TRANSMITTING ANTENNAS
and
GROUND SYSTEMS
for
1750 METERS

Edited by Michael Mideke

1987

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INTRODUCTION

This collection of articles on 1750 meter transmitting antennas, grounds and related topics includes most of what has appeared on the subject in THE LOWDOWN since 1980. Other material has been drawn from the 1750 METER WESTERN UPDATE. I have added a section on ground systems to fill some minor gaps in the existing material. Additional notes and illustrations are being added on a space-available basis as the cutting and pasting proceeds.

In assembling this collection I've indulged my own inclination to browse and compare, and the result is somewhat redundant. Anyone wishing to put up an effective antenna can refer to any of the three basic articles (Phillips, Pinto or Lee) and learn what he needs to know. Although emphasis varies, the authors all start from the same general premises and arrive at the same general conclusions.

But if you are looking for ideas or seeking the most practical solution to some particular problem, it will be well worthwhile to study all of the authors. Even if none of them address your immediate concern, it may be that their combined ideas will suggest an answer.

For the most part these articles deal with one basic antenna type: the vertical radiator with inductive base loading and capacitive top loading. While there are those who grumble about inefficiency and maintain that this is not much of an answer to the problems of radiating a signal at LF, these antennas have at least two important things going for them - they work and, if constructed to the appropriate dimensions, they are acceptable to the FCC.

It may well be that there are more efficient transmitting antennas for the purpose and it may be that such antennas can be constructed within the dimensional constraints of Part 15. Thus far I've not seen what I consider to be a proven design. Keith Olson (7FS) has been doing interesting work with 1/10 scale helical antennas on 160 meters.

The scaled down approach has a lot of merit. One can find out whether the design works before confronting the difficulties of actually implementing it on longwave. These difficulties are far from insignificant; 15 meters is very small in terms of our wavelengths but it is a big hunk of space in the backyard. Mechanical, electrical and adjustment difficulties abound! I hope the following pages will help to smooth the way.

Michael Mideke- November 1987

TRANSMITTING ANTENNAS FOR 1750 METERS

BY ED PHILLIPS W6IZJ

As mentioned in the introduction (Vol. 7 #1 p 8), successful transmission requires that the transmitting antenna be of maximum possible height, and losses in the antenna and ground system be as low as possible. I shall now describe some general properties of small VLF antennas and their ground systems, and give examples of what you may want to build. The antenna system will first be considered from a constructional point of view, and the electrical properties will be discussed in their relation to the coupling system design and construction. The parameters of the antenna as a circuit element will be given next, followed by the design and construction of the circuits for coupling the antenna to the transmitter, together with methods for their adjustment.

In practice the design of your antenna system may be dictated by the space you have available, as is true in my own case. If your space is limited don't give up, but put up the tallest thing you can, as far away from trees and buildings as you can, and then give it a try. You may be pleasantly surprised!

There are no mysteries to working at 175 KHz, since use of this frequency goes back to the very earliest days of "wireless". In fact, any good old wireless book has a wealth of useful information on antennas and grounds. The advice is excellent but hard to follow. A. P. Morgan's "Wireless Telegraph Construction For Amateurs" (1911) devotes chapter 3 to "aerials and earth connections". A few quotes are of interest:

"In fitting up a wireless station the location and erection of an aerial are of prime importance, and the successful reception and transmission of wireless messages will depend largely upon its condition."

"The higher an aerial is placed above the surface of the earth, the wider will be its electrostatic field, and consequently more powerful electric waves will be developed. But after a height of 180-200 feet is attained, the engineering difficulties and the expenses increase so rapidly that few stations exceed it. Other things being equal, the increased range in transmitting varies as the square of the height of the radiating wires. For example, a 25-foot aerial capable of transmitting one mile theoretically will send waves 16 miles if made 100 feet high.".

"After the limit in a vertical direction has been reached, the only remaining possibilities are to increase the surface and spread out horizontally."

"Ground connections--the importance of a good earth or ground connection can hardly be overestimated. Whenever possible commercial stations are located on moist ground or near a body of water so that a good ground may be secured by imbedding zinc or copper plates in the earth or water."

These quotations are still pertinent today, although note that the quantity which varies as the square of the antenna height is the radiation resistance, not the electric field produced by the antenna, as Morgan implies when he says that increasing the height by four times increases the range by 16 times. However, because of the increase in antenna system efficiency which goes with the increase in height, his remarks about increasing the range of the station are almost correct. A few things I did not quote are also pertinent, especially his remarks on making the antenna installation strong enough to withstand any possible weather, and providing the antenna with a grounding switch for use when lightning is possible. He also emphasizes arranging the antenna so it cannot fall down across power lines, thereby leading to all sorts of unhappy events.

The antennas which Morgan describes are all tall structures with some form of "flat top" or capacitive top loading. Figures 1 and 2 are copied from E. E. Bucher's "The Wireless Experimenters Manual" (1920), and illustrate two methods of constructing an antenna with top loading. In each case the loading consists of a group of horizontal wires spread out as much as possible to increase the capacitance to ground. The purpose of this top loading is to increase the current at the top of the antenna, thereby increasing its radiation resistance. The radiation resistance of an antenna is a fictitious resistance which, when multiplied by the square of the current flowing in the base of the antenna, gives the radiated power; increasing the radiation resistance increases the power radiated for a given antenna current. For a very short antenna the radiation resistance is proportional to the squares of the effective height and of the frequency. For an unloaded antenna 50 feet high the theoretical radiation resistance at 175 KHz is only 0.0312 ohms! This is only a very tiny fraction of the minimum total resistance with which the antenna system can be built, and shows the importance of keeping the losses as low as possible. As an example of what this means, if the antenna current is 0.2 amperes, a typical value for a one watt transmitter and fairly low loss antenna system (sum of ground and loading coil resistance equal to 25 ohms), the radiated power will be only about 1/800 watt, and the efficiency will be only 1/8 percent!

For a straight vertical radiator whose length is a small fraction of a wavelength (the wavelength of a 175 KHz signal is 5620.4 feet) the antenna current decreases linearly to zero at the top. If capacitance is added at the top, the current there is increased. If the current at the top is equal to the current at the base the radiation resistance will be four times that of an unloaded antenna. For the example given above this would mean an increase in radiation resistance to 1/8 ohm, of radiated power to 1/200 watt (5 whole milliwatts!), and the efficiency would be 1/2 percent. The effective range of the station would be doubled. Now that I have discussed the merits of top loading I must point out that in all probability you will not be able to use very much of it. I have no idea how the FCC would feel about antenna installations like those in the examples above, particularly if the height of the vertical section is the magic 15 meters, but it is doubtful that they would be very happy. If we fudge the 15 meters to 50 feet, which was in the old regulations before the FCC "went metric", a literal interpretation would say that a single vertical conductor 50 feet long is all that is legal, and if the matter ever came to an argument I am sure that is what the ruling would be. (The best way to win such an argument is to avoid it: keep your signals clean and your out of band radiation to a minimum and you will not bring attention to yourself.)

