LOOP ANTENNAS

DESIGN & THEORY

This reference book is a compilation of articles and reprints that have been printed in DX news over the years past concerning the theories and operations of the Loop antenna.

If you have ever used a loop and wanted to know more about it or if you've been kicking around the idea of designing your own, then this book is for you.

It is recommended that you also have the NRC ANTENNA REFERENCE MANUALS Volumes 1 and 2, with all three booklets, you will have all the pieces necessary concerning the Loop antenna. This booklet does not contain any of the material found in Volumes 1 or 2 of the NRC ANTENNA REFERENCE MANUALS.

CONTENTS:

2

LOOP ANTENNAS, THEORY AND PRACTICE

Dallas Lankford

The purpose of this article is to survey the literature on loops and to develop some general guidelines for those who desire to "roll their own." Our discussion is limited to loops for use in the BCB (0.54-1.6 mhz), but many of the formulas and principles also apply to lower and higher frequencies.

We will consider two kinds of loop antennas, air core loops and loops wound on ferrite rods. For air core loops,

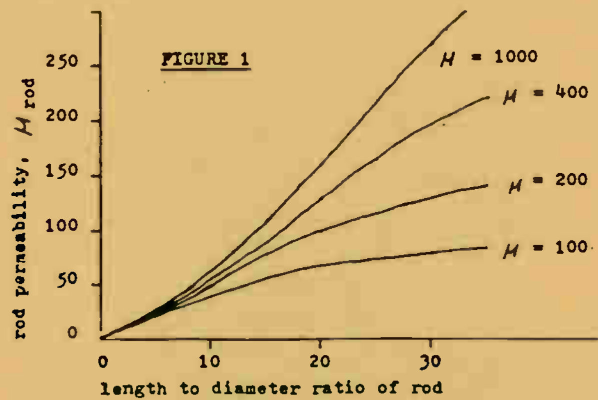
$$V(\text{loop}) = \frac{2\pi AN}{\lambda} V \qquad (1)$$

where V(loop) is the voltage induced in the loop by a passing electromagnetic wave of electric field intensity V in volts per meter, A is the area in meters of one turn of the loop, N is the number of turns, and λ is the wavelength in meters. For ferrite rod loops,

$$V(\text{loop}) = \frac{2\pi AN}{\lambda} \mu_{rod} V \qquad (2)$$

where μ_{rod} is the permeability of the rod.

The permeability of a ferrite rod depends upon the permeability μ of the ferrite material from which it is made and the physical dimensions of the rod. For solid rods this relation is shown in Figure 1.



Ferrite rods come in a wide variety of sizes and permeabilities. For example, the Space Magnets (SM-1 and SM-2) have a length to diameter ratio of about 20 and a permeability of about 400, so they have a rod permeability of about 130. Amidon Associates offer a ferrite rod with length 7.5 inches and diameter 0.5 inches with permeability 125, so the length to diameter ratio is 15 and the rod permeability is about 60. The permeability of 125 is typical for most ferrite rods for use in the BCB, especially those commonly found in transistor portables.

Perhaps the most useful measure of loop performance is sensitivity. When a loop is tuned to resonance by a capacitor in parallel with the coil, the output voltage is given by

$$V(out) = QV(loop) \qquad (3)$$

where Q is the quality factor of the coil. The thermal noise voltage produced by the loop is

$$V(noise) = \sqrt{4kTRb} \qquad (4)$$

where k is Boltzman's constant (= 1.37E-23, where E±n is 10 to the ±n power), T is the temperature in degrees Kelvin (nominal room temperature is usually taken as 288), R is the resistive component of input impedance, and b is the effective bandwidth in Hertz as seen by the detector. Since R satisfies

$$R = 2\pi fQL \qquad (5)$$

where f is the resonant frequency in Hertz and L is the inductance in Henrys, from equations (1) - (5) we can calculate the sensitivity in volts per meter for a 10 db (S + N)/N ratio as follows. Starting with

$$10 = 20 \log_{10}\left(\frac{V(out) + V(noise)}{V(noise)}\right) \qquad (6)$$

we solve for V of equation (1) and find

$$V = \frac{1.09E\text{-}10\,\lambda\sqrt{fLb}}{AN\sqrt{Q}} \qquad (7)$$

for air core loops, and

$$V = \frac{1.09E\text{-}10\,\lambda\sqrt{fLb}}{AN\mu_{rod}\sqrt{Q}} \qquad (8)$$

for ferrite rod loops. Taking b = 2.1 khz, L = 300 microHenrys, and Q = 200, 190, and 180 respectively for the 4' and 2' air core loops and the 12" ferrite rod loop, at 1.54 mhz the sensitivities of the three loops are 0.085, 0.17, and 0.44 microvolts per meter respectively.

The measured sensitivity of the SM-1/SM-2, 3 microvolts per meter, is sufficiently higher to require a brief discussion of the discrepancy between the calculated and measured sensitivities. First of all, the Space Magnets are shielded so that the voltage induced in the loop by a passing electromagnet wave is half the value given by equation (1) (according to comments in the N.R.C. Antenna Reference Manual*). A recalculation of sensitivity gives 0.88 microvolts per meter. Next, we assumed a bandwidth of 2.1 khz as seen by the detector (a reasonable assumption if the loop feeds a good narrow bandwidth receiver such as the HQ180A or

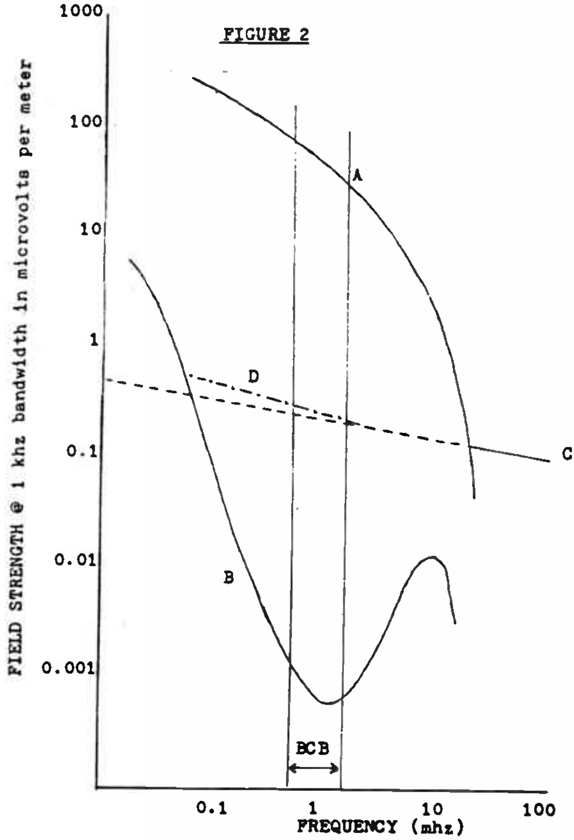
*Vol. ONE

R390A). However, if the bandwidth of the loop alone is used for sensitivity calculations, then taking a Q of 180 at 1.54 mhz we get 1.78 microvolts per meter. We are not certain of the remaining discrepancies between calculated and measured sensitivities, but it may be a combination of inaccuracies in the formulas we have used (which after all are approximations), calibration errors in the test equipmant, and losses as a result of the link coupling used in the Space Magnets.

At this point it is appropriate to ask how sensitive a loop should be for state of the art BCB performance. Recent articles by Hutton [1979] and Lankford [1979] discuss noise levels and usable receiver sensitivity, and both are good supplements to our discussion here. As pointed out by Hutton [1979], there is considerable disagreement in the literature as to the minimum noise levels which can be expected in the BCB. In my article on galactic (cosmic) and atmospheric noise I assumed that galactic noise would be the limiting source. However, after subsequent extensive discussions with Chuck, I have modified my view as follows. The CCIR Report [1963] indicates that while cosmic noise is sometimes present in the amounts indicated, at other times ionospheric shielding does take place. So the values of cosmic noise given by the CCIR Report are sometimes (often?) higher than will be experienced in practice. However, even when present at its maximum level, cosmic noise is usually below man-made noise and far below atmospheric (static) noise. The CCIR Report gives values of man-made noise in a quiet location which are about the same as the (maximum) cosmic noise values, so it would seem that the figures of minimum noise stated in my previous article are about right. But again Hutton [1979] has pointed out that there is also considerable disagreement on levels of man-made noise. To add to the confusion, we have converted the CCIR noise figures to field strength (both by their given formula and their nomogram) and obtained still other values. As Chuck said in his article, minimum noise figures depend upon who you choose to believe. For this article, we choose 0.3 microvolts at 0.54 mhz and 0.2 microvolts per meter at 1.6 khz, which were obtained by extending the galactic (cosmic) noise levels from Figure 5 of Cottony and Johler [1952]. These values are our best guess as to minimum values of cosmic/man-made noise in the BCB, see Figure 2.

Based on these figures and estimating an actual seneitivity of 0.4 microvolts for the 4' AA loop, it follows that the SM-1/SM-2 leaves some room for improvement. On exceptionally quiet nights it seems likely that the SM-1/SM-2 would miss some very weak DX which the 4' AA loop would catch. However, those instances are rare, and for most DXers, especially those in urban areas who experience higher man-made noise levels, there would almost certainly be no noticable difference between the two loops' DX catching ability. Also based on these figures, we would guess that on very quiet nights a 100' long wire antenna might occasionally outperform the 4' AA loop. But that, too, would occur at most a few nights a year.

The hypothetical comparisons above are at best educated guesses and at worst may be significantly inaccurate. Listening with my HQ180A at a quiet location near Hainesville, Texas confirms that a 1200 foot beverage sometimes outperforms my home-brew



A--upper limit of atmospheric noise

B--lower limit of atmospheric noise

C--upper limit of cosmic noise

D--man-made noise at a quiet location

amplified loop (the front end of a Realistic TRF). A few weak signals were readable on the beverage, but inaudible (in some cases not even a het w/BFO) on the loop. Moreover, I almost never hear man-made noise on the loop, while man-made noise is about S3-S6 on the beverage. Still, the loop has been my primary antenna for the last three years, and has given very respectable results. Also, the loop is small, portable, does not require acres of land, and can be used to null local noise sources and QRM. However, claims that a loop, ferrite or otherwise, does not respond to noise are just not true. The fact is that smaller loops are often not sensitive enough to hear background noise (except in a noisy location or on nights of high static levels).

The sensitivity calculations above were done near the top of the BCB because noise levels tend to increase as frequency decreases while loop sensitivity tends to decrease (get better) as frequency decreases. Let us illustrate this point with a calculation of the sensitivity of the (hypothetical) 4' AA loop at 540 khz. In equation (7), everything is constant, except λ, f, and Q. The N.R.C. Antenna Reference Manual* states a Q of about 500 near 540 khz for the 4' AA loop. But if that Q is used, the 6 db bandwidth will be narrowed to 1.08 khz, too narrow for many listening situations. So let us assume a Q of 257 which gives a 2.1 khz bandwidth. By simple ratios, we find that the sensitivity at 540 khz is 0.057 microvolts per meter.

If an air core loop is the loop of your choice, the N.R.C. Antenna Reference Manual* is the reference you need. There you will find detailed plans for both the 4' AA loop and 2' AA loop I should add, though, that Hammarlund users will not be able to take advantage of all the nulling capacity of these loops since all Hammarlund receivers (that I have used) exhibit some pickup of powerful locals with no antenna connected. I don't know who the RF pollution is coming from but I suspect a combination of perforated cabinet, antenna binding posts, and pickup via the power cord. Dick Truax has told me that disconnecting the antenna binding terminals on the HQ180(A) (and using only the coax socket) helps, but there is still some RF pollution. However, since most DXing is done at night when most QRM is sky wave, you will seldome be able to get more than about nulls anyway. So, in my opinion, it is hardly worth the effort to build a large air core loop, especially if you do not live near powerful locals.

The easiest way to get a good ferrite rod loop antenna is to purchase one from Worcester Electronics Laboratory, R.D. 1, Frankfort, N.Y. 13340. The SM-2 is by far the most popular ferrite rod loop used by NA BCB listeners. Write for the current price. If you want to build your own, the Worcester Lab also used to sell a 12" ferrite rod with 400 permeability and 20 length to diameter ratio for about $5. I bought 4 of these rods several years ago and have rolled a number of loops with them. Amidon Associates, 12033 Otsego St., No. Hollywood, Calif. 91607 also sells a ferrite rod, 7.5" long, 0.5" diameter, permeability 125, part no. R61-050-750. A loop wound on their rod will not be as sensitive as the 12" rod, but as I have said

* Vol. One

before, my 7.5" TRF rod is no slouch. In addition, J. W. Miller sells several ferrite rod loops which would be suitable. From personal listening experience, I can tell you that there is just not much difference in signal catching ability between these various rods. For example, in the spring of 1977 I was listening to PORTUGAL 665 on my TRF loop in Austin, Texas when I decided to roll up an unamplified loop on a 5.5" rod. With the unamplified loop, PORTUGAL dropped from S-8 to about S-3, but was still clearly audible (maybe slightly clearer because of reduced distortion products).

Let's get down to the nuts and bolts of loop construction. All you need is a ferrite rod (almost any one will do), some copper wire (about no. 24 to 30), a soldering gun or iron and some rosin core solder, wire cutting pliers, and two el cheapo 365 pf variable capacitors (I picked up a couple from Radio Shack for about a dollar several years ago). The circuit I have used most frequently for unamplified loops is given in Figure 3 below.

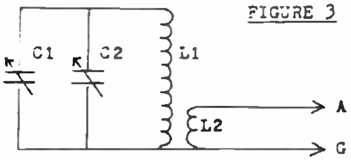


FIGURE 3

Two capacitors are used because the Q of the loop is so high that slow tuning is manditory. Not wanting to go to a lot of trouble in these experimental set ups, I hit on the idea of removing all but two plates from a 365 pf variable for fine tuning. It works.

When I am testing my homebrew loops, I generally lay the entire apparatus on my desk beside the receiver. Ideally, the experimenter should build some kind of framework in which to install his experimental loops, say with a vernier driven tuning capacitor and a means of tilting the loop, but the breadboard technique (with the desk playing the role of the breadboard) works nicely. Another method of low impedance matching is shown in Figure 4.

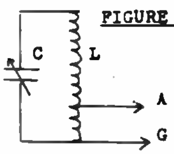


FIGURE 4

The required number of turns to produce an inductance L which allows tuning the entire BCB depends upon a number of factors, such as rod permeability, dimensions of the coil, capacitor range, and extraneous circuit capacitance. The simplest approach is to begin with a coil of about 100 turns and then by trial and error increase or decrease the number of turns until the desired tuning range is achieved. The coil windings of the Space Magnets are spaced so the coil occupies the full length of the ferrite core. It is said by Grimmett [1954] that it has been determined experimentally that a full length winding gives a better pickup than a concentrated winding at the center. However, coil placement and spacing are not very critical and it is probably a matter of personal preference as to spacing and placement. Belrose [1955] has determined experimentally that the sensitivity of a closely spaced coil is more or less independent of the position of the coil on the rod and that Q increases as the coil is moved towards either end of the rod. Everden [1954] mentions that Q increases with decreasing wire size suggesting that there may be some advantage in winding the coil with 9/40 litz wire. The increased Q also results in increased output voltage. Another effect mentioned by both Everden [1954] and Grimmett [1954] is that Q is decreased when the coil is wound directly on the ferrite rod. Grimmett[1954] says that the Q increases rapidly as the separation of the core winding from the rod increases up to about one wire diameter, and then decreases slowly. However, a table in Everden [1954] suggests that Q increases as the coil diameter is increased to about 150% of the rod diameter and then decreases slowly thereafter. I have tried a number of different coil configurations but have noticed no difference in "hearability."

An interesting point raised by Grimmett [1954] is that ferrite rods of the 1950's could be shifted as much as 20% in effective permeability just by tapping the rod on a table. It was at first believed that this shift was caused by the earth's magnetic field. but later believed to be due to molecular instability. The shift was reduced to less than 1% by vibrating the cores during manufacture. Grimmett [1954] mentioned that newer materials were becoming available which do not exhibit vibrational shift. Because of the posibility of vibrational shift it is probably advisable for experimenters to avoid use of old or surplus ferrite rods of unknown origin.

After this article was almost completed we came across two articles concerning cosmic noise in the BCB. In Reber and Ellis [1956] the results of observations on 2130, 1435, 900 and 520 khz are reported. The observed intensity of cosmic radiation was approximately that reported in our Figure 2. At night, cosmic radiation was observed on almost every night on 2130 khz, about one in every six nights on 1435 khz, and about one in every 25 nights on 900 and 520 khz. The cause of the irregular appearance and disappearance of cosmic noise was attributed to ionospheric shielding, though other explanations are possible. The measurements were taken at Hobart, Tasmania during 1955 and it is not certain if these observations apply to other geographic locations. Cosmic noise observations below 10 mhz are also reported in Ellis [1957].

Two of the very best theoretical articles on ferrite loop antennas for the BCB are van Suchtelen [1952a,b]. Additional very useful information is found in Everden [1954] and Grimmett [1954]. The article by Belrose [1955], though primarily for low frequencies (80 - 200 khz), is also useful. Most or all of these articles should be available at a good university library, or, if not, they can be ordered through the interlibrary copying service. Check with your librarian.

In this article we have considered only the sensitivity aspect of loop antenna design and construction. Other important factors in loop design include the quality of the loop null, the loop output voltage, and getting the loop output into your receiver. The subject of loop null quality has been discussed in detail by Nelson [A-13,A-14] and also in the <u>N.R.C. Antenna Reference Manual</u>*. For exceptionally deep nulls, a balanced loop is required. But for nighttime listening, since most received signals are elliptically polarized and deep nulls can therefore not be obtained, an unbalanced loop is seldom a drawback. Loop output voltage and getting the loop output into your receiver are interdependent. A loop functions as a parallel tuned circuit which is a high impedance device, while most receivers' antenna inputs are low impedance. So some kind of impedance matching, usually link or tap coupling, is required. For example, a Space Magnet of 100 turns having a Q of 180 will develop a voltage of 24.7V (where V is the signal strength)

*Vol. I

at 1.54 mhz, while the voltage developed across a 3 turn link coupling is 0.74V. Taking a weak DX signal of 3 microvolts per meter, the signal available to your receiver is 2.22 microvolts. For some receivers, such as the HQ180A or R390A, that might be adequate, but for less sensitive receivers amplification of the loop output may be desirable. The only way to be sure is to wind your loop and try it with and without an amplifier. In my opinion, an amplified loop is manditory for daytime listening (here a large air core amplified loop is state of the art), while at night a good sensitive receiver may give excellent results with an unamplified loop. A discussion of amplifiers suitable for use with loops is beyond the scope of this article, see, for example, the N.R.C. Antenna Reference Manual* and Hagan.

REFERENCES

Belrose, J. S. Ferromagnetic loop aerials for kilometric waves. Wireless Engineer (Feb. 1955), 41-46.

C.C.I.R. World Distribution and Characteristics of Atmospheric Radio Noise, International Radio Consultative Committee, Documants of the Xth Plenary Assembly, Geneva, 1963, Report 322, Published by the International Telecommunication Union, Geneva, 1964.

Cottony, H. V. and Johler, J. R. Cosmic radio noise intensities in the VHF band. Proceedings of the Institute of Radio Engineers Vol. 40 (Sept. 1952), 1053-1060.

Edmunds, R. J., ed. N.R.C. Antenna Reference Manual*, 2nd Edition, Spring 1977, National Radio Club. * Volume One

Ellis, G. R. Cosmic radio-noise intensities below 10 mc/s. Journal of Geophysical Research Vol.62, No. 2 (June 1957), 229-234.

Everden, W. A. Ferrite rod aerials. Wireless World (Sept. 1954), 440-444.

Grimmett, C. A. Ferrite cored antennae. Institute of Radio Engineers Convention Record Part 7 (1954), 3-7.

Hagan, J. V. A large ferrite core loop antenna for long and medium waves.

