferred because it produces smooth, straight edges without making a mess. Drill a small hole through the PC board near the female BNC of each element assembly. Measure the 20-inch distance horizontally along the boom and mark the two end points. Drill a small hole vertically through the boom at each mark. Use a small nut and bolt to attach each element assembly to the boom.

Tuning

The dimensions given throughout this section are those for approximately 146 MHz. If the signal you will be hunting is above that frequency, then the measurements should be a bit shorter. If you wish to operate below that frequency, then they will need to be somewhat longer. Once you have built the antenna to the rough size, the fun begins. You will need a signal source near the frequency that you will be using for your RDF work. Adjust the length of the radiators and the spacing between them for the deepest null on your S meter. Make changes in increments of $^1/_4$ inch or less. If you must adjust the phasing line, make sure that the $^1/_4$-wavelength section is exactly one-half the length of the half-wavelength section. Keep tuning until you have a satisfactorily deep null on your S meter.

THE DOUBLE-DUCKY DIRECTION FINDER

For direction finding, most amateurs use antennas having pronounced directional effects, either a null or a peak in signal strength. FM receivers are designed to eliminate the effects of amplitude variations, and so they are difficult to use for direction finding without looking at an S meter. Most modern HT transceivers do not have S meters.

This classic "Double-Ducky" direction finder (DDDF) was designed by David Geiser, WA2ANU, and was described in *QST* for July 1981. It works on the principle of switching between two nondirectional antennas, as shown in **Fig 30**. This creates phase modulation on the incoming signal that is heard easily on the FM receiver. When the two antennas are exactly the same distance (phase) from the transmitter, as in **Fig 31**, the tone disappears. (This technique is also known in the RDF literature as *Time-Difference-of-Arrival*, or TDOA, since signals arrive at each antenna at slightly different times, and hence at slightly different phases, from any direction except on a line perpendicular to and halfway in-between the two antennas. Another general term for this kind of two-antenna RDF technique is *interferometer*. *—Ed.*)

In theory the antennas may be very close to each other, but in practice the amount of phase modulation increases directly with the spacing, up to spacings of a half wavelength. While a half-wavelength separation on 2 meters (40 inches) is pretty large for a mobile array, a quarter wavelength gives entirely satisfactory results, and even an eighth wavelength (10 inches) is acceptable.

Think in terms of two antenna elements with fixed spacing. Mount them on a ground plane and rotate that ground plane. The ground plane held above the hiker's head or car roof reduces the needed height of the array and the directional-distorting effects of the searcher's body or other conducting objects.

The DDDF is bidirectional and, as described, its tone null points both toward and away from the signal origin. An L-shaped search path would be needed to resolve the ambiguity. Use the techniques of triangulation described earlier in this chapter.

Specific Design

It is not possible to find a long-life mechanical switch operable at a fairly high audio rate, such as 1000 Hz. Yet we want an audible tone, and the 400- to 1000-Hz range is perhaps most suitable considering audio amplifiers and average hearing. Also, if we wish to use the transmit function of a transceiver, we need a switch that will carry per-

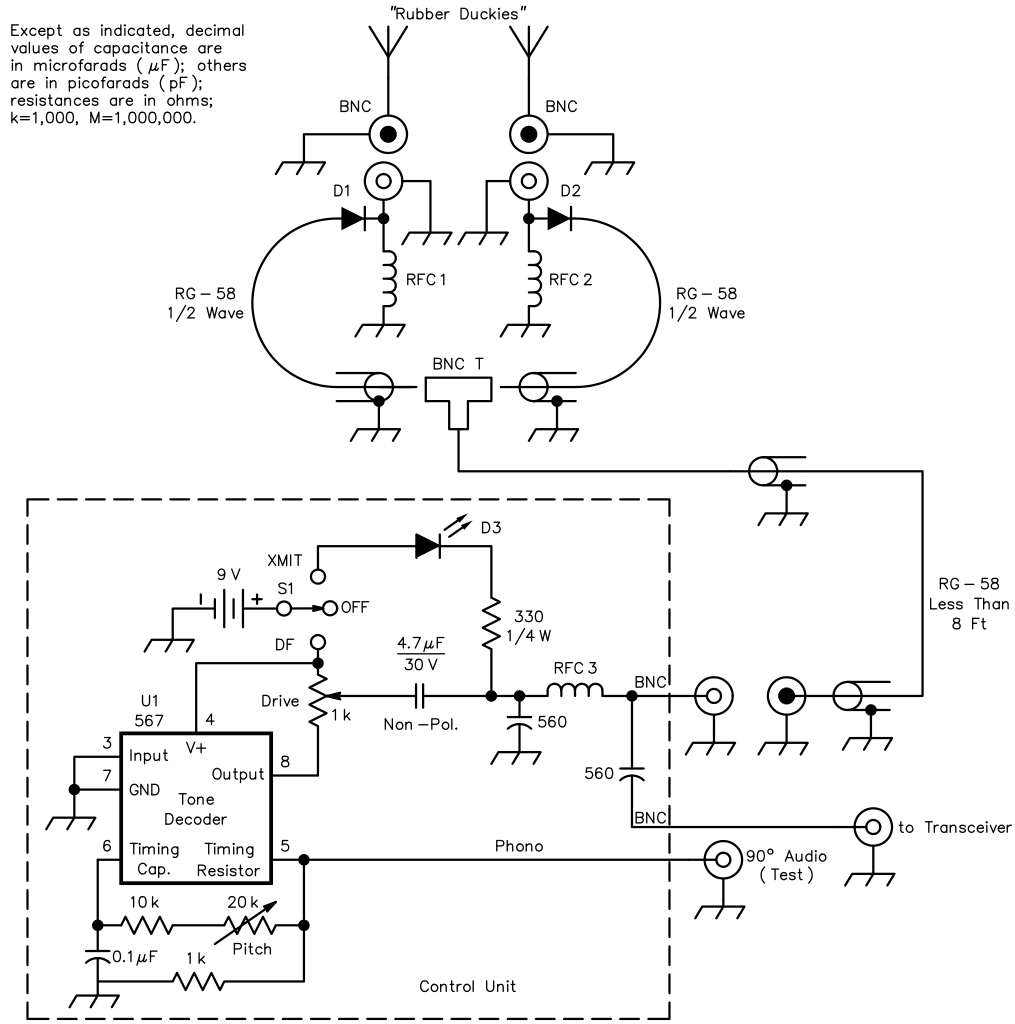


Fig 32—Schematic diagram of the DDDF circuit. Construction and layout are not critical. Components inside the broken lines should be housed inside a shielded enclosure. Most of the components are available from RadioShack, except D1, D2, the antennas and RFC1-RFC3. These components are discussed in the text. S1—See text.

haps 10 W without much problem.

A solid-state switch, the PIN diode is used. The intrinsic region of this type of diode is ordinarily bare of current carriers and, with a bit of reverse bias, looks like a low-capacitance open space. A bit of forward bias (20 to 50 mA) will load the intrinsic region with current carriers that are happy to dance back and forth at a 148-MHz rate, looking like a resistance of an ohm or so. In a 10-W circuit, the diodes do not dissipate enough power to damage them.

Because only two antennas are used, the obvious approach is to connect one diode *forward* to one antenna, to connect the other *reverse* to the second antenna and to drive the pair with square-wave audio-frequency ac. **Fig 32** shows the necessary circuitry. RF chokes (Ohmite Z144, J. W. Miller RFC-144 or similar vhf units) are used to let the audio through to bias the diodes while blocking RF. Of course, the reverse bias on one diode is only equal to the forward bias on the other, but in practice this seems sufficient.

A number of PIN diodes were tried in the particular setup built. These were the Hewlett-Packard HP5082-3077, the Alpha LE-5407-4, the KSW KS-3542 and the Microwave Associates M/A-COM 47120. All worked well, but the HP diodes were used because they provided a slightly lower SWR (about 3:1).

A type 567 IC is used as the square-wave generator. The output does have a dc bias that is removed with a nonpolarized coupling capacitor. This minor inconvenience is more than rewarded by the ability of the IC to work well with between 7 and 15 volts (a nominal 9-V minimum is recommended).

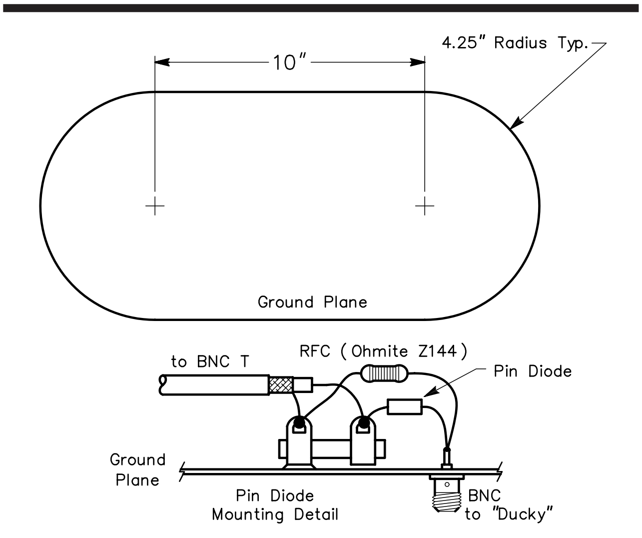


Fig 33—Ground-plane layout and detail of parts at the antenna connectors.