Two points regarding top loading may be in order. First, if we accept the total length of the antenna to be 50 feet, then there is no advantage to reducing the height of the antenna and running part of it horizontally to produce top loading. If you can get 50 feet use it. If not, then make the vertical section as tall as you can and add top loading to bring the total length to 50 feet. An "L" shaped antenna will be slightly better than a "T" shaped one in this case. Second, in principle the top loading can be made more effective if the antenna loading coil (or part of it) is placed at the top of the antenna. Examples of such tuned top loading circuits for use on 160 meters are given in "The ARRL Antenna Book", which is recommended reading, particularly in the older editions which may be available in libraries or from long time hams. I believe that the problems in adjusting such loading coils, together with the fact that their losses will probably be excessive, makes such techniques of little or no value for 1750 meters, and I recommend their use only to the advanced experimenter. In the discussion to follow only base tuning will be considered.

Let us now consider some specific antennas. Figure 3 shows an antenna similar to the previous examples; it is "best but clearly illegal". A 50 foot vertical wire is top loaded by a flat top of horizontal wires, supported by wooden poles. The whole setup is placed over a salt water ground plane, which serves two important purposes. First, a connection to the salt water provides an effective, low resistance ground system. Second, the effect of the salt water is to make the resistance of the ground plane under the antenna very low. This minimizes the losses due to the currents which flow in the ground under the antenna due to capacitive coupling; they are a very important component of the total antenna (as contrasted to the loading coil) loss. More of this later. The only purpose of this example is to show what could be done if the FCC restrictions are ever lifted.

Before discussing "how to build an antenna" let's consider "where to build it?" The environment in which the antenna system is installed is the hardest part of the system to control, but it is of great importance in determining the antenna's overall performance. Because of capacitive coupling from the radiator, RF currents will flow in every object near the antenna, and the presence of electrically lossy material will increase the losses in the antenna circuit. (For all practical purposes only things within a radius equal to the height of the antenna are important loss contributors.) Any buildings or vegetation will have significant electrical loss, and detract from the antenna performance, so the first rule to try to follow is to keep the antenna at least 50 feet from any trees or buildings. This means, of course, that you have to run power and control leads out to the base of the antenna, and they may be inconveniently long.

Even if there are no objects above ground in the vicinity of the antenna, the ground itself can and will provide very significant losses. All of the current which flows in the antenna must return in (or on the surface of) the ground, and most soil is very lossy. For this reason it was common practice in the early days of wireless to locate transmitting stations at salt marshes, and build the antennas over them. In addition, hundreds of conducting cables were laid in or on the ground under the antenna to further reduce the loss, with some installations having literally hundreds of miles of them. These practices are still necessary and are still followed, in spite of the immense cost associated with them. In the case of simple vertical towers the ground system usually consists of "radials", or wires radiating from the base of the antenna in all directions to a distance at least equal to the height of the tower. The radials are usually buried beneath the earth with a special plow, in order to get them out of the way.

In principle there is a clear distinction between radial systems and ground systems. The primary purpose of the radials is to eliminate losses due to currents which are induced in the ground by the electric field of the antenna, and even fairly short radials accomplish this. However, there are still currents flowing in the ground beyond the radials, and a conventional ground is often needed in addition to the radials. If the soil conductivity is poor the radials, together with a few ground rods and a connection to the water pipes, will probably be about the best ground that can be hoped for.

E. A. Laport gives an excellent description of ground systems in his "Radio Antenna Engineering", McGraw Hill, 1952. Section 1.12 discusses VLF ground systems, while section 2.5 describes broadcast antenna ground system design. The latter section is of most interest, since in it he gives data on the performance of a simple vertical radiator with various lengths and numbers of radials. The results may be very crudely summarized by saying that radials of length equal to the antenna height are almost as good as those of infinite length, and that a length of half the antenna height (outside diameter of radial system equal to antenna height) is about 2/3 as effective as very great length. Furthermore, 2 radials are about half as good as a very large number, and 16 radials are within a few percent of being as good as 112. Applying this information to our hypothetical tower installation, we can say that it will be near to ideal in performance if the tower is at least 50 feet away from trees and buildings, and if the ground under it is provided with 4 or more radials whose length is at least 25 feet and preferably 50 feet. Improvements will result from more and longer radials but the increase in performance is probably not worth the extra trouble. The size of the wire used for the radials is not particularly important, so long as it is strong enough to withstand whatever mistreatment it may experience in installation, and even galvanized iron clothesline wire will do in a pinch.

Unfortunately, it will be very hard to find room for this "ideal" antenna installation, and you will probably have to fall back on the advice I gave above. Make the antenna as high as you can, as far away from trees and buildings as you can, put down as many radials as you can find room for, and feel that you have done your best. Your antenna system will certainly work, and the results will probably satisfy you. In this discussion I have omitted one thing which may be of interest to those who really have a lot of space and ambition. The laying of the radials in or under the ground is done mainly to keep them out of the way, and results in an increase in loss because the current must "flow" through the ground to reach them. A better practice, but one which is much more awkward, would be to place the radials above the ground by several feet. I doubt if the difference in performance would be noticeable, but it would be a noble experiment. Such installations are called "counterpoises", and were fairly common in the early days of wireless. They might still be of considerable interest to someone who wished to install his antenna on top of a house, where the length of the ground lead would be considerable. The counterpoise would be installed on top of the roof, with as many radiating wires as possible, run out as far as possible. It would probably be OK to run them over the edge of the roof and down to ground level. I have an idea that such an installation might work very well, since it would place the antenna well out of the way of most trees, and would also be convenient for the use of guy wires.

As an example of an installation which violates most of the rules given above, I will use my own antenna system to show "what not to do". The tower is installed in the only spot my wife would permit, between the "radio room" and the driveway. One wall of our house is only two feet away, and extends up to the 30 foot mark. Two large oak trees grow within less than ten feet of the tower, and numerous camellia bushes are planted near the base. The soil in our neighborhood is shallow, with loose gravel and boulders underneath, and the water table is at least 100 feet down. I have a fairly good ground connection in the form of a number 4 wire running to a recently installed copper water connection to the street. The pipe has a total length of about 200 feet, but there are no radials and I have no space to put them. The total resistance of my antenna system at present is about 65 ohms, although when I first installed the VLF gear and had the oak trees pruned way back I measured something like 25 ohms, and could get about 0.22 amperes antenna current with one watt input to the final. I believe that in this installation the loss due to the trees is dominant, although as a second factor all of the surrounding ground is very dry due to being under houses and driveways. Cliff Walker has a much simpler antenna in the middle of his back yard, with a water pipe ground, and puts out about twice as strong a signal as I do. I think the absence of the big trees is one major difference, and the presence of a watered lawn beneath the radiator may be another.

Now for some specific examples of possible antenna construction. In general, the construction of the radiating section is independent of whether top loading is used, so most of the examples apply with or without it. The simplest and easiest antenna to install is a free standing tower of the type used to support TV antenna arrays or VHF/UHF transmitting and receiving antennas. These towers have the advantage of occupying minimum "floor space" and can be purchased from many manufacturers or distributors. This is a good way to go if you can afford it, but the price is high. As an example picked at random from a recent issue of WORLDRADIO NEWS, Hill Radio, 2503 GE Road, Bloomington, IL 61701, offers a Rohn 48 foot "BX" free standing tower for $213.40. You may be able to do a little better or a little worse by shopping around locally, but this is the general price range. Since the only wind loading on the tower will be that of its own structure, you should be able to get by with the very lightest weight of towers and save some money that way. For this expense you get an antenna which can be installed anywhere you can find a few square feet of ground space, and one that will not involve a tangle of guy wires. If your yard is as crowded as mine this may be the only way you can go.

