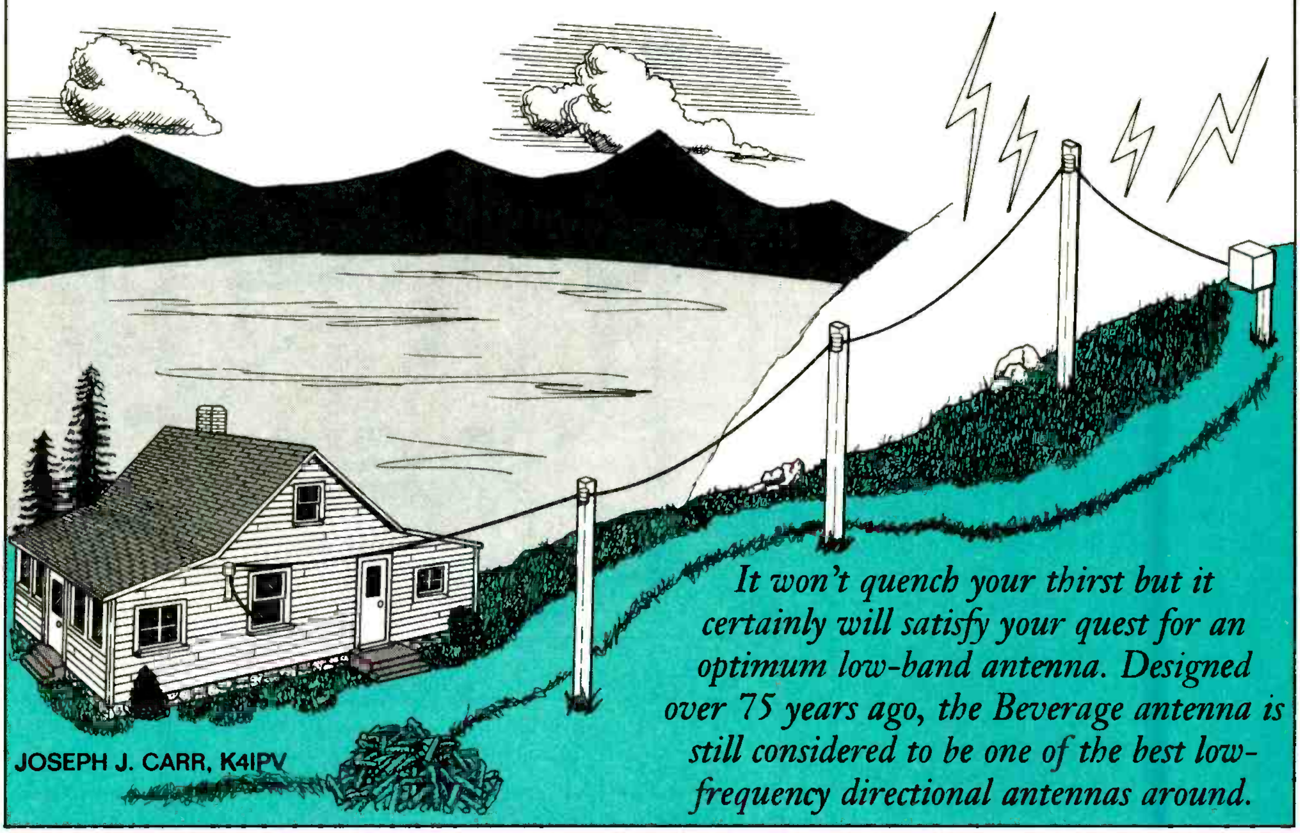
THE BEVERAGE ANTENNA



It won't quench your thirst but it certainly will satisfy your quest for an optimum low-band antenna. Designed over 75 years ago, the Beverage antenna is still considered to be one of the best low-frequency directional antennas around.

JOSEPH J. CARR, K4IPV

The Beverage (or Wave) antenna is considered by many experts to be the best receive antenna available for Very Low Frequency (VLF), AM broadcast band (BCB), medium wave (MW), or Tropical Band (low HF region) DXing. The Beverage was used by RCA at its Riverhead, Long Island, NY station in 1922, and a technical description by Dr. Harold H. Beverage (for whom it is named) appeared in *QST* magazine in November 1922. The U.S. Navy is said to have erected a "Beverage antenna farm" in Hawaii during World War II to listen to Japanese home islands broadcasts on the AM broadcast band. Dr. Beverage, a pioneer in radio communications, was awarded the U.S. Army Signal Corps Certificate of Appreciation in 1944 for numerous wartime contributions to the Army's communications systems. Dr. Harold H. Beverage, W2BML, passed away in January 1993, at the age of 99.

Properties of the Beverage Antenna. The Beverage antenna is a long-wire antenna of very special design—more than one wavelength (1λ) in length, although some authorities maintain that >0.5λ is sufficient. The Beverage provides good directivity and gain in the low-frequency bands, VLF through MW, although good results are relatively easy to obtain up to the 31-meter (9.5 MHz) band. Some attempts have been made at making Beverage antennas work as high as the 11-meter Citizen's Band or the 10-meter ham band (28.0–29.7 MHz).