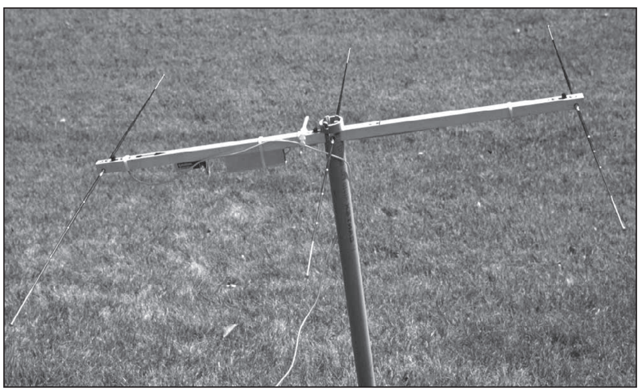


Fig 34—Photo of Fox-Hunting DF Twin 'Tenna set up as a horizontally polarized, 3-element Yagi.

The nonpolarized capacitor is also used for dc blocking when the function switch is set to XMIT. D3, a light-emitting diode (LED), is wired in series with the transmit bias to indicate selection of the XMIT mode. In that mode there is a high battery current drain (20 mA or so). S1 should be a center-off locking type toggle switch. An ordinary center-off switch may be used, but beware. If the switch is left on XMIT you will soon have dead batteries.

Cables going from the antenna to the coaxial T connector were cut to an electrical $^{1}/_{2}$ wavelength to help the open circuit, represented by the reverse-biased diode, look open at the coaxial T. (The length of the line within the T was included in the calculation.)

The length of the line from the T to the control unit is not particularly critical. If possible, keep the total of the cable length from the T to the control unit to the transceiver under 8 feet, because the capacitance of the cable does shunt the square-wave generator output.

Ground-plane dimensions are not critical. See **Fig 33**. Slightly better results may be obtained with a larger ground plane than shown. Increasing the spacing between the pickup antennas will give the greatest improvement. Every doubling (up to a half wavelength maximum) will cut the width of the null in half. A 1° wide null can be obtained with 20-inch spacing.

DDDF Operation

Switch the control unit to DF and advance the drive potentiometer until a tone is heard on the desired signal. Do not advance the drive high enough to distort or "hash up" the voice. Rotate the antenna for a null in the fundamental tone. Note that a tone an octave higher may appear. The cause of the effect is shown in **Fig 34**. In Fig 34A, an oscilloscope synchronized to the "90° audio" shows the receiver output with the antenna aimed to one side of the null (on a well-tuned receiver). Fig 34B shows the null condition and a twice-frequency (one octave higher) set of pips, while C shows the output with the antenna aimed to the other side of the null.

If the incoming signal is quite out of the receiver linear region (10 kHz or so off frequency), the off-null antenna aim may present a fairly symmetrical AF output to one side, **Fig 35A**. It may also show instability at a sharp null position, indicated by the broken line on the display in Fig 35B. Aimed to the other side of a null, it will give a greatly increased AF output, Fig 35C. This is caused by the different parts of the receiver FM detector curve used. The sudden tone change is the tip-off that the antenna null position is being passed.

The user should practice with the DDDF to become acquainted with how it behaves under known situations of signal direction, power and frequency. Even in difficult nulling situations where a lot of second-harmonic AF exists, rotating the antenna through the null position causes a very distinctive tone change. With the same frequencies and amplitudes present, the quality of the tone (timbre) changes. It is as if a note were first played by a violin, and then the same note played by a trumpet. (A good part of this is the change of phase of the fundamental and odd harmonics with respect to the even harmonics.) The listener can recognize differences (passing through the null) that would give an electronic analyzer indigestion.

A FOX-HUNTING DF TWIN 'TENNA

Interferometers give sharp bearings, but they lack sensitivity for distant work. Yagis are sensitive, but they provide relatively broad bearings. This project yields an antenna that blends both on a single boom to cover both ends of the hunt. This is a condensation of a October 1998 *QST* article by R. F. Gillette, W9PE.

A good fox-hunting antenna must meet a number of criteria: (1) small size, (2) gain to detect weak signals and (3) high directivity to pinpoint the fox. Small antennas, however, do not normally yield both gain and direc-

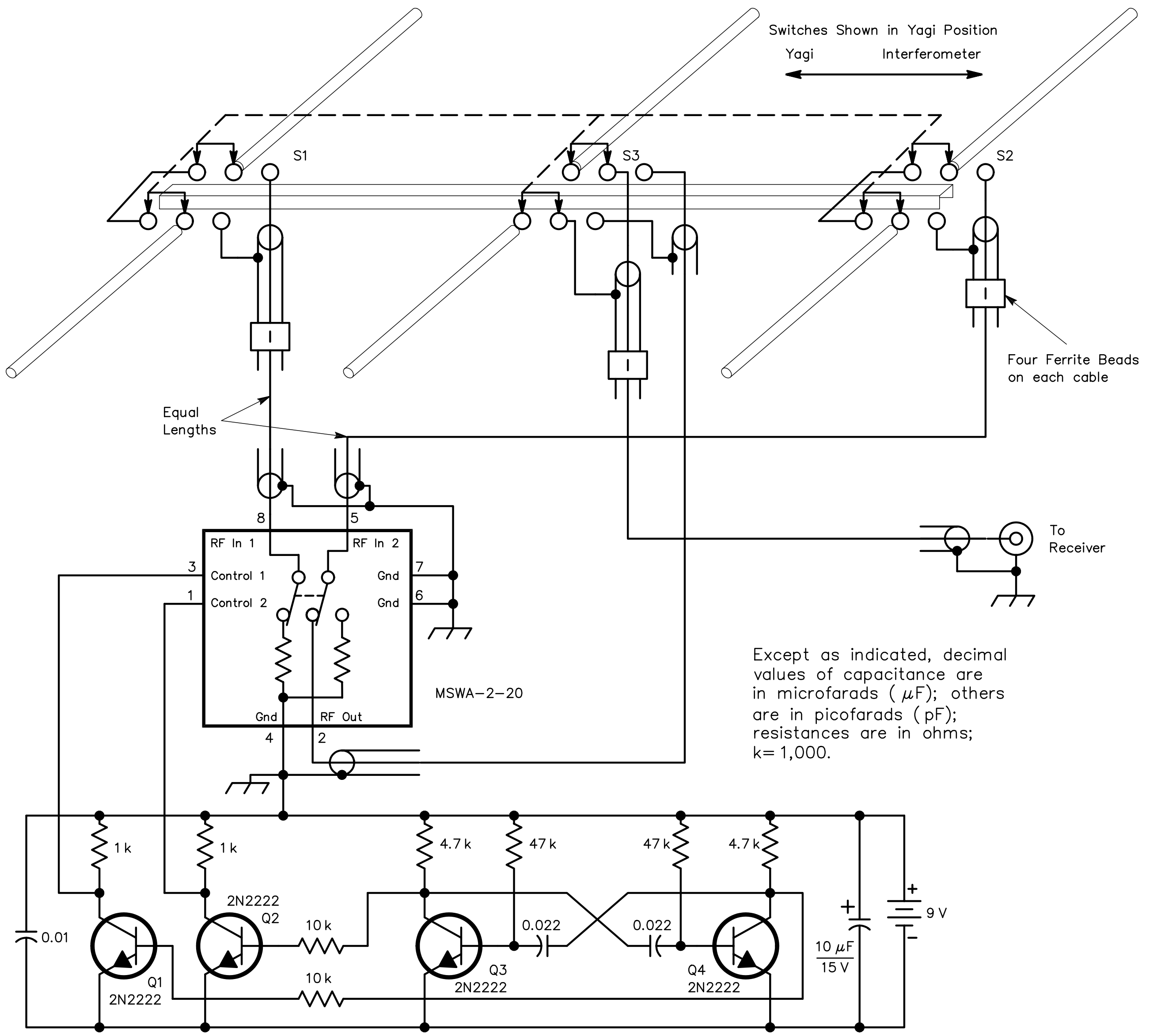


Fig 35—Schematic of the Yagi/interferometer antenna system.

Table 1
Yagi Design

Item	*Overall Length (Inches)*	*Boom to Element Tip (Inches)*
Director length	34.75	17.00
Director to Driven El. spacing	15.75	16.00
Driven El. length	37.75	18.50
Driven El. to Reflector spacing	15.75	16.00
Reflector length	40.75	20.00

*SWR less than 1.3:1 from 144.5 to 148 MHz

tivity. By combining two antennas, all three requirements are satisfied in a way that makes a nice build-it-yourself project.

This antenna uses slide switches to configure it as either a Yagi or a single-channel interferometer. When used as an interferometer, a GaAs RF microcircuit switches the FM receiver between two matched dipoles at an audio frequency. To make the antenna compact W9PE used hinged, telescopic whips as the elements; they collapse and fold parallel to the boom for storage.

The Yagi

The Yagi is a standard three-element design, based on 0.2-λ spacing between the director, the driven element and the reflector. It yields about 7 dBi gain and a front-to-back ratio of over 15 dB. Because a slide switch is used at the center of each element and the elements have small diameters, their resonant lengths are different from typical ones. **Table 1** shows the sizes used and **Fig 34** shows the Yagi.

To make sure that radiation from the coax does not affect the pattern, the author used some ferrite beads as coaxial choke-baluns. This also prevents objects near the coax from affecting signal-strength readings. The Yagi also has a low SWR; with uncalibrated equipment, he measured less than 1.3:1 over most of the 2-meter band.

This Yagi has a lot more gain than a "rubber ducky," but we need more directivity for fox hunting. That's where the interferometer comes in.

