

# ***ELECTRICALLY SMALL RESONANT LOOP ANTENNA FOR MEDIUM WAVE***

**BY BOB COLEGROVE**

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### 1. Introduction

I began listening to radio in 1958 –that is, seriously listening to radio. The longer I've been around, the more often I come back to magnetic-field antennas. A loop antenna is a delight for those of us from the pre-PLL vacuum tube days. It gives you the sensation that you are really tuning your radio and not just pressing buttons.

In the early 1980s, I had access to a large engineering library and availed myself of its wealth of electronic information, particularly regarding loop antennas – my interest at the time. Much of the early research and theory was available, some of it quite intelligible to an English major. My primary interest was medium wave, although I designed and constructed resonant loops operating at long waves and short waves.

There are several properties of loop antennas which make them attractive.

- Properly constructed, they will produce a *signal+noise-to-noise ratio* comparable or better than random-wire, electric-field antennas. Initially, you may be discouraged that the volume and signal strength indication is not as high. However, careful tuning will uncover signals that are not otherwise detectable.
- Loops are highly *selective*. They are not wide-band antennas. They must be tuned as you move up or down the band. Sometimes a change of 5 or 10 kHz will produce noticeable increase in signal strength when the antenna is retuned. Thus, loops of the type describe here are preselectors. By allowing only a very limited band pass to reach the input of the receiver, they greatly relieve the receiver's job of further signal processing, and greatly reduce the susceptibility to overloading and intermodulation.
- Loop antennas are *directional*. In many cases it will be possible to produce total nulls of not only the received signal, but also RF interference or locally produced noise. Since noise and interference are often in opposing directions to that of the signal, it will be possible to greatly mitigate these annoyances. These features give the loop a distinct advantage over random wire antennas commonly attached to portable shortwave receivers.

The design presented here offers no new insights into the subject of loop antennas. It is rather a distillation of hundreds of pages of documentation covering a period of more than 60 years, during which time radio navigation was born and developed into a highly sophisticated science.

This publication describes different loop antennas which can be constructed to operate on long wave, medium wave, or short wave. They are all similar in design and operating principle. They differ primarily in the size of the primary coil winding. The longer the wavelength, that is, the lower the frequency, the larger the coil must be.

These antennas are *electrically small*, that is, the height or width of the coil are much shorter than the wavelength being tuned. There are actually two coils, which operate on the principle of a transformer. The primary coil is the main receiving antenna. It is tuned to resonance by a variable capacitor connected across its terminals forming a tank circuit. This produces a high-Q field which in turn is inductively coupled to the secondary coil. The secondary coil, along with a twisted pair transmission line provide a low impedance input to the radio.

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There is no single, perfect loop design. Materials and dimensions may be selected to optimize anyone of a number of characteristics. For example, low noise and miniaturization may best be obtained with a shielded ferrite core antenna, while remote operation requires a low impedance coil. The antenna described here is an *air core* loop which emphasizes sensitivity, selectivity, and directional response. It is intended for the serious DXer who can accommodate 2 to 4 ft coils in the listening area.

This is a *passive* loop, meaning no amplification is provided outside the receiver. Preamplifiers can be used to some advantage with loops. Their purpose should be as a coupling device, converting the high-impedance of the primary circuit to a low-impedance for the transmission line to the receiver. It must be remembered that the system is only as good as the coil and a preamplifier cannot improve the signal-to-noise ratio of a basically unresponsive winding. Because the signal producing capability of this antenna is comparable to a long wire, and also because of its reasonably close proximity to the receiver, these plans do not include a preamplifier.

### 2. A Little Bit of Theory

The performance of a loop is directly related to the product of its effective height,  $h_e$  and figure of merit,  $Q$ ,<sup>1</sup>

$$h_e \times Q \text{ or } \frac{2\pi AN}{\lambda} \times \frac{X_l \text{ or } X_c}{R}$$

Effective height increases with coil size, or, more specifically the product of loop area and number of turns.  $Q$  is maximized by reducing total circuit resistance, the most significant components of which skin effect of the wire and loading by the pick-up coil and receiver”.

Assuming a high-impedance circuit, that is, a tuned resonant circuit, it is desirable to have the highest possible L/C ratio in order to obtain the largest possible effective height. This requires special consideration in coil design. The distributed capacitance which exists in every coil tends to act in parallel with the inductance. It represents wasted capacitance in the circuit in that it cannot be varied and used in the tuning range of the antenna. It has been found that, for a given size inductor, distributed capacitance is least when the winding is flat, in a single plane. Antennas using this geometry are commonly called ‘pancake loops.’ A 24 inch pancake loop designed to tune the upper end of the broadcast band will have 1/4 to 1/2 the distributed capacitance of a 24 inch solenoid winding used to cover the same band. Because of this, it can have higher inductance resulting in nearly twice the effective height.

$Q$  is increased mainly by using the largest gauge wire possible, and taking precautions not to overcouple the primary circuit to the receiver. At frequencies of 1600 kHz and below, the point of diminishing returns for wire size appears to be AWG 16. Size and weight restrictions come into play for low frequencies, limiting the use of AWG 16 to very large antennas.

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<sup>1</sup> Since loop antennas are directional, a complete consideration of effective height must take into consideration the orientation of the antenna with the incoming electromagnetic field. Response of the antenna is greatest when the axis of the primary coil is normal to the incoming signal. Since we are dealing with flat or ‘pancake’ coils, this means the plane of the coil is pointing toward the station’s ground wave. The response pattern of the antenna is most easily described as a doughnut with an infinitesimally small hole in the center. The resulting response is a cosine function which must be multiplied by the  $2\pi AN$  term in order to calculate the true effective height. When  $\cos \theta = 1$ , the response will be maximum.

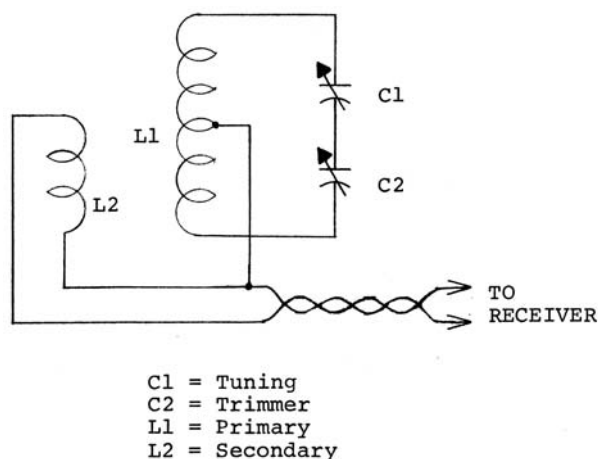
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Overcoupling will cause serious degradation in primary circuit  $Q$ , just as very loose coupling will result in inadequate signal transfer. It has been demonstrated during the development of radionavigation that the best coupling is that which optimizes the signal-to-noise ratio rather than power transfer. With this particular antenna, a small secondary coil wound in the same plane as the primary has proven to be the most effective method of coupling.

One of the serious deficiencies of most loop antenna designs is that they try to cover too much of the rf spectrum. ‘Padding’ capacitors are often switched in to extend the range to lower frequencies. Coils used to cover the entire broadcast band, for example, have  $\frac{1}{3}$  the effective height at 540 kHz as at 1600 kHz. This represents a 10 db loss. A loop having a larger coil with a high end of approximately 800 kHz, the effective height can be more than doubled at the lower end of the band.

The ideal loop response pattern and maximum nulls are produced when the coil is either electrostatically balanced to ground or shielded. Shielding provides the necessary capacitance equalization between each side of the coil and ground, but this is done at a sizeable increase in total distributed capacitance. This results in a lower L/C ratio and lower effective height. Two methods will be described here. One will show how to electrostatically balance the primary coil and the other will use a shielded low-impedance pick-up coil.

Figure 1 shows the schematic for the antenna having a balanced primary coil. L1, C1, and C2 form the primary, high-impedance resonant circuit. L2 is the pick-up coil and functions the same as a low-impedance loop commonly used in radio navigation. L1 and L2 are both flat coils constructed in the same plane with L2 occupying the center area. L2 is coupled to the receiver with a twisted pair. C2 is added to the primary circuit to tailor the main tuning capacitor to the required frequency. Since it is in series, it also lowers the minimum value of added capacitance permitting a slightly higher L/C ratio than if the variable capacitor alone were used. For applications where a single antenna is going to be used to tune the entire broadcast band, a dual-section variable capacitor is used with each section connected in series. A range switch is added to short out one section, raising the capacitance and allowing the antenna to tune to 540 kHz.



**Figure 1. Schematic of Loop Antenna (balanced primary configuration)**

The flat or ‘pancake’ primary coil is somewhat difficult to balance. This is because the capacitive center of the coil is not the center turn or geometric center of the coil. Each turn is a different size and has a different capacitance to ground. The actual balance point is located toward the outer turn of a pancake coil and is found experimentally as is described later.