Hutton, C. Noise levels and useable receiver sensitivity. NRC Reprint

Iron-Powder and Ferrite Coil Forms, Amidon Associates, Inc.

Lankford, D. S. Atmospheric and galactic noise in the BCB. NRC Reprint

Nelson, G. P. Loop distortion - why get skewed?

Nelson, G. P. Pattern controlled loops for the mediumwave DXer.

Reber, G. and Ellis, G. R. Cosmic radio-frequency radiation near one megacycle. Journal of Geophysical Research Vol. 61, No. 1 (Mar. 1956), 1-10.

van Suchtelen, H. Perroxcube aerial rods. Electronics Application Bulletin Vol. 13, No. 6 (1952), 88-100.

van Suchtelen, H. Losses in ferroxcube rods and tubes. Electronics Application Bulletin Vol. 13, No. 7 (1952), 109-114.

Worcester, J. A. The shielded ferrite loop: principles and practice. IRCA reprint A9-10.

Worcester, J. A. How to build the space magnet shielded ferrite loop. IRCA reprint A10-14.

ADDENDA

Two important aspects of ferrite loop design which we overlooked are choice of ferrite material and tangential loss. Different ferrite materials are used for different frequency ranges, so the prospective loop builder should avoid ferrite cores of unknown origin and make sure to use ferrite rods which are made for the BCB (or whatever frequency range he desires). Tangential loss is a complex subject, see van Suchtelen [1952a,b]. The amount of tangential loss of a ferrite material determines the maximum Q of a loop wound on a rod of that material (and therefore effects the sensitivity and output voltage of the resultant loop). As a general rule, older ferrite rods will have higher losses while newer rods will have lower losses (and higher Q's and sensitivities). So the home brewer is well-advised to use recently manufactured ferrite rods.

A few words are also in order concerning possible sensitivity improvements over the loops considered in this article. Since tuning is generally done with a 365 pf variable capacitor, if the entire BCB is to be tuned, then the only variables in equations (7) and (8) are A, N, Q, and μ (assuming a 2.1 khz bandwidth). The 4' air core loop is probably about as large as most DXers would want to undertake, and it is likely that mechanical instability could become a problem for larger loops. Even with the 4' loop a Q reducing variable resistor must be added in parallel with the loop to keep the bandwidth above 2 khz at the low end of the BCB. Thus the sensitivity as given by equation (7) is limited by Q limitations as a result of bandwidth limitations. For ferrite rod loops, Q limitations are usually a result of tangential loss rather than bandwidth limitations, so that increasing sensitivity requires a larger ferrite rod. Radio West has offered a 22" rod, but I do not know if any BCB DXers have constructed loops from that rod or if significant improvements in sensitivity would result.

PATTERN CONTROLLED LOOPS
FOR THE MEDIUMWAVE DX'ER

Gordon P. Nelson

Introduction. As most loop builders have discovered by accident, it's possible for a loop antenna to exhibit a directional pattern with nulls which aren't exactly 180° apart, or of the same depth, or both. "Skewed" patterns are generally undesirable for most BCB DX'ing applications because such distorted loop patterns inevitably show inferior direction-finding and nulling properties. In particular, the ability of a loop antenna to totally eradicate signals from powerful local stations is seriously degraded by even a very slight amount of pattern skewing (see LOOP DISTORTION - WHY GET SKEWED? found elsewhere in this manual.)

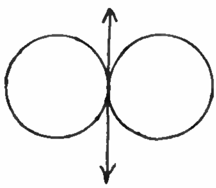
We have discussed the origin of pattern distortion in loop patterns in past issues of DX NEWS, Reprints, and other manuals have offered a number of practical suggestions for improving the pattern properties of existing loop designs. A fully balanced and symmetrical loop such as the FET Altazimuth design can exhibit a pickup pattern which is indistinguishable from that of an ideal cosine loop within the limits of practical measurement (nulls greater than 80 decibels in depth and within 0.05° of symmetry) - but only if considerable care is taken in construction and adjustment. Cleaning up a skewed loop pattern to improve null depth and symmetry often requires quite a bit of thought and experimentation but the results are well worth it.

After a few hours of tinkering in an attempt to clean up the pattern of an ailing loop the following intriguing thought has no doubt crossed the minds of quite a few members. Even though skewed patterns are the result of careless design or loop construction, why shouldn't it be possible to intentionally control the amount of skewing in order to position the nulls where they will do the most good?

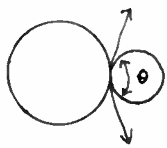
Suppose you're stuck with two semilocals on a particular channel; unless they happen to be colinear (that is, lie in the same direction or 180 apart at your location) you'll never be able to null them both out with an ordinary loop; either one, yes -- both, no. Suppose instead you were able to set the nulls to any desired angular separation instead of being limited to one fixed value such as the usual 180°? Proper adjustment of the pattern could result in a pattern with a null in the direction of each interfering station!! Carried to the logical extreme, it should even be possible to skew the pattern nulls so greatly that they would appear to be superimposed; this would give a loop pattern with only one effective null. The benefits for the MW DX'er of such a controlled pattern loop would be great indeed.......

The mathematical theory describing the simple single-nulled loop pattern (also called the cardioid pattern because it's roughly heart-shaped) was worked out many years ago; both the equations and considerable experimental data were presented by Beverage in the same classic 1923 IRE paper introducing the Beverage antenna. Simple cardioid loop circuits have been in use in all loop-based radio Direction-Finding gear since the 1920's and are included in most radio navigation systems using the loop antenna as the basic directional element. The use of the cardioid pattern circuitry has generally been limited to providing "sense" in DF and navigation systems, however; that is, to permit resolution of the 180 bearing ambiguity common to all cosine (figure 8) loop patterns. In most loop-based DF systems, the exact bearing is taken with the loop operating in the cosine mode and the cardioid circuitry is brought into play only to resolve the bearing ambiguity by converting the cosine pattern into a rough cardioid shape. The question of why such direction finders are not simply operated in the cardioid pattern mode continuously is a fundamental one and the answer will become clear later in this article.

While the ability to resolve the ordinary 180° pattern uncertainty is useful if you're trying to distinguish between a weak TA and LA carrier, for example, the BCB DX'er actually wants much more from a pattern controlled loop: he wants to be able to quickly and easily control the angular separation between the nulls - and this includes the cardioid pattern as a special case. Because the equations and descriptions of the basic cardioid loop pattern have been discussed in many radio texts over the years (Terman, Bond, et al.), quite a number of technically inclined DX'ers have experimented with loop patterns and have attempted to build practical cardioid loops. The great DX magazines of the Thirties such as RADEX featured items on loop experimentation from time-to-time, and a number of NRC'ers have discussed various types of intentionally induced loop pattern distortions in DX NEWS over the years. The author has been working with various types of controlled pattern loops for some years in connection with the design optimizations for the Altazimuth loop design and we'll present a few of our findings - both theoretical and experimental - in this article. In particular we'll attempt to explore some of the basic problems and limitations inherent in the practical controlled pattern loop, explain why these loops often behave "strangely", and offer some suggestions for future research.



Normal Undistorted cosine loop pattern; nulls exactly 180° apart.



"Skewed" loop pattern; nulls are separated by θ degrees; in a pattern controlled loop this angle could be altered at will.

Basic cardioid pattern; the angle θ of the skewed loop has been reduced to zero, thus superimposing the nulls.

The Basic Cardioid Loop. The point of departure for the Seeker-after-the dream-loop is what we'll call the basic cardioid. By this we mean the simple equations and circuits for the cardioid pattern to be found in many textbooks - a highly simplified treatment which neglects a number of difficult problems which arise in the Real World, as we shall see .....

An hour in the library will teach you that all need be done to produce a loop pattern with any desired amount of null skewing is to combine the signal from the loop with the proper amount of signal from a vertical antenna (with an appropriate phase shift). By adjusting the amount of vertical signal until it exactly equals that from the loop and fixing the phase relationship properly - presto!! - a cardioid loop with but a single null. It all seems very simple until you try to do it - then the real fun begins....

Before exploring the complications which arise when you attempt to construct a practical controlled pattern loop suitable for general BCB DX'ing applications, a bit more discussion of the basic cardioid equations is desirable.

In the article Loop Distortion - Why get skewed? (elsewhere in this manual) included a set of equations which we derived to explain the relationship between electrostatic pattern distortion and null skewing and depth. Although our particular derivation was concerned with the effects of small amounts of skewing on loop performance, the equations we derived also describe the properties of the basic cardioid and controlled pattern loop (the final pattern equations are the same as those derived by Beverage, et al., although our approach was somewhat different). These simple equations suggest that the construction of a practical controlled pattern loop should be quite trivial; although this is not actually the case as we'll see when we re-derive the equations taking additional effects into account, it's definitely worthwhile to delve into the basic cardioid as a warm-up for the full treatment....

Suppose we take a loop antenna with a perfect cosine pattern (the Altazimuth is good enough in practice) whose output voltage for a particular signal in peak direction is given by B volts, and combine its signal with that from a perfectly omnidirectional vertical antenna whose pickup for the station in question is equal to E volts. Furthermore let us control the phase of the signal from the vertical so that it differs from that of the loop by some amount of degrees. The angular separation of the pattern nulls is then given by the expression:

$$\Delta\theta = 2\ \mathrm{Cos}^{-1}\ (-E/B\ \ \mathrm{Sin}\ \phi) \qquad \text{Equation 1}$$

in keeping with the following convention:

(see Loop Distortion - Why Get Skewed? article for the derivation)

The RMS voltage pickup in any particular azimuthal direction θ is then given by:

$$V(\theta) = \tfrac{1}{2}\ B^2\ \ \mathrm{Cos}^2\ \theta + \tfrac{1}{2}\ E^2 + B\ E\ \mathrm{Cos}\ \theta\ \mathrm{Sin}\ \phi \qquad \text{Equation 2}$$

And the pickup ratio (in db) between the smaller lobe and the larger (analogous to the front-to-back ratio used in the discussion of more conventional types of antennas) is then given by:

$$B/F = 20\ \mathrm{Log}_{10}\ \frac{B^2 + E^2 - 2BE\ \mathrm{Sin}\ \phi}{B^2 + E^2 + 2BE\ \mathrm{Sin}\ \phi} \qquad \text{Equation 3}$$

What does this mean in terms of actual numbers? As we showed in the article Loop Distortion - Why Get Skewed? , we must fix the phase angle ϕ equal to 90° if we wish to obtain unblunted nulls. For the moment let us assume that we have been able to get an exact 90° phase shift between B and E; what is the effect of increasing the amount of vertical antenna pickup? Let us define the quantity R to be the ratio of vertical to loop signal (= E/B) ans see what happens to the resulting pattern as we vary the amount of vertical pickup.

The following table shows the effect of varying R from zero to unity. The first column is the value of R for that particular pattern; the second gives the amount of angular separation between the nulls; and the third gives us the ratio between the smaller and larger lobe peak pickups.

Value of R	Null Angle Separation	Minor To Major Lobe	Remarks/Comments
0.0000	180 Deg.	0 DB	(Normal Cosine Pattern)
0.0001	180.0 Deg.	-0.00 DB	(Roundoff Effect)
0.0010	179.9 Deg.	-0.02 DB	
0.0100	178.9 Deg.	-0.17 DB	
0.1000	168.5 Deg.	-1.74 DB	
0.2000	156.9 Deg.	-3.52 DB	
0.3000	145.1 Deg.	-5.38 DB	
0.4000	132.9 Deg.	-7.36 DB	
0.5000	120.0 Deg.	-9.54 DB	
0.6000	106.3 Deg.	-12.1 DB	
0.7000	91.15 Deg.	-15.1 DB	
0.8000	73.74 Deg.	-19.1 DB	
0.9000	51.68 Deg.	-25.6 DB	
0.9900	16.22 Deg.	-46.0 DB	
0.9990	5.125 Deg.	-66.0 DB	
0.9999	1.620 Deg.	-86.0 DB	
1.0000	0 Deg.	- ∞ DB	(Basic Cardioid Pattern)

The above table shows a number of the characteristic properties of the pattern controlled loop quite effectively. Note that for very small amounts of vertical pickup the angular separation of the nulls changes quite rapidly; this is the extreme sensitivity of a cosine loop to electrostatic imbalance which was discussed at length in the article Loop Distortion - Why Get Skewed?.

The table showed the effect on the basic cardioid pattern shape as the ratio of the vertical to loop signals was varied (R = E/B)..If there is no vertical antenna at all, R=0 and we have a normal "figure eight" cosine loop pattern, with equal peaks and nulls separated by 180 degrees.

As the amount of vertical signal is increased (by using a taller vertical, for example), R in the equation increases and the nulls begin to pull together. If, for example, the pickup of the nulls are 120° apart and the two peaks are definitely no longer equal in pickup: one is about 9.5 db (about 2 S-units) more sensitive than the other.

By the time the relative amount of signal from the vertical antenna reaches 0.9 of that from the loop, the nulls are still 52° apart but the pickup of the smaller lobe is less than one-tenth of the larger.

By the time we have increased the amount of vertical antenna pickup to within 1% of that from the loop (R=0.99) the nulls are within 16 degrees of each other and the pickup from the small middle lobe is less than one-one hundredth of the main lobe.

When we adjust the signal from the vertical to a value exactly equal to that coming from the loop, the nulls merge together into a single null and we have the basic cardioid pattern. One of the characteristics of the basic cardioid pattern is that the pickup in the peak direction for a cardioid is twice (6 db) that of either the loop or vertical antenna alone.

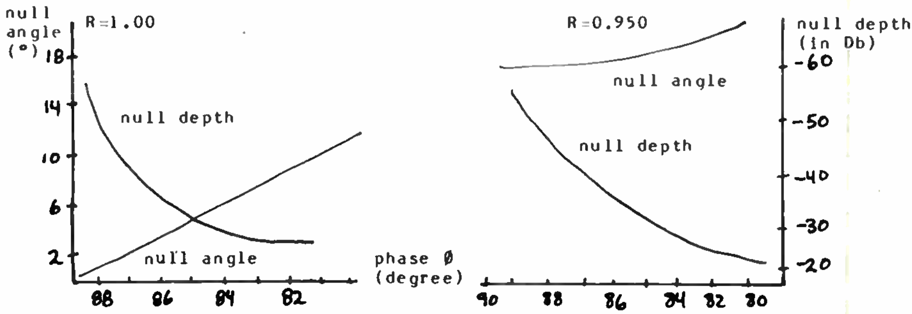
What does this mean to the loop builder? It means that any attempt to construct a practical pattern controlled loop will require very careful adjustment of the relative signals contributed by the loop and vertical antennas. If our loop sum vertical array does in fact perform according to Equation 7 (see appendix) which is the classical textbook behavior, very slight variations in the electronic parameters will produce rather major alterations in the shape of properties of the resulting pattern. A 1% shift in relative signal pickup, for example, will cause the single cardioid null to split into two nulls more than 16 degrees apart.

In order to thoroughly null out a powerful local station (say a 50 KW'er within a few miles) a null depth of at least 80 db is essential. Assuming a cardioid loop as described by equation 7 is adjusted to competely reduce the troublesome local station, observe that a variation in the relative pickup of only 0.1% will result in a new pattern with nulls split by about 5° and only 66 db of effective null in the original direction. Holding the relative signal contributions from the loop and vertical to within the tolerances necessary for really deep nulling will require extreme care in even the best of circumstances because of the sensitivity of the cardioid pattern to very small variations in relative pickup.

The Phase Problem. The previous discussion, you will recall, was based on the assumption that the relative phase shift between the two signals (as given by the quantity Ø in our equations) was adjusted exactly to 90°. But in actual practice it has been our experience that it is even more difficult to adjust and hold the relative phase than it is to control the relative pickup. What will be the effect of variations in the exact relative phase between the two signals?

Whereas variations in the relative pickup (as measured by R) have the effect of shifting the location of the nulls without affecting their depth, fluctuations in the phase adjustment will degrade the quality of the nulls as well as shifting their location. Suppose we have been able to adjust the relative pickup of the two antennas (R) to exactly 1.000; what happens if the phase differential changes by a small amount? The following graph shows the effect of varying the phase by a small amount from the correct setting necessary for the cardioid pattern.

Location of the null angle 0_N and null depth in Db for R=1.00 and R=0.950 as the differential phase angle Ø is varied slightly.



In the first case we set the pickup ratio, R, exactly equal to 1.00 and let the phase drift by a few degrees. Note that the nulls drift apart somewhat but, more significant, the null depth is very seriously affected - only a two degree error in setting the relative phase degrades the nulls so severely that they are only 35 db deep.

The second graph shows the effects of slight variations in both R and the phase angle Ø; a 5% shift in relative pickup along with a 5° phase error changes the pattern from a cardioid with a single infinitely deep null to a rather mediocre one with two shallow nulls (-27 db deep) separated by about 18°. Still a useful pattern for some applications but useless for deep nulling powerful locals!

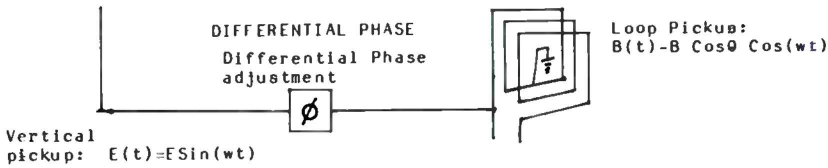
Summary of the Basic Pattern Controlled Array

A pattern controlled loop designed around the basic equations given here and elsewhere will require very careful adjustment of the relative signal pickup ratio and phase differential. Very small deviations from the exact values given by the equations will have rather major effects on the shape of the resultant pattern. Slight variations in the pickup ratio of the loop and vertical antennas will produce significant variations in the locations of the nulls; minor fluctuations in the differential phase will seriously degrade the null depth, thus limiting the ability of the array to null strong stations. Taken together, slight fluctuations in both amplitude and phase (R and Ø) tend to reenforce each other and readily produce significantly distorted patterns.

In the first part of this article we have attempted to describe the basic properties of the simple pattern controlled loop. In addition to our derivation of the basic cosine and cardioid patterns, we have given the equations for the patterns produced by arbitrary values of relative amplitude and phase. In particular we have provided the equations which predict the behavior of null location and depth as we introduce slight fluctuations in the array as are likely to occur in actual practice due to component drift, maladjustment, etc. To the best of our knowledge the equations for the general null location and depth for the arbitrary pattern have not been given before in the texts although their derivation and evaluation are rather trivial.

Since we had performed this mathematical analysis prior to our first attempts to actually construct a pattern controlled loop array, we were spared a considerable amount of experimentation and head-scratching when we actually began to experience the problems produced by the slight fluctuations in amplitude and phase described above. Our first circuits (to be described later) provided us with patterns which, while encouraging - especially for groundwave signals - still behaved somewhat unpredictably on skywave signals even with very tight control of R and Ø. As we shall explain next, the basic cardioid pattern as described in standard textbooks and in this article breaks down in actual practice because of polarization ellipticity, wave tilt, and ground effects. In future articles we shall provide information not previously available about these complications and provide plans for what we've found to be the most effective circuitry for practical pattern controlled loops.

APPENDIX. Equations for Pattern Controlled Loop & Basic Cardioid.