An Interferometer

To form the interferometer, the two end elements are converted to dipoles and the center element is disabled. When the three switches in **Fig 35** are thrown to the right, the feed line to the receiver is switched from the center element to the RF switch output, and the end elements are connected via feed lines to the RF switch inputs. With the Yagi's feed point open and the driven element equidistant from both interferometer antennas, the center element should have no effect on the interferometer. Nonetheless, it's easier to collapse the driven-element whips and get them out of the way than to worry about spacing.

Now if both interferometer coax cables are of equal length (between the antennas and switch) and the two antennas are the same distance from the transmitter (broadside to it), the signals from both antennas will be in phase. Switching from one antenna to the other will have no effect on the received signal. If one antenna is a little closer to the transmitter than the other, however, there will be a phase shift when we switch antennas.

When the antenna switch is at an audio rate, say 700 Hz, the repeated phase shifts result in a set of 700 Hz sidebands. At this point, all that was needed was a circuit to switch from one antenna to the other at an audio rate. W9PE chose a low-cost Mini-Circuits MSWA-2-20 GaAs RF switch driven by a simple multivibrator and buffer. The GaAs switch is rated to 2.0 GHz, hence this switching concept can easily be scaled to other ham bands. The PC board should work through the 440 MHz ham band. The author suggests adding a ground plane under the RF portion of the PC board and testing it before using it at a higher frequency.

The RF switch is controlled by a set of equal-amplitude, opposite-phase square waves: 0 V at one control port and –8 to –12 V at the other. (Mini Circuits is unclear about maximum voltages for this device. For safety, don't power it with more than 9 V.—*Ed.*) The opposite controls the other switch position. A 9-V battery was used as the power supply, with the positive terminal grounded. This results in a 0 V control signal to the RF switch when the buffer transistor is off and a Vsat (about 0.2 V less than the –9 V battery: –8.8 V) signal when the buffer transistor is saturated. The multi-vibrator has two outputs, and each drives a buffer resulting in the required equal-and-opposite-phase drive signals.

Table 2
Bill of Materials

Quantity	*Item*
3 ft	3/4-inch aluminum U channel
6 sets	insulated shoulder washers for elements
1	9 V battery
1	9 V battery connector
1	10 µF, 16 V electrolytic capacitor
1	0.01 µF, 25 V capacitor
2	0.022 µF, 25 V capacitor
2	1 kΩ 1/8 W resistor
2	4.7 kΩ 1/8 W resistor
2	10 kΩ 1/8 W resistor
2	47 kΩ 1/8 W resistor
2	1 kΩ 1/8 W resistor
4	2N2222 transistors
1	Mini-Circuits MSWA-2-20 (Mini-Circuits Labs, 13 Neptune Ave, Brooklyn, NY 11235; tel 718-934-4500, 417-335-5935, fax 718-332-4661; e-mail **sales@minicircuits.com**; URL **www.minicircuits.com**)
3	DPDT slide switch (1 1/8-inch, 29 mm, mounting centers), Stackpole, 3 A, 125 V used
10 ft	50 Ω coax (0.140-inch maximum OD)
1	coaxial connector (receiver dependent)
1	lot, mounting hardware
1	lot, heat-shrink tubing or equal
4	cable ties
1	2 × 3.5-inch single-sided fiberglass PC board
1	1-inch PVC conduit
12	#FB-20 ferrite beads 0.14-inch ID, 0.5-inch long (All Electronics Corp: PO Box 567, Van Nuys, CA 91408-0567; tel 888-826-5432, fax 818-781-2653, e-mail: **allcorp@allcorp.com**; URL **www.allcorp.com/**.)
6	20 1/2-inch telescoping antenna elements (Nebraska Surplus, tel 402-346-4750; e-mail **grinnell@probe.net**)
1	Special resist film (Techniks Inc, PO Box 463, Ringoes, NJ 08551; tel 908-788-8249, fax 908-788-8837; e-mail **techniks@idt.net**; URL **www.techniks.com/**)

Circuit Construction

After he selected the Mini-Circuits RF switch, W9PE realized that its small size would be best handled with a simple PC board. He made the prototype boards with a photocopy transparency technique.

A power on-off switch was not used, as the 9-V bat-

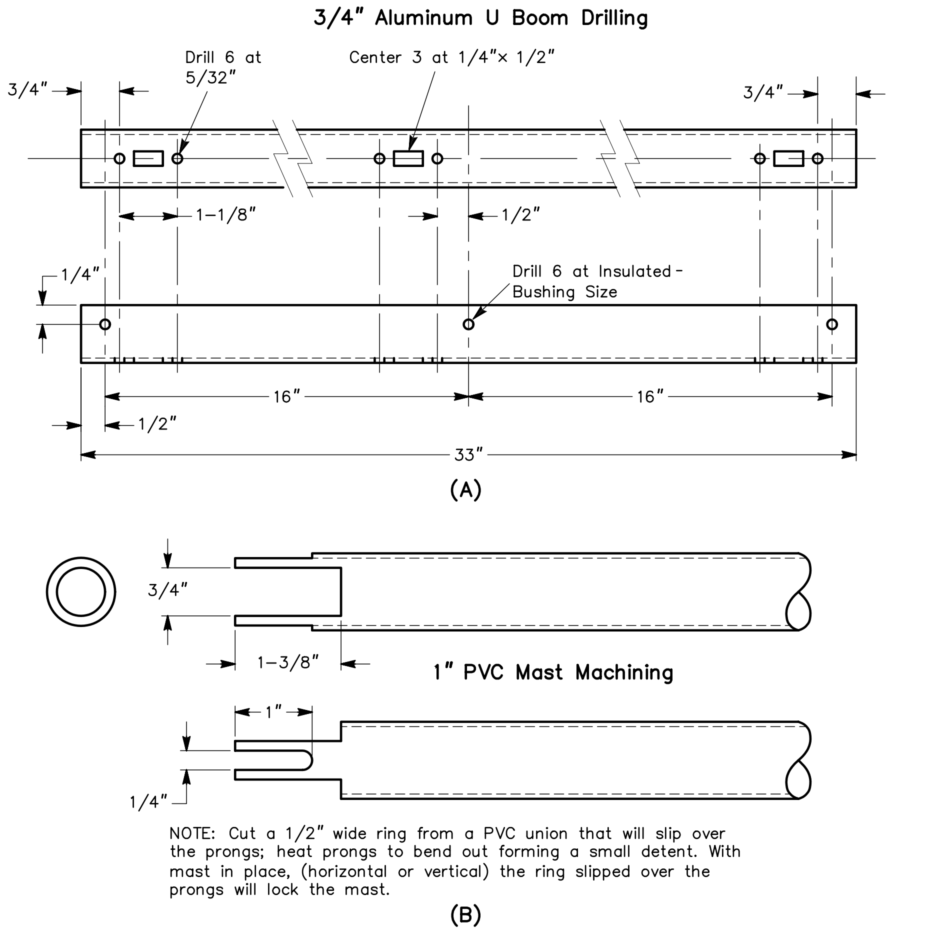


Fig 36—Boom-drilling and mast-machining details.

tery connector serves the same function. The battery fits tightly in the 3/4-inch U channel. W9PE covered the circuit board with a plastic-lined aluminum cover, but plastic film and some aluminum foil, provide the same function. A cable tie will strap either into the U channel.

Table 2 is a complete bill of materials. You can use any telescoping elements, providing that they extend to over 20 inches and have a mounting stud long enough to accommodate the insulated washers. As an alternate to the stud, they can have ends tapped to receive a screw for the insulated mounting. The author picked up his elements at a hamfest from the vendor listed; they are also available from most electronic parts houses. The Mini-Circuit RF switch is a currently available part.

Antenna Construction

Fig 35 shows the antenna schematic. It shows all three switches in the Yagi position; each would slide to the right for interferometer use. Slide switches work pretty well at 2 meters. Each of the elements is mounted to the boom with insulating washers, and a strip of copper stock connects each element to its slide switch. (You can substitute copper braid, solder wick, coax shield or any short, low resistance, low inductance conductor for the copper stock.) This switching arrangement allows you to switch the reflector and director from being parasitic elements (electrically continuous) to being dipoles (center fed).

Because the elements telescope, you can adjust the interferometer dipoles to exactly equal lengths each time you switch the antenna configuration from Yagi to interferometer. Again, choke baluns block RF on the outside of each element's coax.

Caution: Do not transmit when the RF switch is selected. Transmit only when in the Yagi configuration. RF power will destroy the Mini-Circuits RF switch. To be safe, lock out your transmit function. Most HTs have this capability. When using a mobile radio, disconnect the microphone. It is, however, safe to transmit in the Yagi configuration—which is nice for portable operating.

Fig 36 gives dimensions for drilling a standard 3/4-inch aluminum U channel for the boom and shows how the author cut a 1-inch PVC pipe (plastic conduit) for a mast and a mast locking ring. If PVC conduit is not available in your area, PVC water pipe (and a PVC union for the locking ring) will work. This mast allows mounting the antenna for either vertical or horizontal polarization.

Be sure to test the plastic pipe you use for low RF loss. Do this by heating a sample in a microwave oven. Place a pipe sample and a glass of water in the oven. (The sample is not placed in the glass of water; the water keeps the microwave from operating without a load.) Bring the water to a boil, and then carefully check the sample's temperature. If the sample is not hot, its RF loss is low, and the plastic can be used.