As indicated above, another means of balancing the antenna is to shield the secondary coil. This in no way affects the performance of the loop in terms of sensitivity or selectivity, and produces the same fine null characteristics of the balanced primary. In this arrangement, the primary coil and tuning capacitor is allowed to ‘freewheel’ in space acting as a field intensifier.

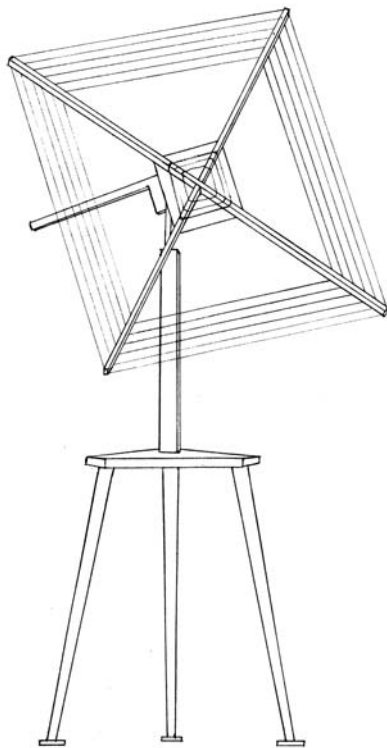
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The shielded or secondary pickup coil functions as a low-impedance, nonresonant loop. In this way, the balancing effect of the shield provides the correct null response. Distributed capacitance of the pick-up coil may be neglected, since it is nonresonant.

Mechanical construction is no less a consideration than electronic theory. A loop must rotate 360 degrees in order to respond to any vertically polarized ground wave. In addition, a minimum of 90 degrees of vertical pitch are required to compensate for skywave reception or electromagnetic field anomalies caused by nearby metal objects. Since nulls are often obtained within a two to three degree arc, the coil must be mounted on a reasonably stable platform and easily adjusted to the proper position with minimal backlash. The tuning capacitor must be mounted so that it requires a minimum wire lead from the coil and can be adjusted without body capacitance affecting the resonant frequency. The higher the L/C ratio, the more important this becomes.

The electronic and mechanical requirements listed here were the guidelines for the antenna described in following sections. Within limits, most dimensions are not too critical.

### **3. General Description and Tripod Construction**



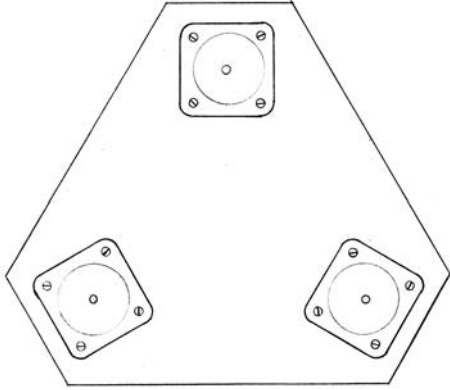
**Figure 2. Overall View of Loop**

Figure 2 shows an overall plan of the antenna, which consists of two separate sections, the coil assembly and the tripod. The coil assembly is intended to cover one band of frequencies and may easily be removed from the tripod so another coil assembly can be installed and used. The use of metal is restricted to avoid creating electromagnetic field anomalies. Each coil assembly is wound on an X frame. A handle is attached at the cross point, and forms an orthogonal assembly with the X frame. The tuning capacitor is mounted to the bottom of one of the X frame cross pieces. The secondary, pick-up coil is located in the center of the frame, and is connected to a twisted pair lead-in wire.

The tripod serves as the platform on which the coil is mounted. It may be located nearby the receiver and adjusted as each station is tuned. It should be constructed first as it is required for trimming and calibration of the coil. The tripod consists of three legs, a platform, and a center post. Dimensions are not critical. Those given here are nominal and will serve for use with any antenna you choose to build. The important characteristic for the tripod is that it be stable.

A set of 30-inch, wooden, bolt-on legs, available at most hardware stores will minimize construction time. They must come with beveled mounting plates, so that, when assembled, the legs will extend outward in tripod fashion. The legs should either come with self-leveling feet or these should be added. If the antenna is to be operated on a carpeted floor, it is recommended that the largest possible furniture cups be purchased and glued on the self-leveling feet. This will ensure a more stable operation.

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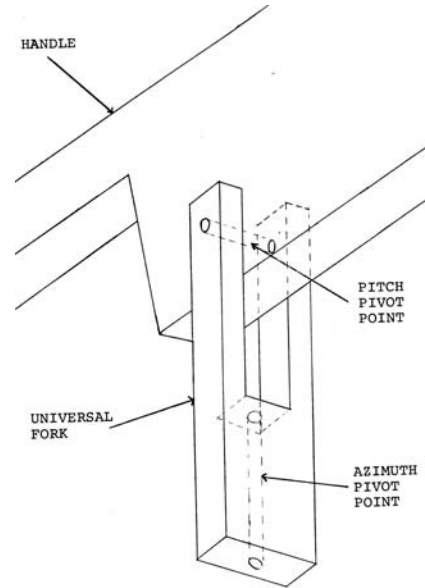
**Figure 3. Platform, Bottom Side**

Figure 3 shows the bottom side of a platform for the tripod with the leg mounting plates installed. The platform serves as a connection point for the legs and center post. The mounting plates should be fastened at 120 degree intervals from the center point of the platform, and must have the bevel oriented so that the legs will extend outward from a center vertical line.

The center post can be a 2-foot section of wood, nominally  $1\frac{1}{2} \times 1\frac{1}{2}$  inches square. It is fastened to the center of the platform with four wood screws. Care should be taken to fit the center post as squarely on the platform as possible. A  $\frac{1}{4}$  inch diameter, 3 inch deep hole is drilled in the top end of the center post and a  $\frac{1}{4}$  inch diameter, 6 inch long steel rod is inserted into this hole. This rod forms the mounting and azimuth pivot point for the coil assembly. Steel rod stock can be purchased at any hardware store.

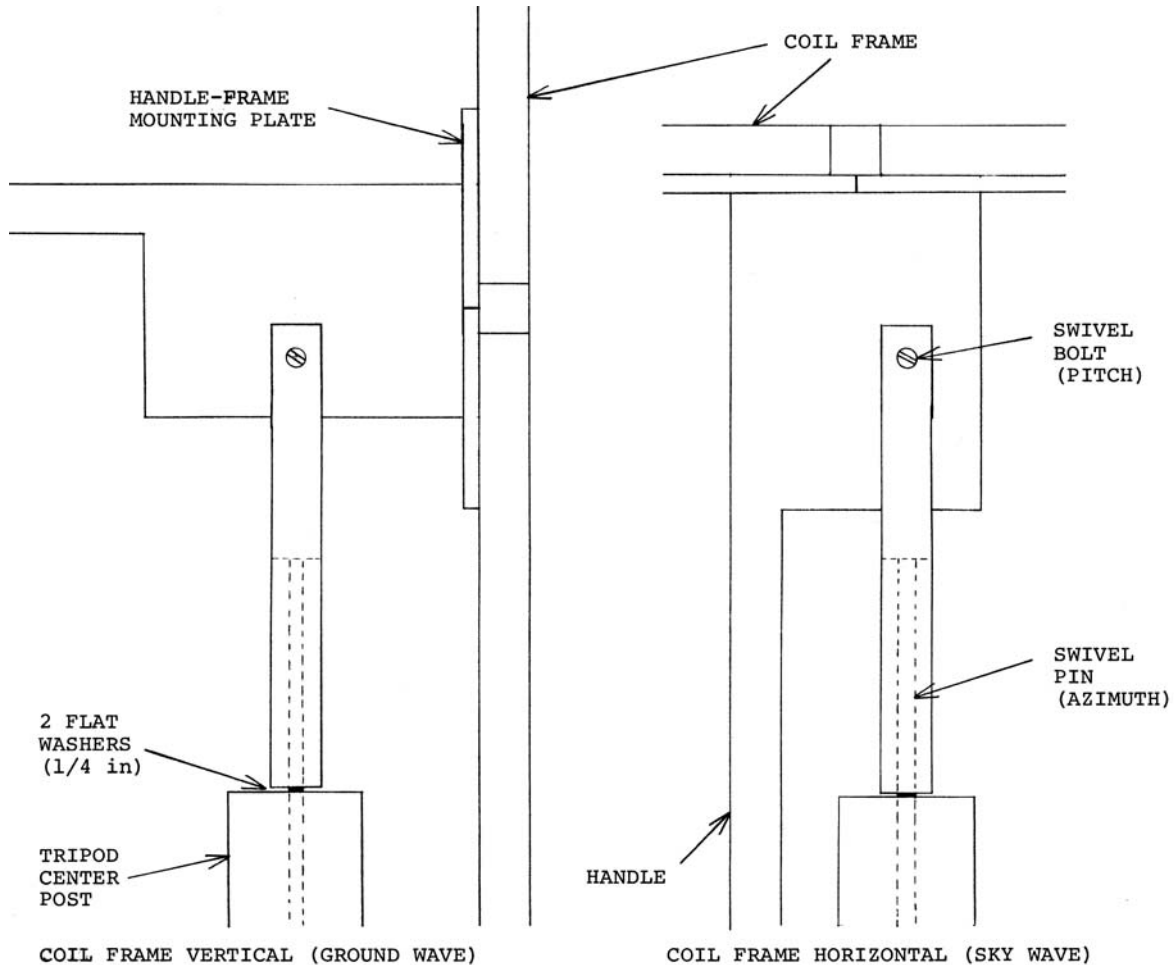
The key to the mechanical construction and operation of this antenna is the universal fork and handle arrangement shown in detail in Figures 4 and 5. Construction is very simple. Yet it provides a stable platform from which to operate the loop. Figure 4 shows the basic operation of the universal fork. The fork is fabricated from a piece of wood approximately  $\frac{3}{4} \times 1\frac{1}{2} \times 7$  inches. One end of the board is channeled out forming a two prong fork which receives the  $\frac{3}{4}$  inch thick handle. A bolt through the fork and handle provides the pivot point for 90 degree variation in pitch. A  $\frac{1}{4}$  inch hole is drilled through the other end of the fork, extending from the end to the prongs. This is fitted over the  $\frac{1}{4}$  inch steel pin which extends vertically from the top of the tripod center post. Rotation of the universal fork on the pin provides 360 degree rotation of the loop in the azimuth. Both pitch and azimuth may be adjusted with the handle in a joystick fashion.

