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Chapter 22

Receiving and Direction-Finding Antennas

22.1 RECEIVING ANTENNAS

The following introduction is excerpted from the section "Introduction to Receiving Antennas" written by Robye Lahlum, W1MK, in *ON4UN's Low-Band DXing*.

Separate antennas are necessary because optimum receiving and transmitting have different requirements. For a transmit antenna, we want maximum possible field strength in a given direction (or directions) at the most useful elevation (wave) angles. We cannot tolerate unnecessary power loss in a transmit antenna, because any amount of transmitting loss decreases signal-to-noise ratio at the distant receiver.

A receiving antenna on the other hand has a different design priority. The goal is obtaining a signal that can be read comfortably, which means having the greatest possible signal-to-noise (S/N) and signal-to-QRM ratio. Receiving antennas providing the best performance can and will be different under different circumstances, even at the same or similar locations. There is no such thing as a universal "best low-band receiving antenna."

Typical low band receiving antennas like the Beverage require more space that most hams have available. In recent years, computer modeling has enabled the development of small loops and arrays that provide meaningful improvements in receiving ability without requiring large areas or overly specialized construction techniques.

22.1.1 DIRECTIVITY AND COUPLING

For a receiving antenna on the low bands directivity is the main concern. There are currently two methods to quantify this directivity as described in the fifth edition of ON4UN's *Low-Band DXing.*

Directivity Merit Figure (DMF)

The average front-to-back (the peak forward lobe versus what happens in the back 180° over the entire elevation angle range) gives a good indication of directivity. The DMF is the forward gain of the antenna at a chosen elevation angle (usually the elevation angle producing maximum gain) minus the average back half-hemisphere's gain. The back quadrisphere is the area between 90° and 270° azimuth — provided the forward lobe is aiming at 0° azimuth — and 0° to 90° elevation. (DMF can be calculated from the table of pattern gain values and using a spreadsheet or other software to perform the averaging function. W8WWV's *DBDXView* will perform the calculations from *EZNEC* data files and is available with *Low-Band DXing*.)

This method of evaluating a receive antenna applies to a case where a dominant noise arrives from a relatively wide half-hemisphere. If the noise is evenly distributed in all directions (eg, in a very quiet location), the RDF ranking system discussed below should be used.

Many noise sources vary in direction, arrival angle and polarization tilt. The same is true for desired signals. Because of this, we really only are considering "average" results over time. Averages are not foolproof under every condition. For example, if you have a strong single-point noise and if that noise arrives in a deep notch in your receiving antenna pattern, the S/N improvement may be much greater than expected. If noise arrives predominantly from a higher antenna response area, the S/N improvement will be proportionally less. Another important thing to consider: Signals almost never arrive from a single angle or direction. A range of angles is involved, and a single-angle evaluation does not fully represent the real world.

Receiving Directivity Factor (RDF)

Developed by Tom Rauch, W8JI (**www.w8ji.com**), RDF goes a step further and compares the forward lobe gain to the average gain of the antenna in all directions (both azimuth and elevation).

While the Directivity Merit Factor (DMF) compares forward gain at the desired wave angle to the average gain in the rear half hemisphere, RDF compares forward gain at a desired direction and elevation angle to average gain over the entire hemisphere above ground. RDF includes all areas around and above the antenna, considering noise to be evenly distributed and aligned with the element polarization. RDF tells you not only how good the average front-to-back ratio is, but also how narrow your forward (wanted) lobe is.

Losses are factored out, and we find the directivity of the array. If noise, on average, is evenly distributed in all directions (including forward and side lobe areas) this method provides an accurate picture of receiving ability. (Keep in mind most antenna modeling programs used by amateurs calculate pattern at infinite distances and ignore ground wave response. RDF models, like DMF models, are not reliable when ground wave noise dominates skywave noise.)

For everything but an omnidirectional antenna, the RDF will be different from the DMF. You have to decide if your location has dominant skywave noise in the rearward area (DMF), or if skywave noise is evenly distributed on average (RDF). Do not compare RDF with DMF.

Calculating the RDF with *EZNEC* is very simple. After ensuring the model is correct, model the antenna with lossy elements and real ground and plot the 3D pattern. The main *EZNEC* window shows average gain at the very bottom. Now, go to a two-dimensional elevation or azimuth pattern and select the desired elevation angle and/or azimuth of the desired signal with the gain cursor and note the gain. The difference between the overall average gain and gain at the desired direction and elevation angle is the RDF. The front lobe does not have to align with the desired signal. You can also move the cursor around and look at the RDF for off-path signals. (W8WWV's *LBDXView* software will also calculate RDF from *EZNEC* tables.)

Using DMF and RDF

Both evaluation systems have their merits. If you're in a location that's always very quiet, with no specific noise or QRM sources from a particular direction, then RDF is most meaningful. The exception would be if you always had grossly dominant noise (or QRM) only from one direction. For a front-to-rear (F/R) selection to be valid, the dominant noise would have to be so strong as to consistently exceed distributed background noise by the null-depth ratio between an antenna selected by RDF compared to one selected by F/R.

John Kaufmann, W1FV, also made the following observation on the Topband email reflector (**lists.contesting.com/mailman/listinfo/Topband**): "As RDF gets higher, the beamwidth of the antenna system generally gets narrower. By making the RDF very high, you are necessarily restricting the angular sector over which the antenna delivers its best performance. This is fine as long as the angular sector coincides with a direction that is important to you. The flip side is you give up some of that performance outside that sector. For switched arrays with a finite number of selectable directions, that could be a disadvantage when a direction of interest falls halfway between contiguous switching directions. Looking at the pattern of the array will tell you what you give up in the "in between" directions."

Polarization of the signals and the noise are assumed to be the same on average for RDF calculations. If the signal and noise have different polarizations, the antenna will have different responses to each and the RDF metric is not valid. For example, if your local noise source has a different polarization than the sky-wave signals you are trying to receive, RDF can be greatly misleading.

Coupling

Most antenna models are developed and evaluated without other antennas or conductive surfaces nearby except for ground under the antenna. This is rarely the case in the real world, with transmitting antennas, metal surfaces and structures, power lines, and numerous other conductors in the vicinity. Especially on the low bands with their long wavelengths, it is common for other antennas to be as close as a few hundredths of a wavelength away. As a result, there will likely be a significant amount of interaction. As W8JI observed, "If [the antenna] receives, it will receive from the mess of things all around it from the dirt below it to the wires down the road."

Coupling can significantly distort an antenna's radiation pattern, whether receiving or transmitting. Separating the antenna from whatever it is coupling to is the best remedy but that is not an option in many cases. De-tuning an antenna when not in use by shifting its resonance out of band is a common technique of reducing coupling. The exact technique depends on the antenna.

Coupling can also result in significant amounts of power being picked up and overloading or damaging receivers. Out-of-band energy can be rejected with filters, but in-band coupling is harder to manage. Front-end protection circuits may be required, or a relay to interrupt the signal path during transmit periods is often used.

Noise pickup from coupling occurs on the outer surface of feed lines where it can then get into the feed line at a termination. It is particularly important to insure that common-mode current on the feed line shield is blocked from entering the feed line where it mixes with the desired signal and cannot be removed. Ferrite chokes (see the **Transmission Line System Techniques** chapter) at the end of the cable can be quite effective against noise *ingress* from coupling. As an added bonus, this also reduces coupling of the feed line's outer surface to other antennas.

22.1.2 THE BEVERAGE ANTENNA

Perhaps the best known type of wave antenna is the *Beverage*. Many 160 meter enthusiasts have used Beverage antennas to enhance the signal-to-noise ratio while attempting to extract weak signals from the often high levels of atmospheric noise and interference on the low bands. Alternative antenna systems have been developed and used over the years, such as loops and long spans of unterminated wire on or slightly above the ground, but the Beverage antenna seems to be the best for 160 meter weak-signal reception. The information in this section was prepared originally by Rus Healy, K2UA.

A Beverage is simply a directional wire antenna, at least one wavelength long, supported along its length at a fairly low height and terminated at the far end in its characteristic impedance. This antenna is shown in **Figure 22.1A**. It takes its name from its inventor, Harold Beverage, W2BML.

Many amateurs choose to use a single-wire Beverage because they are easy to install and they work well. The drawback is that Beverages are physically long and they do require that you have the necessary amount of real estate to install them. Sometimes, a neighbor will allow you to put up a temporary Beverage for a particular contest or DXpedition on his land, particularly during the winter months.

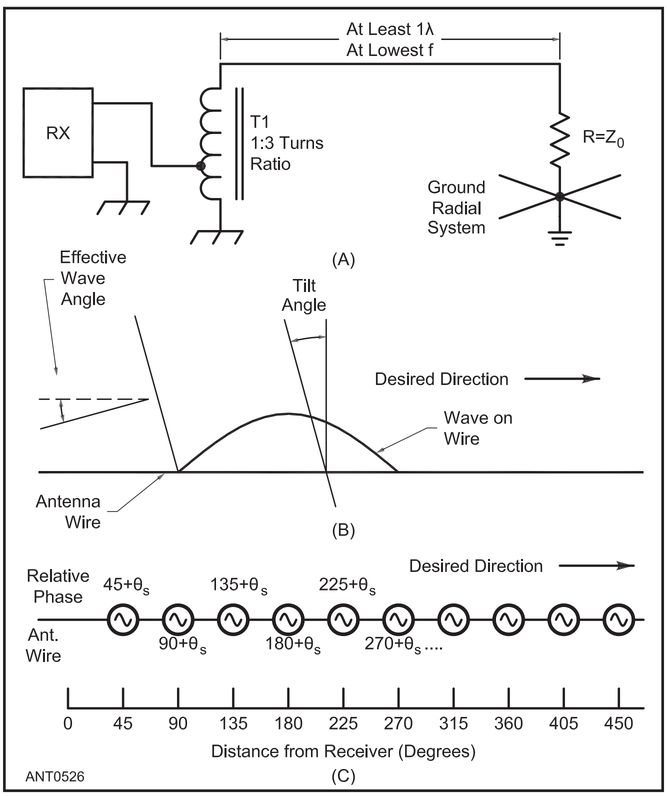


Figure 22.1 — At A, a simple one-wire Beverage antenna with a variable termination impedance and a matching 9:1 autotransformer for the receiver impedance. At B, a portion of a wave from the desired direction is shown traveling down the antenna wire. Its tilt angle and effective takeoff angle are also shown. At C, a situation analogous to the action of a Beverage on an incoming wave is shown. See text for discussion.

Beverage antennas can be useful into the HF range, but they are most effective at lower frequencies, mainly on 160 through 40 meters. The antenna is responsive mostly to low-angle incoming waves that maintain a constant (vertical) polarization. These conditions are nearly always satisfied on 160 meters, and most of the time on 80 meters. As the frequency is increased, however, the polarization and arrival angles are less and less constant and favorable, making Beverages less effective at these frequencies. Many amateurs have, however, reported excellent performance from Beverage antennas at frequencies as high as 14 MHz, especially when rain or snow (precipitation) static prevents good reception on the Yagi or dipole transmitting antennas used on the higher frequencies.

Beverage Theory

The Beverage antenna acts like a long transmission line with one lossy conductor (the ground), and one good conductor (the wire). Beverages have excellent directivity if erected properly, but they are quite inefficient because they are mounted close to the ground. This is in contrast with the terminated long-wire antennas described earlier, which are typically mounted high off the ground. Beverage antennas are not suitable for use as transmitting antennas.

Because the Beverage is a traveling wave, terminated antenna, it has no standing waves resulting from radio signals. As a wave strikes the end of the Beverage from the desired direction, the wave induces voltages along the antenna and continues traveling in space as well. Figure 22.1B shows part of a wave on the antenna resulting from a desired signal. This diagram also shows the tilt of the wave. The signal induces equal voltages in both directions. The resulting currents are equal and travel in both directions. The component traveling toward the termination end moves against the wave and thus builds down to a very low level at the termination end. Any residual signal resulting from this direction of current flow will be absorbed in the termination (if the termination is equal to the antenna impedance). The component of the signal flowing in the other direction, as we will see, becomes a key part of the received signal.

As the wave travels along the wire, the wave in space travels at approximately the same velocity. (There is some phase delay in the wire, as we shall see.) At any given point in time, the wave traveling along in space induces a voltage in the wire in addition to the wave already traveling on the wire (voltages already induced by the wave). Because these two waves are nearly in phase, the voltages add and build toward a maximum at the receiver end of the antenna.

This process can be likened to a series of signal generators lined up on the wire, with phase differences corresponding to their respective spacings on the wire (Figure 22.1C). At the receiver end, a maximum voltage is produced by these voltages adding in phase. For example, the wave component induced at the receiver end of the antenna will be in phase (at the receiver end) with a component of the same wave induced, say, 270° (or any other distance) down the antenna, after it travels to the receiver end.

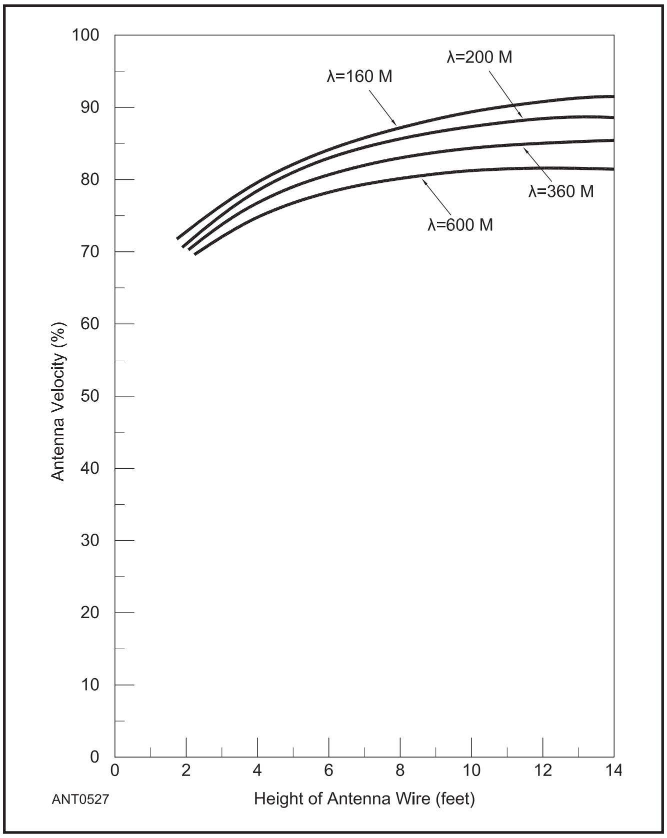


Figure 22.2 — Signal velocity on a Beverage increases with height above ground, and reaches a practical maximum at about 10 feet. Improvement is minimal above this height. (100% represents the velocity of light.)

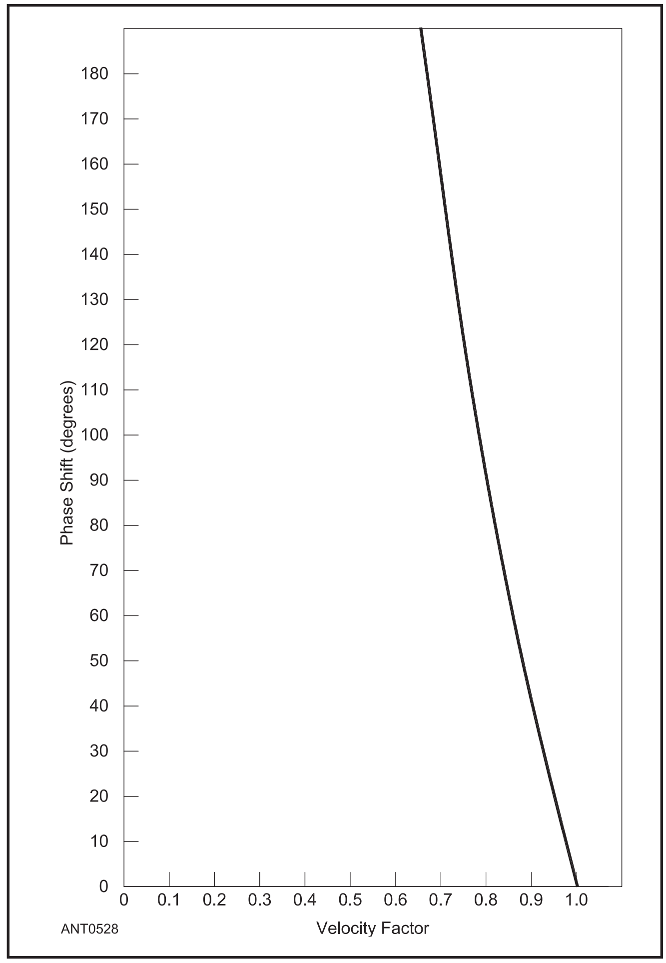


Figure 22.3 — This curve shows phase shift (per wavelength) as a function of velocity factor on a Beverage antenna. Once the phase shift for the antenna goes beyond 90°, the gain drops off from its peak value, and any increase in antenna length will decrease gain.

In practice, there is some phase shift of the wave on the wire with respect to the wave in space. This phase shift results from the velocity factor of the antenna. (As with any transmission line, the signal velocity on the Beverage is somewhat less than in free space.) Velocity of propagation on a Beverage is typically between 85 and 98% of that in free space. As antenna height is increased to a certain optimum height (which is about 10 feet for 160 meters), the velocity factor increases. Beyond this height, only minimal improvement is afforded, as shown in **Figure 22.2**. These curves are the result of experimental work done in 1922 by RCA, and reported in a *QST* article (November 1922) entitled "The Wave Antenna for 200-Meter Reception," by H. H. Beverage. The curve for 160 meters was extrapolated from the other curves.

Phase shift (per wavelength) is shown as a function of velocity factor in **Figure 22.3**, and is given by:

$$\theta = 360\left(\frac{100}{k} - 1\right) \qquad \text{(Eq 1)}$$

where k = velocity factor of the antenna in percent.

The signals present on and around a Beverage antenna are shown graphically in A through D of **Figure 22.4**. These curves show relative voltage levels over a number of periods of the wave in space and their relative effects in terms of the total signal at the receiver end of the antenna.