Using the Antenna

When starting a hunt, set up the Yagi antenna by placing all switches in the Yagi position. Swing all of the telescoping elements perpendicular to the boom and set the whip lengths to achieve the proper element lengths, while keeping each element symmetrical about the boom. The cables or boom can be marked with the length data.

While the signal is weak, use the Yagi. It has 7 dBi gain, but its bearing resolution is only about 20°. When the signal gets stronger, use the interferometer. It has less gain, but its bearing resolution is better than 1°. If the fox transmitter begins overloading your receiver, collapse the whips (equally) to reduce the gain and continue triangulating. Near the transmitter, you should triangulate both horizontally (azimuth) and vertically (elevation). The antenna works both ways, and the transmitter may be located above or below you.

Antenna Alternative

As an alternative to the telescoping elements, George Holada, K9GLJ, suggested using fixed-length elements with banana plugs matched to banana jacks on the boom. Three pairs would be used for the Yagi, an extra driven-element pair for the interferometer mode and two short-element pairs to reduce the received signal level if an overload condition occurs. He also suggested a PVC boom allowing the elements to be stored inside the boom.

THE FOUR-WAY MOBILE DF SYSTEM

This innovative, yet simple, RDF antenna system was described in an article by Malcolm C. Mallette, WA9BVS, in November 1995 *QST*. It is derived from the TDOA design shown earlier in this chapter by David T. Geiser, WA2ANU, and by a design by Paul Bohrer, W9DUU. (See Bibliography.)

Direction-finding often involves two different activities: DFing on foot and DFing from a vehicle. Often, you must track the signal using a vehicle, then finish the hunt on foot. Whether on foot or in a vehicle, the primary problem you'll encounter when trying to locate the transmitter is multipath reception. Multipath reception involves receiving the same signal by more than one path, one signal from the true direction of the transmitter and others by reflected paths that may come from widely different directions. VHF and UHF signals bounce off almost any object and hide the true source of a signal. For example, if there's a large metal building north of you, a signal from the south may arrive from the north because the signal bounces off the building and back to you.

Multipath reception effects can be defeated by taking a number of readings from different positions and arriving at an average direction. While moving at road speeds in a vehicle, it's possible to take a number of readings from different positions and average them, and it's also possible to average a number of readings over a distance of travel by electronic means. The true bearing to the transmitter can usually be found by either method.

DFing equipment for use on foot is simpler than systems for use on a vehicle. While afoot, you can turn at will or easily rotate an antenna. Turning a vehicle while going down a street may result in a fender-bender if you're not careful!

The simplest DFing system to use while on foot consists of an S-meter-equipped hand-held receiver and a small, hand-held Yagi with an attenuator in line between the antenna and receiver. The attenuator keeps the S meter from pinning. The direction in which the beam points when the strongest signal is received is the direction of the transmitter. Of course, you'll want to take readings at several locations at least a wavelength apart to obtain an average heading, as multipath reception can still cause false readings in some locations.

Another approach that many hams have taken is the simple WA2ANU DDFF—it is now commonly known simply as the "buzzbox." Various commercial versions of the hand-held buzzbox system are available. Some sys-

Fig 37—Front panel of the Four-Way DFer. At the extreme left of the front panel is the VOLUME control. Immediately to the right is the RCV/OFF/DF center-off toggle switch, with the damping (DMP) control switch nearby. Four LEDs mounted in a diamond pattern indicate signal direction: front (yellow), right (green), back (orange) and left (red). The horizontally mounted zero-center meter indicates left/right signal reception, the vertically mounted meter displays front/back signal reception. A small speaker is mounted on the top cover.

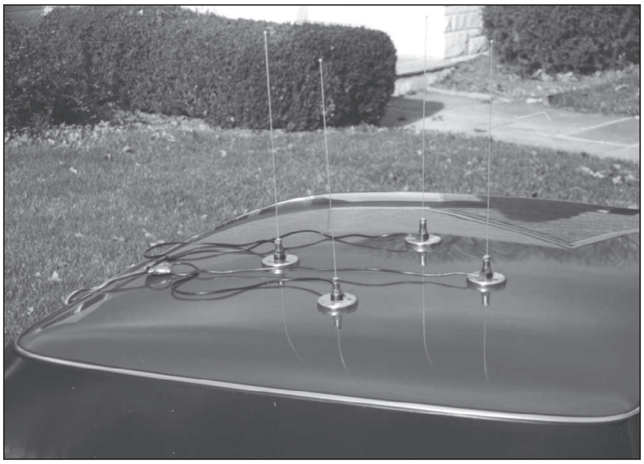


Fig 38—Placement of the four antennas on the author's car roof. The small object to the left of the antennas is the switch board.

tems have been upgraded to indicate whether the signal is arriving from the left or right of your position. The main drawback, however, to the buzzbox is that it's not as sensitive as a simple dipole and not nearly as sensitive as a beam.

In theory, you could take a buzzbox or Yagi/attenuator system in a car, stop periodically, get out and check the direction to the transmitter, then climb back in and drive off. Although this procedure works, it isn't very practical—it takes a long time to find the transmitter.

This design is for a left-right, front-back box (LRFB box) that indicates whether the received signal is to the left or right and whether it is to the front or back of the receiver. The location display consists of four LEDs arranged in a diamond pattern (see the title-page photo). When the top LED is on, the signal is coming from the front. When the top and right LEDs are on, the transmitter is between the front and the right. When only the right LED is on, the signal is directly to the right. When the bottom LED and right LED are on, the transmitter is to the right and to the back. The same pattern occurs around the clock. Therefore, four LEDs indicate eight directions. As most highways and streets have intersections that force a driver to choose moving straight ahead, right or left, the indication is sufficiently precise for practical transmitter hunting.

If the four-LED display is used alone, all parts can be obtained from your local Radio Shack store. Two zero-center 50-µA meters (50-0-50)—M1 and M2—can be used in addition to, or in place of, the LEDs, but RadioShack does not stock such meters. **Fig 37** shows the front panel layout of the LRFB.

The LRFB box uses four mag-mount $^1/_4$-λ antennas placed on the vehicle roof as shown in **Fig 38**. The whips in the mag mounts can be changed to $^1/_4$-λ 440-MHz whips and the antennas placed closer together when switching from 144-MHz to 440-MHz operation.

Circuit Description

See **Fig 39** in the following discussion (pages 26 and 27). U2, a 555 timer, generates a string of square-wave pulses at pin 3. The pulse frequency is determined by the setting of R4. The pulses are fed to the clock input (pin 14) of U3, a 4017 decade counter. On the first pulse, a positive voltage appears at U3, pin 3. On receipt of the second pulse from U2, pin 3 of U3 goes to ground and a positive voltage appears on pin 2. This sequence continues on successive pulses from U2 as pins 3, 2, 4, 7, 10, 1, 5, 6, 9 and 11 go positive in succession.

D1 through D5, and D6 through D10, OR the pulses. The result is that TP3 goes positive on the first pulse from U2, while TP2 is at 0 V. The next pulse of U2 results in TP2 going positive and TP3 going to 0 V. This sequence repeats as the counter goes around to make pin 3 positive again, and recycles.

Antenna Switching

U2 and U3 produce alternating pulses at TP2 and TP3. If we wanted only to alternately turn on and off two antennas, we could use the pulses at TP2 and TP3. The design ensures that the pulses at TP2 are the same length as the pulses at TP3. For the LRFB box, however, we need to switch between the left-right antennas many times, then switch between the front-back antennas many times.

Pin 12 of U3, CARRY OUT, emits a pulse every time U3 counts through its cycle of 10 pulses. The carry pulses from U3 go to U4, pin 14, the clock input of that 4017 counter. As U4 cycles, its output pins pulse; those pulses are, in effect, directed by D11 through D20.

As a result, TP4 is positive during the first 50 pulses from U2 and TP5 is positive during the second 50 pulses of U2. Q1 through Q6 form a quad AND gate. They AND the pulses at TP4 and TP5 with the alternating pulses at TP2 and TP3 so that the result is a pulse at the base of Q9, followed by a pulse at the base of Q10, a pulse at the base of Q9, and so on. The pulses alternate 25 times between Q9 and Q10. Then, as TP4 goes to 0 V, TP5 rises from 0 V to some positive voltage and the alternating pulses appear at the bases of Q7 and Q8. The pulses alternately go to the bases of Q7 and Q8 25 times. Then they alternate between the bases of Q9 and Q10 25 times. This pattern continues as long as the unit is in DF operation.

In **Fig 40**, two leads of a four-conductor-plus-ground cable to the antenna-switch board are connected to points A and B. The same pulses that turn Q7 and Q8 off and on turn on and off the left and right antennas. One of those two antennas is turned on and off in phase with Q7 and the other is turned on and off in phase with Q8. The PHASE switch, S3, determines which antenna is in phase with which transistor. Similarly, the two front/back antennas are turned on and off in phase with Q9 and Q10, and S4 determines which antenna is in phase with which transistor.