Smooth, accurate pitch adjustment depends on proper mechanical balance of the coil assembly. A procedure for balancing the coil is presented later on. Figure 5 shows a side view of the universal fork with the coil oriented in the vertical and horizontal positions. It can be seen that the coil end of the handle is much thicker and the pivot hole located below the extended portion of the handle. This permits the handle to be moved into a completely vertical position. A slight downward pitch is also permitted. Some tension on pitch rotation is provided by tightening a wing nut on the pivot bolt. This is necessary to minimize any backlash or drifting and to balance the azimuth tension, so that the handle can be moved in any direction with minimal change in mechanical resistance. The channel in the universal fork should be cut slightly wider than the handle in order to accommodate flat washers on either side of the handle.



**Figure 4. Arrangement of Universal Fork and Handle**

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**Figure 5. Operation of Universal Fork, Vertical and Horizontal**

The fork should be designed so that the 1/4 inch pin extends into it by at least 3 inches. This minimizes any play in the fork which would otherwise result in backlash in the pitch adjustment. When drilling the hole, it is recommended that a bit slightly less than 1/4 inch be used at first in order to achieve a snug fit with the pin. The pin can be lubricated with paraffin to eliminate any initial sticking in the azimuth direction. Two 1/4 inch inside diameter flat washers are placed over the steel pin on the tripod to serve as a bearing surface.

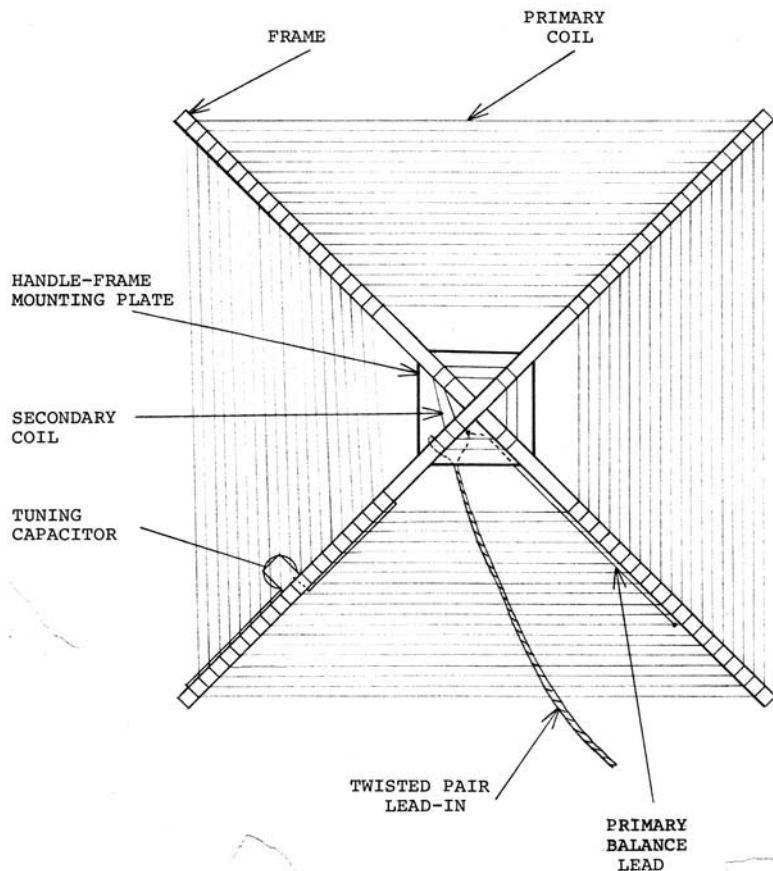
Aside from the requirements listed in the paragraph above, dimensions of the parts described so far are not critical; and you are left to your own resourcefulness and ideas. Dimensions for the coil frame and handle depend on the frequency range and size of the coil to be constructed. More will be said about these later.

### 4. Coil Frame Construction

Two coil designs will be described in this section, a nominal 2 foot square loop and a 3 foot square loop. We have already stated that effective height is directly proportional to the size of a coil and inversely proportional to wavelength. Significant improvements in performance can be obtained by dividing the broadcast band operationally into two bands and using two separate loop antennas covering the ranges above and below about 800 kHz. This is not to say the smaller of the two loops will not perform well below 800 kHz. The smaller coil will be more

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than adequate in most all situations and will require less than half the space. The larger loop will have a self-resonant frequency due to distributed capacitance somewhere in the upper portion of the broadcast band. Therefore, its range cannot easily be extended upward in frequency.



**Note: Illustration is stylized and does not represent any specific coil assembly.  
If braces are used, they should have a cross section approximately 3/8 x 3/4 inch.**

**Figure 6. Coil Assembly Detail**

Figure 6 shows a stylized view of the coil frame. It does not represent any specific loop antenna, so don't try to count turns or take any measurements. This illustration is merely intended to show the relationship of all the parts. Basically, the frame consists of two cross pieces, notched in the center to fit flush together, and a five inch square mounting plate, used in the center to hold the cross pieces square and provide a mounting surface for the handle which will be built later. Side braces may be added around the perimeter of the frame to ensure the cross pieces remain square and to protect the primary coil from damage during operation. The primary coil is wound in a single plane spiral. The depth of the coil is about one third the side dimension. Figure 6 shows an unshielded pick-up coil wound in a similar fashion to the primary coil. This type of pick-up coil requires that the primary coil be balanced to ground in order to

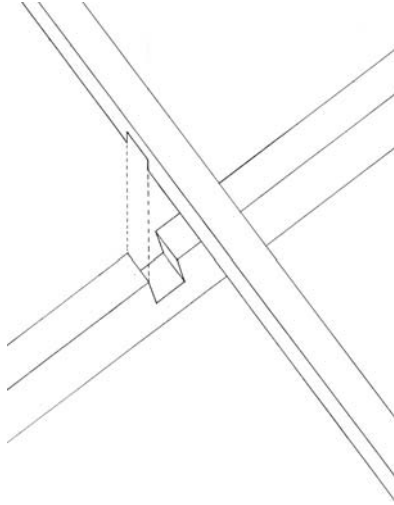
obtain the proper polarization and null response.

The cross pieces are normally cut from 1 inch (nominal 3/4 inch) pine shelf stock. They are cut to length 3/4 inch square. If side

The tuning capacitor is located along one of the lower portions of a cross piece, midway between the outer and inner extremities of the primary coil. The capacitor is mounted with the knob facing the same direction as the handle. The twisted pair lead-in is routed through a hole in the handle-frame mounting plate and attached to the secondary coil. Since the secondary is intended for an unbalanced receiver input, one lead and corresponding secondary coil end are grounded. This is a convenient point of attachment for the primary coil balance wire.