The tower is a radiator (antenna), not an antenna system. In addition to the surrounding physical environment which was discussed above in "where to install it", the complete antenna system includes the radiator, the base insulator(s), and the base itself. The latter two components are worth discussing. Insulation of the antenna is very important, since losses in the insulator can be a major contributor to overall antenna loss, particularly in wet weather. A shunt loss resistance of a megohm in parallel with your antenna can seriously reduce its efficiency. In the case of a free standing tower the base insulators must carry the full mechanical wind load of the antenna, and their choice must be a compromise between electrical performance and strength. My own antenna is a Hygain HT-18 "High Tower" which originally came with some kind of black "mud" base insulators. When I first got on VLF I discovered that I could not load my antenna at all when the base was wet, or even when the weather was moist. I couldn't measure the shunt loss because it was so high, but I would guess it as less than 100K ohms. I was lucky enough to find some Mycalex insulators at a local surplus store, and the antenna now is supported by nine of them, each one inch square and two inches high. Since Mycalex is very weak in tension, I added a bolt, which is insulated by an epoxy-glass bushing, to each corner of the base to keep the insulators under compression when the wind blows. Even this insulation degrades in wet weather, and I regularly clean the insulators and spray them with silicone oil lubricant, which helps make the water "bead up" instead of forming a film across the whole insulator.

The choice of base insulators will depend on what you can find, with ceramic and glass being the best choices from the electrical standpoint, but the poorest mechanically. Glass impregnated epoxy is very strong and expensive, while hardwood boiled in paraffin will also serve well, but is subject to deterioration due to moisture, so that it may need replacing from time to time. Regardless of the material from which the insulators are made, you should keep them clean and spray them with silicone lubricant regularly.

Whatever you do remember that insulating materials tend to be brittle and weak in tension, and that the wind loads at the base of your antenna will be hundreds of pounds. If you can arrange to keep the insulators in compression you will be much safer. The choice of materials is best left to your own ingenuity, but remember that you don't want your antenna to tumble down, wrecking itself and everything in the vicinity! While we are on this subject I must emphasize the importance of following the manufacturer's instructions as to the size and depth of the concrete base which is needed to keep the antenna from overturning in the wind. My tower has a base 3 feet square and 3 feet deep, which is supposed to hold it in a 75 mile per hour wind. That's a yard of Ready Mix, but worth it for the peace of mind it brings.

Most of you probably won't want to go to the expense of a free standing tower, and the inconvenience of providing it with adequate base insulators and guys. The best compromise antenna is probably made from a 40 or 50 foot telescoping antenna mast of the type commonly used to support FM and TV antennas. Radio Shack lists a 36 foot mast for $42.95, and the local radio stores seem to have slightly taller ones for about a dollar a foot. This antenna will need plenty of guy wires, but is relatively easy to erect and has the advantage that almost no construction is required other than to provide it with a good base insulator. Since this insulator will be in compression it may be made of glass, ceramic, or any other good insulating material. A large glass beverage bottle will serve quite well, though you have to be careful to mount it so it cannot be broken by the sideways motion of the mast during installation or while being blown by the wind. To be sure of electrical continuity, the sections should be electrically connected by soldering wires between them (may be difficult, most mast material "doesn't like to solder"), or using self tapping screws and washers to secure wire jumpers between sections. The guys may be metallic, and if so should be broken every 10 feet or less with "egg" type strain insulators. Polypropylene and polyethylene rope is quite cheap, and will serve very well when dry. It has the advantage of not requiring insulators.

If you get a mast of less than 50 feet you have many choices of how to use it. First of all, you can use it as is, with some loss in efficiency. If you don't mind taking it down later for improvements this may be your best choice, since you can get on the air sooner. Second, you can extend it to 50 feet with the 5 and 10 foot mast sections which can be had where you get the mast. This should be pretty easy to do. Third, you can top load it, either at its existing height or with a combination of extension mast and top loading. This is where the interpretation of the FCC rules is fuzzy, since they leave no way to figure what the "length" of a top loading device is. For example, suppose you load a 40 foot tower with a solid disk 10 feet in diameter. Is the "total length" 40 feet plus 10 feet? Is it 40 feet plus 5 feet, the maximum distance from the base to the furthermost extremity of the antenna? I have no idea, and don't advise an inquiry. I would feel free with my conscience if I used the last definition, which would allow a total height of 45 feet with a 10 foot top loading disk, and a total height of 40 feet with a 20 foot one. The latter would be a stinker to build, and would flap in the breeze unless it were guyed well. In practice a solid disk, unless it is made of screen or chicken wire supported with some sort of frame, is impractical and the use of a round "hoop" of wire or tubing supported with cross pieces fastened to the top of the mast, is most convenient. The ARRL Antenna Handbook has several illustrations on the construction of top loading sections. In spite of my remarks that the antenna should be 50 feet high if possible, I feel anyone will be satisfied with the performance of a 40 foot mast with an 8 to 12 foot loading hoop at the top of it.

If you are willing to spend more construction time in

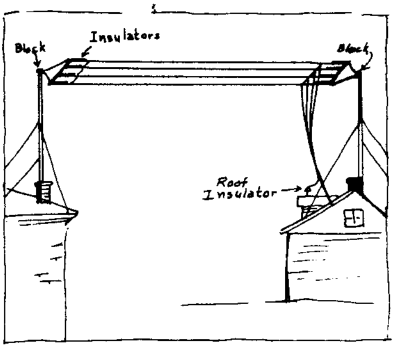

FIGURE 1 AN INVERTED "L" AERIAL

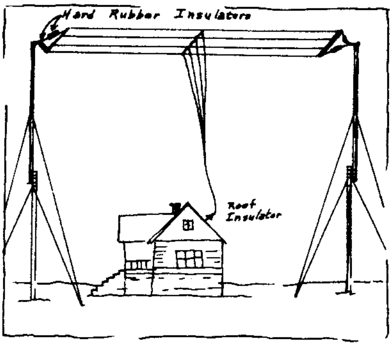

FIGURE 2 A "T" AERIAL

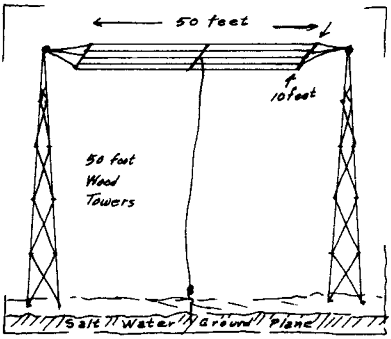

FIGURE 3 BEST BUT ILLEGAL

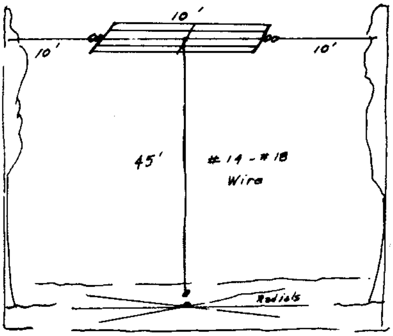

FIGURE 4 FINE IF YOU HAVE THE TREES

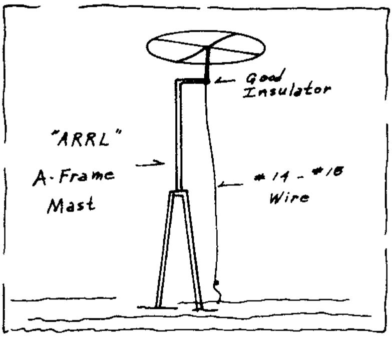

FIGURE 5 "ARRL" A-FRAME MAST AND "HOOP"