THE GENERAL PATTERN:

The signal pickup voltage in any azimuthal direction Θ is directly proportional to:

*** $V(\Theta) = (\cos^2\Theta - 2R\cos\Theta\sin\emptyset + R^2)^{1/2}$ where $R = E/B$

The pickup voltage in any direction relative to peak signal pickup, expressed in Db, is given by:

$$*** \quad \frac{V(\Theta)}{V_{max}}\ (Db) = 10\ \log_{10} - \frac{\cos^2\Theta - 2R\cos\Theta\sin\emptyset + r^2}{1 + 2R\sin\emptyset + R^2}$$

Differentiation of the above expression shows that the nulls of any such pattern are located at the angles Θ_N given by:

$$*** \quad \Theta_N = \pm \cos^{-1}(R\sin\emptyset)$$

Substitution back into the pickup equation shows that the nulls have a depth relative to peak pattern pickup given by:

$$*** \quad \frac{V_N}{V_{max}}\ (Db) = 10\log_{10} \frac{R^2 \cos^2\emptyset}{1 + 2R\sin\emptyset + R^2}$$

The above equations describe the patterns for all arrays produced by combining the signal from an omnidirectional vartical antenna with the output of a perfect loop antenna in any ratio and with any relative phase relationship. The generalized equations above predict the basic cosine and cardioid patterns as found in all standard textbooks. These almost trivially simple equations do not however take into account the effects produced by the following physically significant complications:

a. Polarization ellipticity and rotation (the above equations apply only to linearly polarized wavefronts in general); this is an unrealistic assumption for skywave signals in actual practice.

b. Effective wave-tilt. The above equations not only assume a linearly polarized wavefront, but also assume that the effective wavefront at the antenna is paraller to the ground. This is untrue in the case of all real signals: skywave signals because of skip geometry, and groundwave signals because of the effective wave-tilt produced by the interaction of the wavefront with the nonideal ground beneath the antennas.

c. Deviations from the simple ideal vertical antenna pattern assumed above. In actual practice the pattern of a real vertical antenna is rarely uniform in azimuth and the transmission line from the vertical antenna almost inevitably exhibits a finite pickup of its own.

All of the complications listed above must be taken into account if the behavior of a real pattern controlled loop to real signal wavefronts is to be uniquely described. We'll return to these problems later.

SPECIAL CASES OF THE BASIC EQUATIONS

No Electric or Vertical Pickup, R = 0

In this case the general equation given above reduces to:

*** $$\frac{V(\Theta)}{V_{max}} (Db) = 20\text{Log}_{10} \text{Cos}\Theta$$

which is the COSINE LOOP PATTERN with infinitely deep nulls at $\pm$ 90°.

CASE OF R = 1 AND Ø = 90

In this case the pickup equation reduces to:

*** $$\frac{V(\Theta)}{V_{max}} (Db) = 20\text{Log}_{10} (1/2 (\text{Cos}\Theta - 1))$$

which is the BASIC CARDIOID pattern with an infinitely deep null at $\Theta_N = 0°$ Note that if the inner term is replaced by (CosΘ -1) the pattern is replaced by its mirror image with the null at 180° instead of 0°.

LOOP DISTORTION - WHY GET SKEWED ?

BY GORDON P. NELSON

Loop antennas offer several advantages to the Medium Wave DX'er over other types of antennas. In the presence of local noise (generated by neon signs, etc, within a few hundred feet of the receiver), a loop will actually pick up less noise than a vertical or "longwire" of equivalent signal pickup. In a well designed loop, the very high Q provides such sharp tuning that overload problems caused by powerful local stations are often greatly improved. But the loop's most important feature for the DX'er is its ability to null out unwanted signals; this same nulling ability makes direction finding possible with even simple equipment.

How deeply can a loop null out an unwanted signal? When we first began to research high-gain, deep nulling MW antennas at MIT about 3 years ago, our initial reaction upon reading the standard texts and references was that it ought to be a trivial exercise in engineering to produce an essentially "ideal" loop for DX'ing and so we confidently set out to do so. Our first efforts failed rather miserably - not only were we unable to completely null out our locals, on some stations we hardly got any nulls at all. These first antennas further showed some of the same pathological characteristics reported by many loop users: unequal peaks and nulls, nulls that were not 180° apart, and shallow nulls on most local stations. After much experimentation, loop winding, and equation solving, we believe we have isolated most if not all of the factors responsible for poor loop nulling; the results of this research were designed into the Altazimuth loop (Antenna Manual Volume 1). In all but a few cases the Altazimuth loop is capable of nulling local stations down by a factor of a least 80 db; in most cases this means a drop in signal strength from say 60 db over S9 to an S2 or S3 jumble of unintelligible skywave backscatter sounding somewhat like single-sideband reception. Here in Boston for example, there's no problem logging XEQR on 1030 with WBZ nulled out, or WCBM/WPTF with WRKO eliminated.

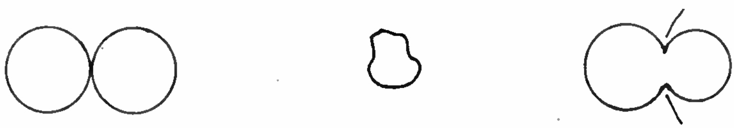
If you are unable to obtain "total" nulling with your loop (i.e., down to the point where all you hear is distorted skywave backscatter during daylight hours) on powerful locals, your problem may be some or all of the following:

a. Defective loop design (poor geometry). A loop whose winding is too wide in comparison with its diameter is insufficiently planar and the skew in the windings will distort the pattern and blunt the nulls. The width of the winding should be as short as possible: "spiral" or "pancake" loops have optimum geometry for null-ing and frequently show better nulls than a box type loop with equivalent pickup.

b. Defective loop design (electrical). It is extremely important that virtually all of the signal delivered to the receiver be from the magnetic pickup of the loop and that there be no pickup from the transmission line to the receiver or the entire body of the loop acting like a short vertical antenna. Unwanted electric field pickup resulting from faulty loop design or construction is the most common cause of blunted loop nulls and distorted loop patterns and we shall look more carefully at this basic problem later in this article.

c. Elliptical signal wavefront. The polarization figure of the signal you are attempting to null is in the end the final determinant of just how deeply the signal can be nulled. Given a mechanically and electrically perfect loop antenna, the maximum null depth (that is, the difference in decibels between the signal peaked and nulled) cannot be greater than the ratio of minor to major axis in the electric vector polarization ellipse of the signal (in db). This means that regardless of how good the loop is, the null depth for a particular signal will depend upon the polarization of the wavefront from the signal in question. What the DX'er wants is a wavefront that is linear as possible, that is, as close to a linear polarization figure as possible. For powerful groundwave locals, the degree of polarization ellipticity depends upon several factors: the transmitting antenna, the properties of the ground between the transmitter and receiver, the frequency, and the amount of reradiation from nearby phone and powerlines, etc. Here in the author's urban Boston location, all but two or our 12 powerful lncal stations have essentially linear wavefronts and can therefore be totally looped out. The remaining two, however, WHDH-850 and WHIL-1430, have "defective" wavefronts and cannot be nulled by more than 26 and 44 db respectively. Fortunately the degree of ellipticity changes somewhat with the season and with routine transmitting antenna maintenance which means there is some hope for the future even if you happen to be unlucky enough to have one of these refractory cases in your area. In effect, therefore, the question of how well you will be able to null your particular locals once you obtain a suitable loop will depend upon strictly local factors. Careful loop design and construction can only bring the null depth down to the point limited by the shape of the signal wavefront itself.

Loop defect (b) above is the most common and serious cause of distorted loop patterns and shallow nulling. Consider the case of a well designed and constructed loop whose width is negligible compared to its diameter and suppose you are attempting to null a perfect local signal with purely linear and vertical polarization by rotating this antenna. If this antenna is properly electrically balanced, the station will be completely eliminated in each null and the nulls will be exactly 180° apart as the antenna is rotated. If, on the other hand, the antenna is not electrically balanced, the station may not be totally eliminated in one or both nulls, the depths of the two nulls may not be equal, and the nulls may not be 180° apart. Any or all of these symptoms indicate the presence of electrostatic imbalance and mean that you are not getting all of the performance from this antenna that you might. How much electrostatic imbalance is acceptable before the performance of the loop is significantly degraded? Let us consider the above case of the ideal loop and the ideal local signal and see what the effect of electrostatic imbalance will be on the null depth and the pattern symmetry (that is, how much the null directions depart from the ideal value of 180°).



Perfect loop pattern + Electrostatic pickup = Distorted pattern

The instantaneous voltage induced in the loop by the signal is given by:

$E(t) = B \cos\Theta \cos(wt)$ where Θ is the azimuth angle of the loop plane, w is the angular frequency, t is time, and B is proportional to the frequency of the signal, the area and number of turns in the loop, and the strength of the signal.
(see High Precision Direction Finding, Part 1, elsewhere in this manual)

Let us suppose that there is also a pickup from the electric field of the

Let us suppose that there is also a pickup from the electric field of the signal caused by electrostatic imbalance due to faulty design or construction; the electric pickup voltage may then be represented by:

$E(t) = E\, f(\theta) \sin(wt + \phi)$ where $f(\theta)$ is the azimuthal dependence of electric component pickup, ϕ is the phase shift between the electric and magnetic pickup voltages (compensated for induction quadrature), and E is the amplitude of the electrostatic pickup.

We will then set the total instantaneous voltage delivered to the receiver equal to the sum of the magnetic and electric pickups and average the squared total voltage over one cycle to obtain the mean squared value:

$$V(t) = B \cos\theta \cos(wt) + E\, f(\theta) \sin(wt + \phi)$$

$$\int_0^{2\pi} (V(t))^2\, dt = \int_0^{2\pi} B^2 \cos^2\theta \cos^2(wt)\, dt + \int_0^{2\pi} E^2 f(\theta)^2 \sin^2(wt + \phi)\, dt$$

$$+ \int_0^{2\pi} 2BE \cos\theta\, f(\theta) \cos(wt) \sin(wt + \phi)\, dt$$

$$= 2\pi \left[1/2B^2 \cos\theta + 1/2E^2 f(\theta)^2 + B\, E \cos\theta\, f(\theta) \sin\phi \right]$$

In order to determine the location of the peaks and nulls of the resultant pattern we must differentiate with respect to θ and set the derivative equal to zero:

$$\frac{d}{d\theta}(V(t))^2 = -B^2 \cos\theta \sin\theta + E^2 f(\theta) f'(\theta) + BE\sin\phi\, (\cos\theta\, f'(\theta) - f(\theta)\sin\theta)$$

The peaks and nulls of the pattern then occur at the angles θ_E which are the solutions to:

$$0 = (\cos\theta_E + E/B \sin\phi) \sin\theta_E$$

in the event that $f(\theta)=1$; i.e. that the electric pickup is omnidirectional.

The second derivative test shows that the pair of solutions:

$0 = \sin\theta_E$, $\theta_E = 0°$ and $180°$

correspond to the peaks in the pattern pickup so long as the quantity

$(B + E\sin\phi) > 0$;

in practice this is always the case unless an extremely long unbalanced feed-line is used. This means that the remaining two solutions represent the pattern nulls:

$$0 = (\cos\theta_E + E/B \sin\phi) \quad \text{or}$$

$$\theta_N = \cos^{-1}(-E/B \sin\phi)$$

This last equation is very important to the loop designer since it now shows that the null skewing (that is, deviation of nulls from 180°) depends only upon the ratio of electric to magnetic pickup and the phase relationship between them. We now have derived the first important result of electrostatic imbalance in a loop antenna, skewed nulls.

What about the effect of imbalance on null depth, that is, the ratio of pickup at null to that of peak? Recall that the mean-square pickup is given by

$$\overline{V^2} = 1/2\, B^2 \,\cos^2\theta + 1/2E^2 + BE \cos\theta \sin\phi \;;$$

since we know that $\cos\theta = -E/B \sin\phi$ at the direction of null, the signal pickup at null is then given by:

$$\overline{V_N^2} = E^2\,(1 - \sin^2\phi)$$

and the ratio of signal pickup (mean squared) at null, that at peak is given by:

$$\frac{V_N^2}{V_P^2} = \frac{E^2\,(1 - \sin^2\phi)}{1/2B^2 + 1/2E^2 + EB \sin\phi}$$

If we assume that B has unit value, we then obtain the final solution for null depth as a function of the amount and phase of the electrostatic pickup:

$$\text{Null Depth (db)} = 10 \,\text{Log}\left[\frac{E^2\,(1 - \sin^2\phi)}{1 + E^2 + 2E \sin\phi}\right]$$

We may now calculate the amount of null skewing and blunting as we vary the phase and amplitude of the electric signal pickup.

Before we proceed to evaluate these expressions in order to get a feel for the sensitivity of the nulling capabilities of a loop to the slightest bit of electrostatic contamination, a few words about Ø. In our experience, the electrostatic component tends to be coupled into the loop signal capacitatively if there is in fact a reactive component at all. In a directly coupled loop (i.e., where the magnetic signal is taken directly from the tank) the electrostatic pickup (usually associated with the feedline) is usually shifted no more than 30 or 40 degrees. A link-coupled loop, on the other hand, introduces an additional phase shift of 90° ; in this case the effective value of Ø is much higher. In other words, coupled loops with link-takeoff are often more sensitive to the effects of imbalance on null skewing than are direct coupled loops.

The following table shows the values of null asymmetry (the difference in null azimuths) and the calculated null depths for various amounts of electrostatic pickup (E/B), expressed in db. Four values of Ø are shown, corresponding to effective phase advance for a direct-coupled loop; the same table is valid for link-coupled loops if the complement of the phase angle is taken instead. Notice the great effect that even a small amount of electrostatic contamination can have on both null depth and symmetry: in thecase of $\emptyset=60°$, as little as 1% (=-40db) electrostatic contamination will limit null depth to -47 db and skew the nulls a full degree.

$\emptyset = 0°$:

F/B (db)	Null depth (db)	Null skew (degrees)
-20 db	-20 db	0
-40 db	-40 db	0
-60 db	-60 db	0

$\emptyset = 30°$:

-20 db	-23 db	5.8
-40 db	-42 db	0.6
-60 db	-62 db	0.1

$\emptyset = 60°$:

-20 db	-28 db	10
-40 db	-47 db	1
-60 db	-68 db	0.1

$\emptyset = 90°$:

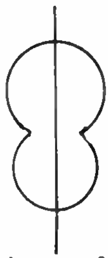
-20 db	$\to\infty$	11.6
-40 db	$\to\infty$	1.2
-60 db	$\to\infty$	0.1

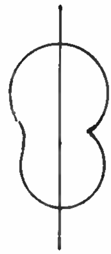
The expressions which we have derived and evaluated agree very well with actual experiment and help to explain many seemingly inconsistent observations about null depth and asymmetry. Note that the symptoms of an unbalanced loop configuration can be skewed but deep nulls, symmetrical but shallow nulls, or, most commonly, both shallow and skewed nulls.

At one point back in the middle of the equations we casually snuck in the assumption that the electric pickup term did not depend upon the azimuth angle, that is, that $f(\theta)=1$. To a first approximation this assumption is pretty good since most electrostatic pickup comes from the feedline and/or the entire unbalanced loop acting as a short "vertical" antenna without pronounced directional properties. What if the source of the electric signal component does have a significant azimuthal pattern? Qualitatively this can be considered by looking at the mean squared pickup expression,

$$(V(t))^2 = 1/2B^2 \cos^2 \theta + 1/2E^2 f(\theta)^2 + BE\cos \theta f(\theta) \sin \emptyset$$

Note that since Cosine is an even function, the pickup at any particular θ angle will be the same at $-\theta$ if and only if $f(\theta)$ is also an even function, i.e., if $f(\theta)=f(-\theta)$. In the case of the earlier assumption of $f(\theta)=1$, this was indeed the case and the resultant patterns, while distorted in azimuth and/or null depth, were symmetrical about the θ axis. This is a most important observation because it frequently provides useful clues about the origin of the imbalance in a particular loop. In the figures below we illustrate what we mean by symmetry about the θ axis in a skewed loop pattern. In the first case (corresponding to the assumption that $f(\theta)$ is an even function), the nulls are skewed and blunted <u>but</u> the depth of the nulls is the same on each side.





In the second case, $f(\theta)$ is not an even function and as a result the null depths are not equal. This is a fairly common form of loop malfunction and is the worst possible pattern for the DX'er; not only are the nulls skewed and shallow, they aren't even the same on each side. Since the general form of $f(\theta)$ is not generally known there is no point in assuming a particular form of the azimuthal dependence aside from considerations of symmetry. We have solved the equations for the assumed $f(\theta)$ of the form

$$E(t) = A \, Cos(wt) \, Cos(\theta + \delta) + B Cos \, (wt + \gamma)$$

and this expression appears to approximate the behavior of at least some actual loops fairly well.

In this article we have attempted to explain the origin of many common types of loop malfunction and to stress the importance of electrostatic balance in the design and construction of loops for DX'ing. Unless your loop has nulls that are exactly 180° apart, of the same depth, and can supply nulls on locals to the limit of the polarization figure of the signal, you aren't getting nulls that are as deep as they might be. In future articles we will give some tips on cleaning up loop nulls and eliminating electrostatic imbalance from a variety of origins. Some of these points have already been mentioned in High Precision Direction Finding-Part 2 found elsewhere in this manual.

+++++

HIGH PRECISION DIRECTION FINDING OF MEDIUM WAVE SKYWAVE SIGNALS

PART 1: FUNDAMENTAL PROPERTIES OF LOOP ANTENNAS AND APPARENT BEARING ERRORS

Historical Perspective. Loop direction-finders first came into use for marine navigation around the turn of the century and quickly found wide acceptance. Through historical accident it so happened that the wavelengths in use at this time were very great (i.e. VLF) and as a consequence most propagation was via groundwave-type modes so that skywave effects were not readily apparent. As radio technology improved the advantages of higher frequencies became obvious and there began a gradual migration to higher operating frequencies. By this time frequencies were high enough to provide considerable skywave return from the ionosphere and marine direction finding stations began to observe violent fluctuations in apparent bearings when both groundwave and skywave signals were simultaneously present. This desturbance of loop bearing measurements was named the "Night Effect" (it is most obvious with nighttime skywaves) and at first seemed to be an insuperable problem. Advances in the state of the antenna art quickly came to the rescue with entirely new forms of direction finding antennas employing very large spaced arrays of vertical antennas. Systems such as the Bellini-Tosti and Adcock are much less sensitive to Night Effect and as a result the simple loop fell into general disfavor (although it remained in use for certain mobile applications were space was limited). At this time there began to germinate a myth which has survived until today which in effect says: "Loop bearings on nighttime skywave signals are intrinsically unreliable and will exhibit violent fluctuations." Reference to any of the standard textbooks will certainly discourage any BCB DXer from attempting high precision Direction-Finding at night; most texts positively state that violent bearing fluctuations which are commonly as great as 90° will make nighttime direction-finding impossible. It is now obvious that most if not all of these textbook treatments are derivative, incomplete, and extremely misleading.

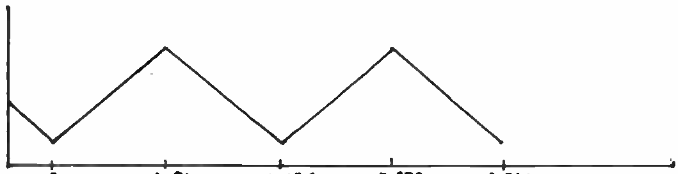
Present Work. During the last year I have been able to obtain consistent and replicable direction-finding bearings on TA (Trans-Atlantic) stations with night-to-night errors never greater than 5° and frequently less than 1° by confining my D.F. (Direction-Finding) attempts to strictly skywave signals. The violent bearing fluctuations so dramatically described in the textbooks seem to occur on the BCB only if both skywave and groundwave components are simultaneously preseht; I have made tens of thousands of bearing measurements on skywave signals and have yet to encounter the violent bearing fluctuations that I had been led to expect. I have accumulated much evidence which suggests that BCB signals usually travel on paths that are very close to the great circle; thus the effects due to deviated paths (scattering, auroral bounce, etc) which make skywave D.F. unreliable on shortwave frequencies are not encountered on the BCB. The rare exceptions which occur on the BCB (dawn tilt modes in particular) will be discussed at length in the next paper of this series.

It must be stressed that MW D.F. bearings do indeed vary with time; while D.F. a weak TA carrier it is not unusual to observe fluctuations of as much as ± 10° over a rather short space of time. A single measurement will be in error as the result of two different types of factors. Measurement errors will be discussed in the next paper of this series. High precision D.F. on the BCB is possible only because the fluctuations observed are the result of random processes and thus can be averaged out to zero over a certain amount of time. Very little significance can be attached to a single bearing measurement; it is only when a number of bearings are treated statistically to remove the random errors that high precision bearings can become meaningful. The statistics of bearing determination will be discussed in Part 2 of this article; here we shall concern ourselves with the various physical mechanisms which can affect the value of a single bearing measurement made at one instant of time by a perfect system with no measurement error.