In reception (and due to reciprocity, also in transmission), the Beverage antenna works on vertically-polarized waves arriving at low angles of incidence. These conditions are normal in the AM BCB, where nearly all transmitting antennas are vertically polarized. In addition, the ground-and sky-wave propagation found in the VLF, AM BCB, and low MW bands are relatively consistent. As the frequency increases, however, two factors become increasingly dominant. First, the likelihood of horizontal polarization increases, since the shorter wavelengths at those frequencies make horizontal antennas easier to construct. Second, shortwave propagation becomes less consistent at higher frequencies. The polarization of the received signals not only changes in those bands, but constantly does so when conditions are unsettled. It is the strong dependence of the Beverage on relatively constant vertical polarization that makes me suspect claims of Beverage-like performance above the 25-meter band.

Beverage antennas are commonly found in receiving stations. For a transmitter, the earth losses are large compared with the radiated energy, and the reduced efficiency more than offsets any improvement in directivity.

Figure 1 shows the basic single wire Beverage antenna. It consists of a single conductor (No. 16 to No.

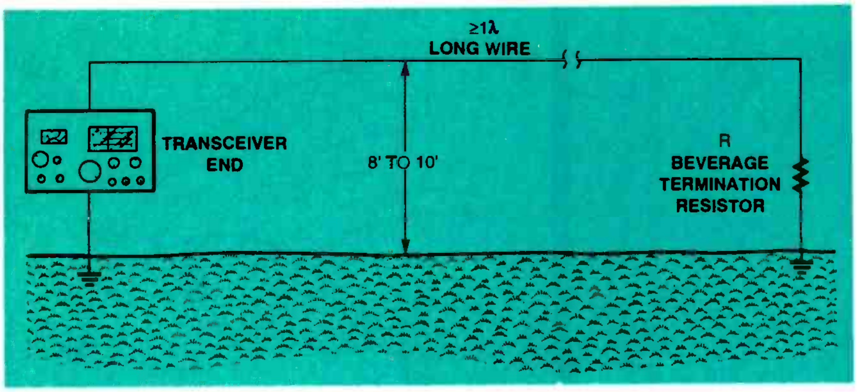


Fig. 1. The Beverage antenna for low frequency reception.

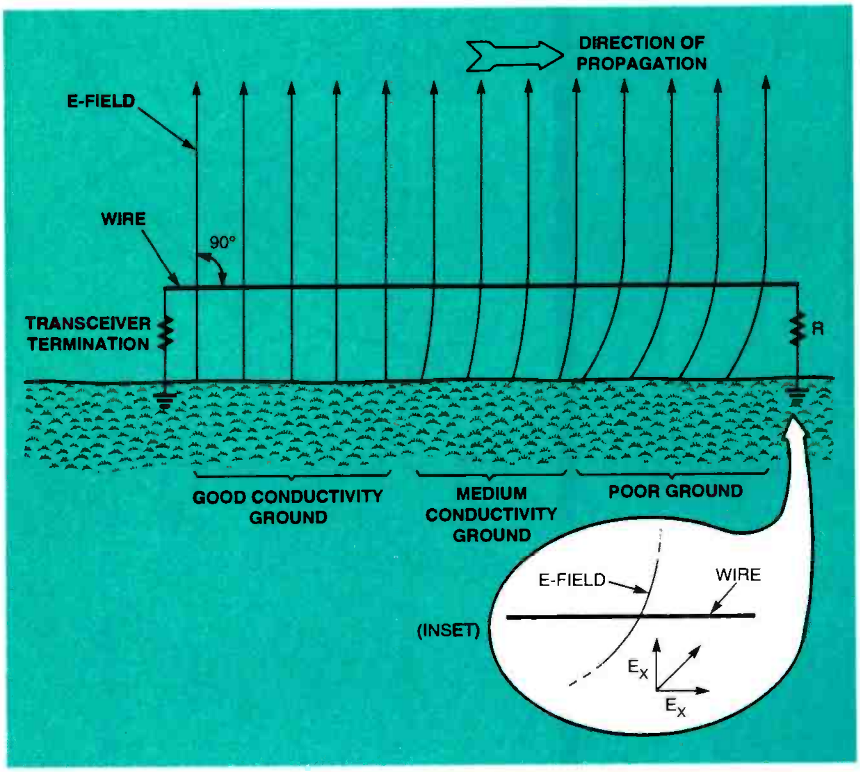


Fig. 2. Beverage antennas work best over poorly conductive ground because of bending of the E-field lines of force.

8 wire, with No. 14 being most common) erected about eight to ten feet above ground. The antenna is pointed in the direction of the desired receiving (or transmitting) station. Some Beverages are unterminated (and bi-directional), but most are terminated at the far end in a resistance (R) equal to the antenna's characteristic impedance. The receiver (or transmitter) end is also terminated in its characteristic impedance, but generally requires an impedance matching transformer to transform the antenna impedance to the 50-ohm impedance input used by most modern transceivers.