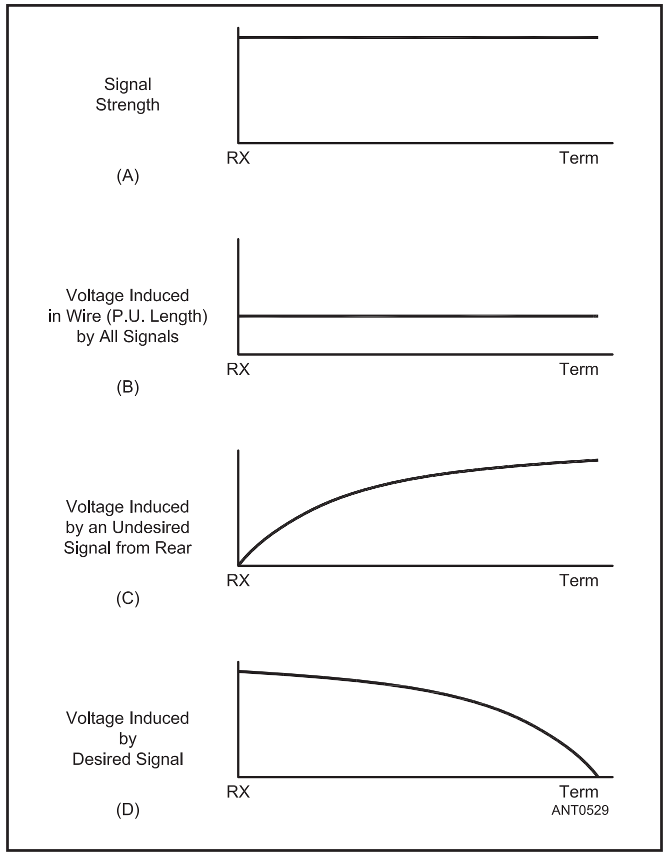
Performance in Other Directions

The performance of a Beverage antenna in directions other than the favored one is quite different than previously discussed. Take, for instance, the case of a signal arriving perpendicular to the wire (90° either side of the favored direction). In this case, the wave induces voltages along the wire that are essentially *in phase*, so that they arrive at the receiver end more or less out of phase, and thus cancel. (This can be likened to a series of signal generators lined up along the antenna as before, but having no progressive phase differences.)

As a result of this cancellation, Beverages exhibit deep nulls off the sides. Some minor sidelobes will exist, as with other long-wire antennas, and will increase in number with the length of the antenna.

In the case of a signal arriving from the rear of the antenna, the behavior of the antenna is very similar to its performance in the favored direction. The major difference is that the signal from the rear adds in phase at the termination end and is absorbed by the termination impedance. **Figure 22.5** compares the azimuth and elevation patterns for a

Figure 22.4 — These curves show the voltages that appear in a Beverage antenna over a period of several cycles of the wave. Signal strength (at A) is constant over the length of the antenna during this period, as is voltage induced per unit length in the wire (at B). (The voltage induced in any section of the antenna is the same as the voltage induced in any other section of the same size, over the same period of time.) At C, the voltages induced by an undesired signal from the rearward direction add in phase and build to a maximum at the termination end, where they are dissipated in the termination (if $Z_{term} = Z_0$). The voltages resulting from a desired signal are shown at D. The wave on the wire travels closely with the wave in space, and the voltages resulting add in phase to a maximum at the receiver end of the antenna.



2-λ (1062 foot) and a 1-λ (531 foot) Beverage at 1.83 MHz. The wire is mounted 8 feet above flat ground (to keep it above deer antlers and away from humans too) and is terminated with a 500-Ω resistor in each case, although the exact value of the terminating resistance is not very critical. The ground constants assumed in this computer model are conductivity of 5 mS/m and a dielectric constant of 13. Beverage dielectric performance tends to decrease as the ground becomes better. Beverages operated over saltwater do not work as well as they do over poor ground.

For most effective operation, the Beverage should be terminated in an impedance equal to the characteristic impedance Z_{ANT} of the antenna. For maximum signal transfer

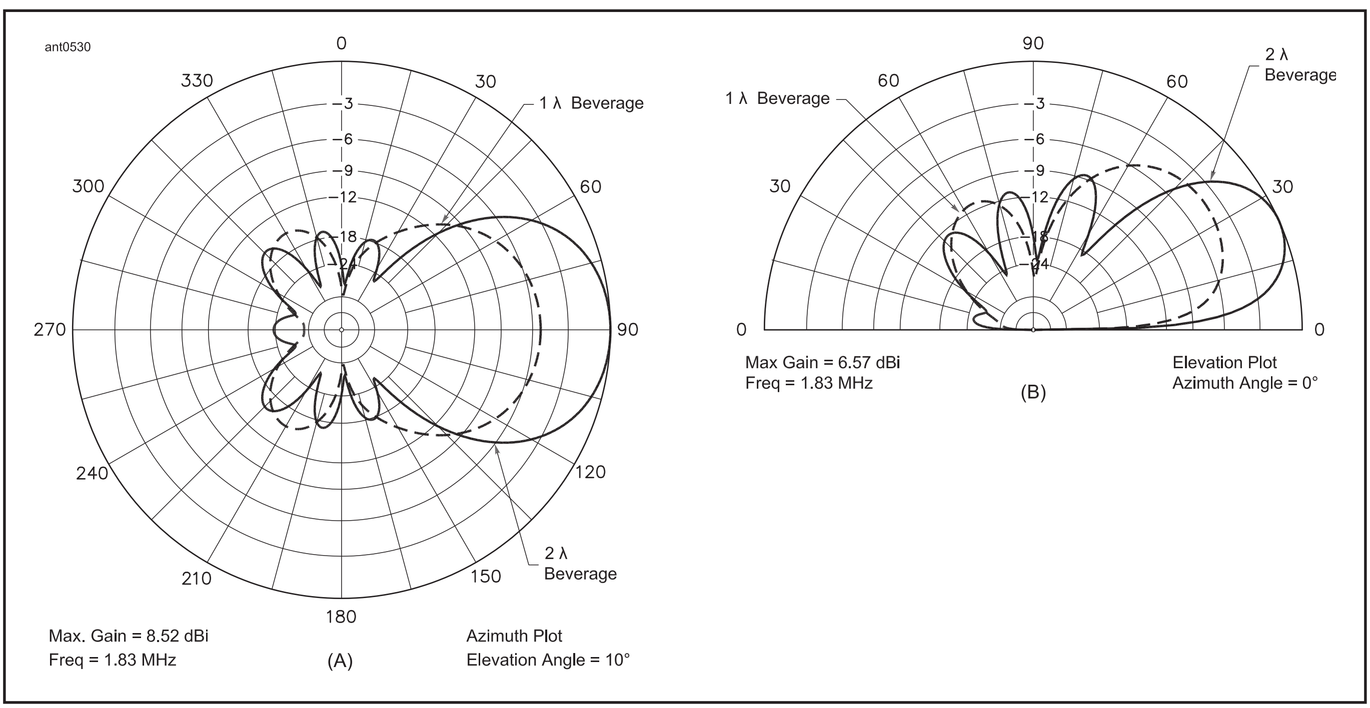


Figure 22.5 — At A, azimuthal patterns of a 2-λ (solid line) and a 1-λ (dashed line) Beverage antenna, terminated with 550-Ω resistor at 1.83 MHz, at an elevation angle of 10°. The rearward pattern around 180° is more than 20 dB down from the front lobe for each antenna. At B, the elevation-plane patterns. Note the rejection of very high-angle signals near 90°.

to the receiver you should also match the receiver's input impedance to the antenna. If the termination impedance is not equal to the characteristic impedance of the antenna, some part of the signal from the rear will be reflected back toward the receiver end of the antenna.

If the termination impedance is merely an open circuit (no terminating resistor), total reflection will result and the antenna will exhibit a bidirectional pattern (still with very deep nulls off the sides). An unterminated Beverage will not have the same response to signals in the rearward direction as it exhibits to signals in the forward direction because of attenuation and re-radiation of part of the reflected wave as it travels back toward the receiver end. **Figure 22.6** compares the response from two 2-λ Beverages, one terminated and the other unterminated. Just like a terminated long-wire transmitting antenna (which is mounted higher off the ground than a Beverage, which is meant only for receiving), the terminated Beverage has a reduced forward lobe compared to its unterminated sibling. The unterminated Beverage exhibits about a 5 dB front-to-back ratio for this length because of the radiation and wire and ground losses that occur before the forward wave gets to the end of the wire.

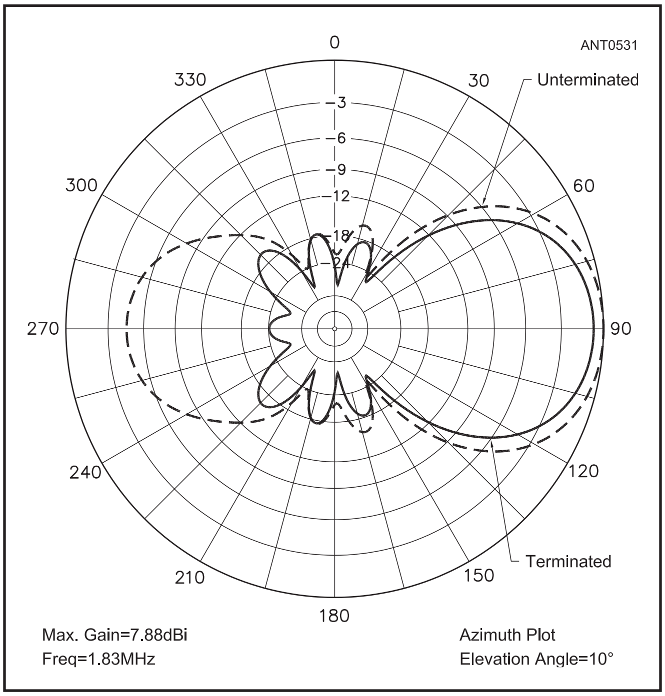


Figure 22.6 — Comparing the azimuthal patterns for a 2-λ Beverage, terminated (solid line) and unterminated (dashed line).

If the termination is between the extremes (open circuit and perfect termination in Z_{ANT}), the peak direction and intensity of signals off the rear of the Beverage will change. As a result, an adjustable reactive termination can be employed to *steer* the nulls to the rear of the antenna (see **Figure 22.7**). This can be of great help in eliminating a local interfering signal from a rearward direction (typically 30° to 40° either side of the back direction). Such a scheme doesn't help much for interfering skywave signals because of variations encountered in the ionosphere that constantly shift polarity, amplitude, phase and incoming elevation angles.

To determine the appropriate value for a terminating resistor, you need to know the characteristic impedance (surge impedance), Z_{ANT}, of the Beverage. It is interesting to note that Z_{ANT} is not a function of the length, just like a transmission line.

$$Z_{ANT} = 138 \times \log\left(\frac{4h}{d}\right) \quad \text{(Eq 2)}$$

where

Z_{ANT} = characteristic impedance of the Beverage = terminating resistance needed

h = wire height above ground

d = wire diameter (in the same units as h)

Another aspect of terminating the Beverage is the quality of the RF ground used for the termination. For most types of soil a ground rod is sufficient, since the optimum value for the termination resistance is in the range of 400 to 600 Ω for

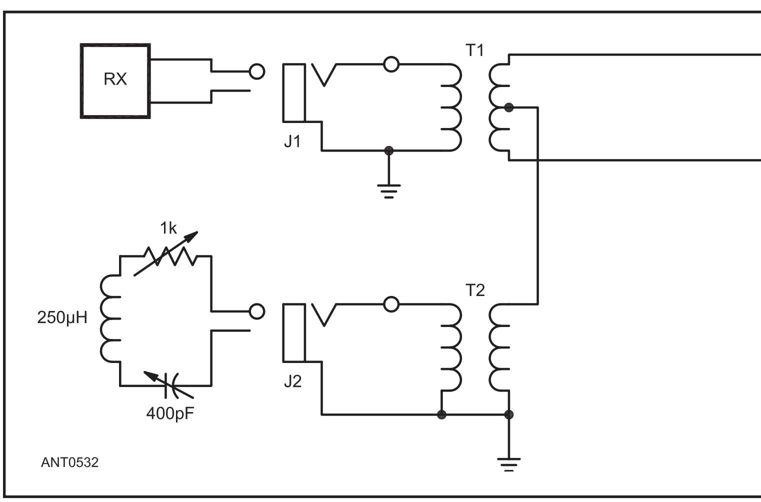


Figure 22.7 — A two-wire Beverage antenna that has provisions for direction switching and null steering in the rear quadrant. Performance improves with height to a point, and is optimum for 1.8-MHz operation at about 10 to 12 feet. Parts identifications are for text reference.

typical Beverages and the ground-loss resistance is in series with this. Even if the ground-loss resistance at the termination point is as high as 40 or 50 Ω, it still is not an appreciable fraction of the overall terminating resistance. For soil with very poor conductivity, however, (such as sand or rock) you can achieve a better ground termination by laying radial wires on the ground at both the receiver and termination ends. These wires need not be resonant quarter-wave in length, since the ground detunes them anyway. Like the ground counterpoise for a vertical antenna, a number of short radials is better than a few long ones. Some amateurs use chicken-wire ground screens for their ground terminations.

As with many other antennas, improved directivity and gain can be achieved by lengthening the antenna and by arranging several antennas into an array. One item that must be kept in mind is that by virtue of the velocity factor of the antenna, there is some phase shift of the wave on the antenna with respect to the wave in space. Because of this phase shift, although the directivity will continue to sharpen with increased length, there will be some optimum length at which the gain of the antenna will peak. Beyond this length, the current increments arriving at the receiver end of the antenna will no longer be in phase, and will not add to produce a maximum signal at the receiver end. This optimum length is a function of velocity factor and frequency, and is given by:

$$L = \frac{\lambda}{4\left(\frac{100}{k} - 1\right)} \qquad \text{(Eq 3)}$$

where

L = maximum effective length

λ = signal wavelength in free space (same units as L)

k = velocity factor of the antenna in percent

Because velocity factor increases with height (to a point, as mentioned earlier), optimum length is somewhat longer if the antenna height is increased. The maximum effective length also increases with the number of wires in the antenna system. For example, for a two-wire Beverage like the bidirectional version shown in Figure 22.7, the maximum effective length is about 20% longer than the single-wire version. A typical length for a single-wire 1.8-MHz Beverage (made of #16 AWG wire and erected 10 feet above ground) is about 1200 feet.

Feed Point Transformers for Single-Wire Beverages

Matching transformer T1 in Figure 22.1 is easily constructed. Small toroidal ferrite cores are best for this application, with those of high permeability (μ_i = 125 to 5000) being the easiest to wind (requiring fewest turns) and having the best high-frequency response (because few turns are used). Trifilar-wound autotransformers are most convenient.

Most users are not concerned with a small amount of SWR on the transmission line feeding their Beverages. For example, let us assume that the Z_{ANT} of a particular Beverage is 525 Ω and the terminating resistance is made equal to that value. If a standard 3:1 turns-ratio autotransformer is used at the input end of the antenna, the nominal impedance transformation 50 Ω × 3^2 = 450 Ω. This leads to the terminology often used for this transformer as a *9:1 transformer*, referring to its impedance transformation. The resulting SWR on the feed line going back to the receiver would be 525/450 = 1.27:1, not enough to be concerned about. For a Z_{ANT} of 600 Ω, the SWR is 600/450 = 1.33:1, again not a matter of concern.

Hence, most Beverage users use standard 9:1 (450:50 Ω) autotransformers. You can make a matching transformer suitable for use from 160 to 40 meters using eight trifilar turns of #24 AWG enameled wire wound over a stack of two Amidon FT-50-75 or two MN8-CX cores. See **Figure 22.8**.

Make your own trifilar cable bundle by placing three 3-foot lengths of the #24 AWG wire side-by-side and twisting them in a hand drill so that there is a uniform twist about one twist-per-inch. This holds the three wires together in a bundle that can be passed through the two stacked cores, rather like threading a needle. Remember that each time you put the bundle through the center of the cores counts as one turn.

After you finish winding, cut the individual wires to leave about ¾-inch leads, sand off the enamel insulation and tin the wires with a soldering iron. Identify the individual wires with an ohmmeter and then connect them together following Figure 22.8. Coat the transformer with Q-dope (liquid polystyrene) to finalize the transformer. White glue will work also. See the chapter **Transmission Line System Techniques** for more information. *The ARRL Handbook* and the chapter **Receiving Antennas** of *ON4UN's Low-Band DXing* book are also good sources of more information on winding toroidal transformers

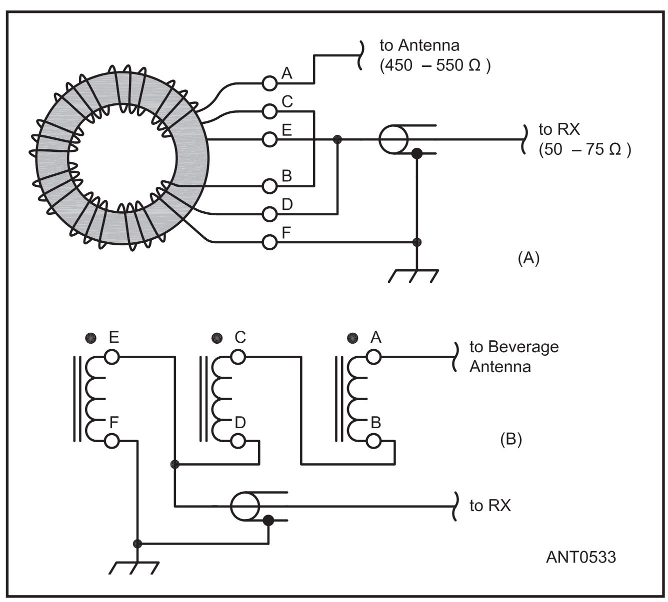


Figure 22.8 — Constructing the feed point transformer for a single-wire Beverage. See text for details.

Practical Considerations

Even though Beverage antennas have excellent directive patterns if terminated properly, gain never exceeds about –3 dBi in most practical installations. However, the directivity that the Beverage provides results in a much higher signal-to-noise ratio for signals in the desired direction than almost any other real-world antenna used at low frequencies.

A typical situation might be a station located in the US Northeast (W1), trying to receive Top Band signals from Europe to the northeast, while thunderstorms behind him in the US Southeast (W4) are creating huge static crashes. Instead of listening to an S7 signal with 10-dB over S9 noise and interference on a vertical, the directivity of a Beverage will typically allow you to copy the same signal at perhaps S5 with only S3 (or lower) noise and interference. This is certainly a worthwhile improvement. However, if you are in the middle of a thunderstorm, or if there is a thunderstorm in the direction from which you are trying to receive a signal, no Beverage is going to help you!

There are a few basic principles that must be kept in mind when erecting Beverage antennas if optimum performance is to be realized.

1) Plan the installation thoroughly, including choosing an antenna length consistent with the optimum length values discussed earlier.

2) Keep the antenna as straight and as nearly level as possible over its entire run. Avoid following the terrain under the antenna too closely — keep the antenna level with the average terrain.

3) Minimize the lengths of vertical downleads at the ends of the antenna. Their effect is detrimental to the directive pattern of the antenna. It is best to slope the antenna wire from ground level to its final height (over a distance of 50 feet or so) at the feed point end. Similar action should be taken at the termination end. Be sure to seal the transformers against weather.

4) Use a noninductive resistor for terminating a single-wire Beverage. If you live in an area where lightning storms are common, use 2-W terminating resistors, which can survive surges due to nearby lightning strikes.

5) Use high-quality insulators for the Beverage wire where it comes into contact with the supports. Plastic insulators designed for electric fences are inexpensive and effective.

6) Keep the Beverage away from parallel conductors such as electric power and telephone lines for a distance of at least 200 feet. Perpendicular conductors, even other Beverages, may be crossed with relatively little interaction, but do not cross any conductors that may pose a safety hazard.

7) Run the coaxial feed line to the Beverage so that it is not directly under the span of the wire. This prevents common-mode currents from appearing on the shield of the coax. It may be necessary to use a ferrite-bead choke on the feed line if you find that the feed line itself picks up signals when it is temporarily disconnected from the Beverage.