order to save some money, you can make your own mast using the 1-1/4" 5 and 10 foot TV mast extensions mentioned above. They cost less than half as much as the telescoping masts, but will require more guys to make them secure, and should be reinforced with a wooden rod at each joint. The suggestions on base insulator, electrical continuity, and guys which were given for the telescoping mast should be followed here too. This mast will be pretty "rickety" so plan out the erection in advance. Make sure you have enough guys, and get enough help so you can handle the emergency situations which are almost certain to develop. Good luck!

If you are fortunate enough to have some big trees in your yard with reasonable spacing between them, you can save even more money by using the construction of Figure 4. Pick two spots about 45 or 50 feet above the ground, and provide them with pulleys and halyards. A top loading structure consisting of several wires held apart with 10 foot spreaders is isolated with insulators, following the same procedure as described above for the guys for the mast. Don't forget that it will be mighty hard to clean the insulators once they are installed, and use good ones to start with. The vertical radiator is a wire descending from the center of the loading section to the ground, where it is anchored with an insulator. This will be a very effective antenna if the trees are at least 50 feet or so apart, and will still work if they are much closer together. A variant of this theme would be to use a single tree with a slanting top loading section, and the halyards brought down to some convenient lower level such as the corner of a house or garage. Remember that trees and antennas like to move around when the wind blows, and leave enough slack to allow for the motion, or else use a spring or pulley and weight to keep the lines reasonably tight.

If all else fails you can always make your own "tree" following the design for an "A-Frame Mast" which was found in all of the ARRL "The Radio Amateur's Handbook" and ARRL Antenna Handbook editions before 1980. (For some mysterious reason the A-frame design is omitted from the new handbooks, even though it has been "the old standby" for generations of hams!) You will need about 60 feet of 2" by 2"s, which even in these days of sky high lumber prices may still be an attractive way to go, and you will need guys and space to install them. If you want a single mast design I suggest that shown in Figure 5. The top of the mast is equipped with a bracket and insulator(s) to hold the top loading hoop, and the radiator is a wire descending to the ground at the base. The same precaution with respect to the top insulator applies as in the previous example, and the guys should be broken with insulators as described for the metallic mast.

With any of these alternate antenna systems the use of a good ground and radials is just as important as it is with the free-standing tower described first, and their design and installation should be considered in planning your antenna.

I have not tried to discuss all possible methods of antenna construction, but just to give some pointers you can use in planning your own version. If you are lucky enough to have space for a 50 foot tower with lots of radials, mounted over good moist ground, you are going to have a really king sized signal. If you can't meet all of these requirements, follow the suggestion in the beginning: put up the tallest structure you can, as far away from trees as you can, with the best ground you can scrape together, and with radials if possible. You can't fail to put out a usable signal!

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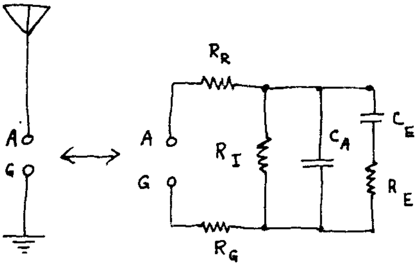
COUPLING THE VLF ANTENNA TO THE TRANSMITTER

By Ed Phillips W6IZJ

The previous section (Vol 7 #7 page 10) discussed transmitting antenna system design, construction and preferred installation sites. Efficient means of tuning the antenna and for coupling it to the VLF transmitter will be considered here, since they have a very strong influence on the success of the transmitting station. The subject will be introduced by examining the electrical parameters of the antenna, to give a feel for the sizing of the tuning components and of the impedance to be coupled.

Figure 1 is a simplified view of the electrical properties of a typical 50 foot antenna at an operating frequency of 175 KHz. If the antenna were mounted



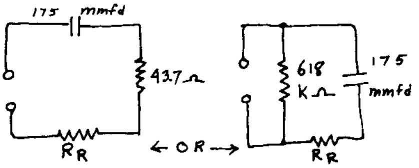
TYPICAL VALUES FOR 50 FOOT ANTENNA

R_G - 10 ohms to 50 ohms
C_A - 150 mmfd
R_I - 1 megohm to 2 megohms
C_E - 25 uufd } Depends on surrounding trees,
R_E - 500 ohms} buildings, etc.
R_R - 0.031 ohms - useful radiation resistance

FIGURE 1 VLF ANTENNA CIRCUIT ELEMENTS

over a perfectly conducting ground plane, and on perfect insulators, its input impedance would consist of the radiation resistance R(R) in series with the capacitance C(A). As discussed before, the radiation resistance is a fictitious resistance which, when multiplied by the square of the RF current flowing into the antenna terminals, gives the value of the radiated power. In this example it is only about 0.031 ohms! The capacitance of the 150 mmfd (pf) would represent a typical telescoping TV mast, mounted well away from any conducting structures. The effect of the non-ideal installation may be seen from the other circuit elements in Figure 1. First, the ground system will have a resistance (R(G)) which appears directly in series with the radiation resistance and the antenna capacitance, with typical values from 10 ohms to 50 ohms, depending on the type and moisture content of the soil, and the size of the ground rods or radial system used. This resistance represents a loss, and a very serious one. Note that even if the resistance can be held to 10 ohms it is still almost 300 times the radiation resistance, and that the maximum efficiency of such an antenna could be only 0.3 percent. In addition to the ground circuit loss, there will be additional losses due to any capacitance between the antenna and surrounding lossy materials such as trees and buildings. These are represented by a capacitance C(E) in series with a loss resistance R(E), and the values shown are only a very rough guess based on my own observations. Their effect is to increase the capacitance of the antenna and to introduce additional loss. A final loss which must be included is the shunt loss resistance of the base insulators, and my experience indicates that a value of one or two megohms is typical for good insulators, while a value of perhaps 100 K ohms is representative of bad ones.

When all of these losses and spurious capacitances are summed up, the antenna can be represented by the series equivalent circuit shown in Figure 2.