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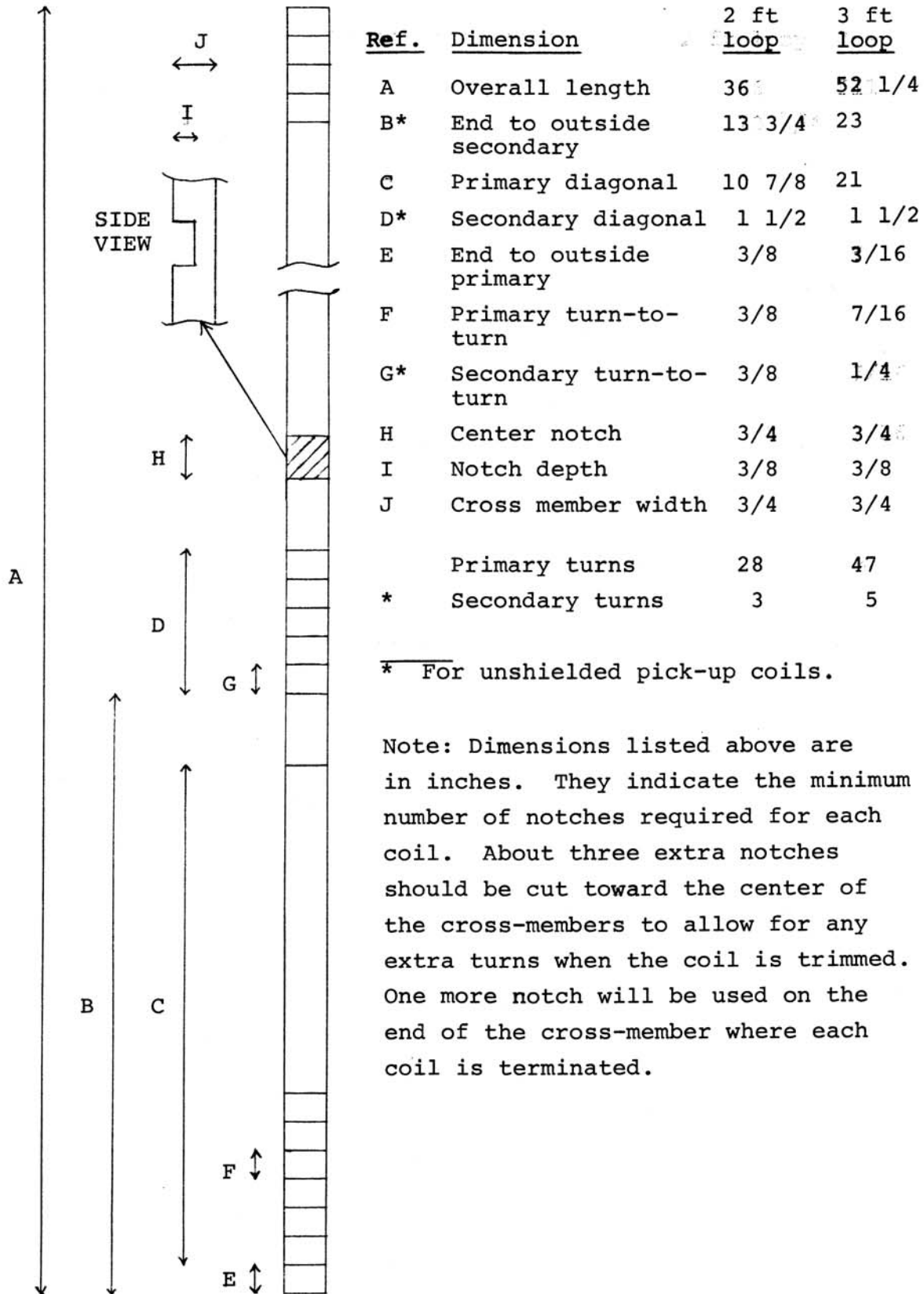


**Figure 7. Notch Cut in Center of Cross Members**

The coil frame is first fabricated by cutting the required wood pieces for the 'x' frame and handle frame mounting plate. The two cross members are notched in the center as shown in Figure 7, so that they fit together with their top and bottom surfaces flush. Notches are then placed along each cross member to receive the wire for the primary, and, if used, the unshielded secondary coil. It is recommended that power band saw or table-mounted scroll saw be used with a fence so that the depth of the notches can be kept even. Slight irregularities will not affect the performance of the antenna. It should be noted that one cross member is notched on the side

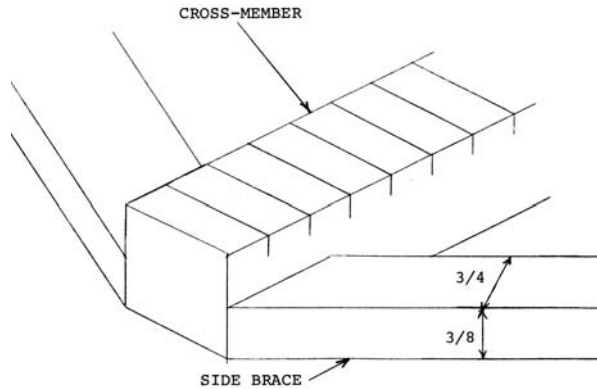
having the center notch and the other cross member on the side opposite the center notch. In this way, all of the wire notches will be on the same side when the unit is assembled. It is advisable to add 3 to 5 extra notches toward the center of each cross member for the primary coil. This permits extra turns to be added when the antenna is trimmed. Figure 8 gives the dimensions for the cross members and notch locations for the 25 inch and 37 inch coil assemblies.

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**Figure 8. Dimensions for Cutting and Notching Cross Members**

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**Figure 9. Side Brace Attachment**

The use of side braces is optional. The performance of the loop will not be affected if they are omitted. Once the primary coil is wound, the frame will be perfectly rigid; however, the side braces will tend to hold the cross members at right angles as the coil is wound. In addition, the braces will minimize the tendency of the cross members to bow with the tension of the wire. The most useful function of the side braces is that they permit the antenna to be operated with less chance of damage to the primary coil. The braces can be made cutting 3/8 in strips from the same 1 in (nominal 3/4 in)

pine stock. They should be fitted after the handle mounting plate is attached. Each end of each brace should be measured and mitered. The ends of each brace are attached to corresponding ends of the cross members using wire brads and wood glue. Pre-drill each end of the braces to fit the wire brads. This will prevent the wood from splitting. Make the joint away from the notched side of the frame. See Figure 9.

### 5. Winding the Coil

When this antenna was designed, an investigation of ac wire resistance was conducted in order to determine the impact of skin effect at frequencies of 1600 kHz and below. It was found that the point of diminishing returns was reached with AWG 16 wire. Beyond this point, increasing wire size produced very little decrease in ac resistance. Unfortunately, with the increased wire size, the problems of weight and coil fabrication become greatly magnified. In addition, there might be some slight effect on distributed capacitance which as yet has not been investigated. These problems become significant at low frequencies where the number of turns is relatively high and the winding pitch is small. For the designs described here, the use of AWG 22 solid or stranded wire has proven to be an adequate compromise. Ac resistance will be low enough to maintain an impressive circuit Q, and the final assembly will be light enough to be mechanically balanced without any problems. Generally, it is advisable to use uninsulated wire or magnet wire. The additional weight of the insulation can cause problems in mechanical balancing and makes it more difficult to electrically balance the primary. In addition, there may be some slight effect on the ac resistance due to dielectric losses.

The use of litz wire has often been recommended, and will make up to some extent for the use of smaller wire. Its cost and availability may well put it out of reach for most experimenters. If litz wire is used, electrical balancing will be difficult. The procedure described later is trial and error and requires several connections between various points on the coil and ground. Connections to litz wire require care to ensure all of the strands are soldered. It is recommended that a coil be wound first using bare wire, balanced, and rewound with litz breaking the litz for the balance position at the same point determined with the bare wire.

If the frame is to be painted, it should be done at this time before the coil is wound. Ensure there is no build up of paint in any of the wire notches. Allow at least 24 hours for all of the paint and glue to dry before attempting to wind the coil.

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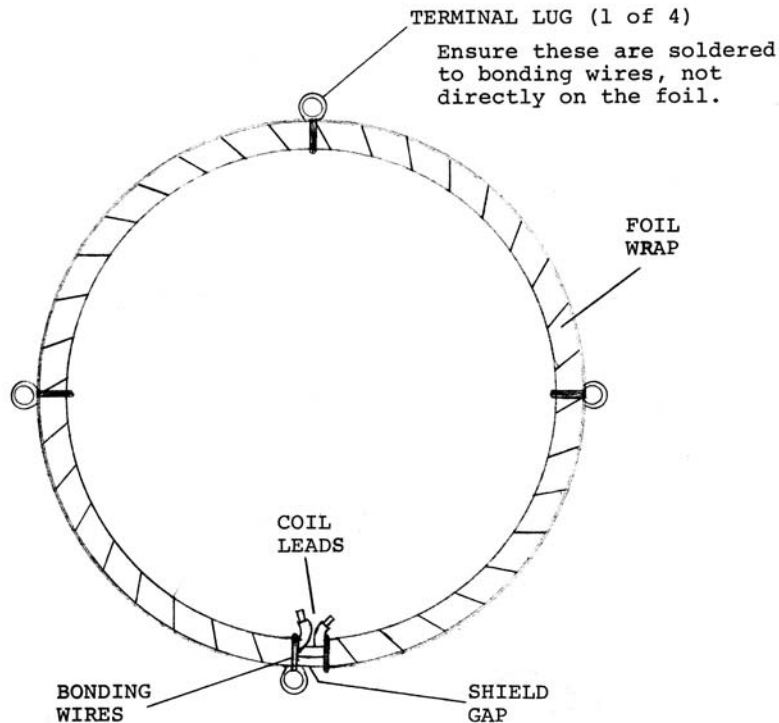
To wind the coils, mount the assembled cross frame in a vice or use C clamps to temporarily secure it to some reasonably stable object. The winding is accomplished most easily with the frame parallel to the floor and wire notches facing upwards. Each end of the coil is terminated on the same cross member end. Therefore, one more notch will be used on this end than on the remaining 3. Thus, if the coil is to have 30 turns, the inner terminal is on the 31st notch from the end. The inner most turn occupies the 30th turn on the remaining three cross member ends. It is advisable at this point to count the notches on each cross-member and label them so that each turn is wound correctly and all the notches are filled when the winding is complete. Locate two small finishing nails in the side of the end of the cross-member where each end of the coil will be terminated. One nail should be opposite the inner most notch where the winding is to start. The other nail should be on the opposite side next to the outermost notch. The nails serve as terminal points for the primary coil. The winding is made starting with the inner most turn and working outward. Solder one end of the wire to the inner nail and wind it across the notch on the cross-member.