8) If you use elevated radials in your transmitting antenna system, keep your Beverage feed lines well away from them to avoid stray pickup that will ruin the Beverage's directivity.

The Two-Wire Beverage

The two-wire antenna shown in Figure 22.7 has the major advantage of having signals from both directions available at the receiver at the flip of a switch between J1 and J2. Also, because there are two wires in the system (equal amounts of signal voltage are induced in both wires), greater signal voltages will be produced. (The April 2006 *QST* article "A Cool Beverage Four Pack" by Ward Silver, NØAX, describes a four-directional array created from a pair of two-wire Beverages at right angles.)

A signal from the left direction in Figure 22.7 induces equal voltages in both wires, and equal in-phase currents flow as a result. The *reflection transformer* (T3 at the right-hand end of the antenna) then inverts the phase of these signals and reflects them back down the antenna toward the receiver, using the antenna wires as a balanced open-wire transmission line. This signal is then transformed by T1 down to the input impedance of the receiver (50 Ω) at J1.

Signals traveling from right to left also induce equal voltages in each wire, and they travel in phase toward the receiver end, through T1, and into T2. Signals from this direction are available at J2.

T1 and T2 are standard 9:1 wideband transformers capable of operating from 1.8 to at least 10 MHz. Like any two parallel wires making up a transmission line, the two-wire Beverage has a certain characteristic impedance — we'll call it Z_1 here — depending on the spacing between the two wires and the insulation between them. T3 transforms the terminating resistance needed at the end of the line to Z_1. Keep in mind that this terminating resistance is equal to the characteristic impedance Z_{ANT} of the Beverage — that is, the impedance of the parallel wires over their images in the ground below. For example, if Z_1 of the Beverage wire is 300 Ω (that is, you used TV twin-lead for the two Beverage wires), T3 must transform the balanced 300 Ω to the unbalanced 500 Ω Z_{ANT} impedance used to terminate the Beverage.

The design and construction of the reflection transformer used in a two-wire Beverage is more demanding than that for the straightforward matching transformer T1 because the exact value of terminating impedance is more critical for good F/B. See the **Receiving Antennas** chapter in *ON4UN's Low-Band DXing* for details on winding the reflection transformers for a two-wire Beverage.

Another convenient feature of the two-wire Beverage is the ability to steer the nulls off either end of the antenna while receiving in the opposite direction. For instance, if the series RLC network shown at J2 is adjusted while the receiver is connected to J1, signals can be received from the left direction while interference coming from the right can be partially or completely nulled. The nulls can be steered over a 60° (or more) area off the right-hand end of the antenna. The same null-steering capability exists in the opposite direction with the receiver connected at J2 and the termination connected at J1.

The two-wire Beverage is typically erected at the same height as a single-wire version. The two wires are at the same height and are spaced uniformly — typically 12 to 18 inches apart for discrete wires. Some amateurs construct two-wire Beverages using "window" ladder-line, twisting the line about three twists per foot for mechanical and electrical stability in the wind.

The characteristic impedance Z_{ANT} of a Beverage made using two discrete wires with air insulation between them depends on the wire size, spacing and height and is given by:

$$Z_{ANT} = \frac{69}{\sqrt{\varepsilon}} \times \log\left[\frac{4h}{d}\sqrt{1+\left(\frac{2h}{S}\right)^2}\right] \qquad \text{(Eq 4)}$$

where

Z_{ANT} = Beverage impedance = desired terminating resistance
S = wire spacing
h = height above ground
d = wire diameter (in same units as S and h)
ε = 2.71828

Beverages in Echelon

The pattern of a Beverage receiving antenna is dependent on the terminating resistance used for a particular antenna, as was demonstrated at the extremes by Figure 22.6. This compared the patterns for a terminated and an unterminated Beverage. The pattern of even a poorly terminated Beverage can be significantly improved by the addition of a second Beverage. The additional Beverage is installed so that it is operated *in echelon*, a word deriving from the fact that the two wires look like the parallel rungs on a ladder. For a practical 160 and 80 meter setup the second Beverage wire is parallel to the first Beverage, spaced from it by about 5 meters, and also staggered 30 meters ahead. See **Figure 22.9**.

The forward Beverage is fed with a phase difference of +125° such that the total phase, including that due to the forward staggering, is 180°. This forms the equivalent of an end-fire array fed out-of-phase, but it takes advantage of the natural directivity of each Beverage. **Figure 22.10** compares the pattern of a single 1-λ 160 meter Beverage that is sloppily terminated with two Beverages fed in echelon. The Beverages in echelon gives a modest additional gain of almost 2 dB. But where the two Beverages in echelon really shine is how they clean up the rearward pattern — from an average about 15 dB for the single Beverage to more than 25 dB for the two Beverages.

Even at a spacing of 5 meters, there is very little mutual coupling between the two Beverage wires because of their inherently small radiation resistance when they are mounted low above lossy ground. If you adjust for a low SWR (using proper transformers to match the feed line coaxes), the phase difference will depend solely on the difference in length of the two coaxes feeding the Beverage wires. **Figure 22.11** shows a wideband feed system designed by Tom Rauch, W8JI, as a "cross-fire" feed system. The 180° wideband phase-inverting transformer allows the system to work on two bands, say 160 and 80 meters. See the **Receiving Antennas** chapter in *ON4UN's Low-Band DXing* book for transformer details.

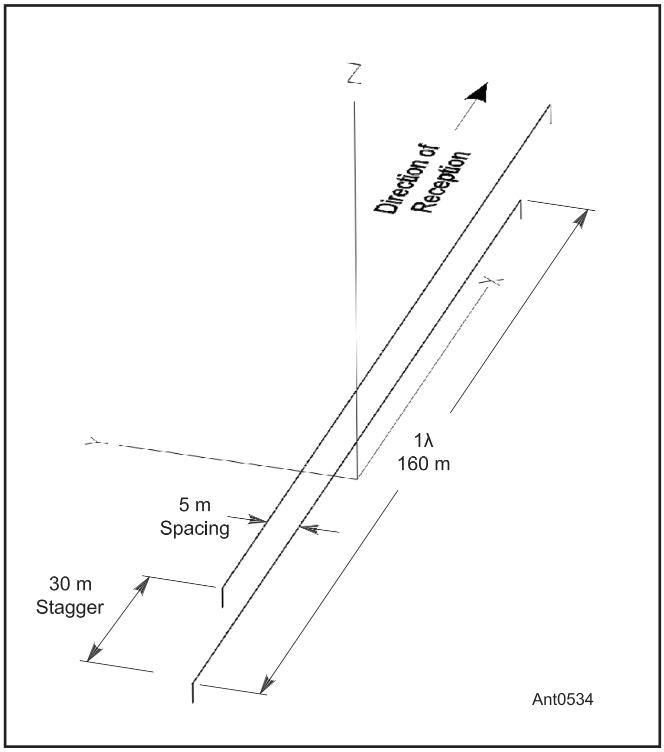


Figure 22.9 — Layout of two 160 meter 1-λ long Beverages in echelon, spaced 5 meters apart, with 30 meter forward stagger. The upper antenna has a 125° phase shift in its feed system.

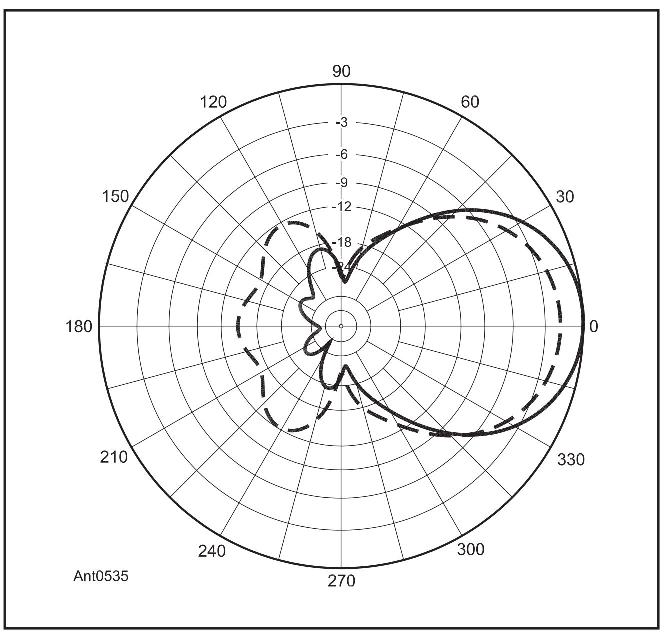


Figure 22.10 — Azimuth pattern at 10° takeoff angle for single Beverage (dashed line) and two Beverages in an echelon end-fire array. The rearward pattern is considerably cleaner on the echelon. Thus, two closely spaced, short Beverages can give considerable improvement over a single short Beverage.

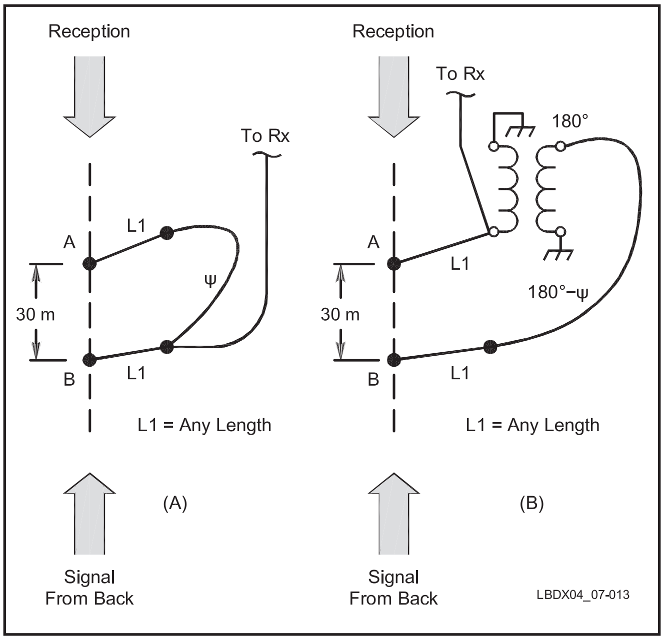


Figure 22.11 — Two ways of feeding the two-Beverage echelon array in Figure 22.9. On the left, a feed system good for one frequency; on the right, a "cross-fire" feed system good for 1.8 and 3.6 MHz. For this system we want a phase shift due to the coax length of +116° at the back Beverage A. The angle ϕ is thus 180° – 116° = 64° long on 160 meters. In the system on the right, a 64° length on 160 meters becomes 128° long on 80 meters. So with the phase-inverting transformer the net phase shift becomes 53° on 80 meters, a reasonable compromise. (*Courtesy W8JI and ON4UN*)

Beverage On Ground (BOG)

A number of low-band DXers have reported improved received signal-to-noise ratios using a Beverage On Ground (BOG). This consists of a wire placed directly on the ground, as if a regular Beverage antenna was simply installed on the ground. Results are mixed as discussed by Guy Olinger, K2AV, in the following excerpt from a discussion on the Topband reflector: "What is often called a BOG is really a ground-mounted low-velocity-factor receive antenna, which has its own set of rules. The technique of terminating the far end of a wire in what amounts to a characteristic impedance, to dissipate the standing wave on the wire, does not produce an optimum BOG.

"160 meter BOGs longer than 220 feet start to not model or perform well. One can easily model a BOG that has a pattern *reversal*. The various serious quirks of BOGs make them [difficult to use].

"Notching the BOG into the ground during installation prevents a large change in velocity factor as over seasons the wire gradually works itself through the grass and into the dirt. To get the BOG adjusted and with a somewhat constant behavior really requires that the BOG be in the actual ground, not laying on the grass where it can move vertically.

"The BOG's pattern will also vary with the ground's water content, which is in turn varying the velocity factor and the best termination strategy. This effect, along with the wire gradually growing down into the grass, can be responsible for the difficulty in obtaining repeatable and satisfactory results."

22.1.3 K6STI LOOP

The K6STI Loop (see Bibliography and this book's CD-ROM) in **Figure 22.12** is a horizontal loop that combines rejection of vertically polarized ground wave signals with a null in the vertical radiation pattern to reject high-angle local and regional noise. The sky wave response to lower-angle signals is approximately omnidirectional.

The 80 meter version of the antenna measures 25 feet on a side, is mounted horizontally 10 feet above ground, and made of #14 AWG wire. It's fed at opposite corners with phasing lines made of #14 AWG wire spaced 1.5 inches apart. A small ferrite transformer at the junction of the phasing lines matches the antenna to 50-Ω coax feed line and also functions as a balun. The trimmer capacitor (about 40 pF is required) in series with the antenna-side winding resonates the loop at 3.5 MHz.

The loop can be constructed as small as 10 feet on a side and still provide noise-rejecting benefits. The loop must be resonated with a variable capacitor and requires a preamplifier in most cases. (See the section on ferrite-loop antennas later in this chapter for a suitable design.) The design can be scaled to higher and lower bands by multiplying lengths, transformer turns, and capacitance values by $3.5 / f_{MHz}$.

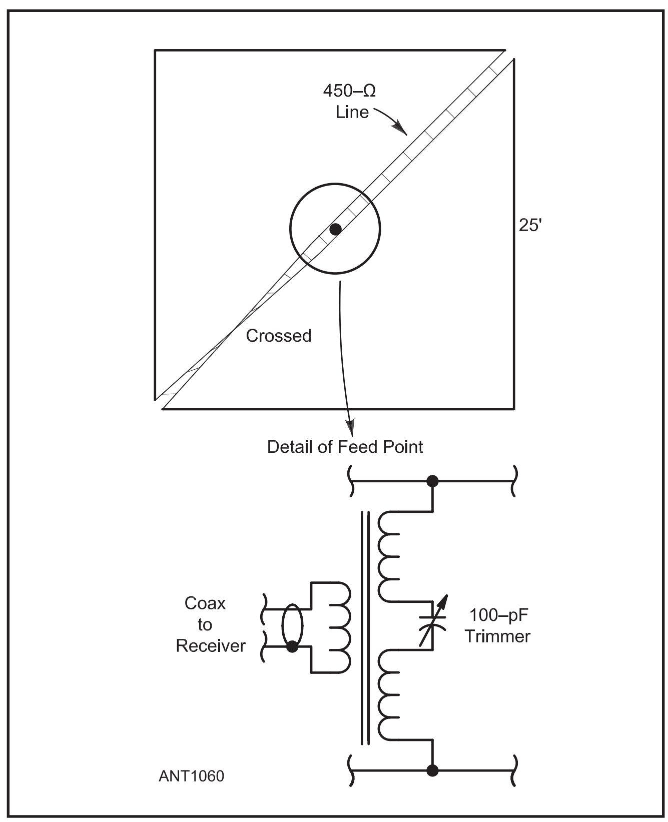


Figure 22.12 — Basic diagram of the 80 meter low-noise loop antenna showing detail of the feed point arrangement.

22.1.4 EWE ANTENNA

The EWE antenna invented by Floyd Koontz, WA2WVL, combines two short vertical wires and one horizontal wire as shown in **Figure 22.13**. (See the Bibliography.) Although the EWE looks similar to a Beverage antenna as described previously, the EWE is essentially a two-element driven array. The antenna receives best in the plane of the array in the direction opposite the termination. The pattern is a broad cardioid with a null in the direction of the terminated "rear" element. The horizontal gain of the antenna is about 20 dB lower than the vertical gain and is directed at a high angle off the side.

The version in Figure 22.13 is designed to operate from 1.8 to 4.0 MHz with a front-to-back ratio of greater than 25 dB without adjustment. The EWE can be bottom fed as shown in the figure or at the top of the front vertical element. If separate feed lines and transformers are used for each of the vertical elements, the termination can be switched between elements, creating a reversible pattern. Arrays can also be created as described in the referenced articles, creating a steerable pattern.

22.1.5 K9AY LOOP

Described here by its inventor, Gary Breed, K9AY, the loop achieves modest, but useful directivity in a small area, making it a popular choice for hams wanting to improve their receiving ability. (See the Bibliography for additional information about the antenna.)

The K9AY loop is a hybrid that combines two antenna types. Referring to **Figure 22.14**, if the termination resistor is zero — a short circuit — the antenna becomes a classic "small loop" (usually defined as less than 0.1 λ diameter). The near-field response of small loops is predominantly to the magnetic field (H-field) component of an electromagnetic wave. Next, with an infinite resistor — an open circuit — the antenna becomes a short, bent monopole. Short monopole antennas respond most strongly to the electric field (E-field) component of an electromagnetic wave.

In the K9AY Loop, the terminating resistor serves to balance the ratio of the small loop and monopole responses, with energy from the two modes summed at the feed point. When the value of the resistor is adjusted to the optimum value (typically near 400 Ω), there is cancellation of arriving signals in one of the directions in line with the plane of

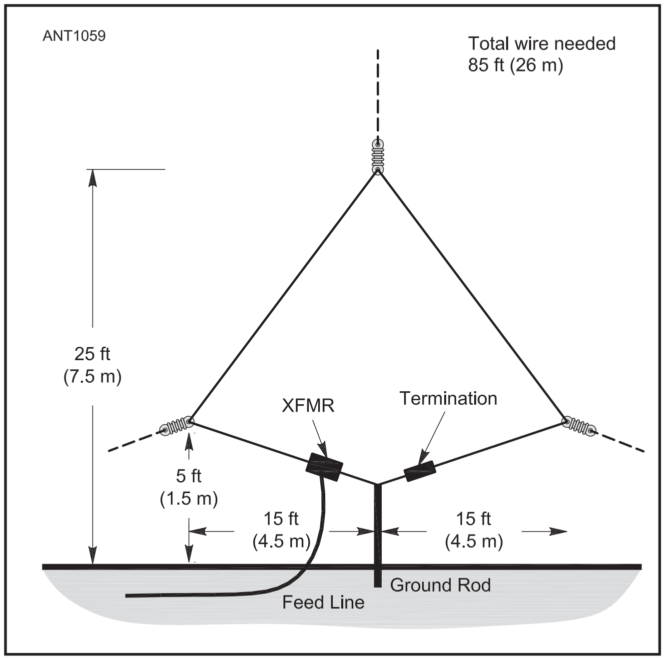


Figure 22.14 — Configuration of the K9AY Loop at the maximum size that allows coverage of both 160 and 80 meter ham bands with a resistive termination.

the loop. This cancellation occurs because of the rotational "sense" of the H-field. While the E-field is one-dimensional (amplitude only), the H-field obeys the "right hand rule" that can be visualized as spiral rotation as a wave travels through space. Waves arriving from opposite directions will thus have opposite rotation. From one direction, the E- and H-field contributions are summed at the feed point. But for signals from the opposite direction, the antenna output is the difference of these contributions.

This same type of behavior is present in two other devices familiar to hams; a directional coupler such as those used in the familiar Bird wattmeter, and the direction-finding (DF) loop with sense antenna described in many (mostly older) antenna reference books.

The tradeoff for obtaining a directional pattern with small size is low efficiency. With the dimensions given above, the K9AY Loop has a gain of approximately –26 dBi. For comparison, a ¼-wave vertical has a gain near 0 dBi, and a typical one-wavelength Beverage antenna has a gain about –11 dBi. The loop should be used with a good high dynamic range preamplifier for best results. It is not suitable for transmitting, since most of the RF energy will be absorbed by the resistor.