Values for R_G = 20 ohms, R_I = 2 megohms, R_E = 500 ohms

FIGURE 2

EQUIVALENT CIRCUIT OF ANTENNA AT 175 KHz

A ground resistance of 20 ohms, an insulator resistance of 2 megohms, and the values of C(E) and R(E) from Figure 1 were used to calculate the values shown; these values represent a pretty good installation. The equivalent capacitance is 175 mmfd, and the total series resistance is 43.7 ohms. Another way of representing the antenna is by the shunt equivalent circuit which is also shown. Examination of these circuits will show that the effects of ground resistance, insulator resistance, and loss due to trees or buildings are roughly equal. In order to increase the station efficiency all must be minimized, and even when everything possible has been done this efficiency won't be very high! For this example it is the ratio of the 0.031 ohm radiation resistance to the 43.7 ohm series loss resistance, or only 0.07 percent. Don't get discouraged at this point; for my own station the total loss resistance is about 65 ohms, and the efficiency is only about 0.05 percent, but I still get out pretty well!

So far we have discussed a hypothetical antenna system. What will the parameters of yours be? Unfortunately there is no practical way of predicting the losses, and you will just have to do your best to minimize them by following the practices outlined in the transmitting antenna section. It is, however, possible to estimate the capacitance of the antenna, and to predict the radiation resistance pretty accurately. The estimation of antenna capacitance is necessary in order to plan the design of the antenna coupling circuit, and the calculation of radiation resistance is an exercise in futility, so formulas for calculating them are given below.

Calculation of the exact capacitance of a short vertical antenna, even for the ideal conditions where it is located over a perfectly conducting ground, and where it is completely isolated from all other conductors which might have mutual capacitance to it, is difficult and no simple formula exists. A rough approximation for this capacitance, and one that is often quoted, is the following (I have changed it to common units):

C = 7.359H/(Log(24H/D) - 0.43)

Where:

C is the capacitance in mmfd (pf)
Log is the logarithm to the base 10
H is the height in feet, and
D is the average diameter in inches.

I have calculated the value of capacitance for several possible types of antenna conductors, and for the entire range of heights which might be of interest. The following Table gives these estimated capacitances for the various combinations of antenna height and antenna diameter I considered. Note that these values are very approximate, and strongly dependent on the surroundings, including effects of nearby trees, buildings, power lines, and other conductors. In general, actual values will be slightly larger due to these effects.

	CAPACITANCE IN MMFD FOR ANTENNA HEIGHT IN FEET OF:				
ANTENNA DIAMETER (INCHES)	10	20	30	40	50
0.064 (#14 wire)	23.4	42.7	61.0	78.6	95.7
0.102 (#10 wire)	25.0	45.4	64.6	83.1	101.0
1.00	37.7	65.4	91.0	115.3	138.9
1.25	39.7	68.3	94.7	119.9	144.2
1.625	42.3	72.1	99.6	125.7	150.9
3.00	50.0	83.0	113.2	141.8	169.4
5.00	58.8	94.8	127.7	158.8	188.7

The diameter of 1.25 inches is typical of common 10 foot TV mast extensions, while the diameter of 1.625 inches is typical of the average diameter of a telescoping type TV antenna mast of 40 or 50 foot height. The diameter of 5 inches is typical of the smaller self-supporting towers.

The capacitance of a top loading device is even harder to estimate. Figures in the ARRL Antenna Handbook show that for a solid disk, the capacitance is given by the following approximation:

C(TOP) = 10 D mmfd

Where D is the diameter of the disk, measured in feet.

A more convenient way to make the top loading device is as a hoop with crossbars to support it, and the capacitance will probably be pretty close to that for the solid disk, particularly if several additional "spokes", even of pretty small wire, are added.

The radiation resistance may be calculated by this formula:

$$R(E) = 0.03124\ (F/175)^2\ (H/50)^2 \text{ ohms}$$

Where F is the operating frequency in KHz and H is the height in feet. This value is correct for an antenna without capacitive loading at the top. For an antenna with top loading the radiation resistance is increased by the factor

$$(1 + I(TOP)/I(BASE))$$

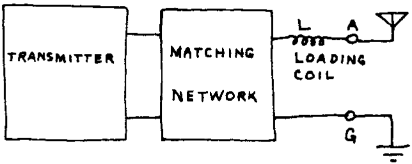
Where I(TOP) is the current flowing at the top of the antenna and I(BASE) is the current flowing in the base. A very crude estimate of this current ratio may be calculated from

$$I(TOP)/I(BASE) = C(TOP)/C(BASE)$$

Where C(TOP) is the top loading capacitance, and C(BASE) is the sum of the antenna capacitance and the top loading capacitance. This last formula will give optimistic results, since the formula for C(TOP) includes the effect of capacitance to the antenna beneath it, but it does show that even modest amounts of top loading will do some good. For example, if an 8 foot diameter top loading hoop predicted capacitance of 80 mmfd is used, the radiation resistance of the example antenna will be increased from 0.03 ohms to about 0.056 ohms, and the radiated power will go up by 80 percent. This is not an enormous change, but it will increase the station range by 40 percent and is certainly worth the effort involved.

To summarize all of this, a typical antenna will look like a capacitance of about 150 mmfd to 200 mmfd in series with a resistance of perhaps 10 ohms minimum to over a hundred ohms maximum. Almost all of this resistance is due to losses; the useful (radiation) resistance is only about 30 milliohms, or an insignificant fraction of the total. The job of the tuning and coupling circuits is to transfer as much as possible of the transmitter output power to the antenna, in order to maximize the current which will actually flow in the radiation resistance and thereby end up being transmitted to the world. If the transmitter is assumed to be 100 percent efficient, which isn't too optimistic, and if the output power is assumed to be coupled to the antenna with 100 percent efficiency, which unfortunately is pretty optimistic, then all of the power will be dissipated in the antenna losses. For the sample antenna with series loss of 43.7 ohms, one watt of transmitter power would result in an antenna current of 0.151 amperes, and the radiated power would be about 0.71 milliwatts, for an overall efficiency of only 0.071 percent! The reactance of the 175 mmfd is about 5200 ohms, so that for this current the voltage drop across it will be about 787 volts. If the antenna were to be connected directly to the transmitter output, this would need to be the rms voltage across its tank circuit, and the DC supply voltage to the final power amplifier would have to be over 1100 volts. Such a transmitter can actually be built with TV sweep tubes, but most experimenters would prefer to go all solid-state, so some form of matching circuit is needed between the antenna and the transmitter.

Figure 3 shows one way of coupling a short antenna to the transmitter. It is typical of the circuits used with a 160 meter vertical antenna, or with a mobile antenna for any of the HF Ham bands. The capacitance of the antenna is resonated with a series loading inductor, and a matching network is used to couple the resulting impedance (of the loading coil and antenna in series) to the transmitter. For our sample antenna parameters if the loading coil were lossless the net impedance would be the series resistance of 43.7 ohms.



Example: For 175 mmfd antenna capacitance
L = 4726 mh at 175 KHz operating frequency.

FIGURE 3

ONE WAY TO COUPLE ANTENNA AND TRANSMITTER

If the transmitter operated from a 15 volt DC supply voltage the rms voltage across its tank circuit would be about 10 volts, and the required load resistance would be 100 ohms for an output power of 1 watt. The matching network would thus need to have an impedance ratio of about 2.3 to 1. While this is a perfectly practical coupling technique, it has two undesirable properties. First, the components in the matching network may be quite lossy, though for cases where the required transmitter load resistance is greater than the antenna circuit resistance the antenna could simply be tapped down on the tank coil, eliminating the matching network. Second, the selectivity, or ability to reject harmonic radiation, is quite poor. This will increase the possibility of harmonic interference with broadcast band receivers, and undesired attention from the FCC.