The Beverage antenna depends on being erected over poorly conductive soil, even though the terminating resistor needs a good ground. Thus, one source claimed that sand beaches adjacent to salty marshes make the best Beverage sites (a bit of overstatement). Figure 2 shows why poorly conductive soil is needed. The E-field vectors are launched from the vertically-polarized transmitting antenna perpendicular to the Earth's surface. Over perfectly conducting soil, the vertical waves would remain nearly vertical. But over imperfectly conducting soil, the field lines tend to bend close to the point of contact with the ground. As shown in the inset to Fig. 2, the bending of the wave provides a horizontal component of the E-field vector, and this provides the means of generating an RF current in the conductor wire.

Beverage directivity is an interesting phenomenon. Considering the Beverage as a receiving antenna, when signals arrive from either side—that is perpendicular or broadside to the wire—all sections of the wire are excited in-phase with each other. When these signals propagate along the wire, they reach the receiver end essentially out of phase with each other, so they cancel. Thus, the Beverage exhibits very deep nulls off the sides at right angles to the wire. The directivity pattern of a 1λ-long terminated Beverage antenna is shown in Fig. 3.

Signals arriving from either end of the wire produce electrical situations that are similar to each other, but with opposite results. Signals from either direction set up in-phase reinforcing waves at the ends. Signals arriving from the forward direction propagate along the wire towards the receiver end, and to build up a strong resultant that is heard by the receiver. Signals arriving from the rear direction also build up in-phase reinforcing electrical signals, but these propagate towards the termination resistor end, where they are absorbed by the resistor and are therefore lost. If the termination resistor, R, is matched to the characteristic impedance of the antenna, Z_O, then there will be no reflections back down the wire (which could reduce the depth of the rear null).

Beverages and Transmission Lines. A good "thought model" for the Beverage antenna is to regard it as a parallel wire transmission line with one good conductor (the wire) and one lossy, poor conductor (the soil underneath). As with any transmission line, the electrical wave in the wire has a lower velocity of propagation than the electromagnetic (EM) wave in free space. The free space EM wave travels at the speed of light (denoted by the letter c), while the electrical signal in the wire set up by the passing EM wave travels at a velocity of 0.85c to 0.98c, depending on the design and installation of the antenna. The velocity factor (k) is the ratio of the actual velocity (v) to the free space velocity (c), or $k = v/c$. The velocity factor is sometimes expressed as a decimal (*e.g.* 0.90), and sometimes as a percent (*e.g.* 90%). The velocity factor for the Beverage increases with antenna height, although the rate of increase slows down above heights of approximately ten feet.

All transmission lines have an attribute called characteristic impedance, symbolized by Z_O. Although the rigorous definition is a bit more complex, it is possible to define Z_O in terms of what happens in practical circuits. If an electrical signal is launched onto a transmission line that is terminated at its far end by a resistance (R) equal to Z_O, then all of the forward signal power is either radiated as an EM wave or absorbed by the terminating resistor; no signal is reflected back down the line towards the source. But if $R \neq Z_O$, a reflected signal will arise, and its amplitude is proportional to the mismatch between R and Z_O.

In a similar manner for the Beverage receiving antenna, a component of the signal set up in the wire by the EM wave travels towards the receiver, while another component travels towards the termination. The signal heading towards the termination is absorbed by the resistor. At the receiver end, if the value of Z_O does not fall on a standard resistor value, then you can do either of two things—make a network of standard value resistors that does match Z_O, or use a potentiometer (variable resistor) and set it to a value equal to Z_O. In any event, only non-inductive resistors such as carbon composition or metal film are suitable (Note: Many potentiometers are wire-wound).

In the ideal situation, the Beverage is a traveling wave antenna and exhibits no standing waves from the incoming EM transmission. Part of the received signal is absorbed in the termination and the remaining energy travels down the line to the receiver.

Like the long-wire antenna, the Beverage antenna needs a termination resistor that is connected to a good ground. This requirement may