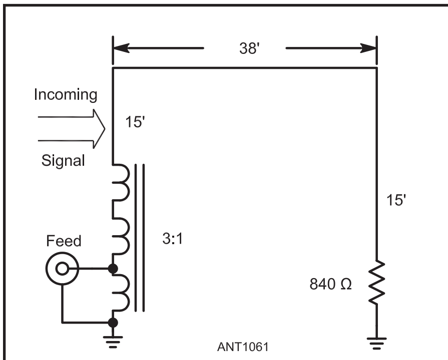


Figure 22.13 — The EWE antenna designed for use on 160 and 80 meters.

Computer Modeling

One of the challenges of designing the K9AY Loop was developing an accurate computer model, since *NEC*-based modeling programs will give inconsistent results for an antenna connected directly to lossy ground. K9AY's approach was to first create a free-space model of the loop, doubled in size with its mirror-image — just like making a ¼-wave vertical into a ½-wave dipole. This model is repeatable and shows

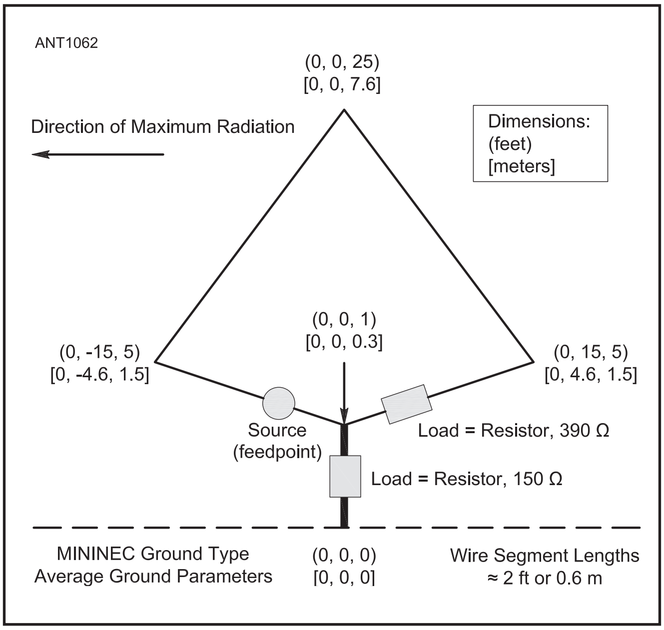


Figure 22.15 — Diagram of the K9AY Loop with dimensions and parameters for computer modeling.

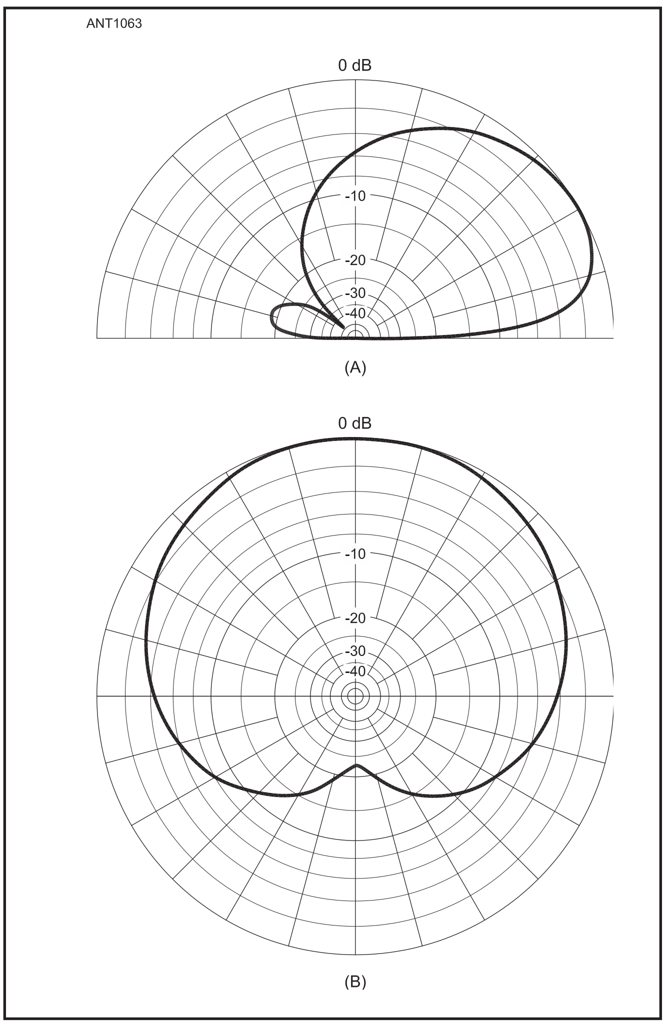


Figure 22.16 — Vertical (A) and horizontal (B) radiation patterns for the K9AY Loop at 1.825 MHz.

the actual gain and pattern shape, including the location of the rearward null.

K9AY then returned to the as-built dimensions, installed over ground. The final model uses the *MININEC* ground option, which assumes perfect ground when calculating impedance. Ground losses are simulated by placing a resistor in the ground connection. A little trial-and-error determined that a resistor of approximately 150 Ω results in a pattern that matched the free-space model (and on-air behavior, as best as it can be determined). **Figure 22.15** is a diagram showing the modeling dimensions and parameters. This model has proven accurate for modeling loops of different sizes and shapes, and for arrays of loops. (K9AY updated his model for the loop in the article "Modeling the K9AY Loop" in the March/April 2015 issue of the *National Contest Journal* which is included on this book's CD-ROM.)

For the chosen shape of the loop, and with the influence of lossy ground, the resulting null appears at an angle about 45° above horizontal, in line with the plane of the loop and toward the side with the resistor. This is shown in the pattern plots of **Figure 22.16**.

Construction

Construction of the K9AY Loop is shown in Figure 22.14. Approximately 85 feet of wire is arranged into a four-sided shape that is almost triangular. This shape was chosen primarily for its mechanical arrangement — it has a single center support approximately 25 feet high, and it can share that support with a second loop installed at right angles (see **Figure 22.17**).

Connections are made at the bottom. One end of the loop wire goes to the high impedance side of a 9:1 matching transformer; the other end to a resistor with an optimum value that is typically about 400 Ω. Because the connections to each end are at a central point, it is a simple matter to include a relay at this point to reverse the connections, which reverses the directional pattern of the loop. As noted above, a second loop

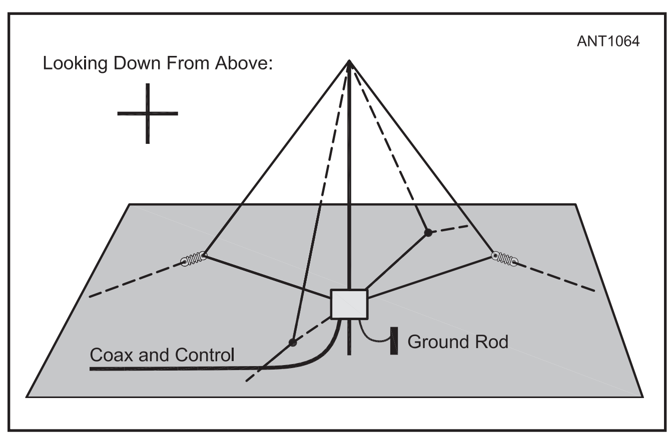


Figure 22.17 — Two loops can be installed with the same central support, creating a two-loop system that can be switched to cover four different directions. In a typical installation for 160 and 80 meter operation, the loops are 25 feet high and ±15 feet from the center (30 feet across).

can be installed. Since its connections are also located in the same place, a switching system with four directions is easily implemented. The ability to switch the pattern to several directions is the primary advantage of the K9AY Loop over other small receiving antenna designs. A schematic diagram of four-direction relay switching is shown in **Figure 22.18**.

Installation and Operating Notes

Location — Because the K9AY Loop will often be installed where there is limited space, there may be interaction with nearby objects. Other antennas, house wiring, metal siding and gutters, overhead utilities, metal fences and other conductors can distort the pattern and reduce the depth of the null. The key test for proper operation is good front-to-back ratio. If F/B is poor, you will need to identify the problem. It is usually easiest to change the loop location compared to changing the surroundings!

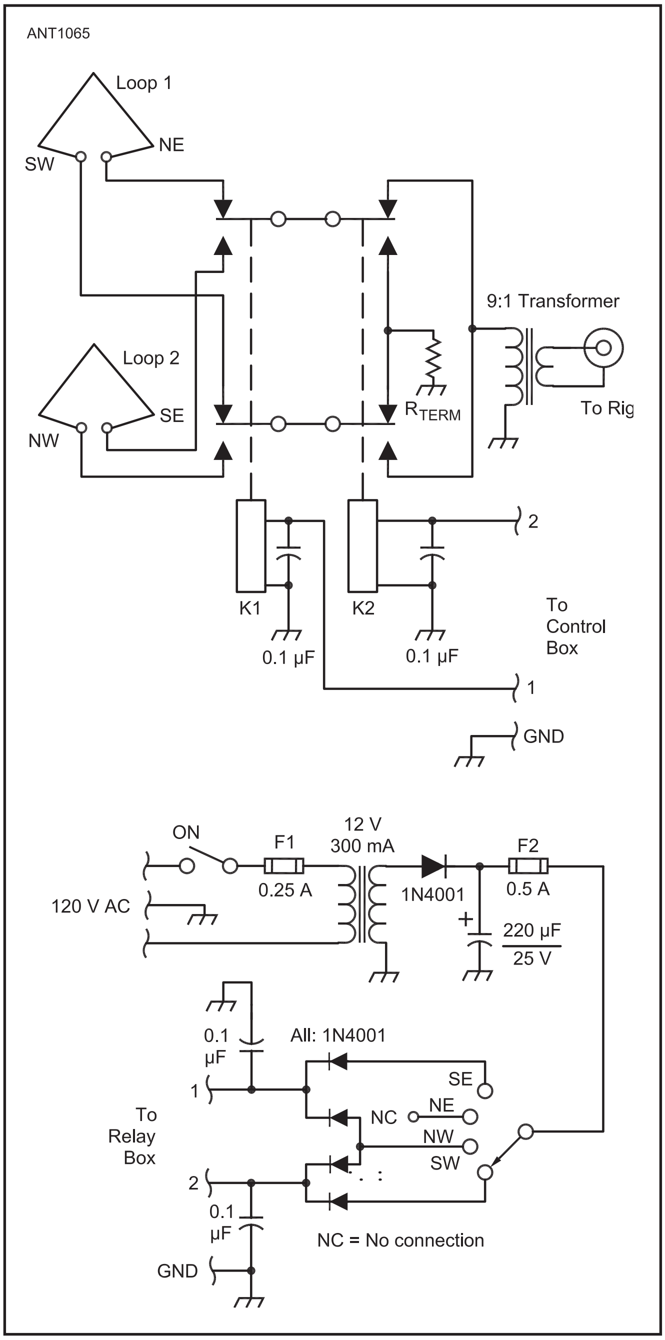


Figure 22.18 — Outdoor antenna switching (top) and indoor control (bottom) circuits for a four-direction, two-loop system.

Transmitting Antennas — Proximity to transmitting antennas may result in high RF levels on the loop, sent into the shack on the feed line. Your receiver should be protected! Protective devices are available from ham radio dealers, or you can make a simple relay box that disconnects the feed line when transmitting. It's best to open both the center conductor and shield connections.

Ground Connection — Experience has shown that locations with almost any type of "real dirt" soil only require a single ground rod for proper operation. However, some installations may experience seasonal changes in soil moisture. Desert and salt water installations will change the behavior, too. It sometimes helps to install additional ground radials to maintain consistent performance. Four or eight short radials are sufficient. Make them the same length, and place the first four directly under the loop wires. Note that the optimum value of the resistor will likely be different when using radials.

Common Mode Isolation — While many installations will work just fine with feed line and antenna both connected to the ground rod, some will require better isolation to avoid having the feed line shield become part of the antenna. The 9:1 matching transformer should have separate primary and secondary windings, with the antenna side connected to the ground rod. The feed line side may work well "floating," although another ground rod for the feed line may be wise, especially with long feed lines. Feed lines that are buried, or placed directly on the ground will be the least susceptible to common mode problems. If at all possible, avoid elevating feed lines above ground (along fences or on posts, for example).

Lack of directivity — If you don't see a deep rearward null and you're sure there is no installation problem, coupling to nearby things, or common-mode issues with feed line and control lines, or you see obvious changes with the seasons (typically in dry summer or with winter frost), then install some radials to stabilize the ground connection. A minimum of four radials located under the loop wires may be okay, but reports suggest that a total of eight radials is a better choice. Radials should extend 10 feet or so beyond the footprint of the loop.

Arrays of K9AY Loops

Although the K9AY Loop has useful directivity, its pattern is modest compared to a one-wavelength or longer Beverage. One way to improve performance, while keeping most of the antenna's limited-space appeal, is to combine two or more of them in an array. One of the simplest arrays is to install two crossed-loop sets with a spacing of ½-wavelength (140 feet on 80 meters, 270 feet on 160 meters). For simplicity, a phase shift of 0° for broadside operation and 180° for end-fire operation can be used to avoid the need for additional

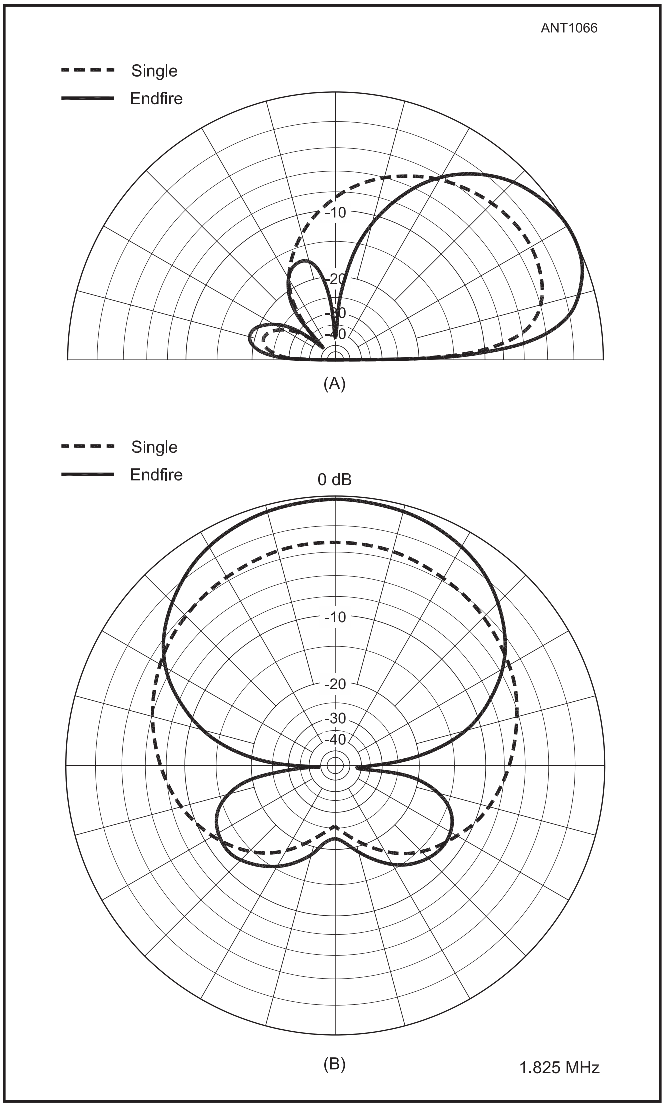


Figure 22.19 — Vertical (A) and horizontal (B) radiation patterns for two K9AY Loops, spaced ½ λ, fed in end-fire mode with 180° phasing. Frequency is 1.825 MHz

phase shift circuitry — phasing can be accomplished by simply reversing the windings of one matching transformer when the array is in the end-fire mode.

Figure 22.19 compares the radiation patterns of a single loop and the two-elements in line with the loops (end-fire mode, phasing = 180°). The array adds two very deep side nulls to the horizontal pattern, and increases the gain by 3 dB. Also, the vertical directivity is enhanced with a deep overhead null. The main forward lobe is narrower than a single loop, but remains quite wide.

Figure 22.20 shows the horizontal pattern for the broadside mode (phase shift = 0°). The main forward lobe is much narrower than a single loop, and good side nulls are present. The vertical pattern is not shown because it is the same shape as a single loop, plus the 3 dB array gain.

Of course, other arrays with different spacings and phase shifts can be designed. The K9AY Loop is a good candidate

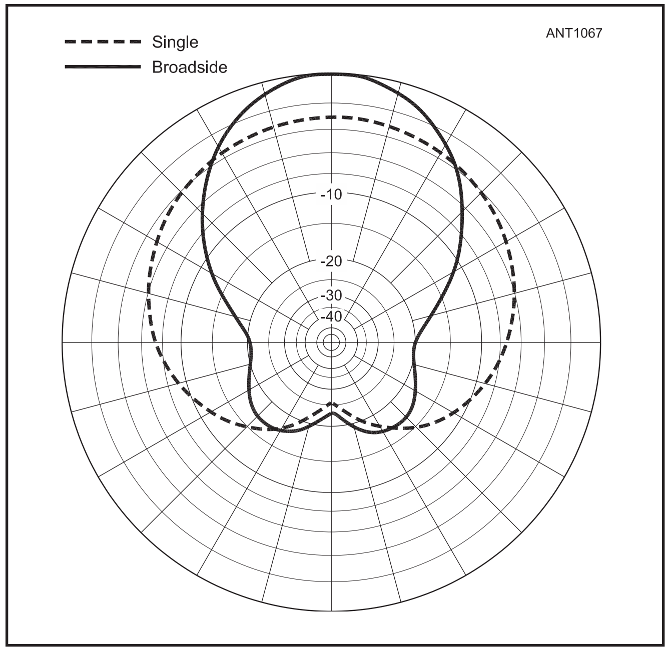


Figure 22.20 — Horizontal pattern for two K9AY Loops, spaced ½ λ, fed as a broadside array with 0° phasing. Frequency is 1.825 MHz.

for an array element. Its inherent directivity results in performance that is better than the same array using omnidirectional elements such as verticals. The loops also have a low VSWR on the feed line, which simplifies the design of a phasing network.