The pulses arriving at points A and B turn on and off the diodes connecting the coax of the left and right

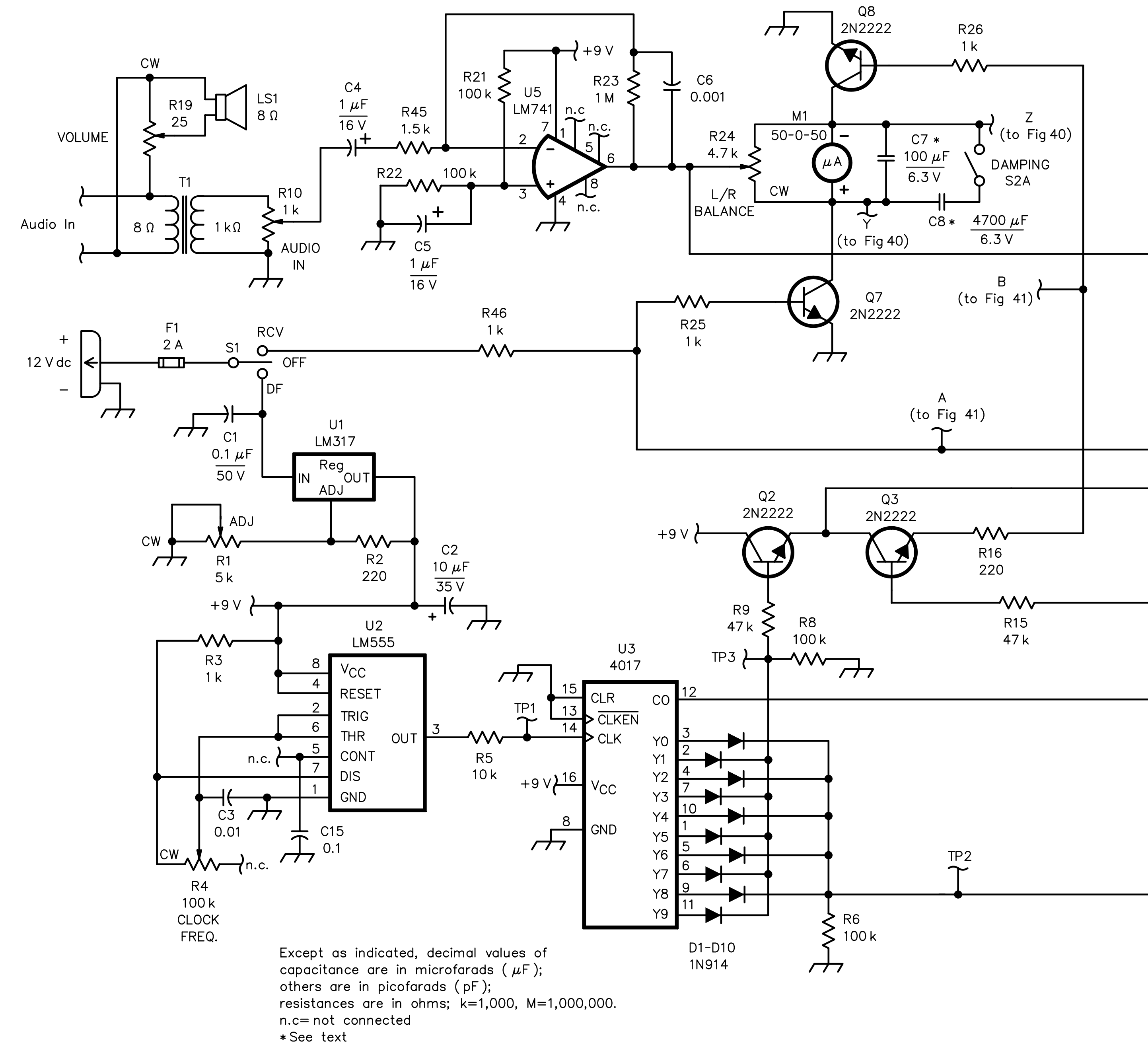
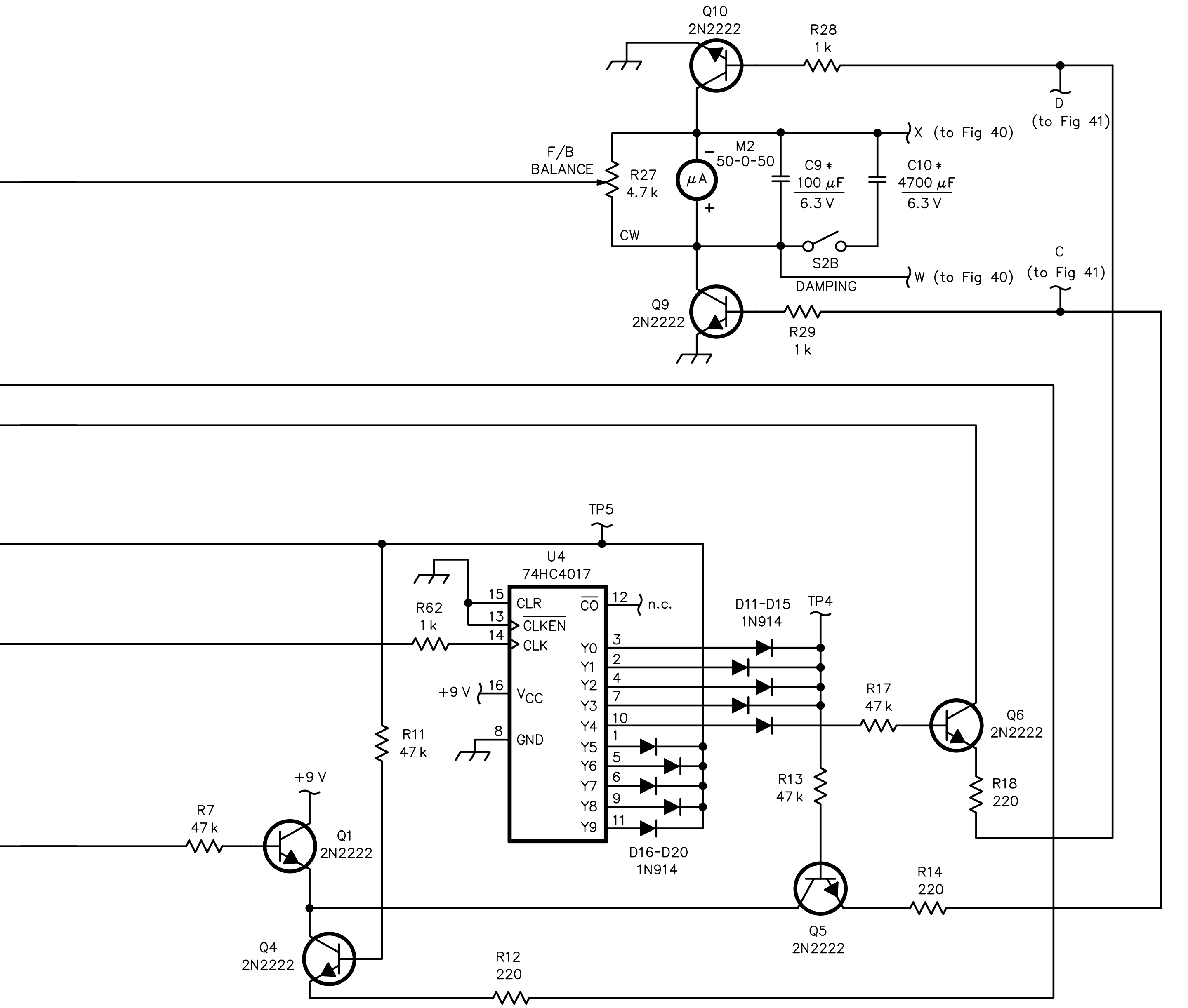


Fig 39—Unless otherwise specified, part numbers in parentheses are RadioShack. All fixed-value resistors are 1/4-W, 5%-tolerance units. Equivalent parts can be substituted.

C1, C15—0.1-μF, 50-V (272-1069)
C2—10-μF, 35-V electrolytic capacitor (272-1025)
C3—0.01-μF, 25-V disc-ceramic capacitor (272-131)
C4, C5—1-μF, 16-V electrolytic capacitor (272-1434)
C6—0.001-μF, 25-V disc-ceramic capacitor (272-126)
C7, C9—100-μF, 6.3-V bipolar (nonpolarized) capacitor; Digi-Key P-1102, available from Digi-Key Corp, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677, tel 800-344-4539, 218-681-6674; fax: 218-681-3880; RadioShack stocks 100-μF, 35-V axial (272-1016) and radial-lead (272-1028) electrolytic capacitors.
C8, C10—4700-μF, 6.3-V bipolar capacitor (made of five 1000-μF, 6.3-V bipolar capacitors), Digi-Key P1106. Standard 1000-μF, 35-V radial and axial-lead electrolytic capacitors are available from RadioShack; a 4700-μF, 35-V axial-lead electrolytic capacitor is also available (272-1022). Note that C7, C8, C9 and C10 are non-polarized capacitors because a small reverse voltage can appear across the meter and capacitors when the system is in use. Standard polarized electrolytics have been used in a number of units using this circuit (the same detector circuit used in W9DUU's unit) without any known ill effects, however.
D1-D20—1N914 silicon switching diode (276-1620 or 276-1122)
F1—2-A fuse (270-1007)
LS1—8-W speaker (40-245)



M1, M2—Zero-center, 50-μA meter; optional—see text
Q1-Q10—MPS2222 or 2N2222 NPN silicon general-purpose transistors (276-2009)
R1, R24, R27—4.7 kΩ (271-281); note: many of the fixed-value resistors can be found in RadioShack resistor assortment packages 271-308 and 271-312.
R2, R12, R14, R16, R18—220 Ω (271-1330)
R3, R25, R26, R28, R29—1 kΩ (271-1321)
R4—100-kΩ trimmer potentiometer (271-284)
R5—10 kΩ (271-1335)
R6, R8, R21, R22—100 kΩ (271-1347)
R7, R9, R11, R13, R15, R17—47 kΩ (271-1342)
R10—1-kΩ trimmer potentiometer (271-280)
R19—25-Ω panel-mount potentiometer (271-265A)
R23—1 MΩ (271-1134)
R45—1.5 kΩ (part of 271-312 assortment)
S1—SPDT, center-off switch (275-325)
S2—DPDT switch (275-626)
T1—8-Ω to 1-kΩ audio-output transformer (273-1380)
U1—LM317T, 1.5-A, three-terminal, adjustable voltage regulator (276-1778)
U2—555 timer (276-1723)
U3, U4—4017 decade counter (276-2417)
U5—LM741 op amp (276-007)
Misc: two 8-pin IC sockets (276-1995); two 16-pin IC sockets (276-1992); experimenter's PC board (276-148) or FAR Circuits PC board set; enclosure; four mag-mount antennas, four-conductor shielded cable; in-line fuse holder (270-1281).