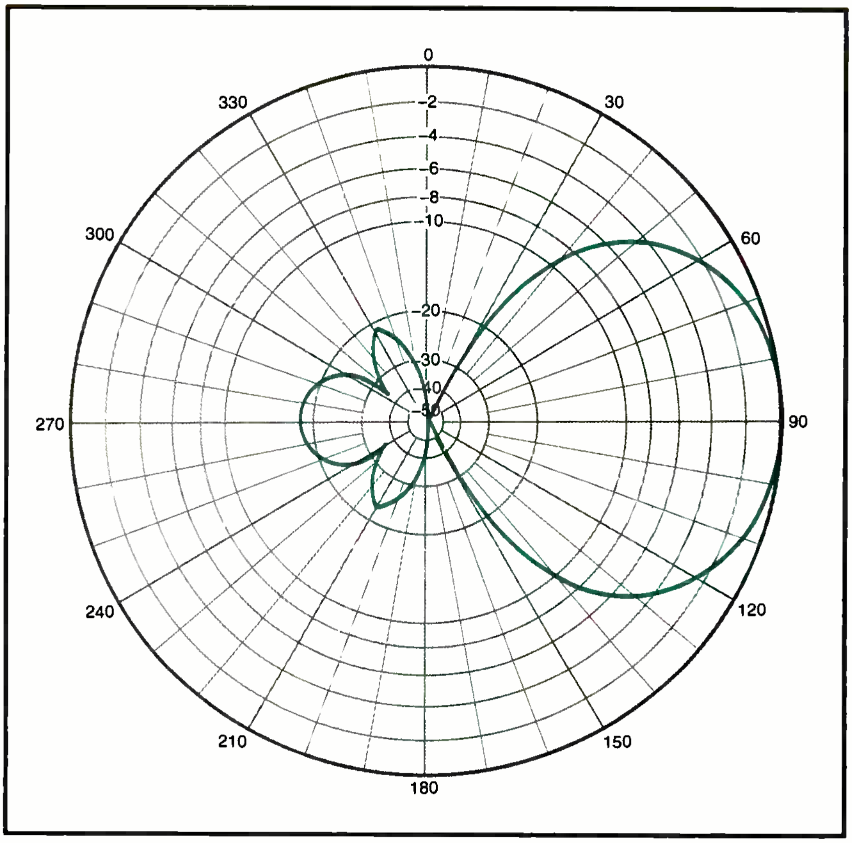


Fig. 3. Directivity pattern for a 1λ Beverage terminated in its characteristic impedance.

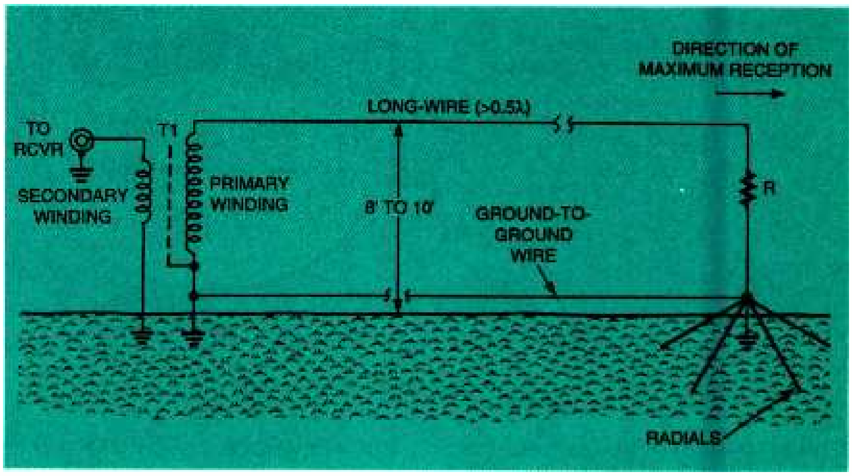


Fig. 4. Use of a ground-to-ground wire and radials to improve Beverage performance.

be harder to meet on Beverage antennas because they work best over lossy ground, which doesn't make a very good ground connection. On Beverage installations, a set of resonant radials can be used at the resistor ground to form an artificial "good ground." Insulated or bare wire, quarter- wavelength long, makes the best radials. However, a substantial improvement in the ground is possible using just bare wires from fifteen to twenty feet long, buried in the soil just below the surface far enough to prevent erosion from bringing it to the surface. Many articles and books on Beverages show ground rods of two or three feet long, which borders on the ridiculous. Poor soil requires longer ground rods, on the order of six to eight feet. Copper-clad steel make the best rods.

In his *Beverage Antenna Handbook* (see sidebar), Victor Misek, who may well be the leading exponent of the Beverage antenna, also recommends using a wire connec-

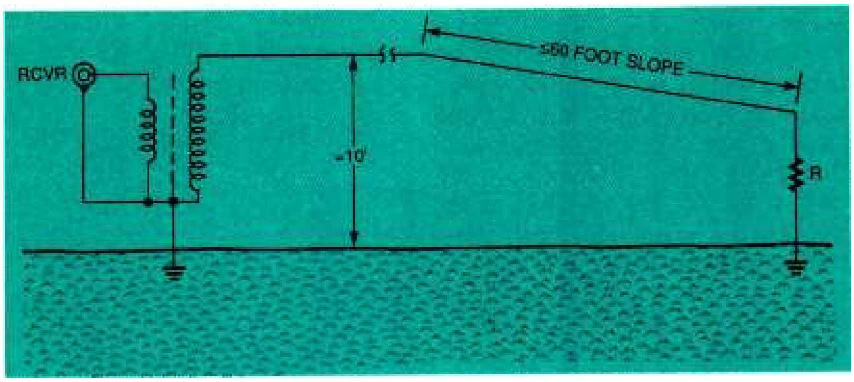


Fig. 5. Slope the last 60 feet or so from the 10-foot height of the wire to the grounded end of the resistor.

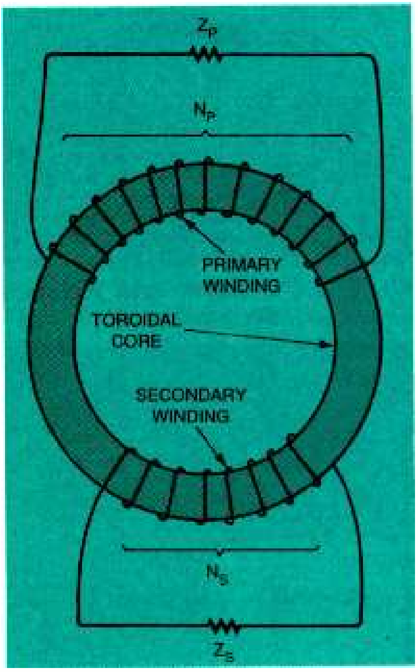


Fig. 6. Toroid transformer for the receiver end.

tion between the ground connection at the termination resistor and the receiver transformer (Fig. 4). According to Misek, this wire helps stabilize the impedance variations at higher frequencies.