One thing which is a function of the antenna parameters alone is worth mentioning at this point. The antenna loading coil will not be lossless. If it has the rather good "Q" (ratio of reactance to series loss resistance) of 250 the effect of its loss will be to add an additional series loss resistance of about 20.8 ohms to the 43.7 ohms of the basic antenna for a total of 64.5 ohms. This means that the maximum antenna current for 1 watt transmitter power input can be only 0.125 amperes, the radiated power will be 0.48 milliwatts, and the efficiency will be only 0.048 percent! This is about the case with my own antenna, which has a measured loss resistance of about 65 ohms. The design and construction of loading coils will be described later. The only way to reduce the loading coil loss is to make its "Q" as high as possible through using a large diameter and winding it with the largest wire you can afford. By increasing the antenna capacitance through use of top loading its reactance, and hence the reactance of the loading coil, will be reduced so that for a given Q the actual series loss resistance will be reduced. This is a substantial added benefit of top loading.

Figure 4 shows an easier way to couple the antenna to the transmitter, and one I strongly recommend. You will find numerous examples of it in Ken Cornell's VLF Scrapbook. The loading coil is connected between the antenna and ground, and is inductively coupled to the transmitter by mutual inductance between it and the tank circuit, as shown pictorially. The advantage of this coupling technique, compared to the previous one is that transmitter loading (the load resistance coupled into the transmitter tank circuit) may be varied by changing the distance between the tank circuit and the loading coil, which should now be called the coupling coil. Large spacing results in "loose" coupling

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or light transmitter loading, while closer spacing increases the coupling and the transmitter power input. The transmitter may be run at any supply voltage where it is efficient and the power output (and hence the input) may be set to the desired value by simply adjusting the coupling. This transmitter may be a transistorized one working with six volts collector supply or it may use tubes and run at 300 volts plate supply, and the loading coil will be the same. "Only the coupling need be changed." While the major attraction for this coupling method is its simplicity, it also provides better harmonic signal reduction than the first one, and at no added cost.

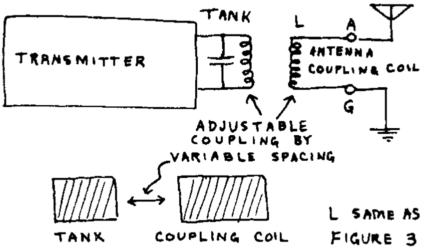
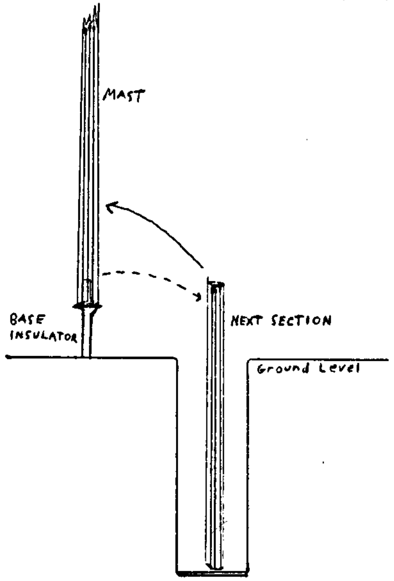


FIGURE 4 AN EASIER WAY TO COUPLE ANTENNA

This discussion is directed toward the design and construction of coupling circuits, and their adjustment will be described later. However, a few additional comments on coupling circuits are in order here. Most solid state transmitters will have a rather low loaded tank circuit "Q" (the load resistance for proper power output will not be very much greater than the reactance of the tank circuit tuning capacitor) and some readjustment of antenna tuning will be required as the coupling is varied. To be specific, if the antenna is tuned to resonance with very light coupling, as the coupling is increased it will be necessary to increase the loading coil inductance in order to keep the tuning at the point of maximum power output. Consequently, the complete antenna coupling circuit must include some provision for adjusting this tuning, and will not be quite as simple as I have shown. As an alternative to varying the inductance of the coupling coil I have found it convenient to adjust the antenna tuning by connecting a variable capacitor across either the whole coil or part of it. While such a tuning method increases the loss somewhat, it is much easier than building a coupling coil with variable inductance, at least in my opinion. I have recently had the opportunity to test some tank circuits built by Ken Cornell and by Jack Althouse of Palomar Engineers. Both used a variable tuning core for inductance adjustment and had very low loss, but the adjustment of tuning required very delicate variation of the position of the slug, and I think the beginner will have an easier time if he follows my suggestion.



ANOTHER USE FOR POSTHOLES

Solo or short-handed erection of sectional masts can be greatly simplified by digging a posthole alongside the antenna base. The hole should be deep enough to contain all but a foot or two of the mast sections you are using. It should have something solid at the bottom to prevent clogging the mast sections with dirt. A lining of 4" plastic sewer pipe will make the hole permanent, preventing cave-ins. Begin by erecting 15 feet or so of mast in the normal fashion. Mount the loosely guyed mast on the base insulator, put the next section in the hole. Then lift the mast from base insulator to the top of the new section. Loosen the guys a bit more and lift the extended mast back to the base insulator. Repeat the process until full height is achieved. The higher you go the harder (and slower!) it gets. 40 feet is about the limit for solo work with 5" sections.

BASIC 1750m TRANSMITTING ANTENNA

by Mitchell Lee

Newcomers to 1750m find a mystique surrounding transmissions on such a low frequency. There is no magic involved; 1750m responds to the same physical principles that apply to other frequencies. In this article we will discuss the transmitting "loop" (not to be confused with a loop of wire) and how to maximize the radiated signal. The transmitting loop consists of a loading coil, an antenna, and a ground.

For the purpose of developing a useful antenna model, let's consider an average city lot 1750m installation (see Figure 1). It is constructed from three 10' TV mast sections with four 20' top loading wires extending out horizontally at all four points of the compass. The antenna stands on an elevated plastic slab that acts as a base insulator. Beneath this is a water pipe and several ground wires that run out in various directions to the property lines where they are terminated by 8' ground rods. There are no buildings or trees anywhere near this antenna because the owner/operator went berserk one day with a Brush Hog. The loading coil is also located at the base of the antenna.

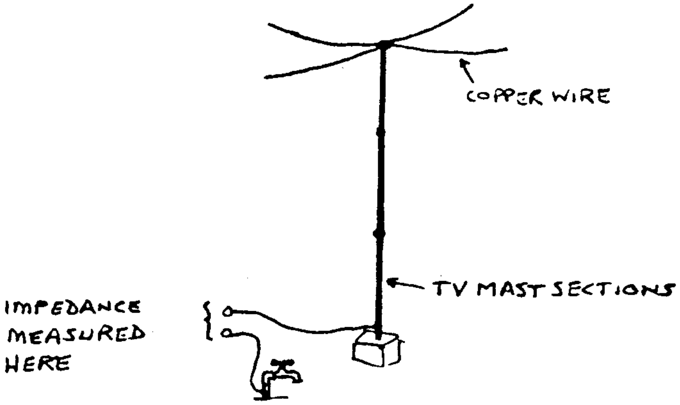


Figure 1. Typical 1750m antenna.