In this article I shall derive the properties of a D.F. loop antenna for the case of an arbitrary plane wavefront with arbitrary polarization. Errors due to polarization, wave tilt, and second station effects will be derived from general electromagnetic considerations. Since to the best of my knowledge this analysis has never before been published, I will present it in its entirety both for reference and to illustrate the general method of attack on loop problems.

* * * * * * * * *

The signal output of a good (i.e. balanced) loop antenna exhibits two symmetric peaks and nulls as follows:



Only under certain conditions will the null angle correspond exactly to the direction of approach of the signal. Usually the indicated bearing will be in error by an amount E* as the result of polarization and wave tilt (second signal "pulling" will be treated separately;) we shall now calculate what this error will be.

Definitions:

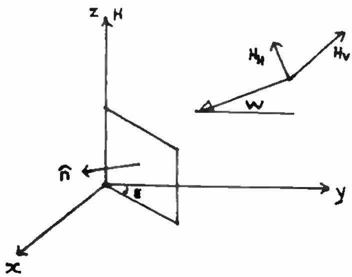
$\vec{H}(t)$	instantaneous vector magnetic field of signal
EMF(t)	instantaneous voltage in loop
$\hat{i}, \hat{j}, \hat{k}$	unit vectors in x, y, z directions
$\hat{n}$	unit vector normal to plane of loop
H_v	magnetic component corresponding to vertical component of electric vector
H_h	magnetic component corresponding to horizontal component of electric vector
A	Area of loop
N	Number of turns in loop
RMS	Root mean square value of voltage induced in loop antenna
E	Apparent error angle; defined as positive in clockwise direction between yz plane and loop plane
w	Angular frequency of signal; radians per second
j	square root of -1
e	base of natural logarithms
t	time
W	Wave angle between signal path and horizontal plane
P	Polarization angle of wavefront; measured as clockwise rotation when facing the approaching wavefront

dl	Differential element of loop conductor
ϕ	Phase difference between horizontal and vertical wave components
u_o	Permeability of free space

++++++++++++++++++++++++++++++++++++

We wish to calculate the Maxwell equation:

$$EMF(t) = N \oint \hat{E} \cdot d\hat{l} = -\frac{\partial}{\partial t} \int_A u_o \, AN \, \vec{H}(t) \cdot \hat{n} \, dA$$



$$\tan P = \frac{H_H}{H_V}$$

$$H(t) = jH_V e^{j\omega t}\hat{i} + jH_H e^{j(\omega t-\phi)} \text{Sin } W \hat{j} - jH_H e^{j(\omega t-\phi)} \text{Cos } W \hat{k}$$

$$\int_A \mu_o N \vec{H}(t) \cdot \hat{n} \, dA = \mu_o NA[jH_V e^{j\omega t} \text{Cos } E - jH_H e^{j(\omega t-\phi)} \text{Sin } W \text{ Sin } E]$$

$$-\frac{\partial}{\partial t}\int_A N\vec{H}(t) \cdot \hat{n} \, dA = -\mu_o NA[-\omega H_V e^{j\omega t} \text{Cos } E + \omega H_H e^{j(\omega t-\phi)} \text{Sin } W \text{ Sin } E]$$
$$= EmF(t)$$

$$[EmF(t)]^2 = (\mu_o NA\omega)^2 [H_V^2 \text{Cos}^2 E e^{2j\omega t} + H_H^2 \text{Sin}^2 W \text{ Sin}^2 E \cdot$$
$$\cdot e^{2j(\omega t-\phi)} - 2H_H H_V \text{Cos } E \text{ Sin } E \text{ Sin } W e^{j\omega t} e^{j(\omega t-\phi)}]$$

$$\frac{1}{2\pi\omega}\int_0^{\frac{1}{2\pi\omega}} [EmF(t)]^2 dt = (\mu_o NA\omega)^2 [\tfrac{1}{2}H_V^2 \text{Cos}^2 E + \tfrac{1}{2}H_H^2(\text{Sin } W \text{ Sin } E)^2$$
$$- H_H H_V \text{Cos } E \text{ Sin } E \text{ Sin } W \text{ Cos } \phi] = (RMS)^2$$

The square root of the previous quantity is the pickup of the loop. To find E we must minimize RMS or equivalently $[RMS]^2$ with respect to E:

$$\frac{\partial}{\partial E}[RMS]^2 = (\mu_0 N A \omega)^2 \left[-H_V^2 \,Cos\,E\,Sin\,E + H_H^2\,Sin^2 W \cdot Sin\,E\,Cos\,E - H_H H_V \,Cos\,\phi\,Sin\,W\,Cos\,2E\right]$$

Setting this derivative equal to zero and solving for E we arrive at our final solution to the problem:

$$\frac{2\,TanP\,Cos\phi\,SinW}{(TanP\,SinW)^2 - 1} = Tan\,2E$$

****

Note that this expression admits 4 solutions corresponding to both nulls and peaks being in error by E°. Also note that if W = 0 (signal coming just off the horizon) there is no error. Similarly there is no error if P = 0 (purely vertical polarization). Also observe that if ϕ = 90° , and TanP SinW = 1, the expression becomes indeterminant (=0/0); this corresponds to the fact that no peaks or nulls will be observed if the projection of the polarization figure into the horizontal plane is circular. For All Other Combinations of P and W There Will Be an Error. Let us examine just how large this error might be expected to be under normal conditions. Long haul DX signals tend to come in a low angles, rarely is W greater than 30° . A reasonable estimate for a large value of polarization rotation is ±20° ; therefore:

$$Tan2E = \frac{2(Tan\,20°)\ \ Cos\,0\ \ (Sin\,30°)}{(Tan\,20°\ \ Sin\,30°)^2 - 1} = -\,0.377$$

And E = ± 10.3°

Therefore we expect to see variations no greater than about ± 10° under normal conditions from this cause. This is in very good agreement with what is actually observed. Incidentally, it is now obvious that is desirable to have as clear as a view of the horizon as possible: the more low angle radiation that can be captured, the less one will see the effects due to polarization rotations in the ionosphere.

Second Station Error. If a null indicator of a sort that indicates total amount of signal being received (e.g. S meters, audio tones) is employed, there is a second type of error that is caused by the presence of a second station in the receiver bandpass coming from a different direction. Consider two vertically polarized signals approaching the loop from different directions; suppose that the first station is coming from 0° and has strength H_1 and the second signal is coming from a direction D° from the first and has a strength H_2. An analysis very similar to that given above indicates that there will be an observed bearing error of E° which is given by the expression:

$$TanE = \frac{SinD}{R + CosD} \qquad \text{where } R = H_1 / H_2$$

Let us now examine just how much of this second signal has to be present in order to "pull" the null by a significant amount. As an example, let us consider a case where the interfering station is 15° from the first station; we will now calculate just how much the null is 'pulled' toward the interfering station as the amount of interfering signal is increased.

If the second station is 60 db below the first (just barely detectable by SAH under ideal conditions; no audio possible from second station), E is 0.015° and is virtually indetectable.

If the second station is 40 db below the first (good SAH, but no audio possible unless the first carrier is unmodulated), E is 0.15° and is still negligible.

If the second station is 20 db below the first (audio begins to be heard under good conditions), E is 1.4° and is becoming significant.

If the second station is 10 db below the first (considerable audio), E is 3.6° and will definitely be noticed.

If the second station is 0 db below the first (equal signals), E is 7.5° which is intermediate between the values for the individual stations. Furthermore, as the amount of the second signal is increased, the observed null is pulled closer and closer to the value for the second station.

++++++++++++++++++++++++++++

Null Depth. A single signal with purely linear polarization (regardless of polarization angle) will yield a sharp and distinct null but the bearing angle may be displaced. An elliptically polarized wavefront (The usual form due to multipath and magneto-ionic effects) will yield a less distinct null which will become increasingly shallow and indistinct as the polarization figure becomes more elliptical until the projection of the ellipse becomes circular in which case there is no peak or null. The bearing error E will be the same as if the elliptical wavefront were replaced with a linear wavefront whose angle of polarization coincided with the semi-major axis of the ellipse.

Error Due to Polarization. If the signal is coming off the horizon (W = 0) there will be no error regardless of the polarization. Likewise if the polarization is entirely vertical (P = 0) there will be no error regardless of the wave angle. Where neither W or P are zero there will be a polarization error whose value depends upon the exact values of P and W. Under ordinary conditions the variation in bearing will not be more than about 10 due to polarization error unless the horizon is blocked in which case it will be greater.

Second Station Error. A second station can pull a bearing toward it if an indicator of total signal strength is used to measure nulls (e.g., S meters). This effect is so small as to be negligible unless the second station is less than about 20 db below the first station. With equal signals, the bearing will be intermediate between the individual values unless the stations are on exactly opposite sides of the loop, in which case no nulls will be observed. The depth of the null is degraded by the presence of a second carrier and is shallowest when the two stations are equal. A general rule-of-thumb is that unless the second station can be heard under the first the bearing error is probably negligible; beware of weak carrier mixtures in noisy backgrounds, however. The overall null observed on a jumbled channel such as 1484 corresponds to whatever station is dominating the channel when the measurement is made but no precise D.F. is possible under such conditions. Only with an SAH null indicator can second station error be completely eliminated.

Effect of Ground Reflections on Bearings. Only in the case of an ideally conductive ground can be exact analysis be generally useful. In the case of an ideal ground, there will be no observed polarization errors since all electric vectors must be normal to ground. Real earth will probably tend to reduce a loops sensitivity to polarization errors but much more work needs to be done on this problem.

Pickup of a Loop. The amount of signal picked up by a loop is directly proportional to the area and to the number of turns, Note however that doubling the area of a loop will only result in an increase of about 1 S Unit of pickup.

PART 2: IMPROVING LOOP ANTENNAS

In this article we will answer some of the most commonly asked questions about loops and direction finding, and provide some tips on improving loop antenna performance, both for use in direction finding and in the elimination of powerful locals. While the techniques to be described for balancing loop patterns must be incorporated into loops for direction finding application, the casual loop user will also benefit from deeper nulls, sharper tuning, etc.

1. Why use a loop at all?
 The MW loop antenaa has several highly desirable properties lacking in the ordinary longwire:
 a) While not directional in the same sense as, for example, a SW beam, the nulls of a loop permit the DXer to null out specific interfering stations. When properly designed and operated, even the strongest locals can be nulled down so far that sideband QRM is all but eliminated; in many cases, DX can be logged on local channels with the stations still on the air. A good alt-azimuth loop can frequently null a powerful local by 50 to 80 db.
 b) A good high Q loop (and Q's as high as 1000 are practically obtainable) provides a large measure of front end selectivity; consequently overload and spurious responses due to high power locals are greatly reduced or totally eliminated.
 c) For the DX'er in an electrically noisy urban location, much less QRN will be picked up by a loop than by a longwire of equivalent sensitivity. This happy circumstance arises because the loop is a magnetic antenna, whereas the longwire is an electric antenna. Near to a noise source, such as the neon sign on the pizza palor at the corner, there is actually more power in the electric component of the noise signal than there is in the magnetic component. Since the energy is divided up evenly, 50:50, in signals coming from distant stations, a loop actually provides quieter reception than an equivalently sensitive long wire. Many urban DXers have found that only loop antennas can supply enough quiet signal pickup to make DX'ing possible This noise suporession advantage is obtained only if the source of the QRN is near (say within ½ a wavelength) and does not hold for atmosphere noise.
 d) The loop can be used for directional finding.

2. But certainly I can't hear as much good DX with a loop as with my longwire, can I?
 a) In an electrically noisy environment, such as discussed above, switching from a longwire to a loop can result in an almost unbelievable signal to noise improvement.
 b) For those DXers fortunate enough to live in electrically quiet surroundings the DX-snagging potential of a good loop is still comparable with a random longwire, once the somewhat lesser pickup of the loop has been compensated for with extra RF amplification.
 c) Eventually, as a rural longwire begins to assume the dimensions and properties of a Beverage or a rhombic antenna, the loop becomes badly outclassed; not only will the 'giant' antenna feature very sharp directionality, but QRM and QRN from outside the antenna's field of view will be greatly reduced while the desired signal is boosted. But did you ever try to figure out how to rotate a 800' antenna?

3. But how can I get good DX when I've found that thepick-up of a loop is much less than that of a longwire?
 a) The loop that you tried might have been too small; since the pick-up of a loop depends upon the area of the loop, doubling the size of the loop will increase pickup by a factor of 4, all else remaining equal.
 b) Your receiver may not have enough sensitivity to make best the advantages of the relatively weak loop output. In this case, a preselector or RF amplifier such as the NRC FET LOOP BOOSTER will increase the signal from

the loop by enough to rival the pickup of a longwire. The relatively low pickup of a reasonable-sized loop (e.g. 3 foot square) is easily compensated for with RF amplification.

4. **Since the pickup of a loop depends upon the area, why not make a really large loop and thus dispense with RF amplication?**
The existence of the loop null depends upon thefact that the total amount of wire involved is short compared to the wavelength of the signals being received (i.e., total conductor must be a wavelength, otherwise the phase and current distribution in the loop is not uniform). Huge loops will indeed feature large pickups, but will inevitably have shallow and distorted nulls. A moderate sized loop, together with either a sensitive receive or a bit of additional RF gain will definitely perform better than a huge loop. Even a loop of the dimensions commonly in use today (4 foot on edge, 7 turn tank) has about 120 feet of oonductor - and this is already enough to 'blunt' nulls at the top of the band.

5. **Why not use ferrite to boost the pickup of my loop?**
a) This question is still 'up in the air' insofar as the technical literature is concerned. While the manufacturers of portable receivers discovered that ferrite-loaded loops were highly desirable many years ago, the question of whether or not the BCB DXer can make effective use of ferrite cored loops remains unanswered at this time. While loading a loop with ferrite increases the effective permeability of the antenna (and thus, in a sense, signals actually are "steered into" the loop), the actual increase in pickup depends upon a number of very complex factors. One rather extensive study reports that loading an air-cored loop with ferrite can result in an increase in pickup of roughly 20; this of course is equivalent to enlarging the size of the loop by a factor of about 4.5 (i.e., the area is increased by a factor of 20). Based upon the results of this particular study, which used commercially available ferrites, the question of ferrite loading of loops for BCB DX'ing seems worth pursuing.
b) The main problem at the moment, however, is that large ferrites are just not available. At one point in the manufacture of say a ferrite rod, the ferrite powder must be heated to a very high temperature; unfortunately ferrite is very brittle material and tends to crack during cooling. At the moment, the largest commercially available ferrite rods are about 3/8" in diameter and 12" long. As best we know, even the simple experiment of winding a MW loop antenna on a bundle of ferrite rods (and effective length can be extended with the use of G.E.'s "Ferrite Glue") has not been attempted, at the time of this writing that is. A bit of enlightened experimentation could well produce a relatively inexpensive ferrite-cored DX loop of considerably smaller size than the air-cored loops presently in use.

6. **I want to put my loop on the roof and control it remotely - how do I do that?**
a) It would do you alot of good to read the chapter on Remotely tuned Directional Loop Antenna found elsewhere in this book. I will say this, it won't be easy and there is a problem with pattern distortion.
b) Pattern distortion. As we'll discuss in a moment, the primary cause of loop malfunctions (either inability to null out locals or inexplicable directional finding errors) is vertical pickup from the loop or the line connecting the loop and the receiver. Since even the slightest trace of signal pickup other than that from the loop will seriously distort or even destroy the loop null (relevant equations forthcoming in Part 3), it will be effectively impossible to prevent the lead-in wire from a remote loop from acting as a vertical antenna and therefore rendering the loop ineffectual. It has been our experience that loop-receiver transmission

lines longer than 6 to 10 feet in length will begin to introduce enough vertical (e.g. electric) pickup to seriously distort the loop pattern. While several methods to eliminate this pickup come to mind, the compensatory networks will be dependent upon signal frequency, and thus very complex to operate in actual practice. In summary: it may be easier to move your DX Shack up to the attic than to put a remote loop there.

7. Why does my loop null better on one side than the other for certain stations and why aren't the nulls exactly opposite (i.e. 180° apart) ?

a) This is the primary problem with most loops in use today. There are several names for this highly undesirable condition: Pattern distortion, vertical effect, reciprocal asymmetry, electrostatic imbalance, etc. These are all equivalent terms and refer.to the fact that one face of the loop behaves differently than the other. In a perfectly balanced loop antenna (essential for reliable direction finding and highly desirable for eliminating locals), both peaks and nulls of the antenna are identical. If you find that it's easier to null some particular station with one null rather than the other, your loop is unbalanced. In a perfectly balanced loop, not only will peaks and nulls be exactly 180° apart, but this will be the case for all stations.

b) The term reciprocal asymmetry is used to describe just how well balanced a loop antenna is. Reciprocal in this context means "opposite" or "back to back"; asymmetry reflects just how much the loop nulls and peaks differ. Accurate, precise, and consistent direction finding is possible only with a balanced loop (i.e. no electrostatic imbalance, undistorted pattern, zero reciprocal asymmetry, no vertical effect, etc.)

c) The test for loop imbalance (from here on, we will consider imbalance to be cause, and reciprocal asymmetry the undesirable result) is very simple. Tune to a local station during the middle of the day, and note both the position of the null and the depth of the null (say on the S meter). Now swing the antenna around to the other side and try the other null. If the loop is balanced, the S meter will show the same value for each null; in addition, the orientation of the loop should have been the same for each null, except for an exact half-rotation. If either or both conditions are not met, the loop is unbalanced and requires modification as follows:

Figure 1 shows the basic circuit for almost all the loops currently in use: a tank circuit of 5 to 10 turns, a 365 pfd tuning capacitor, and a take-off link (one or two turns) which feeds the signal to the receiver.

Step 1 in balancing a 'sick' loop is to replace the feed-line with either a piece of two conductor coax or a piece of shielded two-conductor microphone cable. Note that the outside shield or braid is connected to the ground of the receiver input strip. This simple technique should result in a marked impprovement in loop balance. Figure 2 shows this simple modification.

Step 2 will produce even better balance, but at the cost of some reconstruction. In addition,to the use of balanced feed-line, it is highly desirable to connect the center point of the take-off link to the feed line shielding. This will not affect loop performance, except to improve the balance of the loop. Unfortunately, this simple modification is impossible to make on a loop with a single-turn take-off link since the center point of this turn will be located at the top of the loop; running a wire from the center point of the link on top to the feed-in shield (necessarily located at the bottom of the loop) would introduce enough vertical pickup to worsen the situation, rather than improve it. Figure 3 shows the easiest way to balance the take-off link: increase the number of turns to 2 - now the center point of the link is on the bottom of the loop and therefore near to the point where the feed-line is connected to the loop. Morely connect the center-point of the take-off link to the feed-line ground with as short a wire as possible. Increasing the number of take-off link turns will probably boost loop output, but will affect the frequency range of loop tuning also; in all likelihood, the loop will no longer tune to the bottom of the band. Remedies for tuning problems will be presented later in this article.

Balancing the feed-line and take-off link as described above, should reduce asymmetry to a level where the null directions will be within a degree of the desired value of 180 . If this is not the case, the plane of the loop windings is probably twisted or skewed, and the loop will have to be rebuilt (or atleast rewound).

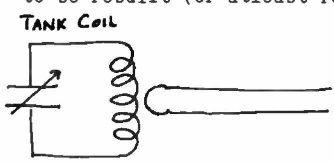


Figure 1. Standard loop design - multi turn tank and single turn take-off link.

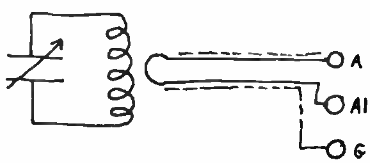


Figure 2. Balanced feed-line: double coax or shielded two conductor mic cable. Connect one conductor to "A" terminal on receiver, and the other to "A1". Shielding is connected to the ground terminal.