Length of the Beverage Antenna. Another of the debates found among Beverage fans regards the best length for the antenna. Some sources say that the length can be anything! $\geqslant 0.5\lambda$, while others say $\geqslant 1\lambda$ is the minimum size. One camp says that the length should be as long as possible, while others say it should be close to a factor called the Maximum Effective Length (MEL), which is calculated from:

$$MEL = \lambda/(4(\{100/k\} - 1))$$

where: MEL is the Maximum Effective Length in meters; λ is the wavelength in meters; and k is the velocity factor of the wire, expressed as a percentage. Just to give you a feel for the numbers, if you want to figure the MEL for a 1.8 MHz amateur frequency Beverage, then use λ = 160 meters. Assuming a velocity factor, k, of 85%, we find that the Maximum Eeffective Length should be around 227 meters or 744 feet long—over two football fields long!

Misek uses numbers like 1.6λ to 1.7λ over the 1.8 to 7.3-MHz region, and 0.53λ to 0.56λ on frequencies lower than 1.8 MHz. Dr. Beverage was once quoted as saying that the optimum length is 1λ.

Building the Beverage. Installation of the Beverage antenna is not overly critical, if certain rules are followed. The antenna should be installed at a height of eight to ten feet off the ground, and should be level with the ground over its entire length. If the ground is not flat enough to make a level installation possible, then try to use a height that is eight to ten feet above the average terrain elevation along its run. A popular installation method is to erect 16-foot 4×4 lumber such that three to four feet are buried in a concrete filled posthole. Use lumber that is treated for outdoor use, that is, lumber sold for add-on decks and porches. The wire can be fastened to the 4×4 posts using either ceramic stand-off ("beehive") insulators or electric livestock control fence insulators (which are preferable). Try to use one contiguous length of wire for the antenna, if possible, in order to avoid soldered splices and joints.

One of the Beverage installation difficulties shared with other longwire antennas is the need to slope down to a point where a termination resistor can be easily installed close to the ground. While the longwire can be sloped over a large portion of its length, the Beverage should only be sloped downwards over the last sixty feet or so (Fig. 5).

Feeding the Beverage Antenna. As pointed out, the Beverage antenna must be matched at both ends with terminations equal to the characteristic impedance of the antenna. At the feed end, where the receiver is connected, this requirement usually means that a transformer is needed because the usual receiver antenna connection wants to see a 50-ohm source.

A transformer consists of two or more coils of wire arranged so that the magnetic field of one coil cuts across the other. Although air transformers are common, those used with Beverage antennas tend to be either powdered iron or ferrite toroid (*i.e.* "doughnut" shaped) cores (see Fig. 6). These cores are available from Amidon Inc. (250 Briggs Avenue, Costa Mesa, CA 92626. Tel. 800-898-1883). Sizes range from 0.125 inch outside diameter (o.d.). to 5.2 inches o.d. For transmitting, size is important, but for receiving, the convenience of building the transformer is more important. The cores are also classified according to material, and this attribute is frequency sensitive. The Amidon catalog gives data and ordering instructions for the various frequency ranges and sizes.

Transformers produce an impedance transformation according to the expression:

$$Np/Ns = \sqrt{Zp/Zs}$$

where: Np is the number of turns in the primary winding; Ns is the number of turns in the secondary winding; Zp is the impedance connected to the primary winding (in Beverage antennas it is Z_O); and Zp is the impedance connected to the secondary winding (typically 50 ohms). We know the required impedance transformation (Zp/Zs) by comparing the value of Z_O (which connects to the primary winding), and the receiver system impedance (which connects to the secondary winding)—the latter is usually 50 ohms.

The usual practice is to select an inductance for the transformer winding that is high relative to the highest impedance to be matched. Beverage antenna experts recommend an inductance of 637 μH for the primary, which translates to 35 turns of wire on the Amidon FT-50-43 core ("FT" denotes ferrite material, "50" means a 0.50 inch o.d., and "43" is the material mixture type. The 43 mixture is nickel-zinc, works to about 50 MHz, and has a permeability μ of 850). To match 500 ohms to 50 ohms, we need 11 turns on the secondary. Thus, we can select an FT-50-43 ferrite toroid core, and then wind the primary with 35 turns of No. 26 enameled wire, and the secondary with 11 turns of the same wire. Other cores are also useful, and indeed may be better for the BCB. These would require different turns ratios from the example given above.

The ≈500-ohm impedance of the Beverage makes a reasonable match to the "HI-Z" (high impedance) inputs of some receivers (as well as the normal impedance of older receivers), but direct connection is not recommended because of safety reasons. The Beverage is a huge static electricity generator. Static build-up on the wire can produce discharges that will destroy the RF input circuitry of solid-state receivers. As a result, even when no impedance transformation is needed, a 1:1 transformer is recommended because of the discharge path to ground through the secondary winding.