When winding the coils, the idea is to keep the wire as straight as possible without putting undue stress on it. Too much stress can cause metal fatigue which will raise the wire resistance and possibly cause it to break. Loose wire will cause some turns to come close together, increasing the distributed capacitance gradient and limiting the amount of inductance which can be used in the circuit. Generally, a gentle tug as you lace each notch is quite sufficient to maintain the proper amount of wire tension. Use a pair of cloth work gloves when making the winding. This will be easier on the hands and help to smooth out the kinks or sharp bends in the wire. The last turn is terminated on the same cross-member end as the coil was started.

If you desire to have an unshielded secondary, it may be wound on the coil frame at this time. Use the same technique as was used for the primary. Secondaries should be 5 turns. Use the dimensions indicated in Figure 8 of Part 3. Since this antenna was first designed, an improved shielded secondary has been developed. This is the easiest coil to construct, because it eliminates the necessity to balance the primary coil. The shielded coil is recommended. A procedure for balancing the primary coil will be given later, if you decide to use the unshielded secondary.

A low impedance shielded pickup coil is shown in Figure 10.

It consists of three turns of wire approximately 7 1/2 inches in diameter. The coil is wrapped with 3/8 inch foil. There is a small gap in the foil shield where the two leads are brought out.



**Figure 10. Shielded Secondary Coil**

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This gap is important. If the circuit of the shield were complete, it would act as a shorted turn, and there would be very little induction in the coil.

AWG 14 solid copper wire is used for the coil. This provides the required strength to maintain a flat shape and low resistance. It is recommended that a six foot section of wire be used. Use a piece of common house wire. The outer cover should be stripped off and either the black or white insulated wire used to form the coil. The wire should be smooth with no significant kinks or bends. The coil should be preshaped on a cylinder having a slightly smaller diameter than the final coil size. The turns do not have to be positioned in the same plane as in the case of the primary coil. Since there are three turns, they should be arranged so that a cross sectional view would show them bedded down in a triangular form. In this way they will have maximum strength as a coil. Temporarily tape the turns together with several small pieces of electrical tape. Ensure each turn is the same diameter with no slack or air gaps between the turns. Bend the terminal ends inward and tape them closely together.

The material recommended for shielding is 3/8 inch lead foil tape with adhesive backing. This will hold the coil in a rigid form. Also, with care, it can be soldered. The tape is commonly used on window glass for security systems, and can be purchased in a variety of stores or through mail order outlets.

Begin wrapping the coil at one side of the coil ends. Keep the coil windings and tape as tight as possible, being careful not to break the tape. Each turn should overlap the previous turn about 1/16 inch. Remove each piece of electrical tape from the coil as it is reached in the wrapping process. Continue wrapping all the way around the coil until you come to the leads. Cut off the unused portion of the lead foil.

The gap in the shield should be just large enough for the two terminal ends to pass through, about 1/4 inch. In order to keep the ends of the lead foil from unraveling or shorting out, bonding wires will be soldered to the foil on each side of the gap. Tin two pieces of AWG 22 or 24 bare wire approximately 3 inches long. Wrap two or three turns of tinned wire around each end of the foil shield as close to the terminal leads as possible. Solder each bonding wire to its corresponding end of the lead foil shield. Use a low power soldering iron. Apply the iron to the bonding wire and not the foil. Allow the solder to flow on the foil. Too much heat will melt the foil causing it to separate from the wire. Some practice using a small piece of the unused foil is advisable prior to soldering the actual shield before trimming the excess wire from one of the bonding wires, wrap two turns of the excess around one of the coil leads. This will be the ground connection for the shield, one side of the secondary coil, and the receiver. Use a knife to trim away any excess foil in the gap between the bonding wires.

Three more bonding wires should be soldered to the shield at 90 degree intervals around the coil. Solder terminal lugs to each of these bonding wires and to one of the bonding wires at the gap. Solder a short jumper wire between one side of the gap and one of the coil leads. This lead should be connected to the ground side of the lead in to the receiver. Finally, attach the secondary coil assembly to the cross-members using small wood screws fastened through the terminal lugs.

### **6. Lead-in and Tuning Capacitors**

By now you should have completed the coil assembly windings including the high impedance primary which will resonate with a tuning capacitor and pick up the incoming signal

## *ELECTRICALLY SMALL RESONANT LOOP ANTENNA FOR MEDIUM WAVE*

and a non-resonating secondary coil used as the low impedance input to the receiver. In this section, we will construct the lead-in cable, offer some advice on capacitor selection, and make some preliminary tuning adjustments.

A twisted pair is used to connect the secondary coil to the receiver low impedance input. This is lighter and more flexible than coaxial cable. Used in moderate lengths, it will not contribute any significant loss or pick up any stray signals. A twisted pair can be fabricated from two pieces of AWG 22 stranded wire approximately six feet long. Attach one end of each wire to a vice or other secure clamping arrangement. Attach the two remaining ends to a drill chuck. With the two pieces of wire stretched out, operate the drill until there are 3 to 4 twists per inch in the wires. Disconnect the wire and strip the ends. Attach whatever connectors are required by your receiver to one end of the twisted pair. Drill a small hole through the handle frame mounting plate near the cross member having the secondary coil terminations and about midway between each termination. Pass the twisted pair through the hole from the rear and solder the leads to the ends of the secondary coil. The ground lead from the receiver should be attached to the shield end of the shielded secondary. If an unshielded secondary is being used, identify which end of this coil will ultimately be connected to receiver ground.

The capacitor used to resonate the primary coil is important, because it determines the range over which the antenna will operate. Choice of a variable capacitor will depend on what you have available or what you may be able to buy. It will be almost impossible to locate a single-section capacitor which will neatly cover the entire broad-cast band. The coils described here have a very high LIC ratio, and the maximum amount of capacitance will be less than 150 picofarads for the two foot loop. At the same time, the coils must operate very close to their self-resonant frequencies. To do this, the minimum amount of variable capacitance must be quite low, typically 4 to 5 picofarads. It is seldom possible to find a variable capacitor which meets these requirements. Single-section variables having a low value of 4 to 5 picofarads typically have a maximum value of 50 to 55 picofarads. Padding capacitors can be switched into the circuit to increase the range, but often this must be done in two additional steps.

The most practical capacitor match for the two foot loop described here turns out to be a standard 2-gang capacitor used in AM radios. These have nominal ranges of 7-140 and 10-365 picofarads. By simply connecting the sections in series, the maximum capacitance is reduced to 4 picofarads. To extend the range down to 530 kHz, a switch is connected across the 10-365 picofarad section leaving only the 7-140 picofarad section in the circuit. If this does not provide quite enough capacitance, connect the switch across the 140 picofarad section, and add a trimmer capacitor having about 250-300 picofarads in series with the 365 picofarad section. The trimmer is adjusted to resonate the antenna at 530 kHz with the 365 picofarad section in the circuit and fully closed. This will spread out the low range of the antenna.

A tuning capacitor having two 365 picofarad sections can often be used with good results. In this case a trimmer of about 25 picofarads is required in the high range with both variable sections connected in series. In the low range, the trimmer is shorted out with the range switch. When connecting the sections of the variable capacitor in series, the metal frame is used as the common electrode. One end of the coil is connected to one set of stators and the other end of the coil is connected to the other set of stators. No connection is made to the frame or ground connection. Since the frame is actually floating, there will be less body influence and greater stability when the capacitor is operated.

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Locate the tuning capacitor about mid-way between the primary terminals on the cross member. The knob should face away from the coil side of the frame. Attach the leads between the capacitor and each end of the primary coil. Dress each lead along the frame away from the coil. If the leads are positioned too close to the coil, an appreciable amount of distributed capacitance will develop.