The capacitance as measured between the base of the antenna and the water pipe/radial system is 320pF. Antennas of this genre run anywhere from 120pF (30' vertical) to 500pF or more (30' vertical with lots of top loading radial wires). Note that top loading wires exhibit 200pF capacitance, while the vertical section ~~which~~ contributes about 120pF. The utility of more top hat capacitance will be illustrated shortly. The resistive component of the impedance (modeled as a resistor in series with the capacitance previously discussed) as measured at the base of the antenna is 40 ohms. The impedance bridge used was a pretty good one; a resistive component of only 40 ohms is difficult to find when the capacitive reactance is 70 times greater, or about 2,842 ohms.

While the the 2,842-ohm capacitive reactance is easily tuned out by a 2,842-ohm inductive reactance, still buried in that 40-ohm resistance is a useful(?) radiation resistance of 0.025 ohms. Graphs showing radiation resistance for electrically short top-loaded verticals are found in various engineering literature (1,2,3,4). Figure 2 shows a schematic representation of the transmission loop.

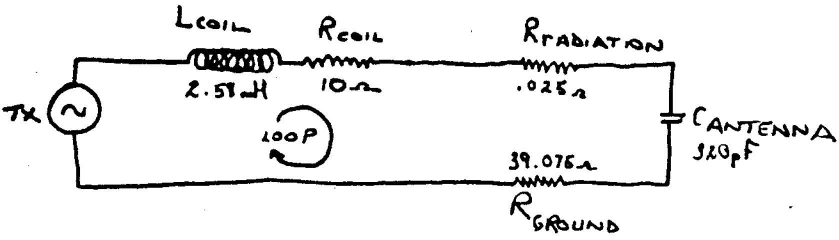


Figure 2. Transmission loop of a typcial 1750m installation.

The most common transmitting scheme is a series tuned circuit. It affords a manageable driving point impedance with transmitter voltages and currents well within the reach of inexpensive components. When the antenna capacitance is series resonated by the loading coil, nothing is left but loading coil loss, radiation resistance, and ground resistance. Therefore the transmitter thinks it is driving a pure resistance.

Our loading coil depicted in Figure 2 has a Q of 284. Q is the ratio of inductive reactance (2842 ohms) to resistance (10 ohms). When the coil is hooked up to the antenna and transmitter the overall Q is 2842/(10+39.975+0.025)=2842/50=57. Q is also related to bandwidth and in this case (175kHz) the bandwidth is 175000/57=3kHz. A +/-1.5% shift in antenna capacitance or coil inductance will drop the output 3dB--half power. Since transmitter characteristics are unkown, the previous statement is at best a very crude approximation, but it is in the ball park and tuning is critical. If we assume that the circuit is resonant, we can further simplify as shown in Figure 3.

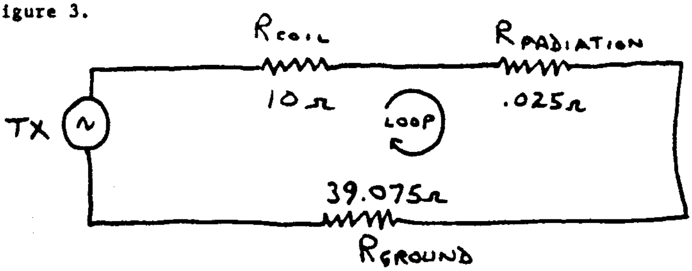


Figure 3. Transmitting loop in resonance reduces to resistances.

Even the most non-technical person can analyze Figure 3, and Ohm's law will suffice for all of our calculations. To radiate a signal it is necessary to dissipate some energy in the radiation resistance, Rr. The power in this resistance (ERP) is given by I^2Rr. Assume that the transmitter is 100% efficient (80 or 90% is more representative) and calculate the antenna current for 1W. I^2=P/R=1/50. Therefore the best antenna current we can achieve is about 141mA (.141A) with 1W of power and a 50 ohm loop resistance. Let's make a table with various ground+coil resistances and show how the antenna current and the relative signal will vary. 1W transmitter power and .025 ohms radiation resistance is assumed, and 50 ohms (a typical loop resistance for someone on good soil with some metal in the ground) is our reference level. The radiation resistance used for this table includes that of the vertical section of the antenna only, and does not consider the effects of radiation from the top hat or the ground. ERP=effective radiated power.

loop resistance	I (mA)	signal (dB)	ERP
10 (copper plate)	316	+7	2.5mW
20 (copper soil)	224	+4	1.25mW
35 (much effort)	169	+1.55	714uW
50 (good soil)	141	0.0dB	500uW
75 (ok)	115	-1.76	333uW
100 (bad soil)	100	-3	250uW
150 (no skywave)	81.6	-4.77	166uW
250 (rocks)	63.2	-7	100uW
500 (find another hobby)		-10	50uW

If you run out and measure your antenna current and find 63.2mA, that doesn't mean that your ground is a total "loss." Your transmitter efficiency might be low, you could be mistuned, your coil could be a loser, or your RF ammeter could be a basket case. If you measure 224mA, don't pat yourself on the back because even if your ammeter is working, you may not be radiating all of it. Look at Figure 2 again. Suppose we add some capacitance from the base of the antenna to ground. Not all of the current that flows from the transmitter through the coil will make it to the radiation resistance. Some will be shunted away in the loss capacitance. The stray capacitance doesn't dissipate power, but it does divert current away from the radiation resistance and therefore decreases the radiated signal. Excessive base capacitance is caused by insufficient base insulation (separation from ground), and non-vertical feed lines running from the coil to the antenna.

Trees, nearby structures and metal objects (such as other antenna masts or wires) will absorb energy or act as a shield, robbing the signal of its precious few microwatts. Other losses such as leaky insulators, conductive guy wires/ropes, and losses in the conductors themselves, such as skin effect, non-copper antenna components, thickly-painted or rusted surfaces, and poor connections, take their toll on the available power.

Why is a horizontal antenna so bad? Providing we take steps to reduce all of the loss factors, why does a horizontal antenna have such a tough time radiating a signal? Horizontally polarized signals at low frequencies are greatly absorbed as they travel along the surface of the earth. If the signal was radiated way up in the sky (miles up) then this effect would be nonexistant. Vertically polarized waves are also attenuated as they travel along the earth's surface, but not nearly as much as horizontally polarized waves. Therefore, stick with a vertical antenna.

Top hats serve two functions. First, the larger the capacitance of the top hat, the greater the effective height and radiation resistance of the antenna. THe .025-ohm radiation resistance is a lumped constant that is based upon uneven current distribution in the antenna. One must realize that the actual radiation resistance of the antenna is distributed throughout its length, as is the antenna capacitance. Therefore, not all of the current flowing into the base of the antenna makes it to all of the radiation resistance, or to all of the antenna. A large top hat will act to hog current from the vertical section. In this example, a fraction of current (200/320pF=62.5%) flows through all of the vertical radiation resistance and makes it to the top hat. The remaining 120/320=37.5% of antenna current flows through only part of the vertical radiation resistance. The bigger the top hat for any given vertical, the larger the EFFECTIVE radiation resistance. The 0.025-ohm value previously used was an effective radiation resistance and accounts for uneven current distribution such that $0.025XI^2$ yields the proper number for effective radiated power.