Better performance, especially noise performance, is achieved if the transformer is wound using a Faraday shield technique. This method is shown in Fig. 7. The primary winding is wound in the normal manner with enameled hookup wire. The secondary, however, is made with a length of coaxial cable for the wire. Small sizes, such as RG-174/U or even RG-58/U, will suffice for medium to large size cores. One end of the wire is stripped back and the shield removed, exposing the inner insulator and conductor; remove about ¼-inch of the inner insulator to expose the conductor. The other end is trimmed to allow ¼-inch of inner conductor to be exposed, along with ½-inch of inner insulator and ½-inch of the shielding outer conductor; solder the inner conductor of the other end to the outer conductor of this end (be sure not to use too much heat, or the inner insulator will melt).

The transformer can be mounted in either a shielded metal box or a non-shielded box, but it must be mounted at the feed end of the wire, with no down-lead (other than the coax). The chief requirement is that the box be weatherproofed. Avoid mounting the transformer on the pole if possible. This can be done if the Beverage wire is sloped gently from the normal height (8 feet to 10 feet) to the ground level (Fig. 8). As in the case of the termination resistor mentioned earlier, the slope should be over about sixty feet, but not significantly more. Also shown in Fig. 8 is an alternate transformer scheme (see inset) that can be used with any Beverage, not just the sloping feed type. This transformer is called an autotransformer because the same winding is used for both primary and secondary. The secondary is merely tapped down on the primary at the correct impedance level. Some people use a series of taps on the primary, and a switch to select one tap from the many, in order to accommodate several different impedance levels.

Figure 9 shows a Zepp-fed Beverage antenna. A parallel transmission line is made by spacing two No. 14 lengths of wire, each long enough to reach the feed end of

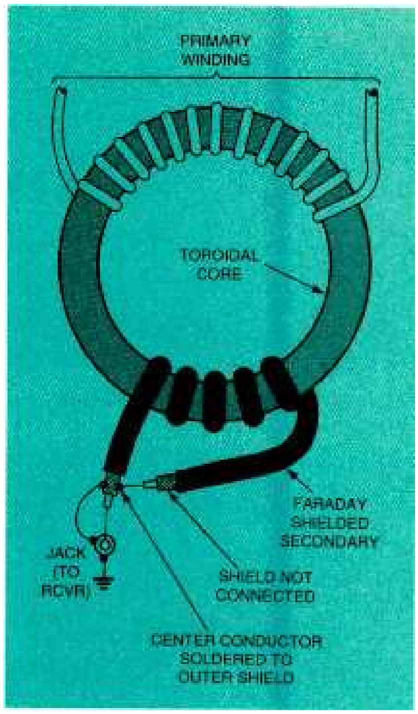


Fig. 7. Use of coaxial cable to form a Faraday-shielded transformer.

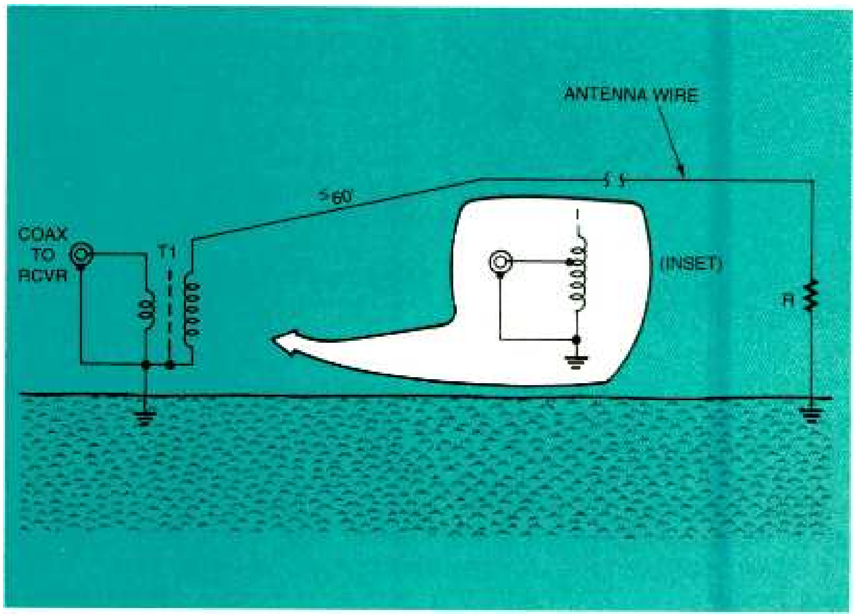


Fig. 8. Use the same sloping of the last 60 feet down to the receiver end as was used at the ground end.

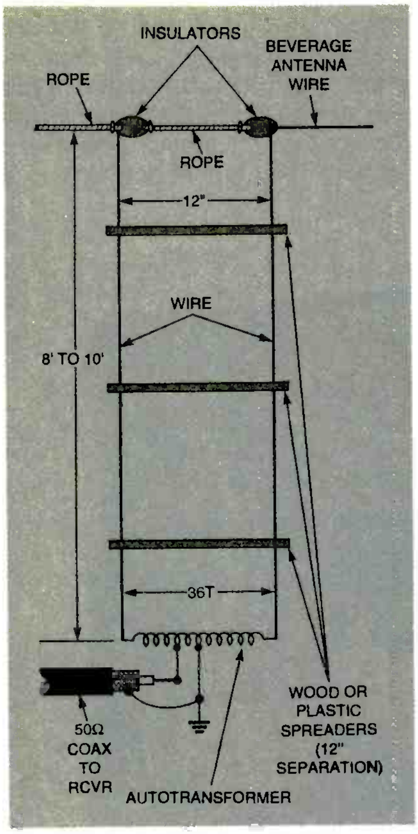


Fig. 9. Zepp-fed Beverage antenna.