Without knowing the exact amount of capacitance being used, it is difficult to describe the electrical trimming procedure which must now be made. In general, what you are trying to do is to get the LIC ratio as high as possible. Both the two foot and three foot loops should resonate at 1600 and 800 kHz respectively with the number of turns specified in Part 3. It may be necessary to remove one or two turns in order to get the coil to resonate with the capacitor you have chosen. If it is necessary to remove more turns than this, you will be affecting the effective height of the antenna and you should locate another variable capacitor or examine the coil winding to ensure all the turns are tight and evenly spaced.

The coil assembly cannot be balanced and mounted to the stand until all items are mounted. For this test, it should be positioned close to the receiver, but several inches away from any metal objects which could affect the distributed capacitance of the coil. Connect the lead in to the receiver observing proper polarity. Turn on the receiver and tune to the high end of the broadcast band. Determine the upper range of the antenna by alternately tuning the receiver and tuning capacitor on the antenna until you are able to resonate a station with the antenna capacitor fully opened. If the antenna is capable of tuning beyond 1610 kHz, begin adding turns to the inside of the primary coil until the maximum resonant frequency is brought down to around 1610. If the maximum resonant frequency is below 1600 kHz, and you are using a single gang capacitor or a series-connected 2-gang capacitor, you need to add a series trimmer. This will likely be in the range of 25 picofarads.

Next, determine how low this capacitor arrangement will tune. Most likely, it will not tune the entire broadcast band. If you are using a series-connected, 2-gang arrangement, temporarily short out one section of the capacitor and try to retune the receiver and antenna to 530 kHz. You may be able to add another series trimmer having a range of 250 to 300 picofarads. This should just tune 530 kHz with the variable capacitor fully closed. Your own unique circumstances will determine whether or not you need trimmers on the high or low ranges.

Make sure that the entire broadcast band can be tuned for the two foot loop. Sometimes in trimming the high and low end, the middle frequencies will not resonate, and you will have to try another approach.

Selecting and trimming a variable capacitor for the three foot loop will be similar, except less total capacitance will be required. This loop is designed to improve performance at the low end of the band where more inductance can be used to give greater effective height. As specified in Part 3, it will resonate around 800 kHz. If a higher resonant frequency is desired, several turns can be removed from the inside of the coil. Maximum amount of capacitance required will depend on the range you select.

Electrical balancing of the loop antenna is essential to null operation of the circuit. If a shielded secondary is being used, the foil shield described in Part 4 fills this purpose. In theory, a null from a ground wave should occur in two azimuth positions 180 degrees apart. In practice, most installations have a significant amount of metal in the area to cause anomalies in the electromagnetic field. This can cause erroneous heading errors, even in a perfectly balanced

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antenna. Since you are concerned more with obtaining the best possible nulls without regard to direction finding accuracy, we will not cover the complex techniques required for null error compensation.

The following procedure must be performed if you are using an unshielded secondary coil. A special technique is used to find the electrical center or balance point of the primary coil which must be connected to ground. If the antenna were a solenoid instead of a flat pancake, we could simply depend on the symmetry of the coil winding, locate the balance point on the center turn of the coil, and expect to be close to the perfect balance. The case of the pancake loop is not that simple. Each succeeding turn moving in an outward direction is larger and presents more capacitance to ground. Therefore, the balance point is not on the center turn, but rather on a turn located more toward the outside of the coil. During design of this antenna an effort was made to find the linear center of the wire and to locate the balance point there. This did not always work. The best approach, regardless of the type of coil winding is to observe the amount of capacitance added to the circuit as the balance wire is relocated to different points of the coil. A coil with the balance wire connected off center will exhibit noticeable increase in distributed capacitance. The variable capacitor will have to be opened slightly to peak the same frequency. To balance the antenna, select a station near the high end of the antenna range. This is the point where the least amount of capacitance is required and any change caused by relocation of the balance wire will have the most effect. For this operation the variable capacitor should be fitted with a temporary dial so differences in capacitance can be noted. First, note the position of the capacitor with no balance wire. Next connect a jumper or balance wire between the ground side of the secondary coil and a point on the primary coil near its center. Repeak the capacitor. The peak position will be higher on the dial indicating some distributed capacitance has been added to the circuit and less variable capacitance is needed to resonate the same frequency. As the balance wire is brought outward on each succeeding turn and the variable capacitor is re-peaked, less distributed capacitance is introduced and more variable capacitance must be added. When the antenna is balanced, the variable capacitor will be at or near the same position it was with the balance wire disconnected. Moving the balance wire further outward will cause distributed capacitance to increase again. It might be possible to note differences in distributed capacitance as the balance wire is moved around the same turn. The balance wire should be tested in several different positions around the turn until the maximum value of the variable capacitor is reached. The balance wire should be cut to minimum length and soldered to the coil at the nearest cross member. To ensure additional distributed capacitance is not introduced by the balance wire, dress the wire along the side of the cross member opposite the coil.

This completes electrical assembly and testing of the coils.

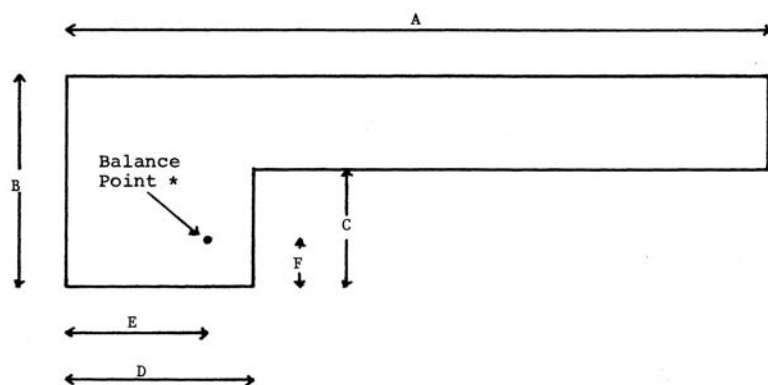
### **7. Handle Construction, Final Assembly, and Mechanical Balancing**

You have now completed all of the electrical work on the antenna in addition to a completed tripod or stand, you should have a coil assembly which is tuned to cover the entire broadcast band, or, in the case of the three foot model, the lower portion of the band from about 800 kHz down to 530 kHz. Those of you who chose to use an unshielded secondary loop should have electrically balanced the primary coil as was described in Part 5. This will give the extremely deep nulls characteristic of a loop antenna. For antennas using shielded secondaries, balancing the primary is not necessary. The shield serves this purpose.



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One interesting note on electrical balancing is that slight variations from perfect balancing cause one response lobe of the antenna to become larger than the other one. This results in increased sensitivity and sharper peak in one direction. Also, the nulls are no longer precisely 180 degrees apart in the ideal pattern -the angle formed by the nulls on either side of the larger lobe being greater than 180 degrees. This phenomenon could prove useful in tuning different pairs of stations on the same frequency, where the null positions are now at different headings than they were with the ideal response pattern.



DIMENSION	2-ft LOOP WITH SIDE BRACES	3-ft LOOP WITHOUT SIDE BRACES
A	24	26.5
B	5.5	5.5
C	3	2.5
D	5	6.25
E*	2.875	3.5
F*	1.625	1.5

\* Initial location of finishing nails used to determine balance point. Refer to text.

All dimensions are in inches. These are actual dimensions of prototype models. Sizes will vary slightly due to variations in loop construction.

**Figure 11. Loop Handle Dimensions**

The handle is mounted to the handle-frame mounting plate on the coil assembly using two wood screws. Ensure the handle forms a right angle with the coil frame. Do not use any glue on this joint. It may be necessary to raise or lower the position of the handle in order to balance the assembly, and this joint serves as a logical disassembly point for transport or storage of the antenna.

Refer to the illustrations contained in Part 2 during the balancing procedure. To mechanically balance the antenna, install the universal fork, previously constructed, on top of the tripod.

Locate a finishing nail in each side of the lower portion of the handle in the approximate position shown in Figure 12. Place the fully assembled coil assembly on top of the universal fork so that each finishing nail rests on the end of its corresponding prong on the universal fork. Proper balance is achieved when you can reposition the coil to any pitch position and have it remain in place without tilting upward, downward, or settling somewhere in between. This requires alternately locating the finishing nails and retesting the balance. When testing the

Figure 11 shows the general plan for the handle. The pieces should be fabricated from 1 inch (nominal 3/4 inch) wood stock. The handle can be cut from a single piece of wood or assembled from several small pieces. Due to variations in assembly and construction techniques, it is recognized that some of your coil assemblies may require slightly more or slightly less weight in the handle. The handle is used as a counterbalance for the coil, so the entire assembly will retain whatever pitch is required. Use the specifications of Figure 11 as a starting point. The handle can always be cut down or weight added near the end during the balance procedure which follows.