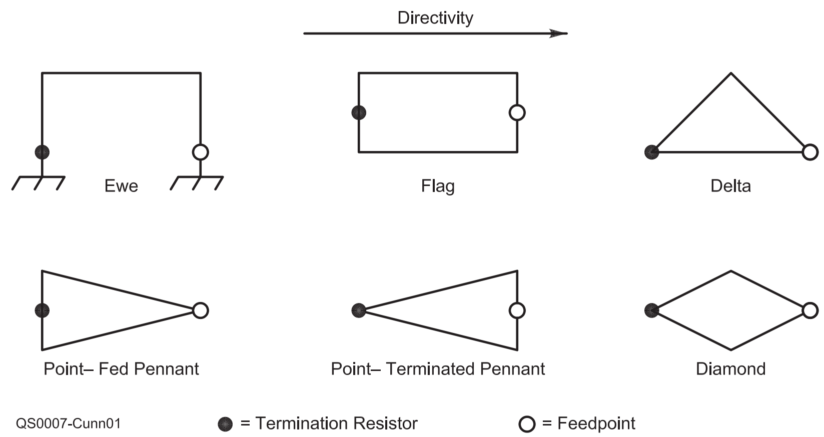
22.1.6 FLAG AND PENNANT ANTENNAS

Jose Mata, EA3VY, and Earl Cunningham, K6SE (SK), developed the pennant and flag receiving antennas in **Figure 22.21** which have become popular for the low band DXer. The antennas were developed to eliminate the need for a good ground for predictable low noise directional reception. Their small size makes them practical for those DXers without the room to construct a Beverage or Four Square. Configured as either a rectangle, triangle or diamond in the vertical plane, the 160 and 80 meter version is about 29 feet long and 14 feet high and mounted about 6 feet above the ground. The reader is referred to the Bibliography for more information along with the original article on this book's CD-ROM.

Pennant and flag antennas have a feed point impedance in the range of 945 Ω (the termination opposite the feed point is also 945 Ω). The flag version shows about 5.5 dB higher "gain" than the pennant version. Their directivity is toward the feed point direction and appears cardioidal. The front-to-back ratio is in excess of 35 dB. A simple 16 to 1 toroidal or balun transformer can be used to couple to low impedance coax lines.

Mark Connelly, WA1ION, (**www.qsl.net/wa1ion**) has come up with a modification to allow a flag antenna to be electrically reversed in direction and also

Figure 22.21 — Configurations of the flag and pennant antennas. The dimensions of the Flag, both Pennants, and the Diamond (a modification of the Flag) are 29 feet by 14 feet. The Delta (a type of half-Diamond) is 17 feet high and 28 feet long. The ground-independent antennas are 6 feet above ground.



to allow remote optimization of the termination. In his version 16:1 transformers are put at both the termination and feed point locations and a coax cable is brought from the low impedance winding of both of these into the shack. The user can then attach one of these to the receiver and the other to a noninductive potentiometer and adjust the potentiometer so that it is in the range of 55 to 70 Ω to see an impedance at the antenna in the 880 to 1120 Ω range (when the transformer ratio is taken into effect). This allows an in-shack switching box to be constructed to allow these receiver and termination connections to be reversed to allow the null to be moved in the opposite direction.

Don Kirk, WD8DSB, has published a design for a three-element point-fed pennant array with a common feed point (**sites.google.com/site/pennantflagantennas**). A single BN-73-202 binocular core transformer is used to match whichever antenna is selected. Two relays are used for antenna switching with a single control line supplying +12/0/–12 V. This same basic switching controller design can be used with any balanced antenna design.

22.1.7 A RECEIVING LOOP FOR 1.8 MHz

You can use a small balanced loop antenna to improve reception under certain conditions, especially at the lower amateur frequencies. (The theory of this antenna is presented in the chapter **Loop Antennas**.) This is particularly true when high levels of man-made noise are prevalent, when the second-harmonic energy from a nearby broadcast station falls in the 160 meter band, or when interference exists from some other amateur station in the immediate area. A properly constructed and tuned small loop will exhibit approximately 30 dB of front-to-side response, the minimum response being at right angles to the plane of the loop. Therefore, noise and interference can be reduced significantly or completely nulled out, by rotating the loop so that it is sideways to the interference-causing source.

Generally speaking, small balanced loops are far less responsive to man-made noise than are the larger antennas used for transmitting and receiving. But a trade-off in performance must be accepted when using the loop, for the strength of received signals will be 10 or 15 dB less than when using a full-size resonant antenna. This condition is not a handicap on 1.8 or 3.5 MHz, provided the station receiver has normal sensitivity and overall gain. Because a front-to-side ratio of 30 dB may be expected, a small loop can be used to eliminate a variety of receiving problems if made rotatable.

To obtain the sharp bidirectional pattern of a small loop, the overall length of the conductor must not exceed 0.1 λ. The loop of **Figure 22.22** has a conductor length of 20 feet. At 1.81 MHz, 20 feet is 0.037 λ. With this style of loop, 0.037 λ is about the maximum practical dimension if you want to tune the element to resonance. This limitation results from the distributed capacitance between the shield and inner conductor of the loop. RG-59 was used for the loop element in this example. The capacitance per foot for this cable is 21 pF, resulting in a total distributed capacitance of 420 pF.

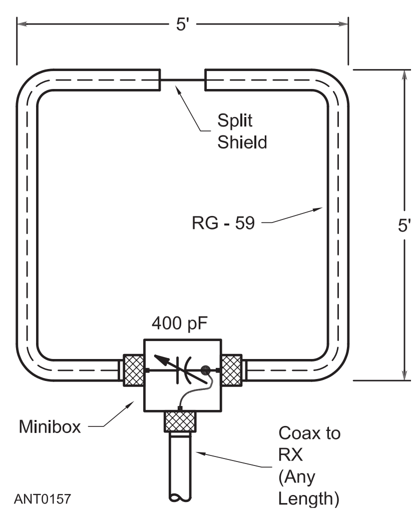


Figure 22.22 — Schematic diagram of the loop antenna. The dimensions are not critical provided overall length of the loop element does not exceed approximately 0.1 λ. Small loops which are one half or less the size of this one will prove useful where limited space is a consideration.

An additional 100 pF was needed to resonate the loop at 1.810 MHz.

Therefore, the approximate inductance of the loop is 15 µH. The effect of the capacitance becomes less pronounced at the higher end of the HF spectrum, provided the same percentage of a wavelength is used in computing the conductor length. The ratio between the distributed capacitance and the lumped capacitance used at the feed point becomes greater at resonance. These facts should be contemplated when scaling the loop to those bands above 1.8 MHz.

There will not be a major difference in the construction requirements of the loop if coaxial cables other than RG-59 are used. The line impedance is not significant with respect to the loop element. Various types of coaxial line exhibit different amounts of capacitance per foot, however, thereby requiring more or less capacitance across the feed point to establish resonance.

Balanced loops are not affected noticeably by nearby objects, and therefore they can be installed indoors or out after being tuned to resonance. Moving them from one place to another does not significantly affect the tuning.

A supporting structure was fashioned from bamboo poles. The X frame is held together at the center with two U bolts. The loop element is taped to the cross-arms to form a square. You could likely use metal cross arms without seriously degrading the antenna performance. Alternatively, wood can be used for the supporting frame.

A Minibox was used at the feed point of the loop to hold the resonating variable capacitor. In this model a 50 to 400-pF compression trimmer was used to establish resonance. You must weatherproof the box for outdoor installations.

Remove the shield braid of the loop coax for one inch directly opposite the feed point. You should treat the exposed areas with a sealing compound once this is done.

In operation this receiving loop has proven very effective for nulling out second-harmonic energy from local broadcast stations. During DX and contest operations on 160 meters it helped prevent receiver overloading from strong nearby stations. The marked reduction in response to noise has made the loop a valuable station accessory when receiving weak signals. It is not used all of the time, but is available when needed by connecting it to the receiver through an antenna selector switch. Reception of European stations with the loop has been possible from New England at times when other antennas were totally ineffective because of noise.

It was also discovered that the effects of approaching storms (with attendant atmospheric noise) could be nullified considerably by rotating the loop away from the storm front. It should be said that the loop does not exhibit meaningful directivity when receiving sky-wave signals. The directivity characteristics relate primarily to ground-wave signals. This is a bonus feature in disguise, for when nulling out local noise or interference, one is still able to copy sky-wave signals from all compass points!

For receiving applications it is not necessary to match the feed line to the loop, though doing so may enhance the performance somewhat. If no attempt is made to obtain an SWR of 1, the builder can use 50- or 75-Ω coax for a feeder, and no difference in performance will be observed. The Q of this loop is sufficiently low to allow the operator to peak it for resonance at 1.9 MHz and use it across the entire 160 meter band. The degradation in performance at 1.8 and 2 MHz will be so slight that it will be difficult to discern.

Propagation Effects on Null Depth

After building a balanced loop you may find it does not approach the theoretical performance in the null depth. This problem may result from propagation effects. Tilting the loop away from a vertical plane may improve performance under some propagation conditions, to account for the vertical angle of arrival. Basically, the loop performs as described above only when the signal is arriving perpendicular to the axis of rotation of the loop. At incidence angles other than perpendicular, the position and depth of the nulls deteriorate. Bond explained this issue in his book on direction finding in 1944 along with the math to calculate the performance.

The problem can be even further influenced by the fact that if the loop is situated over less than perfectly conductive ground, the wave front will appear to tilt or bend. (This bending is not always detrimental; in the case of Beverage antennas, sites are chosen to take advantage of this effect.)

Another cause of apparent poor performance in the null depth can be from polarization error. If the polarization of the signal is not completely linear, the nulls will not be sharp. In fact, for circularly polarized signals, the loop might appear to have almost no nulls. Propagation effects are discussed further in the sections on direction finding.

Siting Effects on the Loop

The location of the loop has an influence on its performance that at times may become quite noticeable. For ideal performance the loop should be located outdoors and clear of any large conductors, such as metallic downspouts and towers. A VLF loop, when mounted this way, will show good sharp nulls spaced 180° apart if the loop is well balanced. This is because the major propagation mode at VLF is by ground wave. At frequencies in the HF region, a significant portion of the signal is propagated by sky wave, and nulls are often only partial.

Most hams locate their loop antennas near their operating position. If you choose to locate a small loop indoors, its performance may show nulls of less than the expected depth, and some skewing of the pattern. For precision direction finding there may be some errors associated with wiring, plumbing, and other metallic construction members in the building. Also, a strong local signal may be reradiated from the surrounding conductors so that it cannot be nulled with any positioning of the loop. There appears to be no known method of curing this type of problem. All this should not discourage you from locating a loop indoors; this information is presented here only to give you an idea of some pitfalls. Many hams have reported excellent results with indoor mounted loops, in spite of some of the problems.

Locating a receiving loop in the field of a transmitting antenna may cause a large voltage to appear at the receiver antenna terminals. This may be sufficient to destroy sensitive RF amplifier transistors or front-end protection diodes. This can be solved by disconnecting your loop from the receiver during transmit periods. This can obviously be done automatically with a relay that opens when the transmitter is activated.

22.1.8 ACTIVE ANTENNAS

The following material is based on the September 2001 *QST* article, "The AMRAD Active LF Antenna," by Frank Gentges, KØBRA. (This article is also included on this book's CD-ROM.) A detailed treatment of active whip antennas and several active impedance-conversion circuits was also published by Dr Ulrich Rhode, N1UL, in *RF Design*. (See the Bibliography.)

An active antenna is an electrically and physically small antenna combined with an active electronic circuit, such as an amplifier. An active antenna uses a small whip — one that is a fraction of a wavelength long at the desired frequency — connected to an active impedance-conversion circuit. Active antennas are used at HF and lower frequencies through VLF. A commercially available model, the DX Engineering DXE-ARAV3-1P (**www.dxengineering.com**), can be used from 100 kHz through 30 MHz and can be combined with other units into highly directional arrays.

An electrically short whip has a high output impedance. For example, a 1 meter whip at 100 kHz has an input impedance higher than 100 kΩ, mostly capacitive reactance. If such a whip were connected directly to a 50-Ω load, signals would be attenuated more than 80 dB than those from a 50-Ω antenna! Thus, some kind of active impedance-conversion is required, usually a high-input-impedance FET-based amplifier.

Signal-to-noise ratio (SNR) is a primary concern for active antennas due to the antenna's small size. Nevertheless, if the noise contributed by the transistor is less than the noise picked up by the antenna, SNR can be comparable to an optimized passive antenna for the same frequency. Below about 4 MHz, atmospheric and man-made noise dominates the antenna output signal. Above 4 MHz, a circuit using an FET with a noise figure of 1-2 dB or less will provide satisfactory results

The major challenges to the impedance conversion circuit are nonlinearity and the resulting intermodulation distortion products. Intermodulation products generated in the signal conditioning circuit can create a significant amount of noise and other interference. This is a particularly difficult issue close to transmitting antennas and filters may be required.

22.1.9 RECEIVE ARRAYS

The various antennas described in this chapter can be combined into arrays with steerable nulls and/or lobes using the techniques presented in the **Phased Arrays** chapter. In fact, the larger loop antennas such as the K9AY, pennants, and flags can be analyzed as a pair of vertical current elements, phased to create directivity. In these designs, the electrically small antennas require extra attention to balance of the current elements and symmetry of the array. This is discussed in the article "Introducing the Shared-Apex Loop Array" by Mark Bauman, KB7GF that is provided on the CD-ROM accompanying this book.

Recently, the "circle arrays" of four to nine vertical antennas have become popular, usually active whip antennas as described in the previous section. (A number of examples can be seen in the Dayton Hamvention Antenna Forum presentations by K7TJR and KB7GF at **www.kkn.net/dayton2014/dayton-2014-antenna-forum.html** and in the Powerpoint presentation "Receiving Antennas" by Frank Donovan, W3LPL, from the 2014 Contest University at **www.contestuniversity.com/attachments/W3LPL_Receiving_Antennas_2014.pptx.**) These designs provide an unprecedented ability to reject noise and improve receive SNR without requiring large pieces of property. The small footprint (electrically small) of these arrays requires careful attention to design and construction detail, however.

The design and construction of an 8-element array was detailed in an exhaustive article by Joel Harrison, W5ZN, and Bob McGwier, N4HY, in the 2010 *QEX* article "Design, Construction and Evaluation of the Eight Circle Vertical Array for Low Band Receiving" that is included on this book's CD-ROM and shown schematically in **Figure 22.23** (on next page). In addition, Dan Maguire, AC6LA, has done some modeling of various circle arrays and published comparative radiation patterns at **ac6la.com/adhoc** — look for filenames beginning with "8circle." Dan also provided additional discussion and links to models in his Topband reflector post from 23 Dec 2014 (**lists.contesting.com/_topband/2014-12/msg00379.html**).

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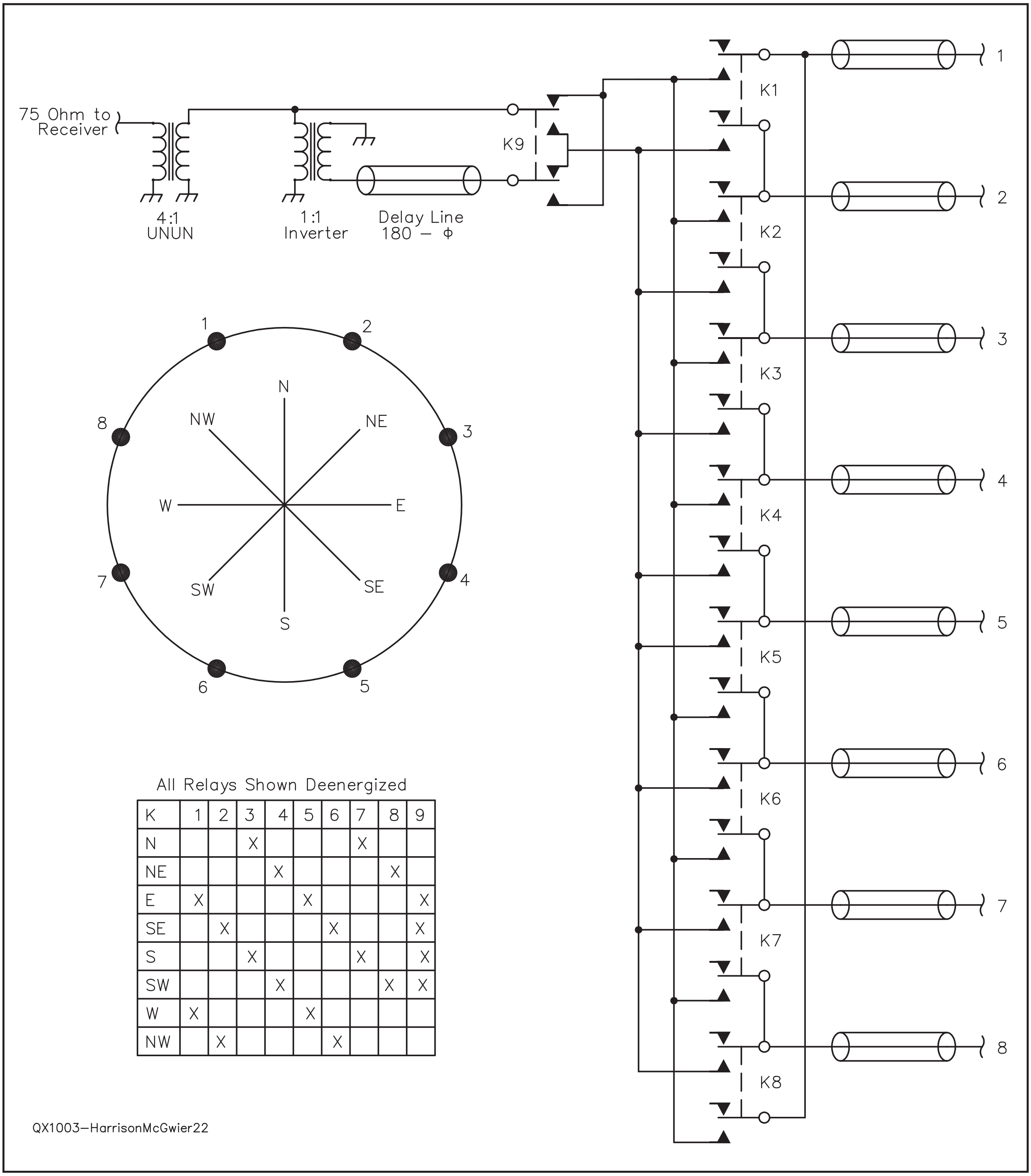

K	1	2	3	4	5	6	7	8	9
N			X				X		
NE				X				X	
E	X				X				X
SE		X				X			X
S			X				X		X
SW				X				X	X
W	X				X				
NW		X				X			

Figure 22.23 — The schematic of the eight-circle receiving array at W5ZN.

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22.2 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. (Amateur RDF which finds a transmitter from its transmitted signal, should be distinguished from aviation's radio direction-finding, which finds a direction based on a signal transmitted from a known location.)

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. Most ARDF activity uses 80 meter or 2 meter transmitters.

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 their location to be determined 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 (Amateur Packet Reporting System), 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 section deals with antennas suitable for that purpose.

The major types of RDF antennas used by amateurs are covered here, with a project or referenced article included for each. In ARDF events, it's very common to use integrated receiver/antenna combinations to reduce the amount of gear the competitor has to carry. Examples of this type of gear can be found through the Homing In website maintained by Joe Moell, KØOV (**www.homingin.com**). In ARDF, both magnetic loop and ferrite rod antennas are popular with magnetic loops being the more popular. On VHF, three-element Yagis are by far the most popular

How accurate should an RDF antenna be? In mobile and portable use, accuracy to a few degrees is fine. While the uncertainty of a few degrees sounds large, as the distance to the transmitter is reduced and more bearings are taken for triangulation, the amount of error also shrinks. If the antenna is fixed, such as for taking sky-wave bearings, precision is more important since distance to the transmitter does not change. In competitive events where the most common technique is to move toward peak signal on a relatively continuous basis, it is more important to be able to take a reading quickly and consistently.