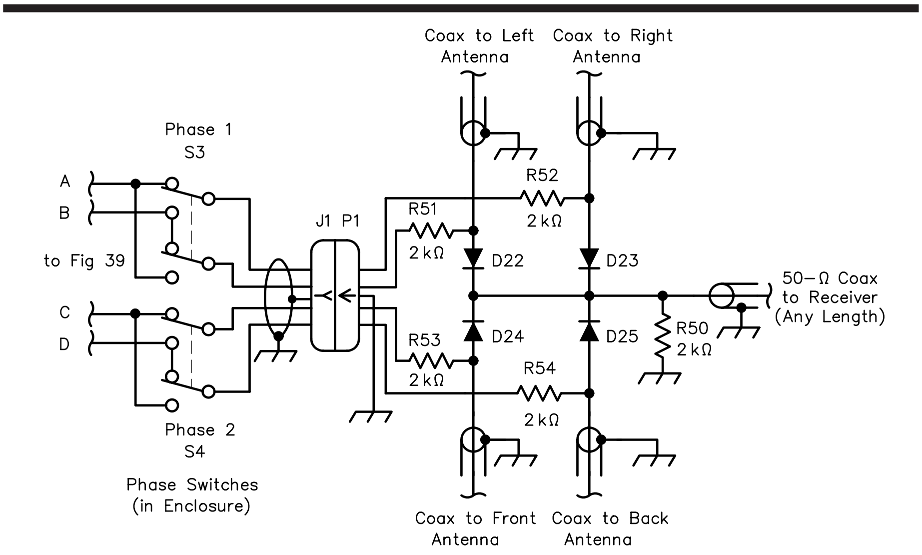


Fig 40—Schematic of the antenna switch board. Part numbers in parentheses are RadioShack. All fixed-value resistors are 1/4-W, 5%-tolerance units. Equivalent parts can be substituted.

D22-D25—1N914 silicon switching diode (276-1620 or 276-1122)
J1—Six-pin female Molex connector (274-236 or 274-155)
P1—Six-pin male Molex connector (274-226 or 274-152)
R50-R54—2.2 kΩ (can be found in RadioShack resistor assortment packages 271-308 and 271-312); also available in pack of five (271-1325)
S3, S4—DPDT switch (275-626)

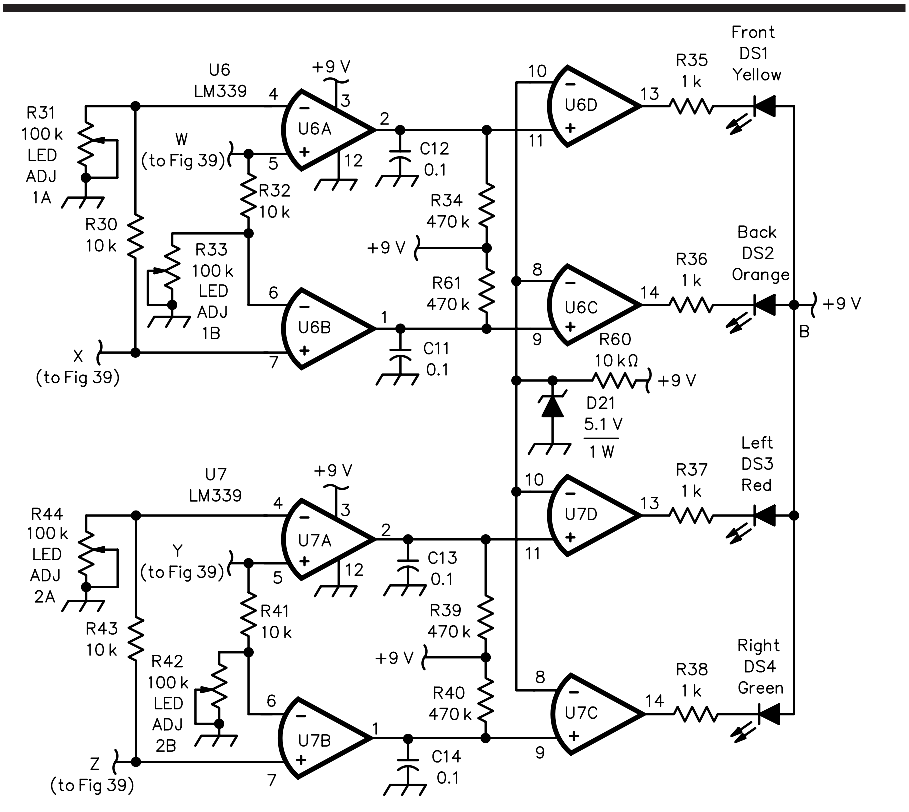


Fig 41—Schematic of the LED driver circuit. Part numbers in parentheses are RadioShack. All fixed-value resistors are 1/4-W, 5%-tolerance units. Equivalent parts can be substituted.

C11-C14—0.1-µF, 25-V disc-ceramic capacitor (272-135)
D21—1N4733, 5.1-V, 1-W Zener diode (276-565)
DS1-DS4—LEDs; one each red (276-066); green (276-022); yellow (276-021); orange (276-012)
R30, R32, R41, R43—10 kΩ (271-1335)
R34, R39, R40, R61—470 kΩ (271-1354)
R35-R38—1 kΩ (271-1321)
R31, R33, R42, R44—100-kΩ trimmer potentiometer (271-284)
U6, U7—LM339 quad comparator (276-1712)
Misc: two 14-pin IC sockets (276-1999)

antennas to the receiver coax. This occurs 25 times, thereby switching the receiver between the left and right antennas 25 times. Similar switching then occurs between the front and the back antennas from pulses arriving at points C and D.

Detector Circuit

The detector circuit (back again in Fig 39) starts with U5, a 741 op amp that amplifies the receiver's audio output. The audio is fed into R24 and R27, two 4.7-kΩ pots. The zero-center, 50-µA meters across R24 and R27 are optional. The meters, as well as the LEDs, indicate front/back and left/right. Such meters can be expensive unless you find surplus meters, and they're not really necessary.

When the left/right antennas are active, one end of R24 is grounded by Q7 and Q8 on each alternate pulse.

If Q7 is conducting, Q8 is not conducting. On each pulse, one of the left/right antennas is turned on and one end of R24 is grounded. On the next pulse, the other left/right antenna is turned on and the other end of R24 is grounded. If there is a phase difference between the signal received by the left antenna and the signal received by the right antenna, a dc voltage is built up across R24. That voltage causes the quad comparator, U7 in **Fig 41** to turn on DS3 (red) or DS4 (green) L/R LEDs. If the optional left/right meter is installed, it deflects to indicate the direction as do the LEDs.

After 25 cycles, the left and right antennas are both turned off and the front and back antennas are cycled on and off 25 times with the same detection process, producing a voltage across R27 if there is a phase difference between the RF received by the front and the back antennas. That voltage across R27 causes quad comparator U6 to turn on DS1 or DS2.

C9 and C10, for the F/B detector, and C7 and C8, for the L/R detector, damp the voltage swings caused by multipath reception. To control damping, S2A and S2B switch the 4700-µF capacitors in or out of the circuit. You want the greatest amount of damping when you drive through an area with a lot of multipath propagation (as from buildings); a lot of damping helps under those circumstances.

Construction

The prototype was built using a pad-per-hole RadioShack board. However, a PC board makes construction a lot faster. Far Circuits offers a printed-circuit project on their Web site: **www.cl.ais.net/farcir**). Except for the optional meters and the nonpolarized capacitors, most parts are available from RadioShack.

First build the power supply so you can power the unit from your car or another 12-V source. Apply 12 V to the DFer and adjust R1 until U1's output is +9 V. (You can use a 9-V battery and omit the power-supply section, but you'd better take along a spare battery when you go DFing.)

Install U2 and its associated parts. Power up and turn on S1. A string of pulses should appear at TP1. If you have a frequency counter, set R4 for a pulse frequency of 2200 Hz at TP1. If you don't have a counter, connect a 0.1-µF capacitor from TP1 to headphones or a small speaker and set R4 for a tone of about 2 kHz. Later, you'll adjust the clock so the unit works with the passband of your receiver.

Turn off S1 and remove the power source. Install U3 and its diodes. Pin 12 of U3 need not be connected yet. Apply power and turn on S1. At TP2 and TP3, you should find alternating 1100-Hz pulses. If you have a dual-trace scope, you can see that the pulses alternate. If you have a single-trace scope, connect TP3 to TP2 and to the scope input and the trace will appear as a solid line as there is a pulse at either TP2 or TP3 at all times. If you don't have a scope, the tone in a speaker or earphones from TP2 or TP3 will sound half as high (about 1 kHz) as the tone at TP1.