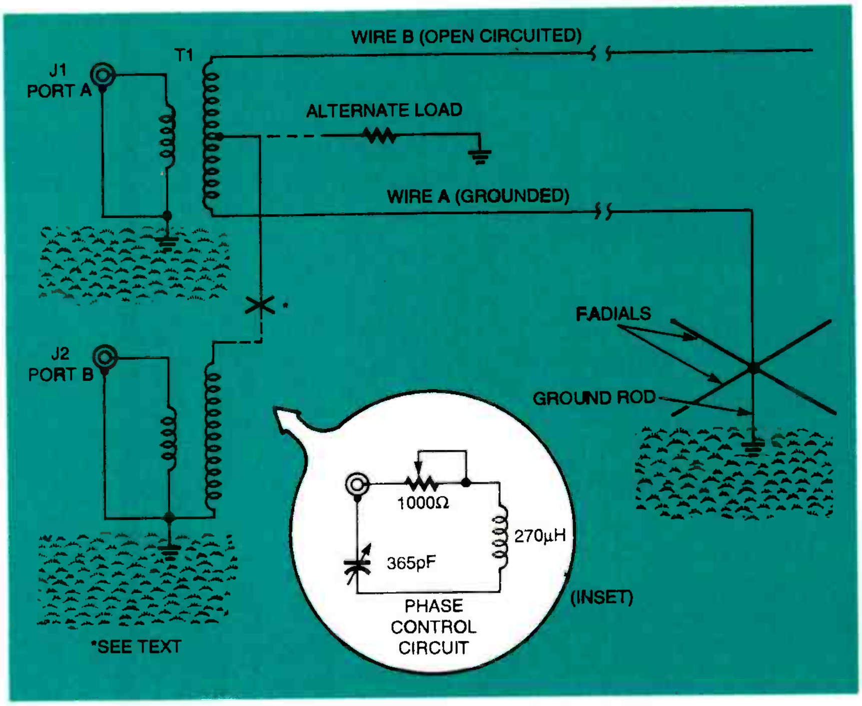


Fig. 10. Steerable-notch Beverage antenna.

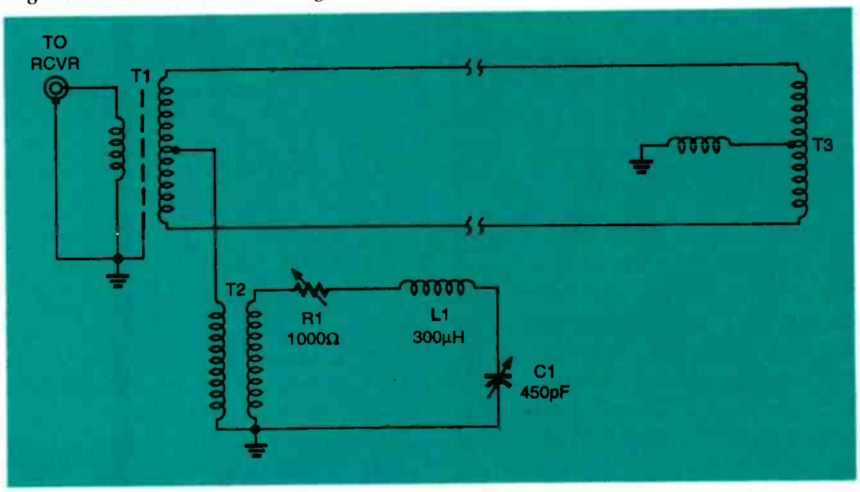


Fig. 11. Balanced version of the steerable-notch Beverage.

the Beverage, twelve inches apart. Use either plastic or wooden dowels to keep the wires spread apart (as many dowels as needed may be used). The feed transformer is a balanced autotransformer consisting of 36 turns of No. 26 enameled wire over a suitable core (e.g. FT-50-43). The center tap is at eighteen turns and is grounded. The center conductor of the coaxial cable to the receiver is connected to a tap on the "cold" end that matches the impedance. For 50 ohms, tap the coil six turns from the ground connection.

Steerable-Notch Antennas. A Beverage erected with two wires—parallel to each other, at the same height, spaced about 12 inches apart, with a length that is a multiple of half wavelength—is capable of null steering. That is, the rear nulls in the pattern can be steered over a range of 40 to 60 degrees. This feature allows strong off-axis signals to be reduced in amplitude so that weaker signals in the main lobe of the pattern can be received. There are at least two varieties of the steerable wave Beverage (SWB). One variety is shown in Fig. 10.