22.2.1 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 at the Homing In website mentioned above.

It is important to note that the directions determined by a DF receiver can be affected by skew paths (HF) and reflections (VHF). In addition, signals arriving by sky wave can appear to be coming from different azimuths than by ground wave. Knowing about and avoiding these errors are part of successful RDF.

22.2.2 DIRECTION-FINDING ANTENNAS

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 measurements, 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. (Resonant loops are too small for VHF DFing and other antennas must be used.) 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. (A more detailed treatment is presented in the **Loop Antennas** chapter.)

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 non-directional 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 **Figure 22.24A**. 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 Figure 22.24B. However, by detuning the loop to shift the phasing, a pattern similar to Figure 22.24C 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, making determining a bearing more difficult.

By suitable detuning, the unidirectional cardioid pattern of Figure 22.24D 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 **Figure 22.25** 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 Figure 22.24A.

For the low-frequency amateur bands, single-turn loops of convenient physical size for portability are generally found to be too large for RDF work. Therefore, multi-turn loops are generally used instead. Such a loop is shown in **Figure 22.26**. This loop may also be shielded, and if the total conductor length remains below 0.08 λ, the directional pattern is that of Figure 22.24A. A sensing element may also be used with a multi-turn loop.

Loop Circuits and Criteria

No single word describes a direction-finding loop of high performance better than *symmetry*. To obtain an undistorted

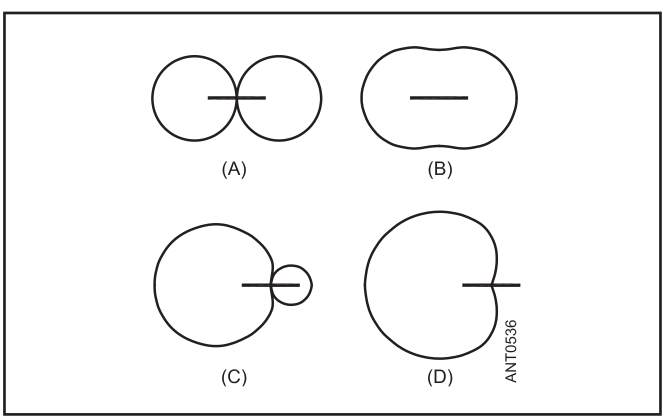

Figure 22.24 — Small-loop field patterns with varying amounts of antenna effect — the undesired response of the loop acting merely as a mass of metal connected to the receiver antenna terminals. The straight lines show the plane of the loop.

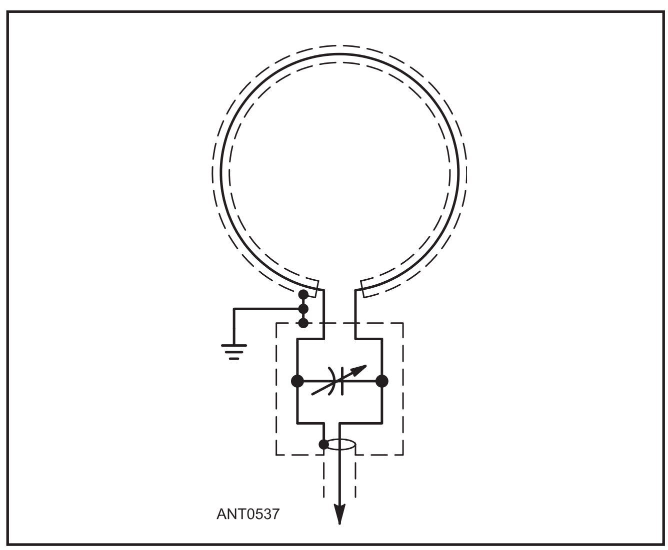

Figure 22.25 — Shielded loop for direction finding. The ends of the shielding turn are not connected, to prevent shielding the loop from magnetic fields. The shield is effective in balancing the loop's response to electric fields.

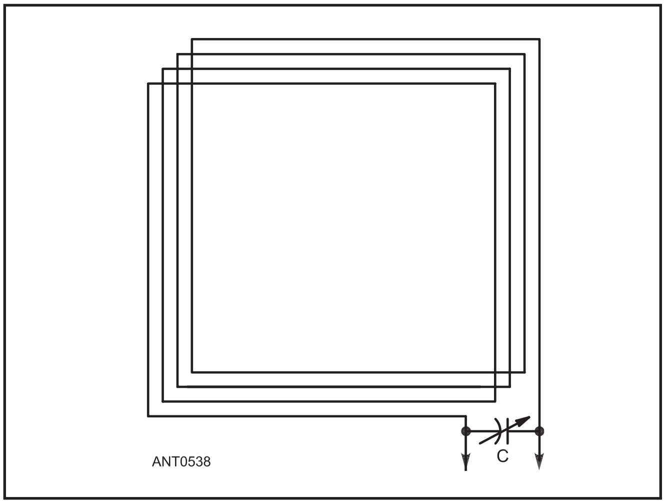

Figure 22.26 — Small loop consisting of several turns of wire. The total conductor length is very much less than a wavelength. Maximum response is in the plane of the loop.

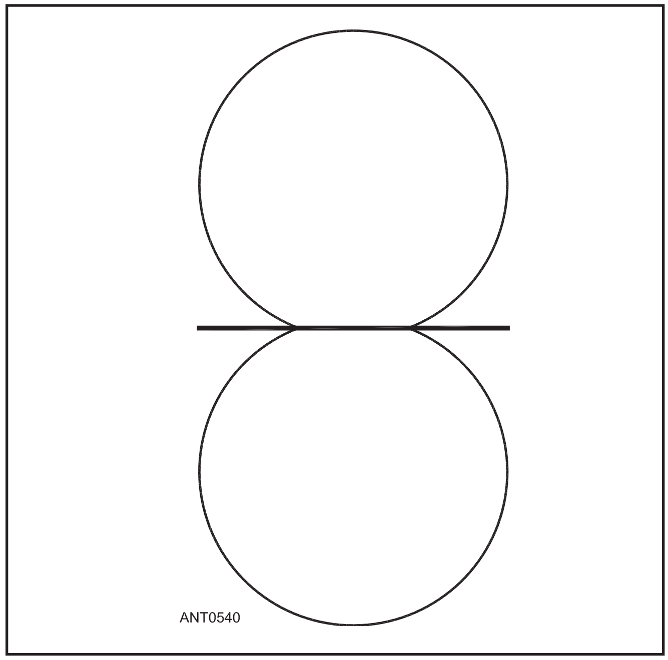

Figure 22.27 — Field pattern for a ferrite rod antenna. The dark bar represents the rod on which the loop turns are wound.

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. Because of their reduced-size advantage, ferrite-rod *loopstick* antennas are used almost exclusively for portable work at frequencies below 150 MHz. Design of ferrite-core loop antennas is described in the **Loop Antennas** chapter and loopstick antennas for construction are described later in this chapter.

Maximum response of the loopstick antenna is broadside to the axis of the rod as shown in **Figure 22.27**, 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 type of metal. 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 on the transmitter from more than one position, the ambiguity may be worked out by triangulation, as described earlier. However, it is sometimes desirable to have a pattern

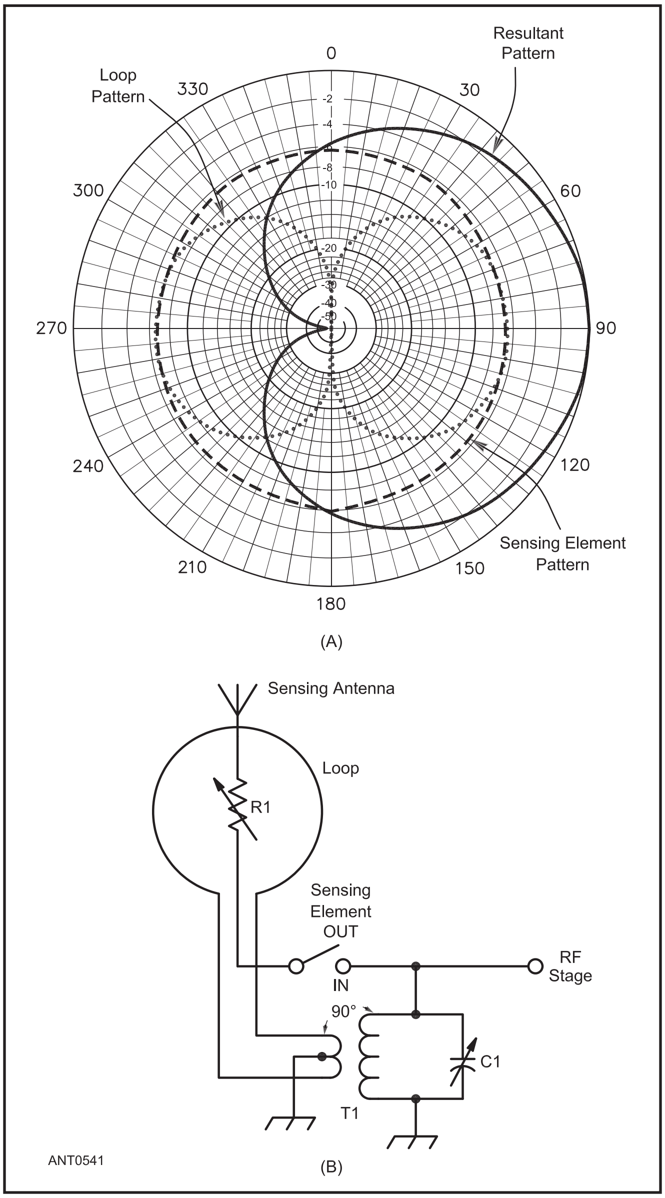

Figure 22.28 — At A, the directivity pattern of a loop antenna with sensing element. At B is a circuit for combining the signals from the two elements. C1 is adjusted for resonance with T1 at the operating frequency.

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 **Figure 22.28A**.

Figure 22.28B 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.

22.2.3 DIRECTION-FINDING 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 ¼ 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 **Figure 22.29**.

This system was invented by F. Adcock and patented in

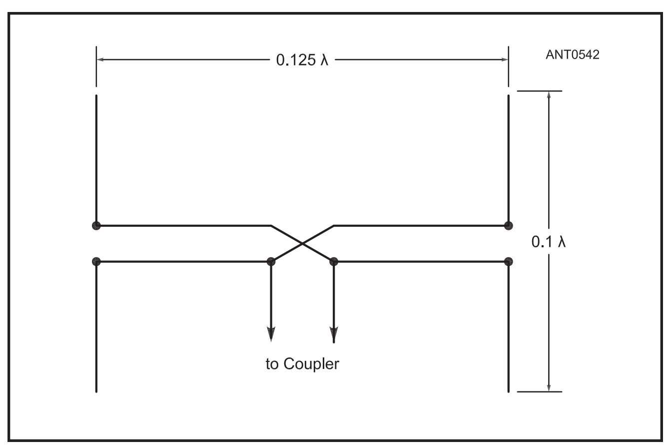

Figure 22.29 — A simple Adcock antenna.

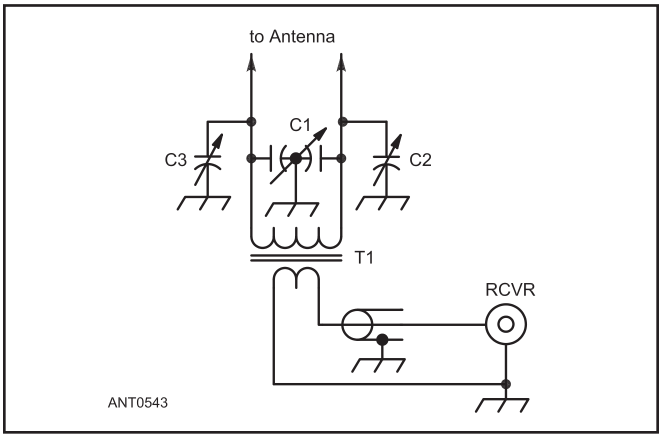

Figure 22.30 — A suitable coupler for use with the Adcock antenna.

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, preserving the null. This effect has been verified in practice, where good nulls were obtained with an experimental Adcock under sky-wave conditions with rapidly varying polarization that produced poor nulls in 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. **Figure 22.30** 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 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 twinlead.

The radiation pattern of the Adcock is shown in **Figure 22.31A**. 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 Figure 22.31B, and the array is unsuitable for RDF applications.

Short vertical monopoles over a ground plane 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. (Replace the bottom half of the elements and feeders in Figure 22.29 with a ground plane.) 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.

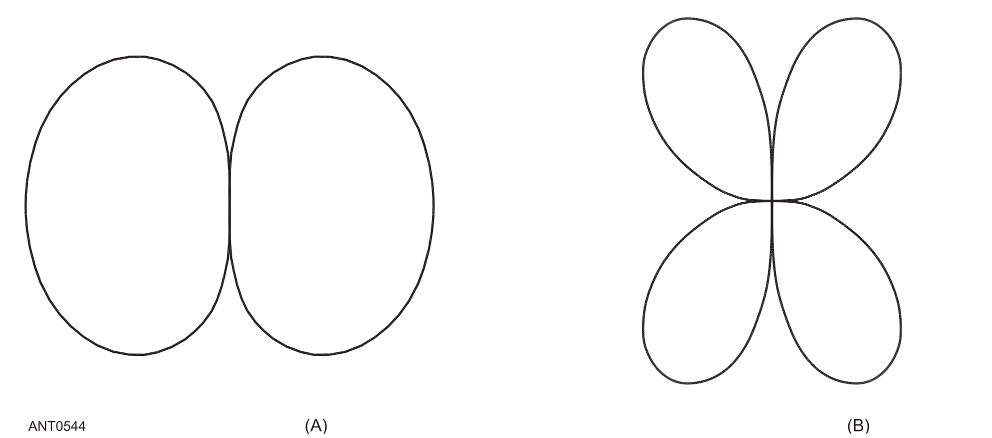

Figure 22.31 — At A, the pattern of the Adcock array with an element spacing of ½ wavelength. In these plots the elements are aligned with the horizontal axis. As the element spacing is increased beyond ¾ wavelength, additional nulls develop off the ends of the array, and at a spacing of 1 wavelength the pattern at B exists. This pattern is unsuitable for RDF work.

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

An 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 **Figure 22.32**. It consists of two fixed coils mounted at right angles to one another. Inside the fixed coils is a movable coil, not shown in Figure 22.32 to 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.

Electronic Antenna Rotation

With an array of many fixed elements, beam formation and 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. Delay lines and electronic switches create a beam-forming network that can be steered in any direction and with a wide variety of patterns.

For the moment, consider just two elements of a Wullenweber antenna, shown as A and B in **Figure 22.33**. 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

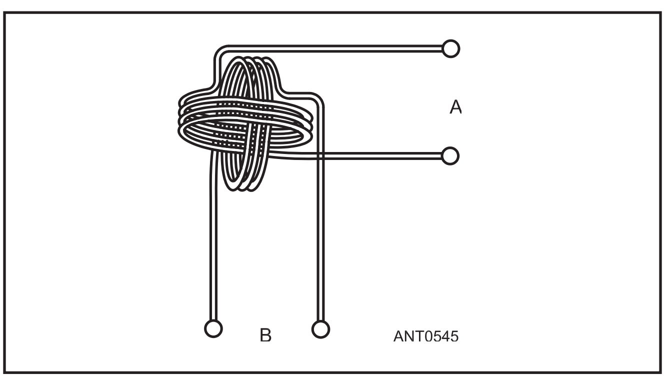

Figure 22.32 — An early type of goniometer that is still used today in some RDF applications. This device is a special type of RF transformer that permits a movable coil in the center (not shown here) to be rotated and determine directions even though the elements are stationary.

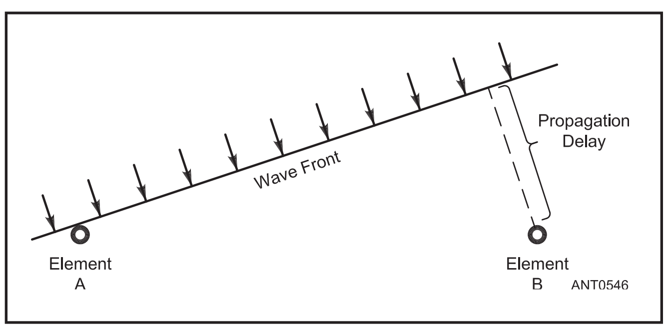

Figure 22.33 — This diagram illustrates one technique used in electronic beam forming. By delaying the signal from element A by an amount equal to the propagation delay, the two signals may be summed precisely in phase, even though the signal is not in the broadside direction. Because this time delay is identical for all frequencies, the system is not frequency sensitive.

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.

A four-element, electronically-rotating RDF antenna system for amateur RDF was described in an article by Malcolm C. Mallette, WA9BVS, in November 1995 *QST* and included on this book's CD-ROM. The system is designed to be used while mobile and is based on *time-difference-of-arrival* techniques.

22.2.4 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.

It is also common to add a regular magnetic compass to an RDF antenna. This provides numeric bearings for events that combine orienteering or if reporting numeric bearings is important.

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 if transmitting on HF must be operating into a vertical antenna. (A quarter-wave vertical or a loaded whip is quite suitable. Omni-directional horizontally polarized antennas work fine on VHF.) 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.

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.

The discussion above is oriented toward calibrating portable RDF systems such as would be used for competitive ARDF events and general-purpose fox hunting. 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 and a table of bearing errors compiled that can be used during actual operation. Fixed DF antennas are rare in amateur service however.

22.2.5 A FRAME LOOP

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. **Figure 22.34** illustrates the details of a practical frame type of loop antenna. This antenna was designed by Doug DeMaw, W1FB (SK), and described in *QST* for July 1977. (See the Bibliography at the end of this chapter.) The circuit in Figure 22.34A 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 Figure 22.34B. 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,

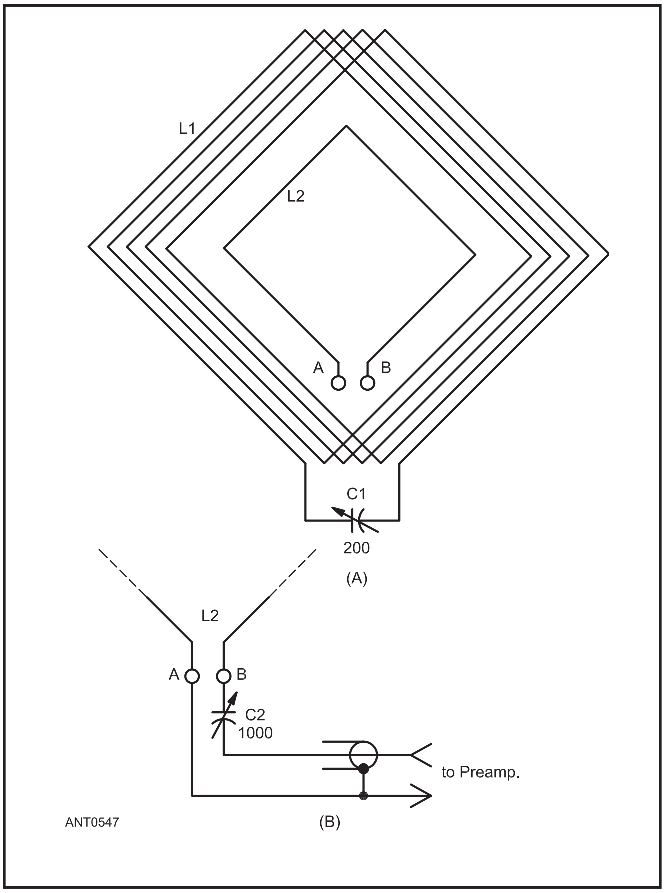

Figure 22.34 — A multiturn frame antenna is shown at A. L2 is the coupling loop. The drawing at B shows how L2 is connected to a preamplifier.