Turn off S1. Install U4 and its diodes. Note that pin 12 of U3 is connected to pin 14 of U4. At TP4 and TP5, there should be long pulses—five times longer than the pulses at TP1, and the pulses should alternate between TP4 and TP5. The pulse frequency should be about 44 Hz. Power down and turn off S1. Install the remaining circuit components. When you power up, 25 alternating pulses should appear at A and B, then 25 alternating pulses should appear at C and D. Use a scope to verify that.

If you're not using the optional panel meters, connect a voltmeter across R24 (L/R BALANCE), using the lowest dc-voltage range. Note that neither end of R24 is grounded. With no audio input, adjust R24 until there is no voltage across it. Do the same with R27 (F/B BALANCE). If you use the optional meters, adjust R24 and R27 so there's no current shown on either meter.

Power down and assemble the rest of the circuit. With power applied, but with no audio input, adjust R31, 33, 42 and 44 so that the four LEDs (DS1 through DS4) are off. The objective of the following adjustments is to get the red and green LEDs to turn on with the same voltage amplitude, but opposite polarity, across R24. Move R24's wiper so a low positive voltage appears across R24, as indicated by the voltmeter connected across R24 or movement of the panel-meter needle. Adjust R44 (LED ADJ 1A) and R42 (LED ADJ 1B) so that the green LED (DS4) comes on when the voltage goes positive at one end of

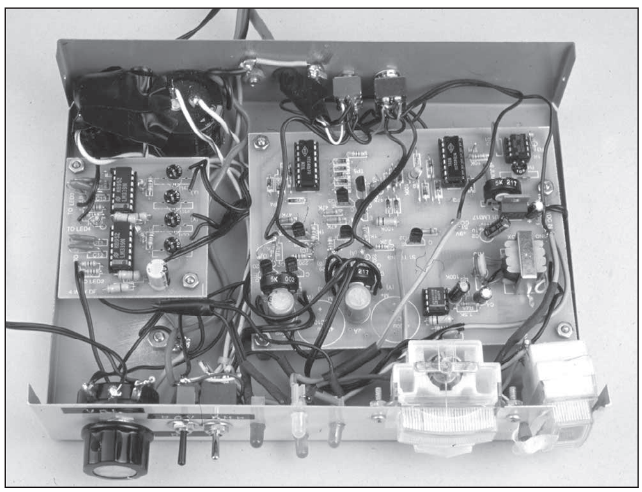


Fig 42—An inside view of one DF unit built into a 2 × 8 × 5¾-inch (HWD) box. Because of the height restriction, the two 4700-µF damping capacitors (C8 and C10) are not mounted on the PC board, but near the rear panel behind the smaller of the two PC boards. One of the 4700-µF damping capacitors is a standard electrolytic, the other is a parallel combination of five 1000-µF, 6.3-V bipolar (nonpolarized) capacitors wrapped in electrical tape.

Fig 43—The rear panel of the DF unit supports the two DPDT PHASE toggle switches. Grommets in the panel holes allow abrasion-free passage of the antenna, dc-power and audio cables. The dc power cord is outfitted with an inline fuse holder and a male Jones plug. A six-pin female Molex connector (five pins are used) feeds the four antennas. The audio-input cable is terminated in a 1/8-inch diameter male plug.

R24, but goes off when R24 is adjusted for 0 V across R24.

Next, adjust R24 for a slight negative-voltage indication and adjust R42 and R44 so that the red LED (DS3) comes on, but extinguishes when the voltage across R24 is 0 V. When you're done, adjusting R24's wiper slightly one way should illuminate the red LED. Both LEDs should be off when there's no voltage across R24; rotating R24's wiper slightly in the opposite direction should turn on the green LED.

Connect the voltmeter across R27 or use the panel meter as an indicator. With no audio input, adjust R27 so that there's no voltage across R27. Adjust R31 (F/B LED ADJ 1A) and R33 (F/B LED 1B) so that a F/B LED (DS1) is on when there is a slight positive voltage across R27 and the other F/B LED (DS2) is on when there is a negative voltage across R27.

Switch Board

Assemble the switch board for the four mag-mount antennas (see Fig 40). You can use half of a RadioShack dual pad-per-hole PC board (RS 276-148) as a platform. Lead length is critical only on this board and in the length of the coax from the switching board to the antennas, so avoid wire-wrap construction here.

Feed Lines

The coax lines from the switch board to each of the four antennas must be of equal length. The coax lengths should be long enough to permit each antenna to be placed slightly less than 1/4 λ from its counterpart, at the lowest frequency of operation. (There's a local belief that 27 1/2 inches is the best length. The author used that length and it works, but other lengths might work as well.) An attempt to locate the switch board inside the vehicle and run equal-length 12-foot-long cables to the antennas failed. Keep the switch board on the vehicle's roof.

Use the same type of coax for all lines—that is, don't mix foam and polyethylene dielectric coax on the antenna lines. If the velocity factor of the lines is not equal, a phase shift in the signals will exist even when the transmitter is dead ahead and it will lead you astray.

Solder the coax from the antennas directly to the board—don't use connectors. From the switch board to the receiver, use 50-Ω coax of any type and length. Equip the receiver end of the line with a connector that mates with your receiver's antenna-input jack. Make the four-conductor shielded cable from the main DFer box to the switch board long enough to reach from the LRFB box's operating position to the roof of the car. Construct the antennas so that the whips can be changed easily for use on any frequency in which you're interested.

Mechanical Assembly

Mount the finished PC boards in a metal box of your choice. You can follow the construction method used in the prototype (see **Fig 42** and **Fig 43**), but do ensure that R4 can be adjusted easily with a tuning tool from outside the box. A hole drilled in the box at the right point will suffice. Arrange the LEDs in a diamond pattern on the front panel, with the left LED (red) to the left, the right LED (green) on the right, and the front and back LEDs at the top and the bottom.

Wrap the switch board with tape to waterproof it, or place it in a watertight box. Arrange the mag-mount antennas on top of the vehicle in a diamond shape. The distance between each antenna pair should be less than 1/4 λ at the operating frequency. (In limiting the distance between antennas in a pair—F/B or L/R—to less than 1/4 λ, the author followed W9DUU's example.)

Final Adjustments

It's best to start on 2 meters. Install the 2-meter whips in the antenna bases. Mount the antennas on the top of your vehicle. Identify the left and right antenna bases with L and R, and mark the front and back antenna bases, too.

A good way to find out if the antennas are properly installed is to short either the left or right antenna with a clip lead from the whip to the metal base; the L/R meter will deflect one way and the left or right LED will light. If you short one of the front and back antennas with a clip lead, the front or back LED will come on. If you short one of the L/R antennas and it makes the meter go to the right, it does not necessarily mean you have the PHASE switch in the proper position. That depends on the relative phase determined by the number of audio stages in your receiver, each of which may contribute a shift of 180°.

Connect the coax from the switch board to your FM receiver. It must be an FM receiver; an AM VHF or AM aircraft receiver won't suffice. Connect the audio output of your 2-meter receiver to the LRFB box audio input. If you're using a transceiver, disable its transmit function by removing the mike. You don't want to transmit into the switch board!

Turn on the receiver and place the LRFB box in receive by setting S1 to the RCV position. Center R10. Only one of the antennas will be turned on and the DF operation will be disabled. Back off the squelch and notice that you hear the audio from the speaker of the LRFB box. Switch to an unused simplex channel. Have a friend with an HT stand 20 feet or so in front of the vehicle. With the receiver in the car turned off, turn S1 to DF. The four LEDs should be off. If an LED lights, adjust R24 and R27 for zero voltage. If the LED is still on, readjust R31 and R33, or R42 and R44 as explained earlier. When all four LEDs are off with the antennas connected, no audio from the receiver and no RF input signal, you're ready. Turn on your receiver and have your friend transmit on the 2-meter frequency (simplex) that your receiver is set to. When he transmits, one or more of the LEDs should illuminate. Ignore the front/back LEDs, but check to see if the right or left LED is on. If the right LED is on and your friend is standing to the right of the center of the vehicle front, all is well. Have him walk back and forth in front of the vehicle and notice that when he is to the right, the green LED turns on, and when he's to the left, the red LED glows. If the indications are reversed, that is, if the LRFB box indicates left when your friend is to your right, reverse the position of PHASE switch S3.

When the L/R indicators are working properly, have your friend walk back and forth between a position 20 feet to the front and right of the car and a position 20 feet away to the rear and right of the car. The right LED should stay on, but the front LED should be on when the HT is in front of the antennas, and the back LED should be on when the HT is behind the antennas. If the front/back indications are reversed, reverse the position of PHASE switch S4.

While receiving a signal from your friend's HT, adjust R4 for maximum deflection on any one of the two optional meters, or on a voltmeter (set on the lowest dc voltage range) connected across R24 or R27. Look for the maximum deflection of the meter needle as the meter swings both ways while the signal source moves from back to front or left to right (depending, of course, on which panel meter you're looking at or which resistor—R24 or R27—your voltmeter is across). The audio passband of FM receivers varies, and if you switch from an ICOM IC-27 to an ICOM IC-W2A, for example, you'll have to change U2's master clock frequency. You may encounter receivers that don't require readjusting R4, but such readjustment should be expected. When changing receivers, you may also need to change the position of PHASE switches S3 and S4. This may also be necessary when changing from UHF to VHF, or VHF to UHF on the same receiver, as the number of receiver stages (and, hence, the audio phase) may change from band to band.