The two parallel wires in Fig. 10 are terminated differently. Wire A is grounded in a radial and ground rod system, without a termination resistor; Wire B is open-circuited. When a passing signal produces a voltage in these wires, the results are exactly opposite. Both wires form a "transmission line" to ground, but one is open-circuited so it sees an infinite load impedance, while the other is shorted so it has a zero load impedance. In both wires, the traveling wave propagates to the other end, and reflects 100 percent back towards the receiver. In Wire A, however, the reflected signal reverses phase with respect to the incident forward signal, while in Wire B the open-circuit load causes an in-phase reflection. Whether these signals cancel or add depends on the nature of the load circuit. If the load is resistive (see "alternate load" in Fig. 10), the antenna is unidirectional. If the second transformer, T2, is used as the load for T1, however, the reception is bi-directional, but only one direction at a time. A two-antenna coaxial switch can be used to select Port-A or Port-B, depending on the desired direction of reception.

If null steering behavior is desired, then use is made of a Phase

FOR MORE INFORMATION

A DXer's Guide to Beverage Antennas
John H. Bryant
Publication No. A9
and
Beverage and Longwire Theory
National Radio Club
P.O.B. 164
Mannsville, NY 13661

The Beverage Antenna Handbook
Victor Misek, W1WCR
142 Wason Road
Hudson, NH 03051

The ARRL Antenna Handbook-18th Edition
Publication 6133
and
Antenna and Techniques for Low-Band DXing
Publication 4661
John Devoldere, ON4UN
American Radio Relay League
225 Main Street
Newington, CT 06111

Practical Antenna Handbook-2nd Edition
Joseph J. Carr
TAB Books, 1994.
ISBN 0-07-011105-7

Control Circuit, PCC, (see inset to Fig. 10) consisting of a potentiometer, an inductance and a variable capacitor in series with each other. Varying both the "pot" and the capacitor will steer the null. You can select the direction of reception, hence the direction of the null, by using a switch to swap the receiver and PCC between Port A and Port B.

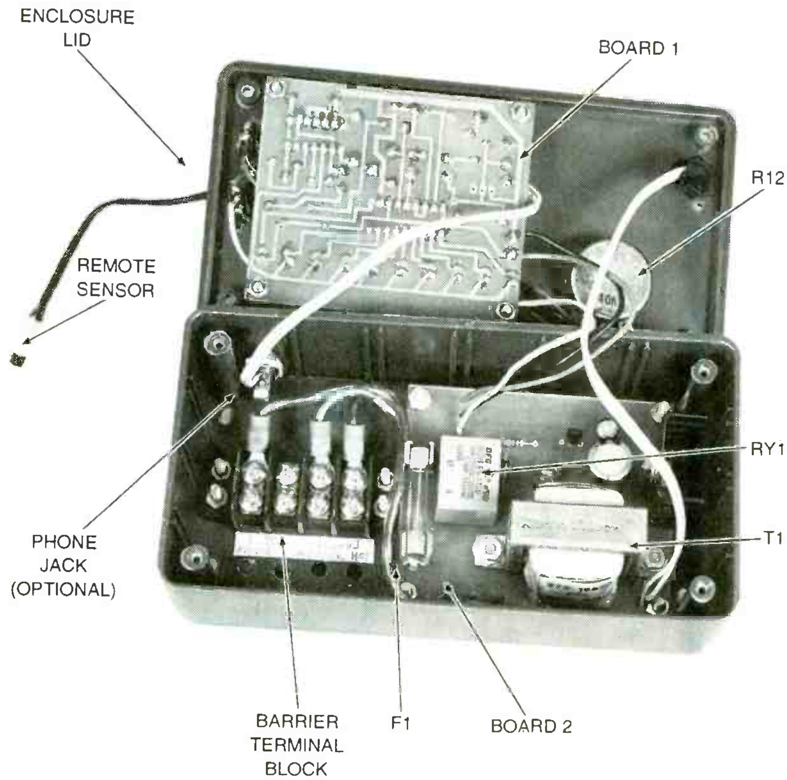
The other variation on the theme is shown in Fig. 11. This antenna is the same as the previous case on the receiver end, except for the PCC being hard-wired, rather than movable—both designs are acceptable. On the termination end, however, a trifilar transformer (three interleaved windings) is used to terminate the two wires.

So there you have it—designed over 75 years ago, the Beverage antenna still finds wide usage for the low-frequency *aficionados*. With its unique propagation properties coupled with its inexpensive material cost, the Beverage antenna is the optimum low-frequency antenna available today. ■

CLIMATE CONTROLLER

(continued from page 36)

made at the appropriate locations (the shaded areas), and glued to the lid of the enclosure to give the unit a professional finish. Now all that's left to do is install your Electronic Climate Controller in your environmental control system and sit back in complete comfort. ■



The two printed-circuit boards, as well as the off-board components that make up the Electronic Climate Controller's circuitry, are easily housed in and mounted on the unit's simple plastic enclosure. The optional barrier block makes it easy to wire the unit into your existing climate control system, while the optional phone jack allows for easy connection of a remote sensor.

The appearance and functionality of the finished project can be greatly enhanced by affixing a photocopy of the author's front panel label to the lid of the enclosure. The label includes switching designations as well as outlining the significance of each lighted LED.