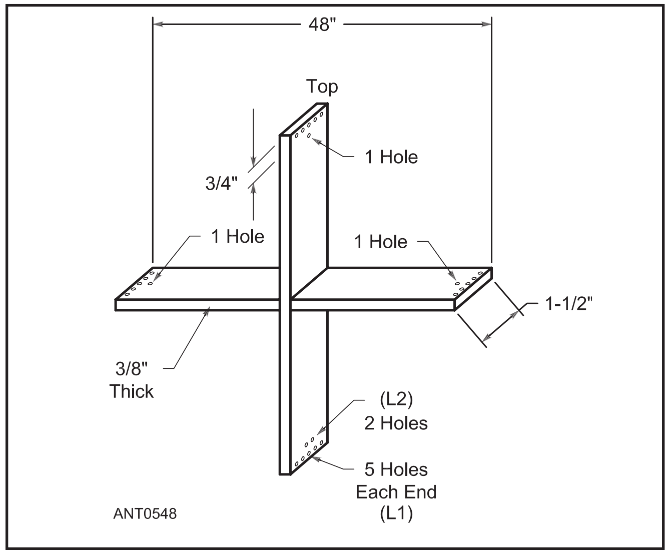

Figure 22.35 — A wooden frame can be used to contain the wire of the loop shown in Figure 12.

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 Figure 22.34 can be constructed of wood, as shown in **Figure 22.35**. The dimensions given are for a 1.8-MHz frame antenna. For use on 75 or 40 meters, L1 of Figure 22.34A will require fewer turns, or the size of the wooden frame should be made somewhat smaller than that of Figure 22.35.

If electrostatic shielding is desired, the format shown in **Figure 22.36** and **Figure 22.37** 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 (Figure 22.34A) 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.

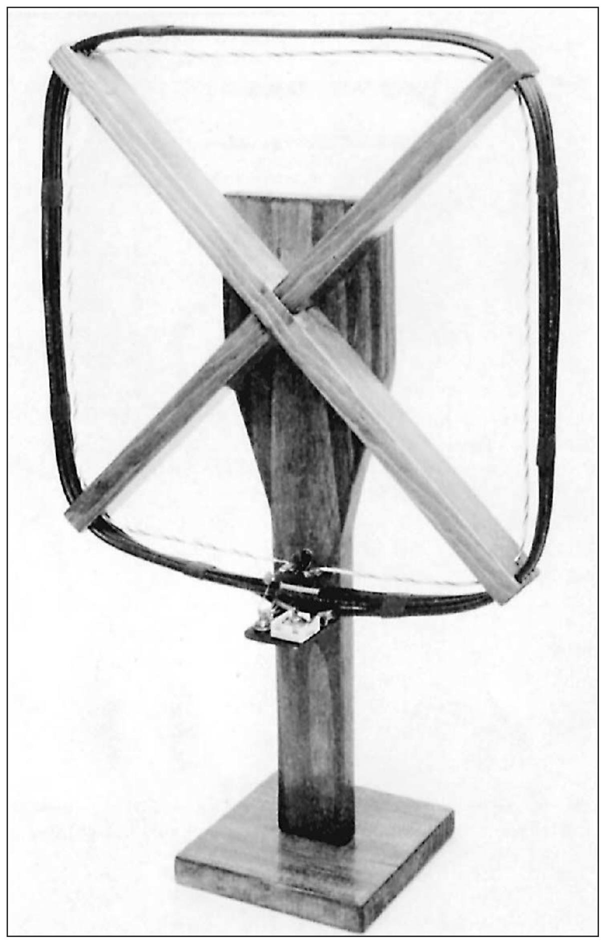

Figure 22.36 — An assembled table-top version of the electrostatically shielded loop. RG-58 cable is used in its construction.

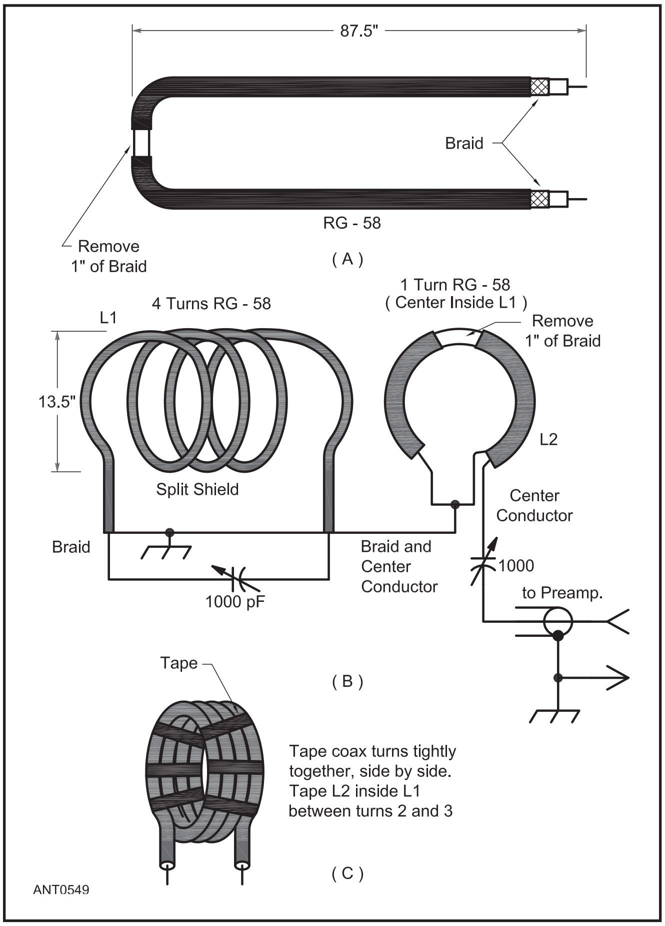

Figure 22.37 — Components and assembly details of the shielded loop shown in Figure 22.36. The dimensions and values given are for 1.8 MHz operation.

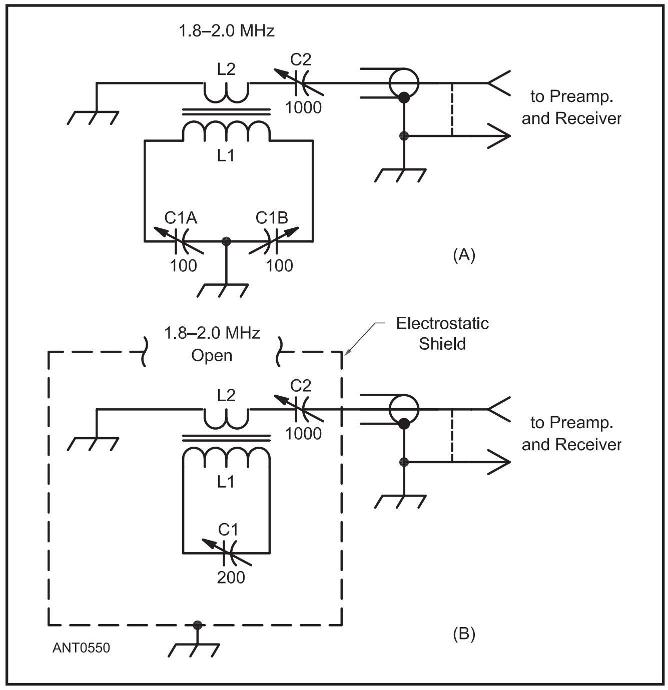

Figure 22.38 — At A, the diagram of a ferrite loop. C1 is a dual-section air-variable capacitor. The circuit at B shows a rod loop contained in an electrostatic shield channel (see text). A suitable low-noise preamplifier is shown in Figure 22.41.

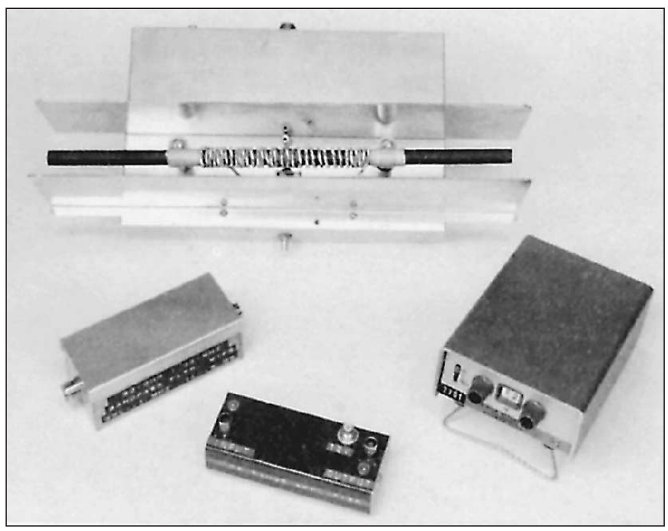

Figure 22.39 — The assembly at the top of the picture is a shielded ferrite-rod loop for 160 meters. Two rods have been glued end to end (see text). The other units in the picture are a low-pass filter (lower left), broadband preamplifier (lower center) and a Tektronix step attenuator (lower right). These were part of the test setup used when the antenna was evaluated.

22.2.6 A FERRITE-CORE LOOP FOR 160 METERS

Figure 22.38 contains a diagram for a rod loop (loopstick antenna). This antenna was also designed by Doug DeMaw, W1FB (SK), 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 ⅓ of the core center. Litz wire will yield the best Q but enameled magnet wire can be used if desired. A layer of electrical tape is recommended as a covering for the core before adding the wire since ferrite is somewhat abrasive.

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 Figure 22.37 is maintained for the same reason.

Figure 22.39 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 Figure 22.24A.

Obtaining a Cardioid Pattern

Although the bidirectional pattern of loop antennas 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 Figure 22.24D.

Figure 22.40 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

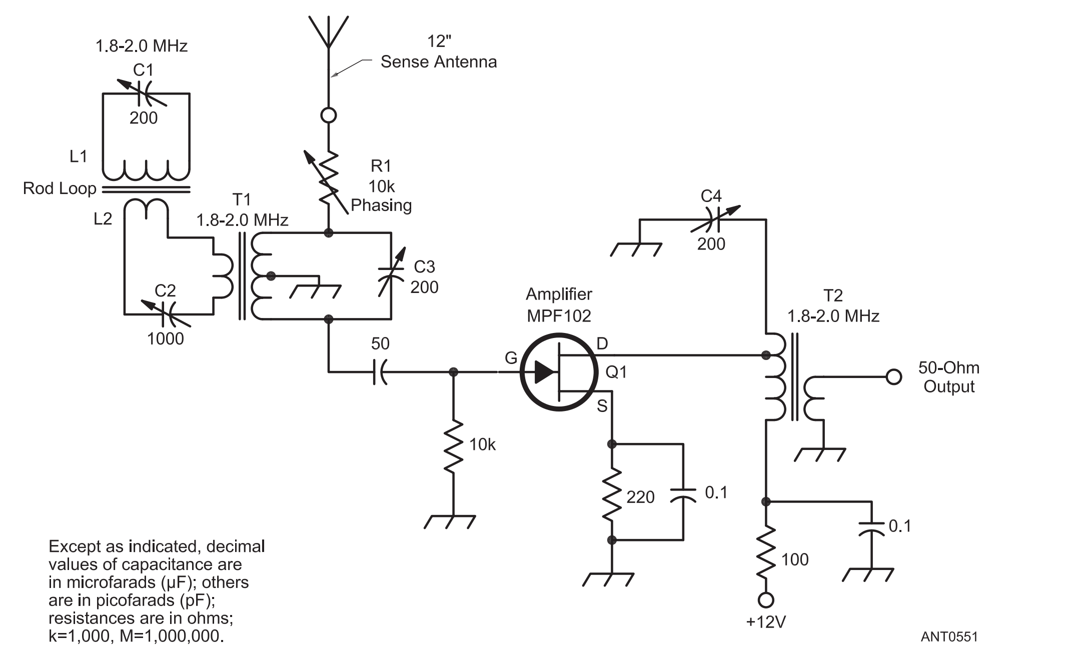

Figure 22.40 — Schematic diagram of a rod-loop antenna with a cardioid response. The sensing antenna, phasing network and a preamplifier are shown also. The secondary of T1 and the primary of T2 are tuned to resonance at the operating frequency of the loop. T-68-2 to T-68-6 Amidon toroid cores are suitable for both transformers. Amidon also sells ferrite rods for this type of antenna.

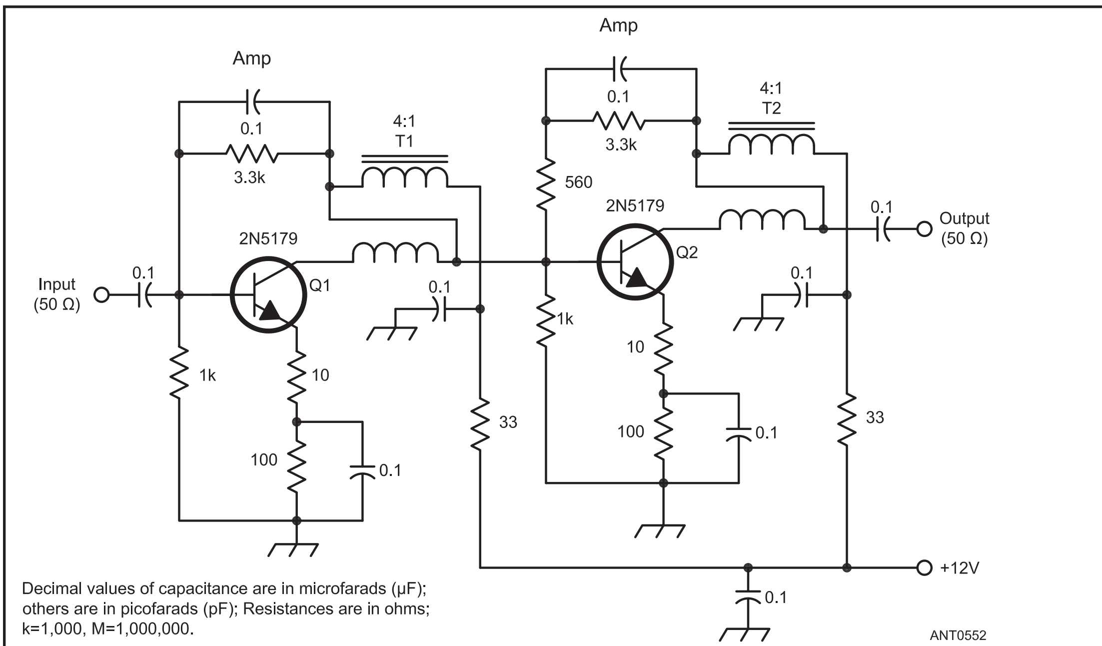

Figure 22.41 — Schematic diagram of a two-stage broadband amplifier patterned after a design by Wes Hayward, W7ZOI. T1 and T2 have a 4:1 impedance ratio and are wound on FT-50-61 toroid cores (Amidon) which have a μ_i of 125. They contain 12 turns of #24 AWG enamel wire, bifilar wound. The capacitors are disc ceramic. This amplifier should be built on double-sided circuit board for best stability.

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 Figure 22.40 on 80 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 Figure 22.40 will deliver approximately 15 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 3N201 MOSFET would be satisfactory. The circuit of **Figure 22.41** can be used following T2 to obtain an additional 24 dB of gain. The sensing antenna can be mounted from a few mm to 6 inches from the loop. The vertical whip need not be more than 12 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.

22.2.7 A SIMPLE DIRECTION-FINDING SYSTEM FOR 80 METERS

This section gives an overview of the article by the same name in September 2005 *QST* by Dale Hunt, WB6BYU. (The full article is included on this book's CD-ROM.) The antenna (a multi-turn loop) and receiver are combined into a single package as shown in **Figure 22.42.** The receiver was designed to hear a 1-W signal from up to 3 miles away, to have low battery drain and to be lightweight and rugged for competitive RDF use.

The four-turn loop is tuned to resonance to provide RF selectivity. Without the sense antenna, the loop alone is bidirectional. With the sense antenna switched in, a cardioid pattern is obtained. A shielded coupling loop of RG-174 coaxial cable is used to transfer the signal to the receiver which is described in detail in the article.

Operation is straightforward — plug in the headphones and turn on the radio. Adjust the RF gain to max and tune in the desired signal. Rotate the receiver to find the null in the pattern that is perpendicular to the loop. If the signal is too loud, reduce RF gain and try again. To resolve the direction of the transmitter (the loop's natural pattern is bidirectional) rotate the receiver 90° in either direction, switch in the sense antenna, and check signal strength. Then rotate the loop 180° and compare — one direction should be stronger than the other.

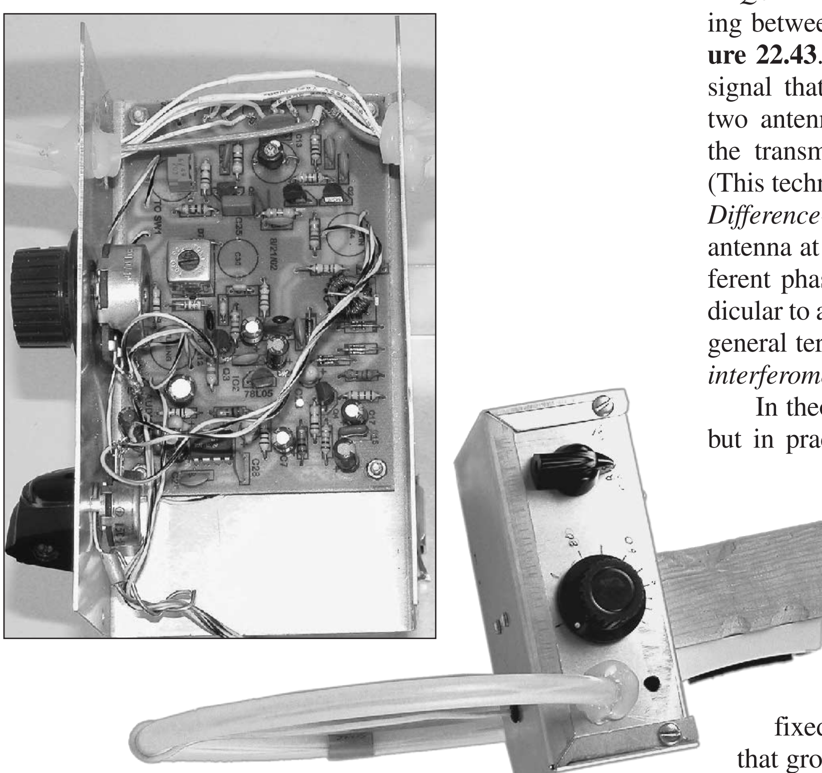

Figure 22.42 — The integrated antenna, handle, and receiver are built into a RadioShack aluminum box. The controls are made to be operated with one hand while using the antenna.