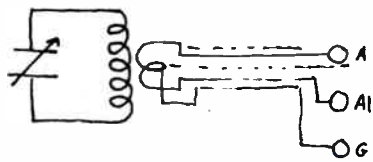


Figure 3. Balanced lead and balanced take-off link. The center point of the 2 turn take-off link is connected to the feed-line shield at the loop.

8. Now that my loop is balanced (nulls 180 apart and equally deep), why can I null some locals better than others?

a) There are two distinctly different causes for this situation - one has to do with the nature of the ground between the receiving site and the local transmitter (groundwave tilt)[2] and the other results from the presence of wires (power lines, phone lines, cable tv, etc) near the loop (reradiation)[3]. The technique to be now described will essentially cure the first problem, and will often help with the second. In most cases, conversion of a well-built, well-balanced loop into an altazimuth loop will permit the urban DX'er to null most if not all of his locals by at least 80 db, We have, for example, often nulled local WHDH-850 (S9 + 70db) to a level below S9, thus obtaining good reception of WJW, WJAC, et al. Before describing the altazimuth conversion, a few words about groundwave tilt and reradiation for those interested.

b) Groundwave tilt is a phenomenon which affects even very close and powerfull locals. As the groundwave spreads over the earth near the station, the imperfect nature of real earth causes the wavefront to become tilted forward in the direction of propagation, even though the signal may have come from a perfectly vertical transmitting antenna. In addition, the polarization figure of the signal is also altered as it passes over the ground. Thus, even in the daytime when skywave return is essentially negligible, a situation similiar to those producing skywave polarization errors can exist with local signals. This phenomenon can often result in considerable DF errors on nearby locals, even in the daytime.

c) Reradiation from phone lines, power lines, nearby antennas, etc., can also produce what is equivalent to polarization rotation and wave tilt on locals. The "shallow nulls" resulting from this are usually accompanied by direction finding errors, and these errors are termed site errors to distinguish them from groundwave tilt errors, skywave polarization errors, etc. A good balanced altazimuth loop will often permit effective elimination of locals, even in areas where reradiation is severe. Reliable direction finding is not possible in such an area however, even with a perfectly balanced loop. The only way to find out whether or not your location is suitable for DF is to actually give it a try.

d) To obtain the deepest possible nulls on locals, it is necessary to modify the loop so that is can be tilted as well as rotated. Tilting the plane of the loop compensates, in effect, for the signal tilt and rotation produced by the factors outlined above. Figure 4 illustrates this modification; in keeping with the conventions established in astronomy, rotation of the loop changes the azimuth of the loop, and tilting changes the altitude. Thus, the term "altazimuth" will be used to describe such a loop. The mechanical problems raised by introducing tilt in a large loop can be formidable. In Figure 4, an additional pivot point has been installed at the top of the loop shaft. A counterweight must be added to physically balance the tilt-arm; and a wingnut used at the pivot point "P" to permit locking the loop into any particular position.To use the altazimuth form of loop to eliminate a local, first rotate the loop (with zero tilt) and find the null. Then increase the tilt slowly and "rock" the azimuth back and forth a few degrees. In one position, and one position only, the signal will drop to a very low value (typically 50 to 80 db down), and even become inaudible. This will hold for only one particular position of the loop face, i.e., when the plane of the loop face is parallel to the major axis of the magnetic polarization figure.

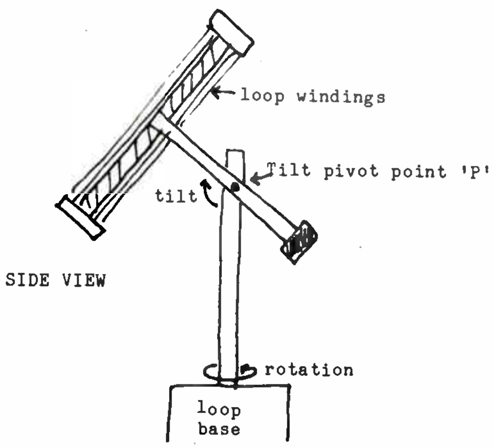


Figure 4.
One way to convert an ordinary box loop to an altazimuth loop. Dotted lines represent loop windings. A wing nut on the pivot bolt will permit the operator to 'freeze' the position of the loop face.

9. Why can't locals be TOTALLY eliminated?
The ultimate amount that a local can be nulled depends upon the shape of the polarization figure of the arriving signal - only a purely linear polarization figure can be nulled away totally. Because of slight skywave return (even in the daytime), and the effects of groundwave tilt and reradiation, actual local signals are slightly elliptically polarized. This ordinarily minor factor is the ultimate determinant for null depth on a local signal.

10. Why does the null position for a local seem to vary slightly with time even in the daytime?
When a powerful local is nulled very far down in the daytime, the tilt and azimuth must be readjusted slightly from time to time; this is due to the presence of very small quantities of skywave return, which varies slowly as the daytime ionosphere changes. This is a very sensitive technique for the actual observation of this otherwise invisible daytime skywave return. At night the amount of skywave return is greater and consequently the local null position is even more variable.

11. Why do night bearings on distant stations seem to change so rapidly?
a) Ionospheric structure is constantly changing and these variations produce continuous variations in wave angle (W in part 1). Polarization angle (P) and polarization ellipticity (O). For direction finding purposes, the effect of these variations can be greatly reduced by averaging bearings over a long period of time.
b) When attempting the elimination of non-locals at night, all the DX'er can do is attempt to 'follow' the wandering null position. This task is greatest for stations near enough for both skywave and groundwave reception to occur simultaneously.

12. What is the effect of tilting the loop face on direction finding bearings?
Even a slight bit of tilt will change DF bearings considerably. For DF, an altazimuth loop must be maintained in a "no tilt" position, ie with the plane of the loop face vertical.

13. What if the loop won't tune to the top of the band?
a) This is a very common problem, and arises when the sum of the minimum tuning capacitance (usually about 5 pfd) and the distributed capacitance in the tank coil winding is too high. Several alternative solutions are possible, although some are more desirable than others.

First, examine the tuning capacitor and see if there are small padding capacitors on the capacitor body. If present, there will be one per capacitor gang, and a small flat-headed adjustment screw will be seen near the solder lug on the stator. Unscrew this capacitor all the way, or remove it if possible. The loop will now tune higher and no other properties will be affected.
If this is not sufficient, increase the spacing between the windings on the tank coil. The distributed capacitance will usually be reduced. This will often add 50 - 100 KHz of additional tuning at the top of the band. Excess spacing will tend to skew the loop plane and blunt the nulls, however.
The most extreme solution is to remove a turn from the tank coil. Both the tank inductance and distributed capacitance will be reduced, and the loop will tune considerably higher. Pickup of the loop will be reduced however, and it may no longer tune to the bottom of the band.

14. And if it won't tune to the bottom of the band?
More capacitance is needed across the tank coil. Since it is much easier to add capacitance than to remove it, many loop designers prefer to simply switch in additional capacitance to get to the bottom of the

band. Figure 5 shows this addition; once the loop will tune to the top of the band, just switch in additional capacitance to cover the bottom portion of the band.

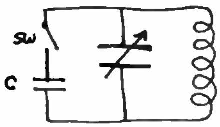


Figure 5. In the event that the loop won't tune to the bottom of the band, switching in additional capacitance (C= 300 pfd, mica) will extend the tuning range.

15. How do I make the tuning sharper?

a) Just how sharply the loop tunes (the Q of the loop) is primarily determined by two factors: tank resistance and loading. Generally speaking, it is desirable to obtain as high a Q as possible - not only because the additional antenna selectivity will reduce overload from locals, but because the pickup of the loop increases with Q.

b) The Q of the tank is directly influenced by the total resistance of the wire in the tank coil (as measured at the frequency of operation). With over a hundred feet of wire in the tank circuit, the type of wire used will affect the tuning Q greatly: the higher the resistance, the lower the Q. Since "skin effect" is significant at BCB frequencies, it is therefore desirable to use multistrand wire in the tank coil; the more strands the better. Ordinary lamp cord (split down the middle) will provide higher Q than a single conductor of equivalent size. Even better is to wind the tank with miniature coaxial cable (RG-174/U, for example) with both shield and center conductor connected together to form a single conductor.

c) The effective Q of the tank is also directly related to the nature of the circuitry connected to the output of the take-off link. In particular, the higher the impedance of the circuit receiving the loop output, the higher the Q of the tank tuning. The very large gain of the NRC FET Loop booster is due partially to the amplification provided by the FET, and partially because the high input impedance of the circuit greatly increases the Q of the tank circuit. Addition of a FET booster to a good loop often results in loop tuning that is so sharp that a vernier must be added to the tuning capacitor.

16. What do I do - all stations null in the same direction!?

This is site error at its worst - we've seen two cases like this so far. This is the result of extreme reradiation and shielding due to the presence of nearby steel beams, aluminium-foil coated wall insulation, wire meshing in the walls, etc. The only cure is to move.

17. What is the optimum loop for DX?

There isn't one best design - it depends upon what the loop is going to be used for. "Box" or "frame" loops (like the NRC loop) deliver more signal than "spiral" designs, but the fact that the spiral design features all windings in a single plane can make construction and balancing easier. A large loop delivers more signal, but is more prone to distorted patterns and shallow nulls because of excessive conductor length than a smaller loop.

****

A LARGE APERTURE FERRITE CORE LOOP ANTENNA FOR LONG AND MEDIUM WAVE RECEPTION

By: James V. Hagan

It didn't require many sessions at the dials after completing the NRC 3-foot altazimuthal loop to realize what a valuable DXing aid it is. Being a longwave DXer, I could visualize the advantage to be gained by using a similar antenna for longwave DX reception. What was needed was a loop smaller and more portable than the NRC loop. It would tune from 10 kHz to 500 kHz or higher, while still maintaining the excellent performance characteristics of the large NRC loop. This is a "tall order" for any small antenna, but all performance characteristics were obtained with the use of an oversize ferrite core. The antenna is described in this article. For those readers who are interested, details are provided later to enable procurement of a kit of parts for the antenna itself, which covers both long and medium wave reception, as well as a sophisticated long wave converter to enable operation with a high-frequency receiver.

SOME THEORETICAL BACKGROUND

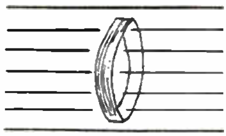
Since loop antenna theory is well described in numerous texts, it won't be covered here. However we will present a few not so well known facts applying to loops with magnetic cores.

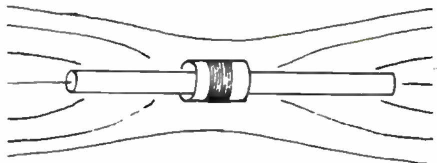
A radio wave consists of oscillating electric (E field) and magnetic (H field) fields propagating through space. Both fields are perpendicular to each other and to the direction of propagation. The two fields are also displaced in time such that when the H field is increasing to its maximum value, the E field is decreasing to zero, and vice versa. In this way the energy in the wave is alternately exchanged back and forth between the E and H fields as the wave propagates forward. Antennas can be made that will respond to either of these fields. A short vertical whip responds to the E field, while a loop or magnetic antenna like the one in this article responds to the H field.

A loop antenna consists of a coil of wire through which some of the magnetic lines of force from the H field pass. Since the field is oscillating, an AC voltage is induced in the coil. The magnitude of the induced voltage is dependent on the frequency of the field, the number of turns on the coil, and more importantly for our purposes the number of magnetic lines of force passing through the coil.

At the receiving antenna, it is not possible to control the frequency of the field or the number of lines of force passing through a unit of area (strength of the field) as these two things are determined by transmitter frequency and power, and the number of turns on the loop is fixed within certain limits by the desireability of tuning the coil to the particular frequency. This leaves the physical size of the loop as the only parameter that can be varied to affect the induced voltage in the coil. As the cross-sectional area of the coil is increased by making the coil larger more lines of force will pass thru the coil since they are evenly distributed thru space near the antenna. More lines of force through the coil thus yields a higher induced voltage, as prevoiusly explained. If the loop is tuned, the voltage induced in the loop will be multiplied by the "Q"of the circuit. This means that the loop "Q" (which can be described as sharpness of tuning) should be as high as possible.

In an air core loop the effective area of the loop is very nearly the area enclosed by the loop. In the case of the NRC Altaz loop this is about 9 ft^2 (9 square feet). When a ferrite core is used, the effective area can be many times larger than the cross-sectional area of the coil wound on the core. This can be explained as follows. The magnetic lines of force behave somewhat like an electric current, following the path of least resistance. Air or space offers a relatively high resistance to the passage of a magnetic field whereas ferrites have a relatively low resistance to the magnetic field. Therefore when a ferrite rod is placed in a magnetic field, many of the lines of force near the rod will bend toward the rod and enter it to take the lower resistance path through the rod, rather than remain in the higher resistance air path.





Lines of force; vicinity of air loop. Lines of force; vicinity of ferrite.

By referring to the above diagram it is easy to see how the ferrite core "attracts" lines of force from an area considerably larger than its own cross section. It can be shown that if certain conditions are met, a ferrite core loop will have the same effective area as an air core loop having a diameter equal to the length of the ferrite core. In other words - a coil wound on the center of a suitable ferrite rod of 36 inches length can be equal to the much bulkier NRC loop in signal snatching ability. As actually built, the 42 inch ferrite core provides an effective area about 1000 times larger than the actual cross-sectional area of the coil at its center.

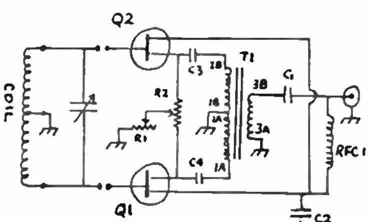
The use of a ferrite core also results in a much increased inductance of the coil as compared to the inductance of the same coil with an air core. This makes it possible to wind coils with sufficient inductance to tune the long wave bands with a relatively small number of turns of wire. The use of less wire results in a lower resistance for the coil which in turn causes the coil to have a higher Q. This of course is another desireable effect.

DESCRIPTION OF THE ANTENNA

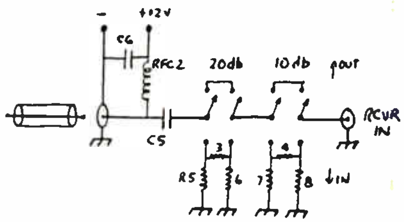
The 42 inch (1.0668 meter) ferrite core is made by gluing seven smaller 12" x 0.6" cores together. An overlapping pattern is used to keep magnetic resistance low and to reduce flux leakage at the joints. This arrangement was proven to be the best of several including a simple bundle of all seven with the ends in the same plane. This was determined in actual receiving tests. A set of coils are wound on sections of rigid PVC plastic pipe. The coils are each center-tapped and consist of 40 turns, 246 turns and 1280 turns of #30 wire. The respective tuning ranges of the three coils are 350-1950 kHz, 64-365 kHz and 13.6 to 75 kHz when resonated with an inexpensive Japanese 365 pf variable capacitor. This particular capacitor is used because it has an unusually low minimum capacity of about 8 pf. A fourth tuning range can be obtained, from 10 to 14 kHz, by connecting a fixed capacitor of 330 pf across the 1280 turn coil. The 40 and 246 turn coils are wound in a single layer, while the 1280 turn coil is wound universally in 32 quarter-inch wide pi's of 40 turns each. This makes a difficult winding job, but it is absolutely necessary to obtain a low distributed capacity value in a multilayer coil of this size. The unusually wide tuning ranges are a result of low distributed capacity of the coils, low input capacity of the FET preamp and the low minimum capacity of the variable capacitor. With more conventional tuning ranges, an extra coil would be required to reach the lowest frequencies. The Q of the coils is high, ranging from 50-75 at the high end of each range to 250-360 at the low end. The coils are fitted with binding posts so that they can be slipped over the core and connected to the FET preamp when changing the tuning range.

The small physical size of the tuning capacitor produces less loop unbalance than the usually used type capacitor with its large metal frame connected to one side of the loop. Still, a small amount of capacity must be added to the other side by means of a "gimmick" capacitor (very small value) in order to get perfect loop balance. The housing for the core is made by sawing a 43" length of 2½" diameter PVC pipe in half along its length. One side is hinged while the other is fitted with latches so that the housing can be opened to allow removal of the core while changing coils. Provision is made for rotation of the housing in both azimuth and elevation so that the best possible null may be found regardless of wavefront tilt.

The FET preamp used is the same one, basically, described earlier in DX News except that it is built on a PC card and component values have been increased to extend the frequency response down to 10 kHz. An actual size print of the PC card foil pattern is provided with the manuscript. Due to the reduction effect of printing the bulletin, the resulting illustration you see here will be only about 70% of scale, more or less. However a suitable card may be etched by the reader, or a true scale template obtained (SASE please!) or it may be preferable to obtain the kit of parts which of course includes the board. Below are preamp and attenuator schematics.



LOOP PREAMP



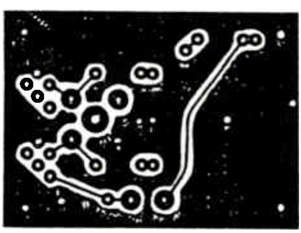
POWER COUPLER/ATTENUATOR

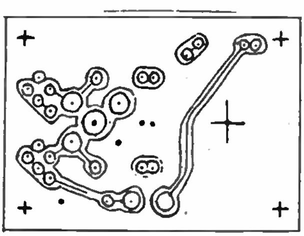
Parts List

1 ea. 2 uf 16v.	2 ea. feedthrough
2 ea. 1 uf 3v.	1 connector
1 ea. 1 uf 16v.	1 minibox, 2 x 2.75 x 1-5/8
1 ea. 22mhy RFC	4 spacers, 1/4 inch
1 ea. 1K ohm pot	4 screws, 6-32 x 1/2"
1 ea. 2500 ohm pot	5 hex nuts 6-32
2 ea. 2N4416 trans'r.	20 feet #30 magnet wire
2 ea. sockets for above	1 screw 6-32 x 1 inch
1 PC board	1 popsicle stick
*1 [illegible]	

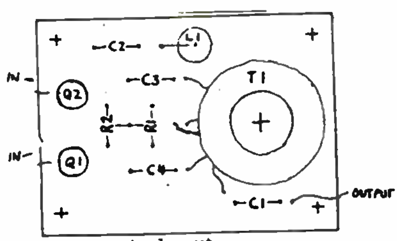
(attenuator parts, see previous DX News article as detailed in reference section)

*1 18 turns #31 wire, trifilar wound on an Amedon FT-114-75 core





board foil



parts layout

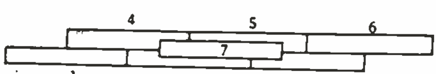
PERFORMANCE

Results when using this antenna have been everything I had hoped for. Nulls of at least 70 db are possible with signals received by groundwave. My 1240 khz local WMMB can be nulled well enough to permit reception of other stations on 1240 even in the daytime. On longwave, local 400 watt beacon "SQT"-257 (Satellite, FL.) can be nulled down into the noise level, allowing daytime reception of distant "AEN"-256 in Allenhurst, GA. The use of nulling techniques has provided good sunset reception of MSF in England (60 kHz) over WWVB in Colorado, also on 60 khz; a previously impossible feat. QRM-free reception of the longwave Trans-Atlantics such as Azilal, Morocco on 209 kHz and Tebessa, Algeria on 251 kHz are also available for the first time ever, by nulling beacons in the Bahamas on the same frequencies.

Weak signal performance is very good, although not quite equal to the NRC loop. However, Hawaiian KORL-650 was heard here in the fall of 1975. Other stations heard were Moscow-173, and many other TA's on both MW and LW. On the very lowest frequencies, all presently operating Omega stations - Norway, Trinidad, Hawaii, North Dakota, Japan and Argentina have been heard. Super-powered Navy teletype station NAA operating on 17.8 kHz in northern Maine produces an incredible signal of 20,000 uV at the input of the FET preamp. At the other end of the spectrum, many very low power 160 meter amateur signals from all parts of the country have been copied around the 1800-1820 kHz range.