Audio Level Adjustments

With meter damping (S2) off, adjust R10 so that you have full deflection of one of the two meters (or your multimeter) with the signal source at a 45° angle from the vehicle (halfway between ahead and right), and a reasonable audio level from the speaker. Turn the rig's volume control all the way up to ensure that the audio circuit doesn't overload. If it overloads, the meters won't deflect. From zero to full blast, the meter should deflect more and more (unless the signal is straight ahead or exactly left or right). If you're using an H-T, maximum deflection of the meter should occur before the volume control is $^{3}/_{4}$ of maximum, or before the volume control is at $^{1}/_{2}$ of maximum if you're using a mobile rig. If R10 is properly adjusted, turning the volume control to maximum won't cause the meter to fall back toward zero. If increasing the volume causes the meter to deflect less, then R10's setting is too high.

Now have your friend walk around the vehicle with the HT transmitting and notice that the LEDs indicate the signal direction. On 2 meters in a clear field, the indications should be correct 80 or 90% of the time. The erroneous readings that occasionally occur are due to multipath propagation caused by the irregular shape of the vehicle. Slight adjustments in the positions of the L/R and F/B antennas may be necessary to make the zero points fall directly in front of the vehicle (neither left nor right LED on) and at the center of the antennas (neither front nor back LED on).

Try the same procedure on 440 MHz. You may have to flip the PHASE switches when you move to another band, even when using the same receiver. Remember that the total length of the 440-MHz antennas must be $^{1}/_{4}$ λ or less, and the antennas must be placed less than $^{1}/_{4}$ λ apart. The results on 440 MHz probably won't be as consistent as the results on 2 meters, as there is likely to be a lot more multipath propagation caused by the irregular shape of the vehicle.

Fox Hunting

Before heading out to find the fox, check to be certain the LRFB box is working properly. Tune to the fox's frequency and drive off. Turning on the DAMPING switch stabilizes the indication as you drive along. Follow indications generated as you travel over the road or street. If an indication is constant for 15 or 20 seconds while you're moving down the road, it's probably the true direction to the fox. It's possible to have a reflection from a mountain over a long distance down the road, however. When you can hear the fox with no antenna, it's time to get out of the car, switch to the hand-held system and hunt for the fox on foot.

If you switch to a new receiver, you may have to readjust R4, CLOCK FREQ. That's because both receivers may not have the same audio bandwidth. Author WA9BVS forgot this while chasing a balloon once and the results were comical. When chasing balloons with ham radio transmitters, the readings you get are likely to be confusing when the balloon is at a high angle with respect to the plane of the car top. Use a hand-held Yagi to verify the balloon location. Even with a simple buzzbox, you should be able to find a keyed transmitter.

AN ADCOCK ANTENNA

Information in this section is condensed from an August 1975 *QST* article by Tony Dorbuck, K1FM, ex-W1YNC. Earlier in this chapter it was mentioned that loops are adequate in applications where only the ground wave is present. But the question arises, what can be done to improve the performance of an RDF system for sky-wave reception? One type of antenna that has been used successfully for this purpose is the Adcock antenna. There are many possible variations, but the basic configuration is shown in **Fig 44**.

The operation of the antenna when a vertically polarized wave is present is very similar to a conventional loop. As can be seen from Fig 44, currents I1 and I2 will be induced in the vertical members by the passing wave. The output current in the transmission line will be equal to their difference. Consequently, the directional pattern will be identical to the loop with a null broadside to the plane of the elements and with maximum gain occurring in end-fire fashion. The magnitude of the difference current will be proportional to the spacing, d, and the length of the elements. Spacing and length are not critical, but somewhat more gain will occur for larger dimensions than for smaller ones. In an experimental model, the spacing was 21 feet (approximately 0.15 wavelength at 7 MHz) and the element length was 12 feet.

Response of the Adcock antenna to a horizontally polarized wave is considerably different from that of a loop. The currents induced in the horizontal members (dashed arrows in Fig 44) tend to balance out regardless of the orientation of the antenna. This effect is borne out in practice, since good nulls can be obtained under sky-wave conditions that produce only poor nulls with small loops, either conventional or ferrite-loop models. Generally speaking, the Adcock antenna has very attractive properties for fixed-station RDF work or for semi-portable applications. Wood, PVC tubing or pipe, or other nonconducting material is preferable for the mast and boom. Distortion of the pattern may result from metal supports.

Since a balanced feed system is used, a coupler is needed to match the unbalanced input of the receiver. It consists of T1, which is an air-wound coil with a two-turn link wrapped around the middle. The combination is then resonated to the operating frequency with C1. C2 and C3 are null-clearing capacitors. A low-power signal source is placed some distance from the Adcock antenna and broadside to it. C2 and C3 are then adjusted until the deepest null is obtained. The coupler can be placed on

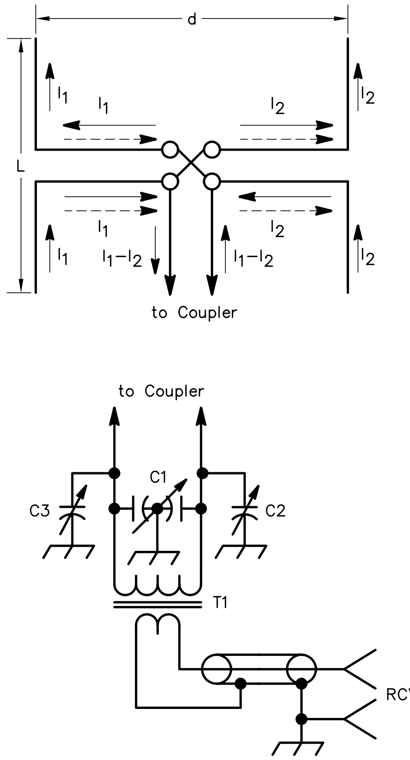


Fig 44—A simple Adcock antenna and suitable coupler (see text).

the ground below the wiring-harness junction on the boom and connected by means of a short length of 300-ohm twin-lead. A length of PVC tubing used as a mast facilitates rotation and provides a means of attaching a compass card for obtaining bearings.

Tips on tuning and adjusting a fixed-location RDF array are presented earlier in this chapter. See the section, "RDF System Calibration and Use."

BIBLIOGRAPHY

Source material and more extended discussion of topics covered in this chapter can be found in the references given below and in the textbooks listed at the end of Chapter 2.

W. U. Amphar, "Unidirectional Loops for Transmitter Hunting," *QST*, Mar 1955.

G. Bonaguide, "HF DF—A Technique for Volunteer Monitoring," *QST*, Mar 1984.

D. S. Bond, *Radio Direction Finders*, 1st edition (New York: McGraw-Hill Book Co).

R. E. Cowan and T. A. Beery, "Direction Finding with the Interferometer," *QST*, Nov 1985.

D. DeMaw, "Beat the Noise with a Scoop Loop," *QST*, Jul 1977.

D. DeMaw, "Maverick Trackdown," *QST*, Jul 1980.

T. Dorbuck, “Radio Direction-Finding Techniques,” *QST*, Aug 1975.

D. T. Geiser, “Double-Ducky Direction Finder,” *QST*, Jul 1981.

D. T. Geiser, “The Simple Seeker,” *The ARRL Antenna Compendium, Vol 3*, p 126.

N. K. Holter, “Radio Foxhunting in Europe,” Parts 1 and 2, *QST*, Aug and Nov 1976.

J. Isaacs, “Transmitter Hunting on 75 Meters,” *QST*, Jun 1958.

H. Jasik, *Antenna Engineering Handbook*, 1st edition (New York: McGraw-Hill, 1961).

R. Keen, *Wireless Direction Finding*, 3rd edition (London: Wireless World).

J. Kraus, *Antennas*, 2nd edition (New York: McGraw-Hill Book Co, 1988).

J. Kraus, *Electromagnetics*, 4th edition (New York: McGraw-Hill Book Co, 1992).

C. M. Maer, Jr., “The Snoop-Loop,” *QST*, Feb 1957.

M. C. Mallette, “The Four-Way DFer,” *QST*, Nov 1995. A set of two PC boards is available from FAR Circuits for the “Four-Way DFer” project. 18N640 Field Ct, Dundee, IL 60118-9269, tel 708-576-3540 (voice and fax). Note: No component pads for C15 exist. Mount C15 between U2 pin 5 and ground on the bottom (foil) side of the board. A PC-board template package is available from the ARRL free of charge. Send your request for the MALLETTE 4-WAY DFER, along with a business size SASE, to the Technical Department Secretary, 225 Main St, Newington, CT 06111-1494.

L. R. Norberg, “Transmitter Hunting with the DF Loop,” *QST*, Apr 1954.

P. O’Dell, “Simple Antenna and S-Meter Modification for 2-Meter FM Direction Finding,” Basic Amateur Radio, *QST*, Mar 1981.

Ramo and Whinnery, *Fields and Waves in Modern Radio* (New York: John Wiley & Sons, 1944).

F. Terman, *Electronic and Radio Engineering* (New York: McGraw-Hill Book Co, 1955).

Radio Direction Finding , published by the Happy Flyer, 1811 Hillman Ave, Belmont, CA 94002.

For more information on direction finding, see *The ARRL Handbook* and *Transmitter Hunting: Radio Direction Finding Simplified*, by Joe Moell, KØOV, and Thomas Curlee, WB6UZZ. These books are available from your local dealer or can be ordered directly from ARRL.