22.2.8 THE DOUBLE-DUCKY VHF 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 **Figure 22.43**. 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 **Figure 22.44**, 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 ½ λ separation on 2 meters (40 inches) is pretty large for a mobile array, ¼ λ gives entirely satisfactory results, and even ⅛ λ (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.

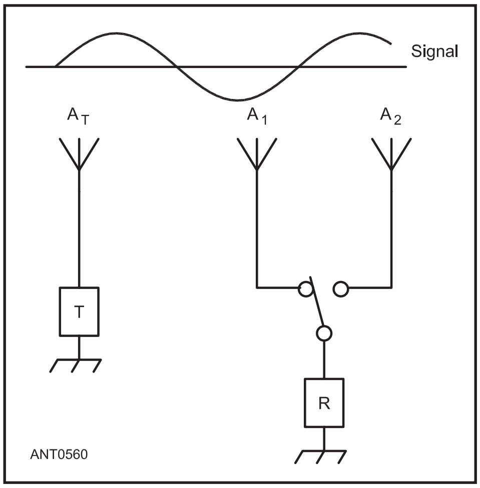

Figure 22.43 — At the left, A_T represents the antenna of the hidden transmitter, T. At the right, rapid switching between antennas A_1 and A_2 at the receiver samples the phase at each antenna, creating a pseudo-Doppler effect. An FM detector detects this as phase modulation.

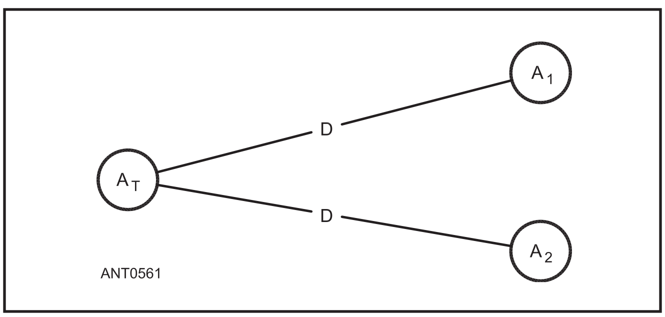

Figure 22.44 — If both receiving antennas are an equal distance (D) from the transmitting antenna, there will be no difference in the phase angles of the signals in the receiving antennas. Therefore, the detector will not detect any phase modulation, and the audio tone will disappear from the output of the detector.

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 perhaps 10 W without much problem.

A solid-state switch, the PIN diode is used. The intrinsic region of this type of diode is ordinarily free 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. **Figure 22.45** 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 V (a nominal 9-V minimum is recommended).

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 ½ λ 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 **Figure 22.46**. 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.

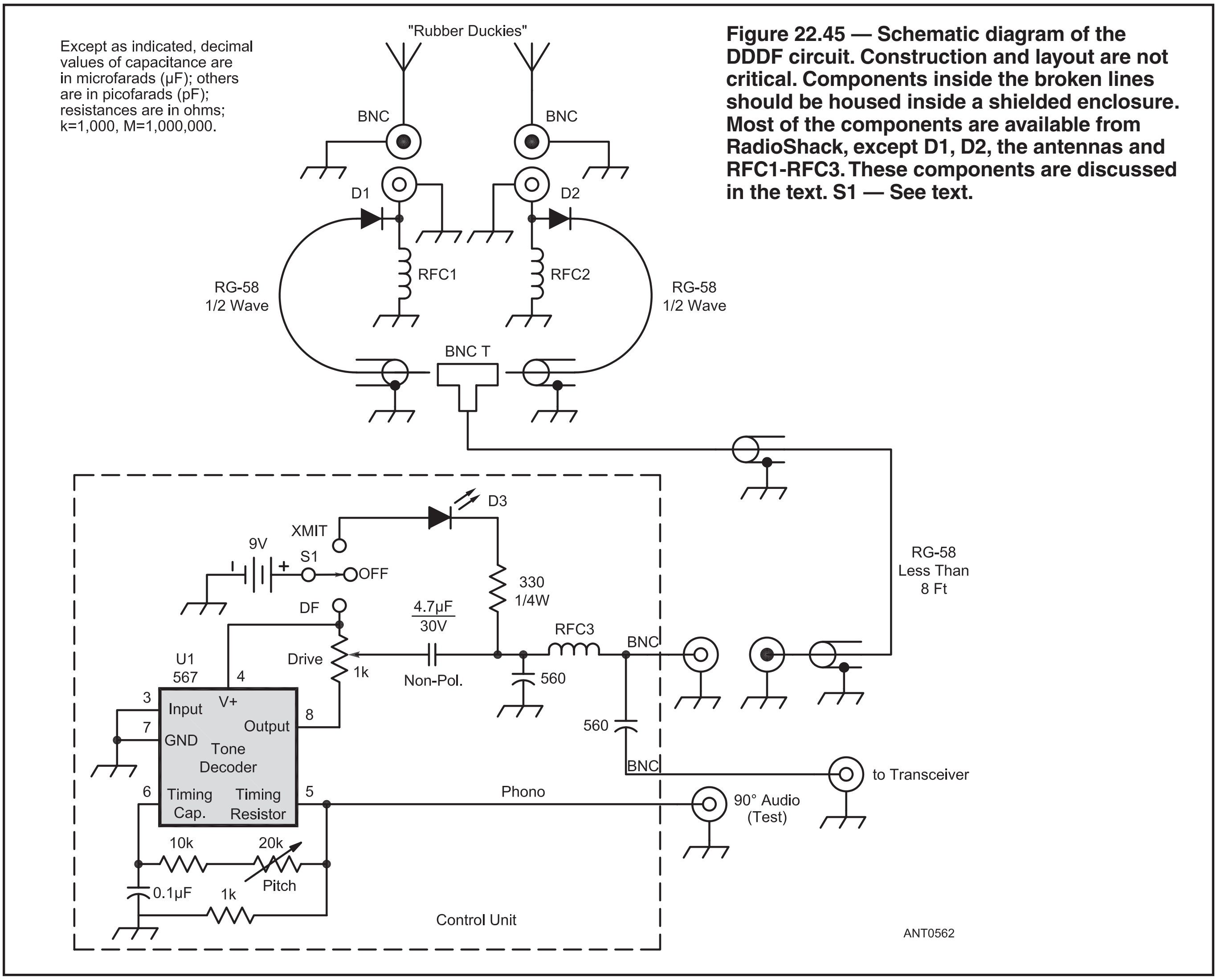

Figure 22.45 — Schematic diagram of the DDDF circuit. Construction and layout are not critical. Components inside the broken lines should be housed inside a shielded enclosure. Most of the components are available from RadioShack, except D1, D2, the antennas and RFC1-RFC3. These components are discussed in the text. S1 — See text.

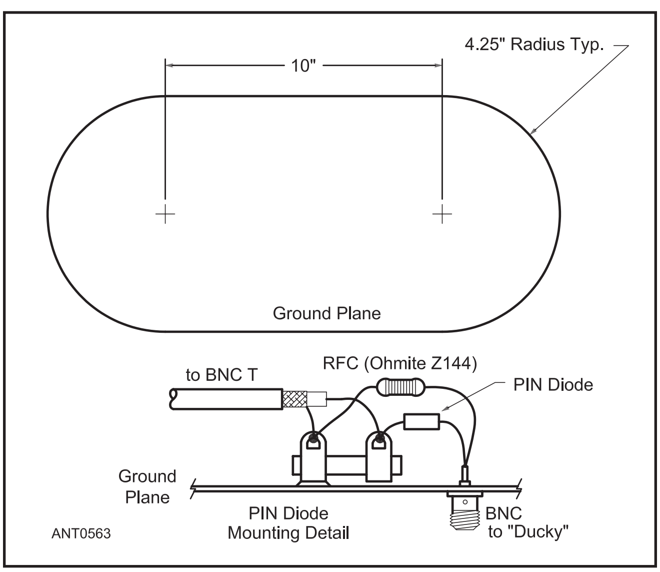

Figure 22.46 — Ground-plane layout and detail of parts at the antenna connectors.

Note that a tone an octave higher may appear.

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. It may also show instability at a sharp null position. Aimed to the other side of a null, it will give a greatly increased AF output. 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.

22.2.9 A COMBINED YAGI — INTERFEROMETER VHF ANTENNA

Interferometers give sharp bearings, but they lack sensitivity for distant work. Yagis are sensitive, but they provide relatively broad bearings. The Oct 1998 *QST* article by R. F. Gillette, W9PE, "A Fox-Hunting DF Twin 'Tenna" describes a three-element Yagi antenna that blends both on a single boom to cover both ends of the hunt. (The article is included on this book's CD-ROM.) Being rigid, the elements of the antenna described in the article make it somewhat impractical for competitive DFing in brushy or wooded areas, but the design provides a starting point for experimentation and modification.

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.

To form the interferometer, the two end elements are converted to dipoles and the center element is disabled. 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.

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 that can be heard by the operator as in the preceding DDDF design.

22.2.10 A TAPE-MEASURE ELEMENT YAGI FOR 2 METERS

Joe Leggio, WB2HOL, designed this antenna while searching for a beam with a really great front-to-back ratio to use in hidden transmitter hunts. It exhibits a very clean pattern and is perfect for RDF use. You can construct this beam using only simple hand tools, and it has been duplicated many times.

WB2HOL's first design requirement was to be able to get in and out of his car easily when hunting for a hidden transmitter. He accomplished this by using steel "tape-measure" elements, which fold easily when putting the antenna into a car and yet are self supporting. They also hold up well while crashing through the underbrush on a fox hunt. (This antenna isn't designed for mobile use — *Ed.*)

WB2HOL decided to use three elements to keep the boom from getting too long. He used inexpensive schedule-40 PVC pipe, crosses and tees that can be found at any hardware store for the boom and element supports. He used a simple hairpin match, consisting of a 5-inch length of #14 AWG solid wire bent into the shape of a U, with the two legs about ¾ inch apart. This gave in a very good match across the 2 meter band after he tweaked the distance (1-inch on his prototype) between the halves of the driven element for minimum SWR.

You can cut the 1-inch wide tape-measure elements with a pair of shears, chamfering the ends of the elements. Be very careful — the edges are very sharp and will inflict a nasty cut if you are careless. Use some sandpaper to remove the sharp edges and burrs and put some vinyl electrical tape or conformal coating such as Plasti-Dip on the ends of the elements to protect yourself from getting cut. Wear safety glasses while cutting the elements. See **Figure 22.47** for dimensions.

Ken Harker, WM5R recommends using wider tape measures to provide stiffer elements or stacking thinner elements. He also notes that when taking apart a tape measure, the internal spring tension can cause the pieces to fly apart. Covering the entire element with heat shrink provides additional stiffness and comes in a variety of colors. Ken also notes that a handheld-size receiver can be mounted to the boom of a beam to further integrate the package. Plastic brackets or hook-and-loop fasteners both work well.

Make sure you scrape or sand the paint off the tape-measure elements where the feed line is attached. Most tape measures have a very durable paint finish designed to stand up to heavy use. You do not want the paint to insulate your feed line connection!

If you are careful, you can solder the feed line to the element halves, but take care since the steel tape measure does not solder easily and the PVC supports can be easily melted. Tin the tape-measure elements before mounting them to the PVC cross if you decide to connect the feed line in this fashion.

If you decide not to solder to the tape-measure elements, you can use two other methods to attach the feed line. One method employs ring terminals on the end of the coax. The ring terminals are then secured under self-tapping screws or with 6-32 bolts and nuts into holes drilled in the driven-element halves. However, with this method you cannot fine-tune the antenna by moving the halves of the driven element in and out.

The simplest method is simply to slide the ends of the feed line under the driven element hose clamps and tighten the clamps to hold the ends of the coax. This is low-tech but it works just fine.

WB2HOL used 1½-inch stainless-steel hose clamps to attach each driven-element half to the PVC cross that acts as its support. This allowed him to fine-tune his antenna for lowest SWR simply by loosening the hose clamps and sliding the halves of the driven element in or out to lengthen or shorten the element. He achieved a 1:1 SWR at 146.565 MHz (the local fox-hunt frequency) when the two elements were spaced about 1 inch apart. **Figure 22.48** shows the

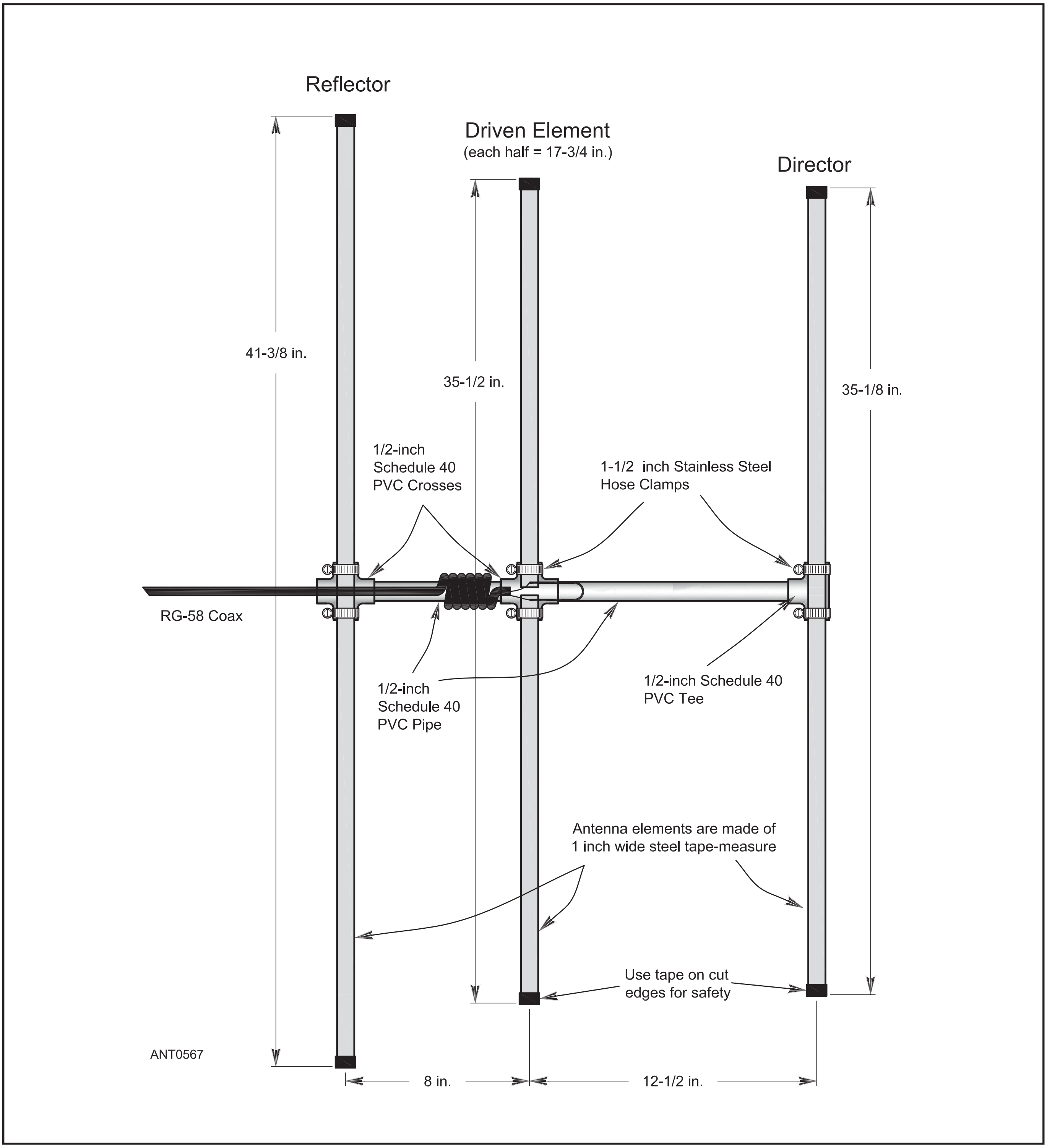

Figure 22.47 — Tape-measure beam dimensions.

Figure 22.48 — Photo of driven-element mounted to PVC tee using hose clamps. The hairpin match wires are shown here soldered to the tape-measure elements, along with the RG-58 feed line.

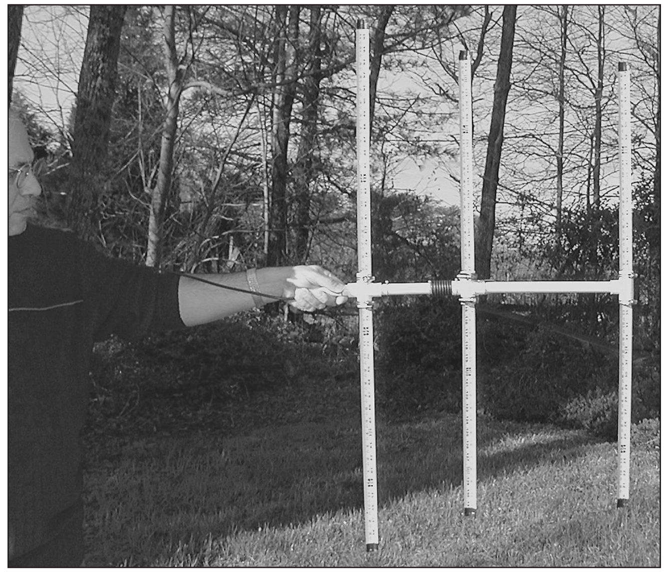

Figure 22.49 — Photo of complete tape-measure beam, ready to hunt foxes!

hose-clamp method for attaching the driven element to the PVC cross, along with the hairpin wire and feed line coax. **Figure 22.49** shows the completed antenna.

Some builders have used rubber faucet washers between the tape-measure elements and the PVC-cross fittings on the director and reflector. These allow for the tape to fit the contour of the PVC fitting better and will make the antenna look nicer. It is normal for the reflector and director elements to buckle a bit as they are tightened to the PVC tee and cross if you don't use faucet washers. You can also eliminate the buckling if you use self-tapping screws to attach these elements instead of hose clamps. The beam will not be as rugged, however, as when you use hose clamps.

The RG-58 coax feed line is wound into an 8-turn coil along the boom to form the choke balun required to prevent feed line interaction from distorting the antenna pattern. (RG-174 is much lighter and does not introduce significant loss in the short length used here — *Ed.*) The coil is covered with electrical tape or tennis racket grip tape to secure it to the boom.

This beam has been used on fox hunts, on mountain tops, at local public-service events, outdoors, indoors in attics — just about everywhere. The SWR is typically very close to 1:1 once adjusted. Front-to-back performance is exactly as predicted. The null in the rear of the pattern is perfect for transmitter hunts.

22.2.11 DIRECTION FINDING 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 the **Antenna Fundamentals** chapter.

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For more information on direction finding, see *Radio Orienteering-The ARDF Handbook* by Bob Titterington, G3ORY, David Williams, M3WDD and David Deane, G3ZOI 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(**www.arrl.org/shop**).