CONSTRUCTION

Begin by gluing six ferrite rods together such that each overlaps another by 6 inches to form a single unit of rod 42 inches long. It is easiest to lay the six cores and glue the flat interfaces and ends between the rods. Eastman 910 adhesive is highly recommended for this but it may not be available to everyone. (The factory is in Kingsport, TN.-ed.) Any good epoxy glue can be used in place of Eastman 910. When the glue has set completely go over all joints with a generous supply of epoxy glue. It is best to let the glue set on one side, then turn the cores over and do the other side. Glue a seventh core over the center of the rod formed by the six cores at the time the second side is glued. Again let the glue set, then apply a generous supply of glue along the entire seam formed between the seventh core and the other six. It is important to glue in this manner so that the rod will withstand the repeated handling when coils are changed. Refer to the diagram below.



Top view of core

End view of core

Slip a 15 inch length of 1 inch heat shrinkable plastic tubing over each end of the rod up to the seventh core. Carefully shrink the tubing over the kitchen stove. Tightly spiral-wrap the cores with black plastic electrical tape in the center for the entire length of the seventh core. A 42" length of some very large size heat shrink tubing would be a better cover for the rod than the one just described, but this is difficult to locate. If any heat shrink tubing is not available, the whole rod could be wrapped with electrical tape. Do not omit the tubing or wrap as it helps strengthen and protect the assembly. Although the finished rod is strong, use extreme care when handling it because ferrite is a ceramic material and is subject to breakage, just as china and glass are.

Next cue three sections of 1¼" ABS sink tailpiece, one each of 2-7/8, 4-1/2 and 8-7/8 incles length. Do not confuse this with 1-1/4 inch ABS pipe. It is similar but the diameter is different. Sink tailpiece is the pipe that makes the connection from the sink drain to the trap. This is available in 12 inch lengths from Montgomery Ward stores, and probably most other plumbing stores as well. Two lengths are needed.

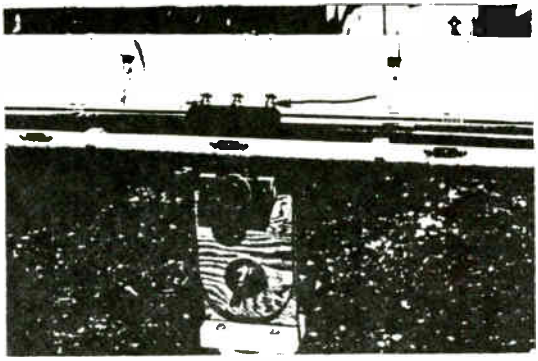


Fig. 1. Center of loop, top unhinged. Note balance wire on right hand binding post. Tuning knob is directly below coil. Wing nut for elevation adjust is visible below tuning knob. Detail of core support is visible to left. 350-1950 khz coil shown in place.

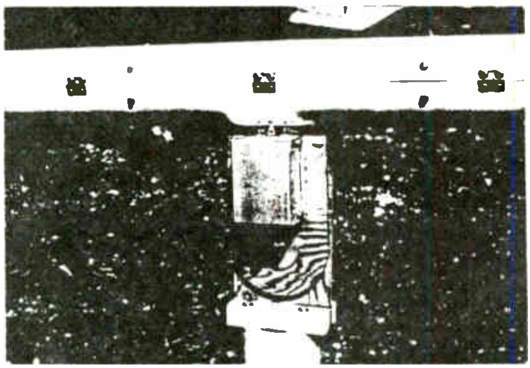


Fig. 2. View as Fig. 1. except from other side. Preamp (cover in place) visible in center. Top is locked in place, protecting core and coil. Note feedthroughs (coil to FET gates) on top of the preamp.

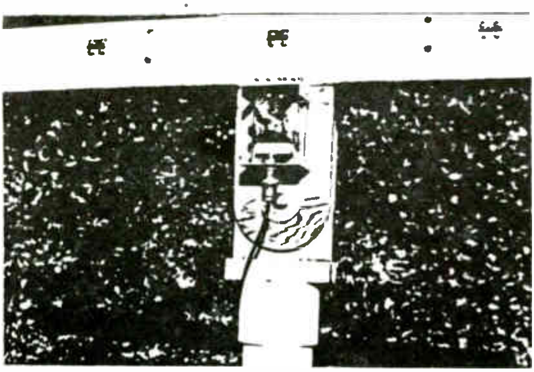


Fig. 3. View as Fig. 2. Preamp cover removed. FETs are the 2 white dots at extreme top inside preamp; toroid at bottom. Coax lead (signal and power) to attenuator box is in place, a BNC connector used. (Black area at bottom is shadow of loop).

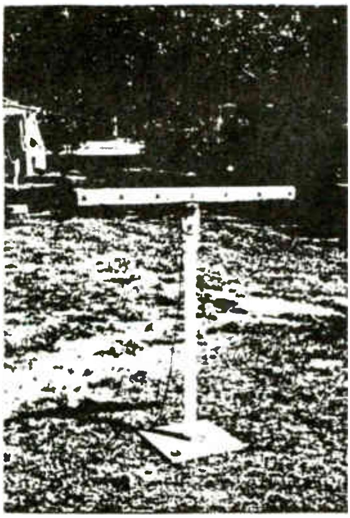


Fig. 4. Complete loop assy.

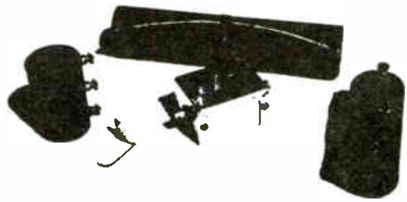


Fig. 5. Attenuator (0-10-20db) and power coupler in center; 3 coils; pointer for setting circle.

Fig. 6. Internal view of attenuator.

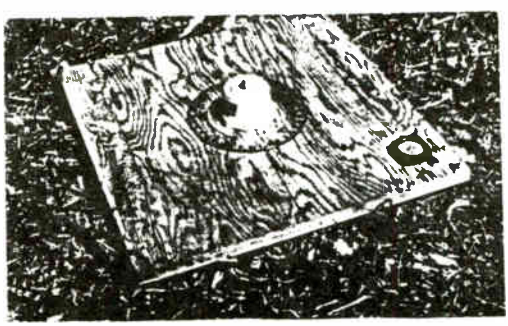
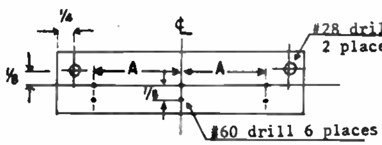
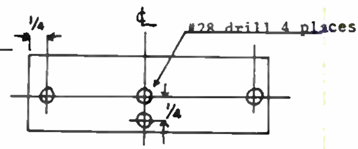


Fig. 7. Base, PVC plug, 360° setting circle; compass at right.

Also cut identical pieces of 1-1/2" ABS drain pipe. PVC pipe could be used here if the thin wall kind is available. Do not use Schedule 40 PVC as its inside diameter will be too small. Be sure to cut the pipe ends square. It may be possible to do this with a mitre box but the following method works well. Wrap a sheet of notebook paper around the pipe. Carefully square it up and tape it to itself in 2 or 3 places to keep it from unwinding. If one end of the pipe is already square, measure the desired length from this end and mark the spot. Slide the paper over to this mark. Use a marking pen or pencil to lightly trace back and forth over the edge of the paper, onto the pipe, all the way around the pipe. When the paper is slid off the pipe, a series of closely spaced lines, very neat and even at one end will remain. Using the even line ends as a guide, draw a continuous line around the pipe. This line will be perfectly square. If you are careful enough, it may be possible to use heavy construction paper and use the paper's edge itself as a straight edge to guide the pen directly around the pipe. Or perhaps a tubing cutter large enough is available. Once the pipe is marked, use a hacksaw to cut around the pipe. Do not attempt to cut through the pipe all at once. Cut in just a little, then rotate the pipe a bit and cut some more. Go around the pipe at least once before cutting through to the interior surface at any point. Thus with care, a very good squared end can be made. Use a fine file to remove the burrs and smooth the end. Drill the pipe sections according to the diagram below. Note that the two end holes in the 1-1/4" tail piece must match the two end holes in the 1-1/2" ABS pipe when the tail piece is fitted inside the 1-1/2" ABS pipe of the same length.



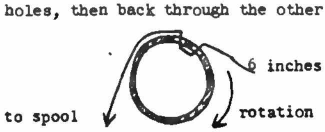
1-1/4" tail piece



1-1/2" ABS pipe

(For pipe length of 2-7/8", Dimension "A" is 3/8 inch. For pipe length of 4-1/2", Dimension "A" is 1-13/16 inch and for 8-7/8 length, "A" is 4 inches.)

Start winding the coils beginning with the 2-7/8" length of 1-1/4" tail piece. Thread about 6 inches of #28 magnet wire from a spool through one of the #60-drilled end holes, then back through the other hole as shown.



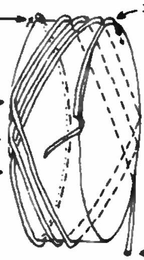
Winding is accomplished by applying tension to the spool and turning the pipe, rather than wrapping the wire around the pipe.

Tuck the six inch free end into the end of the pipe to get it out of the way and wind 20 turns of wire from the spool onto the pipe. The spool can be supported on a dowel rod or piece of metal rod, the other end of which can be clamped in a vise. Tension must be maintained on the wire to insure a good wind. Cut the wire about 6 inches longer than the 20th turn and thread this through the #60-drilled center holes as before. Thread another 6 inches of wire from the spool through the center holes so that the free end comes out the same hole as the free end of the 20th turn. Continue winding another 20 turns on the pipe by turning the pipe in the same direction as before. This is important to insure that all of the turns are wound in the same direction. At the end of the second 20-turn wrap, again cut the wire 6 inches too long and thread this through the remaining end holes and pull tight. Use chemical dip compounds or if not available, fine sandpaper to remove the enamel insulation from the free ends of the wire. Twist the center leads together and solder.

You should now have a tight and even 3/4" long winding of 40 turns, center-tapped. This will be the 350 to 1950 kHz coil. Set this aside. Now, the 4-1/2" length of 1-1/4" tail piece is similarly wound with #28 magnet wire except that the total number of turns will be 246, and the center tap is made after the first 123 turns.

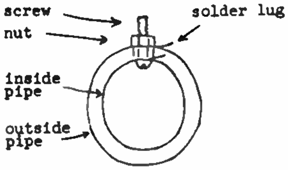
A different and unfortunately more difficult technique is required for the 1280 turn coil. Unlike the previous two coils - which can probably be wound in a single sitting of 15 to 20 minutes each - this coil will require 4 to 8 hours' labor and should not be attempted in a single sitting, or else you may reinvent a modern version of the Chinese Water Torture. Keep some Scotch tape nearby to secure the end of the winding between sittings or during interruptions. A modified form of the Universal winding is used. It is not easy to wind and may require a few short practice runs before beginning the winding of the coil itself.

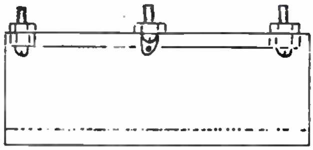
Begin by marking the 8-7/8" length of tailpiece into thirty two 1/4" sections; 16 either side of center. Thread 6 inches of #30 wire (note change in wire # from other coils) through the #60 center holes and wind 21 turns on the pipe. The 21st turn should end on the first 1/4" mark one side of the center. The next 19 turns will be universally would on top of the first 21. This will result in a "pi" of 40 turns with a width of 1/4 inch. To make the universal winding, refer to the drawing below.



Universal Wind showing 1/4 of first, and 3/4 of last solenoid turns; and 2½ turns of Universal winding.

The drawing shows part of the first turn and 3/4 of the 21st turn. The turns between the first and 21st are omitted for clarity. Notice that the universal turns 22, 23 and up to 40 cross the width of the pi and return, once each turn, zigzagging from edge to edge. It will be easier to visualize this if a universally wound coil such as a multi pi RF choke or a TV flyback transformer is inspected. Be sure you understand the universal winding concept before proceeding. When the first whole pi is complete, apply a small amount of coil dope (cement) or Duco glue over the turns at 3 equally spaced places around the pi. When the glue has set, the second pi will be wound, exactly like the first but in the second 1/4" section from the center. Continue winding pis, moving away from the center of the pipe, until you have wound 16 pis and have reached one end of the coil. Cut the wire only after the 16th pi is complete, and secure it by threading it through the end holes. At this point there will be 640 turns on the coil. Now, starting again at the center but working towards the other end of the form, wind the 2nd sixteen pis. When these are done, sandpaper and solder the ends of the wire, joining center leads for the center-tap, as was done on the previous two coils. Each coil is fitted inside the section of 1-1/2" ABS pipe of corresponding length. Use 6-32 x 3/4" round head brass hardware and #6 solder lugs as shown in the drawing. Note that the end solder lugs are installed inside the 1-1/2" ABS pipe, while the center lug is installed on the outside. Also note that the center screw is only 5/8" long, does not go through both pipes, and has only an external nut.
(see drawing on next page.)

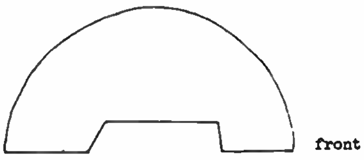




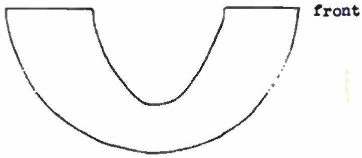
Solder the coil center and end leads to their respective solder lugs. Clip off the excess wire. The end leads will now be completely inside the assembly and the center lead will pass through the remaining #28 hole to reach the external center solder lug. The protruding #6 machine screws are fitted with #6 knurled thumbnuts. The coils are now complete. To make the range extender for the low frequency coil, solder a length of bare hookup wire to both leads of a 330 pf silver mica capacitor. Cut these leads just long enough to reach the end terminals of the large coil when the capacitor is positioned near to the center terminal. Put sleeving over both leads and solder a spade lug to each free end, so as to slip under the knurled thumbnuts. This will be attached only when coverage below 14 kHz is desired.

Cut a 43-1/2" length of 2-1/2" thinwall PVC pipe. If this size is not available, 3" PVC of any wall thickness can be used, although larger end plugs and internal supports will have to be fabricated. When cutting, square off both ends as was done with the coil forms. Carefully mark a straight line along the pipe from one end to the other. Be sure this line is parallel to the center line of the pipe. Measure exactly half way around the pipe from this line and mark the pipe with another line from end to end. Using the blade removed from a hacksaw, saw the pipe lengthwise along one line. Turn the pipe over and saw along the other line. Use a fine file to remove the burrs and smooth the cut surfaces.

The two halves are hinged together with seven small brass hinges equally spaced along the pipe beginning 1-1/8" from the ends. Use #4 x $\frac{1}{4}$ screws. Small brass latches are fastened to the other side of the pipe opposite each hinge. Circular end plugs are cut from $\frac{1}{2}$-inch plywood. The plugs are made the same size as the inside diameter of the pipe for tight fit. Place the plugs just inside each end of the pipe. Secure each plug to the section of pipe that you designate as the bottom half with three #6 x $\frac{1}{2}$" sheet metal screws. Now, upper and lower supports are required for the ferrite core itself. These are also cut from $\frac{1}{2}$" plywood. Two of each are required. A pattern is shown below, approximately 70% of full size. (view from side).

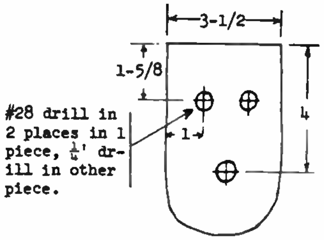


Upper Support

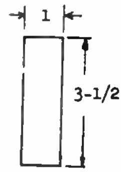


Lower support

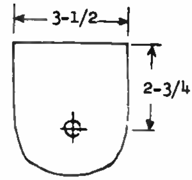
The supports are fastened inside the housing pipe with #6 x 1/2" sheet metal screws. Locate them 5 inches from the center of the tube, the upper and lower supports going respectively into the top and bottom sections of the housing. Use 3 screws in each support. Next, make the elevation yoke. Cut the following parts from 1/4" plywood.
(see next page)



Yoke Side (need 2)

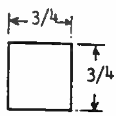


Spacer (need 1)

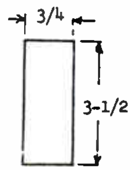


Yoke Pivot (need 1)

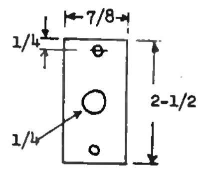
Above Material: 1/4 inch plywood



Capacitor Mounting Block (need 2) (1/2 inch plywood)

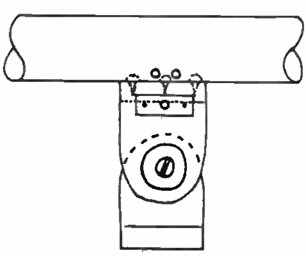


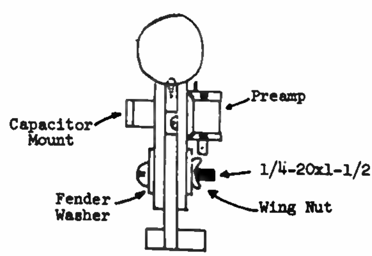
Pivot Mount (need 2) (1x2 cut in half)



Capacitor Plate (need 1) (center piece cut from protractor)

Assemble the parts as shown in the photographs and following diagram. The housing is fastened to the yoke spacer with three #6 x 1" sheet metal screws. All other parts are glued together, except for the capacitor mounting plate which is mounted with two #4 x 1/2" sheet metal screws. The FET preamp is mounted to the elevation yoke with two #6 x 1/2 inch sheet metal screws. Refer to the diagrams below.





The yoke pivot is mounted to the vertical PVC pipe with four #8 x 1-1/4" sheet metal screws. The vertical support is a 36 inch length of 2-1/2" PVC pipe. A female threaded adapter is glued to one end to serve as the azimuth pivot, enabling bearing selection. A 2" to 1-1/2" reducing bushing is glued to the other end to take the elevation pivot mount. A 3/4" plywood square 18 inches each side serves as a base plate. This is the foot of the assembly. A 2-1/2" PVC pipe plug is mounted in the center of the base with two fender washers and a 1/4-20 screw 2-1/2" long, which runs through its center and through the base plate. This serves as the other half of the azimuth pivot. A 360° protractor, a compass and pointer are added as an aid to direction-finding. Rubber feet may be fastened near the corners underneath the base plate. The compass is useful in field work where the antenna is set up in unfamiliar terrain, to orient the protractor setting-scale correctly to North = 0.

Short bare wires connect the terminals of the variable capacitor to the corresponding terminals of the preamp on the opposite side of the elevation yoke. These wires should be as short as possible. Route them through 1/4" holes in the housing. A flexible lead 4 inches long is soldered to each of these leads inside the housing. Another bare wire 2-1/2 inches long is soldered to the ground lug of the preamp. This enters the housing through a 1/4 inch hole. Solder lugs to the free ends of these wires.

OPERATION

Slip the 40-turn coil over the ferrite core, to the center. Open the housing and place the core inside so that it rests on the lower two core supports. Connect the bare wire to the center terminal of the coil and the flexible leads to the end terminals. Tune the receiver to 550 kHz (or some other frequency above about 360 kHz). Connect the preamp to the receiver via the attenuator box. Set the attenuator for 10 db loss and apply power. Slowly tune the variable capacitor to peak the signal in the receiver. If no signal is present, a sharp increase in the noise level should still be heard. Once a signal has been tuned in and peaked, the loop can be rotated and if necessary, tilted for best reception. Test the other coils by tuning in a signal near 200 kHz while using the 246 turn coil and near 17.8 kHz while using the 1280 turn coil. Check for an overlap of tuning ranges on adjacent coils. The crossover points will be near 350 kHz for the 40 and 246 turn coils, and near 70 kHz for the 246 and 1280 turn coils. As mentioned previously the range extension capacitor is connected across the 1280 turn coil to extend tuning down to 10 kHz.