The handle is mounted to the handle-frame mounting plate on the coil assembly using two wood

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balance, allow the assembly to seek its natural position of unbalance and move the nails straight down slightly.

When the perfect balance point has been determined and before drilling the hole, ensure that the back corner of the lower handle will pass through the fork when the coil is rotated to its horizontal position. See Figure 5, where the coil is shown adjusted for reception of a 90 degree sky wave. Be sure to allow for the fact that the nails are resting on top of the fork and not in the bolt holes which will be about 1/2 inch lower. If the lower corner of the handle will not clear the center of the fork or the coil cannot be adjusted through a complete 90 degree arc from vertical to horizontal, it will be necessary to remount the coil assembly higher or lower on the handle. This will have a corresponding effect on the location of the balance point, and a new balance point will have to be located as described above.

When you are certain that the balance point is correct and the antenna can be adjusted throughout its pitch range, note the last position of the finishing nails, remove the nails, and drill a small hole

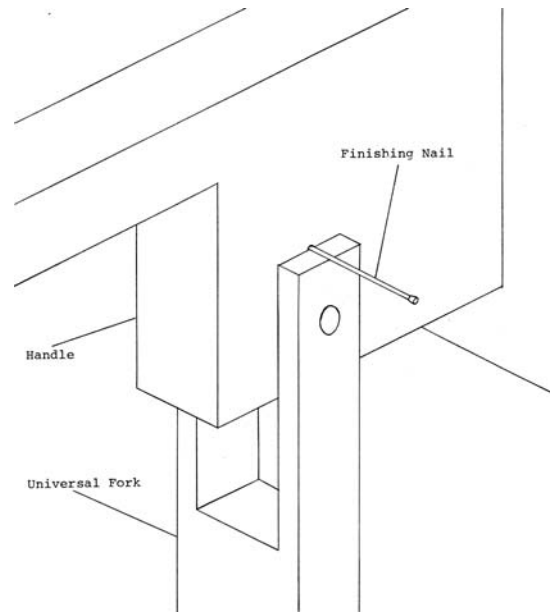
squarely through the handle at this point. Obtain a suitable stove bolt, three matching flat washers, one lock washer, and a wing nut. Assemble the universal fork with this hardware using the lock washer next to the bolt head, one flat washer on each side of the handle and the remaining flat washer between the other prong of the fork and the wing nut.

Mount the completed coil assembly on the tripod. The coil assembly should operate smoothly throughout a 360 degree azimuth and a minimum 90 degree pitch. If the hole in the universal fork which mates with the mounting pin in the tripod is too large, there will be play in the pitch adjustment. If this is a problem, you will probably have to construct a new universal fork. If the hole is too small there will be some backlash in the azimuth adjustment. Carefully ream out the hole and lubricate it with parafin. The pitch tension can be controlled with the wing nut. This should be adjusted so that the amount of force required to change the pitch is about the same as that used to adjust the azimuth.

Well, you made it. Congratulations: The construction of your antenna is now complete. In order to get the most out of this device, you should know how to operate it.

### 8. Operation

Two adjustments must be made to the loop antenna each time a different station is tuned. The capacitor must be tuned to the point of circuit resonance and the coil must be directed to either the point of peak or null signal. This sounds simple enough. However, just like playing a musical instrument, some skill is involved in 'playing' the loop. This requires a working knowledge of linear polarization of radio waves and the response of the loop, an analysis of band conditions and relative signal levels, and a good deal of practice and experience.



**Figure 12. Arrangement for Balancing the Coil Assembly**

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Basically, the loop can be used to peak the signal strength of the desired station, or null a source of interference, either on the same frequency or on a different frequency. Local noise can also be eliminated or significantly reduced by orientation of the loop counter to the direction of the noise field. A review of linear polarization and the response of loop antennas is recommended at this point. It will be assumed that the reader is familiar with the orthogonal arrangement of electric field, magnetic field and direction of wave travel; also that the response pattern of the is well understood. It is also assumed for this discussion all transmitted signals are vertically polarized. All reference to vertical wave components refer to either night effect or anomalies caused by nearby reflecting or distorting influences such as metal receiver cabinet, household wiring, venetian blinds, aluminum siding, etc.

A properly designed and constructed loop intended for maximum sensitivity will have a very high LIC ratio and Q. Slight changes in orientation of the coil or adjustment of the variable capacitor will affect resonant frequency to which the circuit is tuned. Often aof 2 or 3 picofarads will detune the loop out of the intended signal. For this reason, the orientation of the capacitor should be alternately adjusted and the results receiver S-meter. Generally, start by adjusting the capacitor to the approximate resonant frequency, next orient the coil in the general direction of peak or null response. Retune the variable capacitor to peak the signal in this direction, Finally, direct the loop to the precise null or peak angle.

The purpose in adjusting for null is a) to tune a station on the same frequency as another which is dominant, b) to eliminate interference from a station on the same frequency or an adjacent frequency, or c) to eliminate noise.

The ability to tune two signals on the same frequency with little or no mutual interference is a unique characteristic of the loop antenna. It virtually doubles the number of stations audible at any given time. Generally, one station will be dominant on each frequency. Rarely will the two stations be at precisely 90 degree heading differences. This means, with the dominant station nulled, the weaker station, although it is being received quite clearly, may not be near the maximum response lobe of the antenna. The broad peak response characteristics of the antenna will generally provide adequate reception.

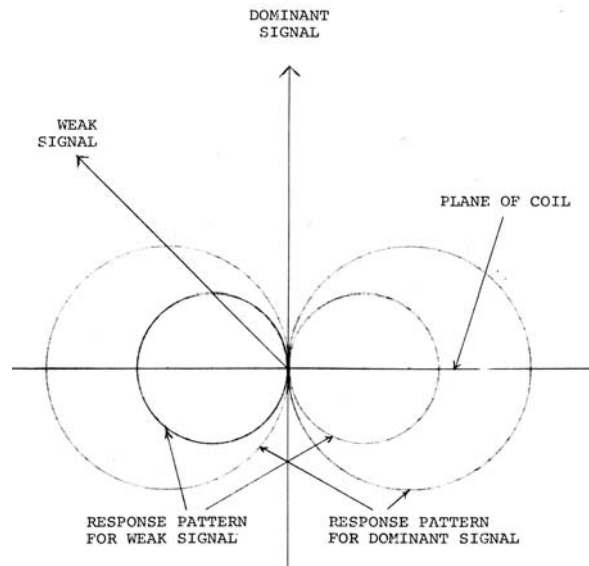
There will be two nulls at 180 degree intervals. With most broadcast stations having continuously changing modulation, it is generally difficult to tune to a null by ear alone. Observe the indication on the S-meter and watch for a complete drop in the carrier. The response with an ideal antenna will provide alternate and nulls at 90 degree intervals. the peak response is so the peak is often found by first locating a null direction rotating the coil one way or the other 90 degrees.

Adjacent signal interference from local stations may be eliminated by first adjusting the to the null position for the interfering local station, retuning receiver to the desired adjacent frequency, and re-peaking the loop capacitor to the desired frequency. It should be noted that even though receiver selectivity may permit elimination of carrier interference, only a loop can suppress sideband interference which may extend up to or even past the carrier frequency of the desired signal. In the case of extremely powerful or close interfering signals, the loop may mean the difference between receiving an adjacent signal or not receiving one. A slight reorientation of the antenna may result in significant interference, so that it is only possible to receive one signal on the adjacent frequency, whereas the strong local can be completely nulled and another signal received on its frequency.

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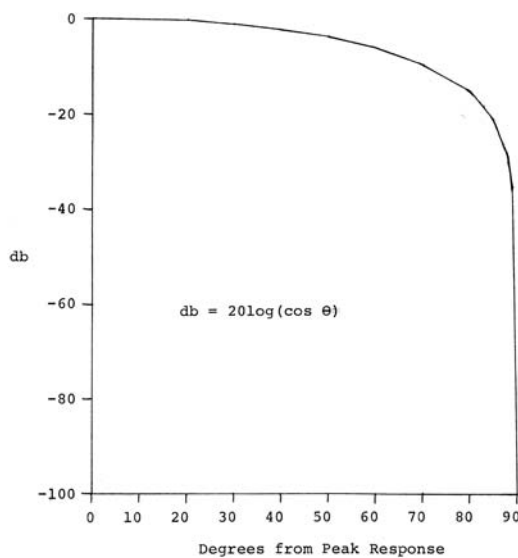
In the case of noise, the loop is simply adjusted for null noise response. Whatever signals lie within the antenna's response lobes in this direction will be received with reduced or eliminated noise.