To null a station, rotate the loop for minimum signal. Loosen the wing nut slightly and tilt the loop a few degrees. Rotate the loop slightly to see if the null is improved. Try this with various amounts of elevation until the best null is obtained. This point is very critical. A degree or so off in either direction (azimuth or elevation) will make a large difference in depth of the null. Even the proximity of the operator to the loop housing will disturb a deep null. The best (deepest) nulls will be obtained only when the loop is located well away from house or street wiring, metal siding, air ducts and vents or other conductive objects. Really good, sharp nulls will be possible only on signals that reach the loop via groundwave. Nulls will not be as deep when sky-wave propagation is present because the various components of the sky wave do not all arrive from the same direction. It may be noticed that the null off one end of the loop is not as deep as that off the other, or it may not be exactly 180° bearing away from the other, or may not have the same tilt angle. Any of these symptoms of asymmetry is an indication of improper capacity balance of the loop circuitry. As previously mentioned, this is largely due to the non-symmetrical construction of the variable tuning capacitor. It can be corrected by fastening about 2 inches of some heavy guage wire under the right hand binding post of the coil in use. The exact length of this wire must be determined by experiment. Once this has been determined, a spade lug can be crimped on one end of the wire so that it can be more conveniently fastened in place. Be sure to position this wire the same way each time the coil is changed.

It will also be noticed that the tuning of the loop will vary slightly as the antenna is rotated. This effect is much more obvious on the lower frequencies, and makes it necessary to retune the loop slightly when it is rotated through a large angle. I do not completely understand the reason for this and have never observed the effect with the usually shorter and lower Q ferrite loops. Ferrite materials are notoriously susceptable to magnetic saturation. The inductance of a coil, and therefore its tuning will not be the same on a saturated or partially saturated core as on an unsaturated core. I believe that a large core such as this one intercepts enough of the earth's magnetic field when aligned in the north-south direction to become partially saturated, even though this field is relatively weak. The core would intercept less of the earth's field as it is rotated towards the east-west position, and of course become less saturated at the same time. The change is not instantaneous, however, and requires a few seconds to complete, as the core does not lose its magnetism immediately. At any rate, this retuning phenomena seems to be a small price to pay for a relatively large aperture directional antenna that provides the frequency coverage that this one provides.

MATERIALS LIST

Quantity	Item
3.5 feet	2 inch PVC pipe
4 feet	2.5 inch PVC pipe
16 inches	1.5 inch ABS pipe
2	sections, 12 inch each;1.5 inch ABS sink tailpiece (Montgomery Ward p/n 81-1 20810)
1	2 inch PVC coupling
1	2 inch x 1.5 inch PVC reduction bushing
1	2 inch PVC female threaded adapter
1	2 inch PVC pipe plug
1	piece plywood, 1/4 inch thick, 9 x 7 inches
1	piece plywood, 3/4 inch thick, 16 x 16 inches
1	piece plywood, 1/2 inch thick, 6 x 6 inches.
1	piece of 1"x2", 3.5 inches.
7	Ferrite rods, 12" long x 0.6" dia. (OR use 9 ferrite rods, 9 x 0.7 inch)
several	tubes of epoxy glue.
1	small bottle Eastman 910 adhesive, or Super-Glue.
1	miniature 365 pf variable capacitor (Radio Shack 272-1341)
1	silver mica capacitor, dipped, 330 pf
550 ft.	magnet wire, # 30
120 ft.	magnet wire, # 28
15 inches	standard hookup wire
15 inches	solid bare wire, # 22
1	roll plastic electrical tape
3 feet	heat shrink tubing, 1 inch dia.
9	6-32 knurled brass thumbnuts
9	6-32 x 3/4 round head brass machine screws
15	6-32 brass hex nuts
9	solder lugs, # 6
6	spade lugs, # 6, crimp-on style preferred
28	pan head sheet metal screws, # 4 x 1/4
2	round head wood screws, # 4 x 1/2
3	flat head wood screws, # 4 x 1/2
20	pan head sheet metal screws, # 6 x 1/2
4	pan head sheet metal screws, # 8 x 1-1/4
4	flat washers, # 8
1	carriage bolt, 1/4-20, length 1-1/2 inch
1	wing nut, 1/4-20 thread
1	round head machine screw, 1/4-20, length 2-1/2 inches.
1	hex nut, 1/4-20 thread.

(continued)

4	Fender washers, 1-1/2 " diameter, 1/4" center hole
1	protractor, 360° or other device to act as setting scale.
1	pocket compass ("girl scout" type)
7	Brass hinges, 3/4" x 5/8" (Brainerd Mfg. Co. 5075 XC -or- Montgomery Ward 84-9 962-001)
7	Brass Latch, 3/4" x 1-1/4" (Stanley CD 5345 US3 -or- Brainerd 865 XC)
-	Roll of solder
-	Preamp assembly. Attenuator assembly; power source with cabling.

REFERENCES

Watt, A.D.; "VLF Radio Engineering" pages 413-429, Pergamon Press (1967)

Hagan, J.V.; "An FET Loop Amplifier with Coaxial Output", NRC ANTENNA REFERENCE MANUAL, VOLUME TWO

Nelson, G.P.; "FET Altazimuth Loop Antenna", NRC Antenna Reference Manual, Vol. I (1974) (original text appeared in DX News in 1969)

* * *

The above article by Jim Hagan was transcribed by Bob Foxworth. As of this writing, Jim has been rounding up parts and materials preparatory to offering both the loop antenna, and the companion long wave converter (to be described in a forthcoming issue of DX News very soon) in kit form. Tentative pricing information indicates that the antenna will sell for $75 and the LW converter will sell for $55. with a discount if both items are purchased at one time.

A word about the LW converter. It uses a rejection circuit to keep out strong MW broadcast signals and utilizes a double-balanced mixer to eliminate problems with local oscillator feedthrough, as is commonly experienced with the majority of currently available designs. It can be set to up-convert to any frequency in the HF range, though a frequency of 3, 3.5 or 4 mHz would be optimum in the majority of cases.

I experienced the operation of the antenna and converter first-hand when Jim stopped at my house for an afternoon in September 1976. We tried out the system in portable mode in my front yard. I can personally testify that the performance of the system was very, very satisfying and I intend to obtain both a loop and converter as soon as practicable. I can very strongly recommend the loop, and the converter as well (for the LW DX enthusiast) as being the best available on the market anywhere today.

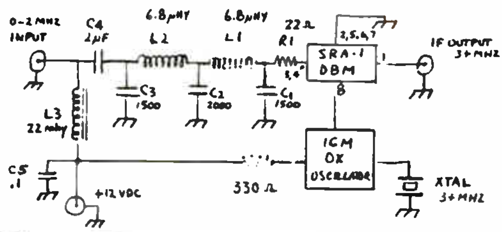
-Bob Foxworth

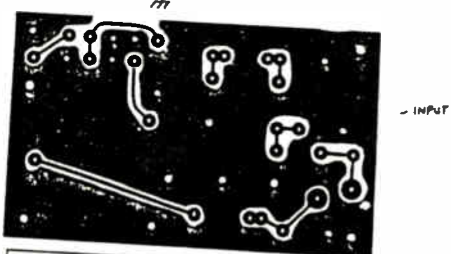
Inquiries and prospective orders should be sent to the author of the article, James V. Hagan, 896 Port Malabar Blvd., Palm Bay, Florida 32905 Please include a Self-Addressed Stamped Envelope with all correspondence to ensure a timely reply.

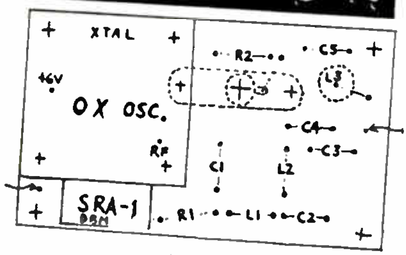
LONG WAVE CONVERTER DETAILS

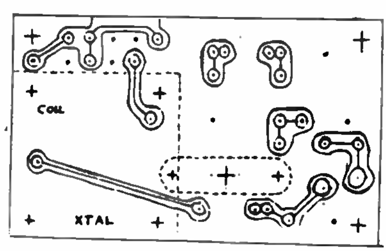
by Jim Hagan and Bob Foxworth

Here are details of the long wave converter that is being offered along with the multi-core ferrite loop antenna that was just described A schematic and foil pattern is provided below. The oscillator subassembly is a commercial item, available from International Crystal. The frequency of the crystal may be selected to suit the user's requirements. Suggested frequencies would be 3500 kHz which would permit the user to tune the first 500 kHz range on a bandspread range for the 80-meter amateur band on his HF receiver, or 3000 or 4000 kHz which would permit use of a digital frequency readout with minimum changing of the preset (e.g. 164 would come in at 4164 on the dial). The double-balanced mixer is a commercially available assembly and use of it allows the user to tune much closer to the oscillator frequency before undesirable osc. feedthrough effects become a problem. This represents a considerable improvement in performance over typical mixing type LW converters. The lowpass filter incorporated around L1 and L2 is effective in keeping out unwanted broadcast station feedthrough. This converter is intended specifically to operate with the ferrite core loop/preamplifier described earlier. Note that the operating voltage appears on the input jack. This allows use of a single coax cable between the preamp and the converter. The procedure for inquiries is the same as that described in the antenna article.









PARTS LIST

1-OX Oscillator
1-EX Crystal (above from International Crystal Co. Oklahoma)
1-SRA-1 double balanced mixer.(Brooklyn, NY)
1-coax jack .085
1-2.uF 16 volt cap.
1-.47 uF 16 volt cap.
2-1500pF silver mica cap.
1-3000pF silver mica cap.
2-6.8uHy RF choke
1-22.mHy RF choke (note multipliers u,m)
1-330 ohm half watt res.
1-22 ohm half watt res.
2- connectors (ph. jack)
4- ¼ inch spacer
4- 4-40x½ screw w/hex nut
1- 4x2¼x2¼ alum'n box.
1-PC board as shown to lef

* * *

Roll Your Own !

By Ghoti

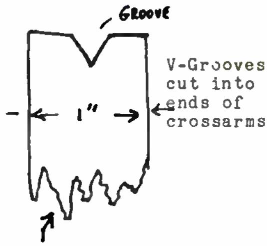
Hands down, the most perfect and sophisticated loop antenna to date is the FET-Altazimuth Loop designed and developed by Gordon P. Nelson - it is the state-of-the-art loop for BDB DX'ing today.

Herein is described a very simple type of loop antenna which although not state-of-the-art performs respectively well and is constructed on a mast - frame structure that is chosen by the DXer to meet his needs or space limitations. This loop is less bulky than conventional box loops and hence can serve as a loop to use for portable use away from the main BCB den, as a standby loop, or it can serve as well for the main DX'ing antenna in your BCB den. This loop, because of its ease-of-construction, is excellent as a "first" built loop antenna for the beginning DX'er.

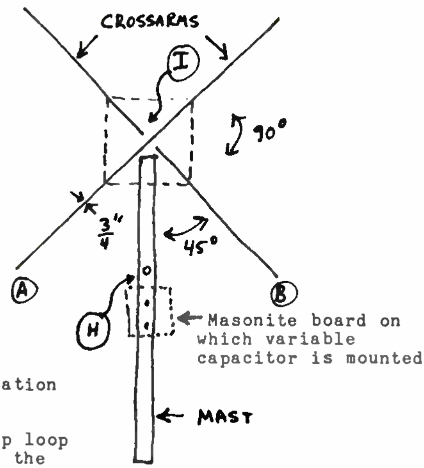
The purpose of this writing is not to describe state-of-the-art loop antennas but rather to give a design-construction technique for inductively coupled loops of a shape and size to be chosen by the BCBer. Thus, it is important to state that although only one mast-frame structure is defined here, it need not be used and any mast-frame structure conceived by a DXer will likely serve as well and after this structure has been selected and constructed, the winding, pruning-tuning procedures described here are applicable.

Supplies and components needed: a 365 picafarad, 2-section variable capacitor (popularly known as a "standard broadcast" variable and obtainable from a junk table radio, etc, or may be purchased from most radio supply stores at the cost of around $2.00), about 150 feet of insulated wire of the stranded type in size #12, #14, #16, or #18, a 2-terminal terminal strip, a 1" oak dowel, a 5" x 5" (or so) piece of masonite, 5 to 10 feet of 300 ohm TV twinlead, 1" x 3/4" lumber, ¼" drill, hammer, nails, saw, soldering iron, solder, and two pieces of ¼ to ½" thick lumber cut about 7" square.

The mast-frame structure is built first. The appearance is sketched on the next page. Note that one crossarm has been cut into two sections, the double line figure represents the oak dowel mast on which the antenna rotates. At the point 'I' of intersection of the crossarms and mast use nails and the two squares of wood to "sandwich" the crossarms and mast rigidly together. The square dashed in the figure denotes this "sandwich". The 90° and 45° angles can be aligned "by eye" since they are not exceptionally critical. The crossarms can be made from 1" x 3/4" lumber easily obtained from a lumberyard and the 1" side should be used to keep the sandwich 1" thick on the inside--note that the oak dowel is also 1" in diameter. The length of the crossarms is up to the builder! Suggested total length per arm is in the range of 24" to 72". The dowel-mast should be long enough to allow the antenna to rotate when set in a stand or supporting base (to be designed by the builder). Next, stretch a piece of wire or string between points A and B as shown in the sketch. Mark where this line crosses the mast and drill a ¼" hole (H) through the mast (the line of the hole is at right angles to the plane of the crossarm structure). Next drill a small diameter hold just below one end of hole H and mount the 2-terminal terminal strip on this small hole. Strip one end of the 300-ohm TV twinlead and attach the wires to the terminal strip--one wire to each lug. Now cut off enough stranded wire to make a one turn loop around the frame with about 6" to 7" to spare. Strip one end of this wire and attach it to one lug of the terminal strip and solder the two wires now attached to that lug. For reference henceforth, the end of hole H next to the terminal strip will be called "X" and the other end of hole H will be called "Y". Run the stranded wire attached to the lug from X to Y and then once around the frame of crossarms back to Y passing thru to X, pull the loop taught, strip the free end of this wind and attach



END OF CROSSARM



it to the unsoldered lug. Now solder the two wires attached to this lug. The other end of the TV twinlead runs to the receiver and the length of this run can be cut to suit the physical location of the antenna and the receiver.

This completes the winding of the pickup loop (that winding which inductively couples the main winding of the receiver). If you wish, cut grooves in the ends of the crossarms (as shown in the sketch) to hold the wires in place as they are wound over the ends of the crossarms and around the frame. Next, mount the variable capacitor on the masonite board and attach the board to the mast just below hole "H" at end Y. The top of the masonite can be flush with hole H. There are three points or terminals of interest on the variable capactor. The frame of the variable capacitor will be called terminal F, the other terminals are lugs on the fixed-plate sections of the variable with the lug on that section with the smaller number of fixed plates called terminal P and the other lug called terminal Q. Now strip one end of the roll of stranded wire, pass it from Y to X and connect (solder) to terminal F. Now wind all the wire around the frame in the groves cut in the crossarms making as many turns as the length of wire allows. The last complete turn ends at point Y passes thru to point X and attaches (solders) to terminal P. You now have a loop antenna!!!!

Tune up procedures: Connect the TV twinlead to your receiver and tune to 1580-1600 KHz. Rotate the variable capacitor (better put a good knob on the tuning-rotating shaft) for a sharp peak in signal. If no sharp peak is obtained, unsolder at P, remove (cut off) one turn of the main winding, connect the new end as before to point P. Try again for a sharp peak very near 1600. Continue this process until you get a peak of signal at 1600KHz with the plates of the capacitor almost completely UNmeshed! When you have reached this point, tighten the main loop windings and solder the end at terminal P taking up any slack. The loop is now tuned to the high end of the band. If your variable capacitor has a trimmer capacitor mounted on the section with terminal P you can adjust it (a small screw mounted on the side of the section of fixed plates) so that with the plates fully unmeshed the signal peaks right on 1600 KHz.

Now start tuning down the BCB peaking the signal with the loop variable as you go down from frequency to frequency. You will reach a point at which the signal peaks and the plates of the variable are competely (or very nearly so) meshed. For reference, we shall call this frequency ZZZ KHz. Now mount a single-pole single-throw toggle or slide switch on the masonite board nest to the variable capacitor, connecting one terminal of the switch to terminal P and the other to terminal Q. Close the switch, keep the receiver tuned to ZZZ KHz and repeak the signal. Continue tuning the receiver downward toward 540 KHz and continue tuning the variable capacitor. With the plates fully meshed you should reach a point close to 540 KHz.if not at 540 KHz. If you reach 540 and can obtain a sharp signal peak, then you're finished!! The loop is ready for BCB DX'ing !!!

If you don't reach 540 and the plates are again fully meshed, then the following procedure is to be followed:

Purchase several values of fixed capacitors in the range 50 to 100 picafarads. (or 'find' them). These units are pretty cheap and can be obtained easily--coast something like 30¢ each. Connect one end of one of these fixed units to terminal F the other end to terminal Q. Now retune at 540 for a peak. Use the smallest valued fixed capacitor that will allow you to tune a sharp peak at 540 KHz.

That's all there is to it!!! Best of DX !! When you decide to make another loop, remember this tuning technique it should be applicable to any type loop. and remember Roll your Own ! at least give it a try!!

+*+++*+*+*+*+*+*+*+*+*+*+*+*++*+**+*+*+*+*+*+*+++*+*+*+*+*+*+*+*+++

54

MULTI-ROD FERRITE LOOP ANTENNAS

Dallas Lankford

I have never been completely satisfied with the single-rod ferrite loop antennas I have used for several reasons. All have required amplification for best sensitivity because their unamplified outputs are not sufficient to drive my receivers (R-390A's, HQ180A, HQ150). When amplified, the noise floor of the loop is on the same order of background noise during quiet periods. It is not known whether this limiting noise is amplifier noise or the noise floor of the ferrite rod antenna, but the former is suspected based upon calculations in Lankford [1981] and my experiences with multi-rod loops described below. Also, all amplifiers I have used seem to exhibit some distirtion products in the presence of very strong signals. So I have been experimenting with multi-rod loop antennas to determine whether they produce significantly higher output voltages and are more sensitive than single-rod loops. My experiments have demonstrated to my satisfaction that they do significantly increase output voltage and are more sensitive than single-rod loops. These conclusions are qualitative because they are based upon listening comparison tests with a home-brewed amplified loop whose sensitivity is comparable to a Space Magnet.

Theoretical analysis of ferrite rod loop performance is notoriously difficult for the simple reason that actual ferrite rod loop antennas often do not perform as predicted, see, for example, Grimmett [1954,1955] who discusses this subject in greater detail. Furthermore, all of the theoretical formulas refer to single-rod loops, so there is currently no theory upon which to base multi-rod designs.

A loop antenna, whether amplified or unamplified, can always be considered as an unamplified loop antenna driving an amplifier (either the loop amp or a receiver) with a certain noise figure NF. The noise floor N_0 in dBm of an amplifier with noise figure NF in dB is given by

$$N_0 = 10\log(kTB) + NF$$

where $k = 1.38\ 10^{-23}$ is Boltzman's constant, T is the temperature in degrees Kelvin (usually taken as 290), and B is the bandwidth in Hz. Minimum usable selectivity for AM listenting is on the order of 2 khz, so we take B = 2000 and obtain

$$N_{AM} = -141 + NF \text{ dBm.}$$

For the sake of discussion let us assume an amplifier with a 6 db noise figure and an input impedance of 200 ohms. The noise floor is thus -135 dBm which corresponds approximately (using $P = V^2/(R\sqrt{2})$) to a signal of 0.095 μV across 200 ohms. Let us suppose the amplifier with 6 dB noise figure is fed by the link coupled loop described in Lankford [1981] so that 0.74 V_s volts appears across the 200 oohm load, where V_s is the magnitude of the signal strength in volts per meter. Let us also make our assumptions more like reality by assuming loss in the link coupling reduces the voltage across the 200 ohm load to 0.37 V_s.