Figure 13 shows how the null feature of the loop can be used to receive a weak signal on the same frequency as a strong signal. Assume that the dominant signal lies due north of the receiver. A signal approximately half as strong is situated toward the northwest. The antenna is adjusted so that one of the null positions is aligned to the north. The plane of the coil is aligned in an east-west direction and peak response of the antenna is towards either the east or west. The larger circles represent the ideal polar response pattern of the loop for the dominant signal and the smaller circles represent the pattern for the weaker signal. In the north direction, there is no response. The strong signal is not received. In the northwest direction response is not peak but is significant. The response is equal to  $E \cos \theta$ , where  $E$  is the peak voltage. In this case the station is 45 degrees from response, so  $\cos 45$  degrees 0.707. For the dominant  $r \cos 90$  degrees equals zero.



**Figure 13. Polar Response Pattern Used to Null a Signal**

With the dominant signal completely nulled, the weaker signal will be attenuated 3 db from its peak. It can be seen from the figure that the antenna can be operated quite close to the null position before there is significant reduction in signal level. For example, at 6 degrees from null, there is only a 20 db drop in signal level. Figure 14 shows Signal response as a function of antenna angle.



**Figure 14. Normal Loop Response as a Function of Angle**

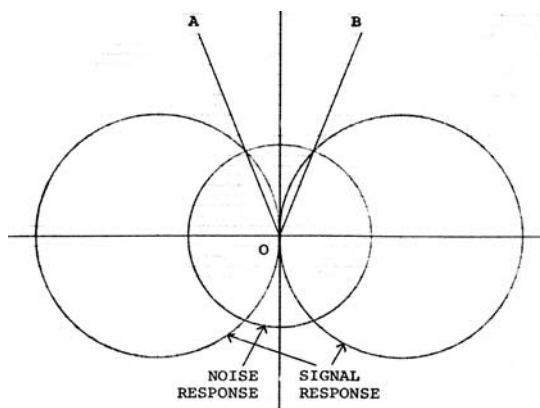
The existence of any large metal object in the vicinity of the coil will cause signals to be reflected or the electromagnetic field to become distorted. This will often result in the electric field not being perfectly vertical. The same effect occurs at night when the signal arriving at the antenna has been reflected off the ionosphere. In either case, the null points are no longer tuned with the plane of the coil oriented vertically. The pitch of the coil must be changed, sometimes by nearly 90 degrees in order to achieve a null. Nulls are located by rotation of the coil in the azimuth until a dip is indicated on the S-meter. The pitch of the loop is then adjusted until further reduction in the signal strength is indicated. If the reduction comes as a result of a downward pitch (mechanically limited movement), the azimuth should be adjusted 180 degrees to the other null position and

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the pitch adjusted upward until the null is found. It may be necessary to alternately adjust the pitch and azimuth until the precise null is located.

The inability of the loop to completely null a station may be caused by anyone of several conditions. Stations at intermediate distances can have both sky wave and ground wave signals arriving at the reception site at the same time. This creates the same effect as two separate signals arriving at the antenna. It will be possible to null one or the other, but not both.

Perhaps the most common complaint is the inability to null strong local signals. This is due primarily to the extremely high signal to noise ratios. The angle of rotation through which the complete null may be observed is a function of the signal to noise ratio. The angle becomes smaller as the signal/noise ratio increases. Even a slight rotation of 1 degree or less can result in a significant signal level. An antenna which produces easily defined complete nulls on 50 kW stations 5 miles away is more insensitive than directive. It will take a significant signal strength in order to receive a second station on the same frequency. The polar diagram of Figure 15 illustrates how the null



**Figure 15. Null Response as a Function of System Sensitivity**

response of a loop antenna is dependent on the signal to noise ratio of the system. The two circles tangent to the 0/180 degree line represent the ideal response pattern of the loop. Peak response is along the 90/270 degree line and nulls along the 0/180 degree line. The center circle represents the non-directional response pattern of background field noise and receiver noise. The angle AOB represents the amount of antenna rotation in which the noise level exceeds that of the signal. As the signal-to-noise ratio is improved, this angle becomes smaller. Ideally, a sensitive antenna will have an infinitesimally small angle in which a complete null is observed.

Quite often, when the precise null point is reached on a strong local station, the carrier will all but disappear, but strong, distorted modulation will remain. This has been attributed to a wave scattering effect caused by nearby reflecting surfaces and structures.

Adding to the difficulty in finding a null position is that of maintaining it. The direction of the incoming wave changes with variations in propagation conditions, particularly with sky waves. Deviations of 20 or 30 degrees can occur within a few seconds during turbulent evenings.

This completes the description of the high-performance loop. I have tried to stress the important factors without being too restrictive in what materials you had to use. In some cases, precise dimensions depended on your unique requirements, as in the case of the loop handle where final mechanical balancing procedures could not take into account all of the possible construction variations which could have occurred. All of these variations aside, operation and performance of your finished antenna should be 'as advertised' as they say.

## **9. Some Tips on Using Your Loop**

### *Precautions*

The primary coil of your loop is made from AWG 22 stranded copper wire. This will stretch and become loose if subjected to moderate and repeated contact with hands, furniture, etc. This will cause the turns to sag and probably come in close proximity with each other. The result will be poor performance and could cause the tuning of high frequency stations to become impeded. The coil can be pulled tight, but this is something of a delicate operation. As the saying goes, an ounce of prevention is worth a pound of cure. By avoiding any unnecessary contact with the coil, it will retain its shape indefinitely.

### *Tuning Ranges*

The primary circuit of your loop has been designed to have the highest possible L/C ratio. This means that the coil is electrically as large as possible and the amount of capacitance used to resonate the tuned circuit is small. This arrangement gives the loop the greatest sensitivity and selectivity possible. In order to minimize the amount of capacitance, two sections of the tuning capacitor have been connected in series. The metal frame acts as the common side of each capacitor and 'floats.' Neither one section by itself nor the two sections in series have enough range to cover the entire broadcast band, so a switch has been installed to provide an upper (switch up) and lower (switch down) band. There is an overlap roughly between 1250 and 1450 kHz. In addition to minimizing the total circuit capacitance, this arrangement gives you greater bandwidth than would normally be possible with a single capacitor. This is especially helpful at the upper end of the band where signals normally tend to be bunched together in a logarithmic fashion.

### *Universal Fork*

The coil assembly rotates 360 degrees horizontally and at least 90 degrees vertically. This allows you to tune at least one of the two normal null positions for any incoming signal. In order for the loop to remain in the position you set it, the coil assembly has been carefully balanced. It is important that nothing be added or deleted from the coil assembly, otherwise the balance will be compromised and the loop will tend to pitch full up, full down, or settle some place in between. The universal fork permits rotation in the azimuth as well as pitch. The tension on the handle can be adjusted by alternately tightening or loosening the nut on the universal fork bolt. Normally this should be set so that the coil assembly will move freely up or down without continuing to drift after you take your hand off the handle. If there is too much tension, the coil assembly will exhibit some backlash, or tendency to move back slightly in the direction from which it came. Although this may sound somewhat critical, the nulls from many stations will only be achieved within a few degrees, and it will be important to keep the pitch adjusted for smooth operation. There is no tension adjustment for azimuth. Azimuth is changed by turning the coil assembly on the 1/4 inch steel pin on the center post on the tripod. The hole in the universal fork has been made long and snug, so there will be no play in the coil assembly as it is turned. The tripod should be kept on a level surface so the center pin is as vertical as possible, otherwise the coil assembly may tend to drift in the azimuth.

The universal fork should be lubricated with candle wax periodically. This includes the contact surfaces in the center post hole and the bolt through the handle. Remove the handle bolt

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and lubricate each flat washer between either side of the handle and the prongs of the fork. Also lubricate the 1/4 inch steel pin in the tripod and operate the fork on the pin several times to ensure the wax is well distributed inside the hole. Do not use petroleum lubricants as these will just be absorbed by the wooden fork. When lubrication is complete, reassemble the parts and adjust the tension on the bolt.

### *Body Capacitance*

When operating the loop, particularly at high frequencies, you will notice that bringing your hand into close proximity to the coil will tend to detune the loop. This is the one disadvantage of the high L/C ratio. The circuit is very susceptible to small changes in capacitance. When tuning the antenna, you should turn the capacitor toward you and adjust the capacitor for peak response, then turn the coil assembly in the direction of peak or null. If you have to reach around the coil, chances are your arm will tend to detune the coil, and you will notice some fall-off in the signal strength. Avoid contact with the metal capacitor frame. This will also detune the circuit. The capacitor has been fitted with a plastic or wooden tuning knob, and operates smoothly enough to peak the circuit without having to brace your hand against anything else.

### *Silence Is Golden*

What you don't hear using this antenna is just as important as what you do hear. It is highly selective, allowing only those signals close to its point of resonance to pass on to the receiver. This virtually eliminates harmonics and images which would normally be produced by the receiver if it were connected to a long wire. For this reason, you should keep the loop close in tune with the receiver whenever you are 'scanning' the band, particularly during daylight hours when the power on any particular frequency is minimal. Normally, only the strongest local stations not in tune with the loop will get through to the receiver.