It has previously been hypothesized in Lankford [1981] that man-made noise of about 0.2 - 0.3 μV/meter limits sensitivity on the BCB throughout most of the continental U.S.A. So it follows that the hypothetical single-rod loop produces as little as (0.37)(0.2) = 0.074 μV across 200 ohms, which is slightly below the 0.095 μV noise floor of the amplifier. Comparison listening with a 100 foot long wire has confirmed that during low noise periods man-made noise is generally inaudible or barely audible with all single-rod ferrite loops that I have used, which suggests that the above theoretical analysis is reasonably correct.

A similar analysis also shows that the sensitivity of our hypothetical loop is about 0.8 μV/meter for a 10 dB signal to noise ratio. Space Magnets generally have a measured sensitivity of about 1.5 μV/meter, so the theoretical analysis tends to predict slightly better sensitivity than in practice. Worcester has mentioned to HQ that Space Magnets have a somewhat lower Q than the 180 value assumed for our hypothetical loop which would bring the sensitivity magnitude up.

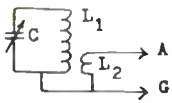
The above analysis assumes an amp with a 200 ohm input impedance, which is typical of bipolar amps and common gate FET amps. A similar analysis can be given for high impedance amps (such as common source FET amps) with direct coupled loops. Using 24.7 V_s and 300,000 ohm input impedance we get an amplifier noise floor of 3 μV which is covered by 11 μV of loop noise. But while a direct coupled loop feeding a high impedance amp would seem to be advantageous because of improved sensitivity, the higher output (24.7 V_s) unfortunately degrades strong signal handling performance. This strongly suggests that balancing both loop and amp is required for good strong signal handling performance when using high impedance amps with direct coupled loops.

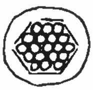
Our analysis above has shown that greater output voltage is required to improve the sensitivity of ferrite rod loop antennas for the BCB when using link coupling to low impedance amps. However, significantly larger rods are generally unavailable as well as expensive. Larger and longer rods can also be made by "bundling". In a lengthened bundle there should be considerable overlapping of rods, see, for example, Hagen [1977].

My experiments were prompted by a cheap source of ferrite rods: ETCO Electronics, North Country Shopping Center, Rt 9 North, Plattsburgh, N.Y. 12901 sells 8 inch by 3/8 inch ferrite rods for 29¢ each (25¢ each in orders of 10); write for their catalog which will have up-to-date prices and availability.

My first experiments were with a 7-rod bundle (no overlapping) wrapped with black vinyl electrical tape in a "hexagonal" bundle. Other configurations are possible, but the hexagonal configuration provides good mechanical stability. The circuit I used is given below and fed my HQ180A. Output was significantly better than an unamplified space magnet, but not adequate for the HQ180A without amplification. So a larger version with 19 rods was tried. The bundled rods were taped as before, wrapped in insulation, and stuffed inside a 10" length of 2" dia. plastic pipe. L_1 was 34 turns, and L_2 was 2 turns for best match to the '180. Capacitor C was a 365 pf variable with gear reduction tuning.

end view of 7-rod bundle





end view of 19-rod bundle inside 2" dia. plastic pipe

Listening tests during the last few weeks suggest that the 19-rod loop is about optimal for the '180. During quiet daytime periods man-made noise is clearly audible throughout the BCB with S-meter readings in the S 0 - S 1 range. I should mention that my '180 has been modified like late production '180's so that S-meter readings are very close to the 6 dB per S-unit ideal. At night atmospheric noise is typically S 1 - S 3, with man-made noise evident on quiet nights (through occasional "holes" in the usual slop). Daytime weak-signal reception is outstanding, with readable signals produced when my GE Superadio or amplified TRF loop (the front end of a Radio Shack TRF) produce little or nothing. Very little improvement is noted during nighttime listening over other loops, primarily because higher nighttime signal levels produce "slop" which is frequently considerably above man-made noise. On quasi-slop-free split frequencies the 19-rod loop has a slight advantage in

(56) extracting signals near the noise level. The 19-rod (unamplified) loop also seems to have slightly better strong signal handling performance than any amplified loop I have used.

Lengthening (by overlapping rods) was not tried because it was desired to keep the overall size of the multi-rod ferrite loops as small as possible. For single-rod loops, best performance for a given amount of ferrite is obtained with large length to diameter ratios (typically 20 to 1). This suggests that the optimal configuration of rods is lengthening by overlapping so that a 20 to 1 length to diameter ratio is maintained. Unfortunately this approach leads to stability problems (the rods must be glued for good mechanical stability; a support for long, multi-rod assemblies must be devised, etc.).

As we have said before, there is presently no theoretical treatment of multi-rod ferrite loops. If it is assumed that all single-rod formulas apply in the multiple rod case, the formulas would seem to predict little improvement. For example, assuming all other factors constant, the voltage output of a ferrite rod loop varies as the product $AN\mu_{rod}$ where A is the cross sectional area, N is the number of turns, and μ_{rod} is rod permeability. Our 19-rod antenna has a length to diameter ratio of about 4/1 so that its permeability is about 1/4 that of a single rod. A single rod loop for tuning the BCB with a 365 pf variable is about 110 turns, so the 19-rod loop would have 4(34/110) = 1.24 (1.84 dB) the output of a single rod. I can definitely tell you that the preceeding theoretical analysis is incorrect because the 19-rod loop has about the same output as an amplified single-rod loop. I don't have equipment for precise measurements, but estimate the voltage gain of the 19-rod loop as about 20 dB over a single-rod loop. This agrees with graphs in Grimmett [1954,1955] which show that voltage output increases approximately linearly with diameter while keeping length constant. On the basis of Grimmett's graphs the increased output would be 20 log(5) = 14 dB. We should emphasize that Grimmett's graphs are for single-rod loops, but our multi-rod experiments suggest that similar graphs describe multi-rod loops.

The multi-rod loops did not seem to have deep or well-defined nulls, so balancing may be useful. No efforts were made to optimize wire size or coil placement and length. For single-rod loops solid # 30 or litz wire is optimal, but no information is available for multi-rod loops. I used #18 stranded copper because it was handy.

Output of the 19-rod loop was not quite adequate for my R-390A's or HQ150 so I plan to try out some amplifier designs or a 37-rod loop.

It is hoped that these notes will be useful to other BCB DXers who are experimenting with ferrite rod loops.

REFERENCES

Grimmett, C. Ferrite cored antennae. Institute of Radio Engineers Convention Record Part 7 (1954), 3-7.

Grimmett, C. Improving ferrite cored antennas. Tele-Tech and Electronic Industries 14, 2 (Feb. 1955), 84-85, 116, 118, 120.

Hagen, J. A large ferrite core loop antenna for long and medium waves.

Lankford, D. Loop antennas, theory and practice.

THE HOT ROD ---

AN INEXPENSIVE, FERRITE BOOSTER ANTENNA

Gerry Thomas

As most of you know, I've been pretty impressed with Sony's ICF-6500W, especially in its modified (i.e., narrow IF passband) form. Most of you also know that the 6500's naked front end has been of some concern in that it does overload, especially at night, with anything longer than a 50' external antenna attached. One of the things I've recently built in an attempt to remedy the situation is an outboard, tuned booster antenna. These devices have been around for years and plans for their construction appeared frequently in the older radio magazines but I don't recall ever seeing the construction details in any BCB club publications. Because this thing (I call it the "Hot Rod") should work on virtually all portables with built-in loopsticks, I thought I'd take a few minutes to pass on the details for building one.

What it is

Actually the Hot Rod is nothing more than an oversized (16" x 3/4") ferrite rod assembly, tuned by a conventional 365 pF variable capacitor (VC), and inductively coupled to the built-in antenna of whatever portable radio is being used. It works on the same principle as Radio West's "Shotgun" and Edmund Scientific's "Select-A-Tenna" but costs signficantly less than the $35 these two commercially available units run. In fact, if it weren't for satisfying the minimum purchase requirements of the suppliers, the Hot Rod could be built for around $10.

What it does

Besides giving a significant boost to weak signals, the Hot Rod also resonates any external antenna attached to it. This reduces, but doesn't totally eliminate, the tendency to overload that some portables exhibit. For example, the SW feedthrough and image problems I experienced with the 6500 when a 150' dipole was attached are completely corrected, although I can still detect a weak birdie on 540 kHz (from WBSR-1450 kHz; the closest station to my QTH). Also, devices like the Hot Rod create a notch that can sometimes be useful in reducing interference on the low end of the band. In addition, the greater signal levels provided by the Hot Rod permit lower volume control settings, thereby resulting in lower battery consumption. Finally, I've also found that the insertion loss caused by the substitution of narrow IF filters is easily offset by the use of the Hot Rod. With the 6500, the narrow muRata plus the Hot Rod configuration provides much higher tuning meter readings than the 6500 in its stock (i.e., wide IF, no Hot Rod) mode. The boost is, in fact, so satisfactory that I've yet to encounter the need to attach an external antenna at night (I do use various external antennas for midday DX'ing though).

What you'll need

** 6 ferrite rods (8" x 3/8" each) from Etco Electronics, North Country Shopping Center, Rte. 9 N., Plattsburgh, NY 12901 (they didn't have a minimum order the last time I dealt with them). These cost $.29 a piece but the price drops to $.25 if you buy 10. I'd advise buying 10 because not all of them are perfectly straight and you will need six fairly straight rods. Alternatively, you can purchase two of Amidon's 7-1/2 x 3/5" rods but these have gone to over $10 each now. The address for Amidon is 12033 Otsego St., North Hollywood, CA 91607 (I'm unaware of their present minimum order requirements).

** 16" length of 1" (outer diameter) PVC pipe. This can be purchased at just about any hardware store (most stores will cut it to length) and should run under a dollar.

** 1 365pF variable capacitor. I used the small 1" x 1" polyvaricon type that comes with a (coarsely) calibrated tuning knob. These are also available through Etco ($3.95) as well as from local electronics supply stores that handle Calectro products (about $3.50). The least expensive source of these VC's that I know of is Mouser Electronics, P.O Box C, Lakeside, CA 92040. They cost $2.37 each but Mouser has a $20 minimum order.

** 10' of high gauge wire. I used litz (obtained from Amidon) but 30-34 gauge magnet wire can be substituted (although Q and gain seems to suffer some). Don't go to a heavier gauge than recommended or the ferrite/coil assembly won't fit in the PVC tube.

** 1 small plastic box for housing the VC. These are really hard to find but a very neat 1-1/2" x 2" x 1" box and lid are available from Allied Electronics, 401 E. 8th St., Ft. Worth, TX 76102, for about $1.25. Allied's minimum order, unfortunately, is $30 though. If you have one of the old Radio Shack VC's that came with a little plastic dust cover for the VC plates, you're in luck. This can be used very adequately to mount the VC to the PVC tube and you won't have to worry about locating a box.

** 1 external antenna terminal. You can use a binding post, Fahnestock clip, jack, or whatever is handy.

** Some kind of mounting system. Two 5" cable ties and two 1" x 1" self-adhesive mounting platforms work well (available from Mouser) but I ordered some "Kwik Klips" from Allied which can be permanently mounted to the radio and "lock" and "unlock" their grip on the Hot Rod to allow optimal gain/selectivity positioning as well as transfer to other radios similarly Kwik Klip-equipped. I should have them by the time this article sees print, so drop me a line.

** Spray paint. Krylon or similar (I used semi-gloss black and clear satin overcoat).

** Epoxy glue (for cementing the ferrite rods).

** 2 short length (i.e., 1/8"-1/4") screws for mounting the box to the tube (the tips of the screws should <u>not</u> extend into the interior of the PVC tube).

** Miscellaneous supplies including a screwdriver, soldering iron and solder, drill and suitable bits, several grades of sandpaper, a ruler, and electrical tape.

<u>How to build it</u>

1. Take the six straightest ferrite rods you have and try different end-to-end rod pairings until you have three pairs whose ends "kiss" well and whose overall lengths are relatively straight. Form a triangle (actually a 16" long "prism") with the three pairs, again trying different combinations and positions to attain the best matching of ends and sides. See Figure 1.

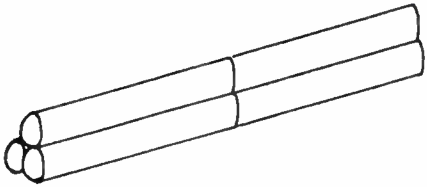


FIGURE 1

2. After you've determined the best pairings, mix the epoxy and cement the pairs end to end so that you now have three 16" rods. It is best to do this on a flat surface.

3. After the epoxy has completely hardened, arrange the three 16" rods in the prism shape illustrated in Figure 1 applying liberal amounts of epoxy to all surfaces which "kiss" to form the prism. You might want to then wrap a rubber band or twist tie around the assembly until the epoxy cures.

4. While the epoxy is hardening, drill two small holes along the center line of the bottom of whatever box you are using so that it can be mounted on the PVC tube. Drill two more small holes along the same center line so that the coil wires can pass from the PVC interior into the box and connect to the VC. Also drill a hole in the side of the box to mount an external antenna terminal and a hole in the lid of the box to mount the VC. Figure 2 illustrates the approximate locations of the holes.

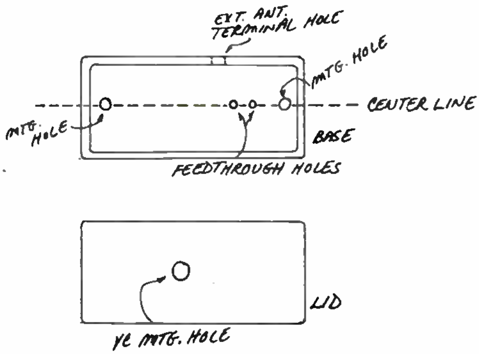


FIGURE 2

5. Position the box on the PVC tube so that it is about 3-4" from the end of the tube and stick a pin or other sharp, narrow object through each hole in the bottom of the box so that an impression is made on the PVC tube.

6. Drill holes in the PVC tube corresponding to the pin pricks.

7. Take the PVC tube and lightly sand the surface (heavily sand the ends).

8. Now apply several light coats of a good quality paint to the PVC tube, sanding very lightly between coats. Finish with a coat of protective clear coat, if you want.

9. After the epoxy has thoroughly hardened (an overnight wait is best), it's time to wind the coil. Take the 10' length of wire and scrape and tin the ends. If you're using litz, make sure you've adequately scraped the insulation from each individual wire; check for continuity with an ohmeter, if you have one.

10. I've found that best performance results if the coil covers about the central two-thirds of the ferrite bar (although I haven't tried all possible winding schemes), so start winding the coil about two inches from one end. Leave about a 6" tail of wire on the end where you start and secure the initial turns with a piece of tape. If you desire, you can make marks about every 1/4" so that the 48 turns are accommodated in the central 12" of the rod, but I now find that I can "eye ball" the proper spacing with little trouble.
   It's easiest for me to wind one of these coils if I sit down with the rod across my lap, my right hand holding and rotating the rod, while my left hand holds the wire tautly (and creates the spacing) as it is being taken up by the rotating rod. For some reason, I find rotating the rod toward me with the wire feeding over the top of the rod to be easiest.

11. After you've wound the central 12" of the rod, tape down the last few turns and trim (only if necessary!) the remaining wire so that a tail of about 12" remains.
   To prevent the coil from coming unwound, tape each end securely with a turn or so of electrical tape (if your initial taping of the ends was of a temporary nature). If you have some Q-dope around, coat the entire coil and set aside to dry.

12. Loading the coil into the PVC pipe comes next. First, take two piece of light gauge scrap wire, each about 16"-18" long, and thread them down into the interior of the tube through the two feedthrough holes you drilled earlier. Continue feeding them into the holes until they exit the end of the tube closer the holes.

13. Lightly solder one scrap wire to one end of the coil and the other scrap wire to the other end of the coil.

14. Now gently insert the ferrite rod assembly into the PVC tube, taking up the wire slack as you go. Continue until the rod is completely inserted into the tube and the entire length of each scrap wire has been pulled back through the feedthrough holes. See Figure 3.

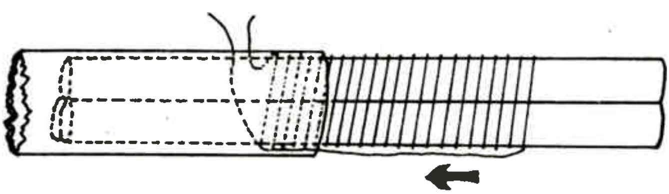


FIGURE 3

15. Desolder the scrap wires from the coil. You should now have the rod/coil assembly inside the tube with only the two ends of the coil wire protruding through the feedthrough holes of the tube.

16. Thread the two coil ends through the holes in the bottom of the box and mount the box to the PVC tube with the two screws. You can add a bead of adhesive to the box/tube interface if you choose.

17. Now solder one end of the coil to one tab of the VC, and the other end to the other tab. Also, solder a short length of wire to either one of the tabs or to the washer tab on the shaft of the VC (if yours came with one). See Figure 4.

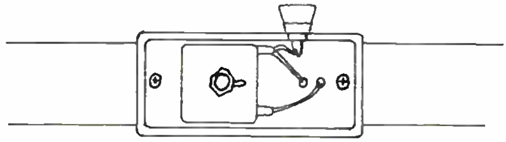


FIGURE 4

18. Mount whatever kind of external antenna terminal you've chosen on the box and solder the loose wire end to it.

19. Place the lid on the box and mount the VC and knob.

20. Confirm that everything is working properly by positioning the Hot Rod near (1-2") the back or top (where ever the internal loopstick is located) of your radio so that the length of the Hot Rod is parallel to the loopstick. Tune the radio to a weak station and rotate the Hot Rod's knob while listening for a peak or sharp drop in signal strength. If you hear either, move on to Step #21. If you can't detect anything happening as you tune the Hot Rod, try positioning it differently (i.e., move it closer or farther from the radio; slide it lengthwise; etc.) If you still don't hear any action, try a different weak station in the middle of the band. If still nothing occurs, recheck your wiring and solder connections.

21. After you've confirmed that the Hot Rod is working, check its range by tuning and peaking stations near 540 kHz and 1600 kHz. If all is well, go to Step #22; if not, try re-positioning the Hot Rod. (There's an optimal gain/selectivity/coverage point of coupling between the Hot Rod and your radio.) If the Hot Rod doesn't tune the high end, remove wire from the coil; if it doesn't tune to 540 kHz, add wire. This shouldn't be a problem, however, if you are using components comparable to those recommended.

22. Lightly glue the lid to the box and, if the rod assembly doesn't fit snugly in the tube, put a dab of glue at each end.

23. Mount the Hot Rod on your radio using whatever method you've chosen (Kwik Klips, mounting platforms and cable ties, etc.). If you don't want to permanently attach the Hot Rod to your radio, you might want to mount it on a small piece of Plexiglas and simply place it near the radio. I suspect, though, that the Kwik Klips will be the mounting method of choice.

24. Go DX.

I think you'll find that the Hot Rod is a worthwhile accessory for portable radio DX'ing, especially if you sometimes use an external antenna. Incidentally, when using an external antenna, the gain of the Hot Rod can be controlled to some extent by sliding the Hot Rod toward one end of the radio or the other. This is really only practical, though, if you use the Kwik Klip system.

In closing, I'd like to mention that since I had to observe the minimum purchase requirements of several suppliers, I now find myself loaded down with far more components than I need. If you are interested in the Hot Rod, I'll be happy to supply you with a kit of all the required parts (you'd still need epoxy to glue the rods, a soldering iron and solder, and some electrical tape) for $13. Or, if you are really mechanically disinclined, I'll (I know I'm going to regret this offer, hi) put one together for you for $19. PLEASE include an additional $2-$3 to help cover packaging and UPS charges. Thanks in advance.

If you have any questions about the construction or operation of the Hot Rod, don't hesitate to drop me a line at:

P.O. Box 2036
Pensacola, FL 32503

73's---GT

NOTES:

NOTES:

NRC PUBLICATION CENTER
P.O. BOX 164
MANNSVILLE, NY 13661
USA

CAMBRIDGE
NOV 2? '87
WIS.
U.S. POSTAGE
.56

NATIONAL
RADIO CLUB