The second benefit of larger top hats is that the increased antenna capacitance will result in a proportionately smaller loading inductance. Less inductance means less coil loss resistance, and less capacitance from the physically smaller coil to ground. If a smaller coil is used, the loop Q will drop making tuning less critical. Antenna voltage will drop as well making for less stringent insulation requirements.

The analysis above has benefited from a few assumptions and has obtained some numerical values (antenna/top hat capacitance, effective radiation resistance) from formulae not shown here. However, calculating these numbers for any given antenna is a tedious and useless pursuit since there are so many effects that cannot be quantified. What is shown will serve as a reference from which several conclusions may be drawn regarding optimizing a 1750m antenna. Before we state the conlcusions, let us consider one last bit of information.

Our discussions assumed a flat top hat. In most instances a flat top hat is impossible to construct owing to a lack of support structures from which it may be suspended. Various studies have show that for drooping top hats, the length of the conductors may be extended until their ends are at approximately 1/2 the height of the vertical antenna. Beyond this point the top hat wires begin to exhibit a shielding effect on the prime radiating portion of the vertical, thereby reducing the radiated signal. Lowfer experiments have shown that a 10' vertical with a flat 40' radius top hat does not radiate as well as a 40' vertical with a 10' radius top hat. Given the 50' (15m) antenna length (vertical+top hat radius) restriction of Part 15.112(c) of the FCC rules, a 20' to 40' vertical with the balance in top hat is optimum. More exacting generalizations are pure speculation. A point is reached where much depends upon the individual transmitting site, ground conditions, and the characteristics of the receiving setup.

If safety and convenience are an issue, the 20' vertical is optimum since one person can easily erect 20' of TV mast. A 30' vertical really requires 2 people or more. 40' requires an antenna party. As an example, erecting the 45' LAH beacon vertical (with a spoked top hat) took 11 people. It was constructed from 5' military thick-wall aluminum mast sections. 3 people lifted the mast at the base, a fourth person positioned and inserted the next section, and 6 other persons fed out 3 sets of 3 guy ropes. The eleventh person ran around monitoring the lean angle. 6 months later a particularly windy storm compressed the antenna until it bowed in the center, and upon springing back into shape, so much upward velocity was generated that the entire antenna disintegrated into 5' sections distributed all over the back yard. All guy rope anchors were still in place and only one or two sections showed any signs of stress. Viewing such a spectacle at the base of the antenna could have been a most impaling event. Fortunately, the hot tub was vacant at the time.

Now for some rules of thumb regarding 1750m transmitting antennae:

1) Put as much copper into the tophat as possible. Remember, don't let the top hat droop further that 1/2 way down the vertical. Try to maintain geometrical symmetry in the top hat for maximum capacitance per foot of conductor used.

2) Try to use copper throughout. Copper pipe can be bought in concentric sizes and brazed or soldered together. Maintain the integrity of each copper-to-copper connection by soldering or joining with sheetmetal screws and covering the connection with RTV or other suitable silicone sealant. TV mast can be shunted by copper wires to increase conductivity, and a cage of vertical wires can be substituted for a mast where the antenna is suspended.

3) Connect as many metalic objects and ground rods as possible to the ground system. Optimum radial length is slightly longer than the antenna is tall. For a 30' vertical, ten 40' radials make a better ground than one 400' wire.

4) Use an efficient coil. From the considerations of Figure 2, a coil Q of about 50 (57 was the overall loop Q) would result in an immediate loss of 6dB. The use of Litz wire vs. enameled wire is worth a factor of 2 improvement in coil loss. Ferrite loading is useful for producing Qs of 250 to 350 and physically small coils. A 7.5"X0.5" type 33 ferrite rod (available as part number R33-050-750 from Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91607, cost is around $3.50 including postage) is an excellent choice for loading coils. 100 turns or so will produce a maximum inductance of 5 or 6mH which can be tuned by sliding the coil around the ferrite rod. Large air-core coils or "basket" coils are probably the best, and they can exhibit Qs in excess of 600 in the 2 to 10mH range. For the curious, a ratio of 2.5:1 diameter:height is the optimum geometry for such a coil. Tuning a basket coil is best accomplished with a variometer.

5) Use an efficient transmitter. Its efficiency can be determined by measuring the ratio of output power (into a load resistor that is approximately the same value as the loop resistance) to the DC input power. You will need an AC voltmeter with enough bandwidth to cover 1750m (or an RF ammeter) to measure the output power into a resistive load. Replace the loading coil and antenna with a carbon composition resistors until a value is found which results in the same DC input power as was observed when operating

into the coil/antenna. Power MOSFET transmitter circuits with 80 to 90% efficiency can be constructed.

6) Use high-quality insulation throughout. A 1' porcelain base insulator is not overkill. In addition, pyrex or ceramic strain insulators are not an excess used in series with nylon guy ropes. Do not use metalic guy wires. The top hat often substitutes as part of the top set of guy ropes. It has been found that polypropylene guy rope deteriorates rapidly when exposed to sunlight. 0.1" nylon weed-eater line has a useful lifetime and yet is low-profile and lightweight. This material can be purchased in bulk at most hardware stores. Beware of PVC pipe. Tesla coil tests show that while white-colored PVC pipe seems to be an adequate insulator, gray (and perhaps other colors) PVC pipe is very lossy. Do not use gray PVC pipe for coil forms or insulators. Use other colors at your own risk.

7) Tune your loading coil frequently until you have an idea about how the system tuning varies with time, season, and weather. Most air-wound loading coils detune when a hand is brought within 3', and some are even more sensitive than this. Tune with a proverbial "ten-foot pole." Observe your tuning by watching antenna current (measured in line with the antenna itself), a neon lamp, or a field strength meter. An ammeter and neon light will each take a small amount of power, but in most cases it is inconsequential when compared to the available power. For instance, an RF ammeter might take 20mW or power from a transmitting circuit which has an available power of 800mW. The loss is about 0.11dB. A friend with a receiver and a telephone can provide excellent remote field strength measurements.

8) Locate the antenna in as clear a location as possible. A mountain top is best; leaning it up against a metal barn in the bottom of a canyon is the worst. Keep the area near the base of the antenna clear of bushes, fences, buildings, and other lossy capacitances. A clear area with a diameter equal to the height of the vertical is a plus. Buildings, power poles and other antennas are the worst offenders. In a residential situation it is best to locate the antenna on the peak of the roof.

9) Try to reconstruct a "Figure 3" for your installation. Given the Q of the coil and figures for the transmitter output power and loop resistance this is easy to do. Inspection of Figure 3 will give an indication of where some improvement might be made. For instance, if the coil loss is 10 ohms and the ground loss is 90 ohms, your extra Litz wire is better utilized as ground radials.

10) Keep your beacon running 24 hours a day, 7 days a week. There have been relatively few reports of people hearing beacons that were not running.

References worth reading:

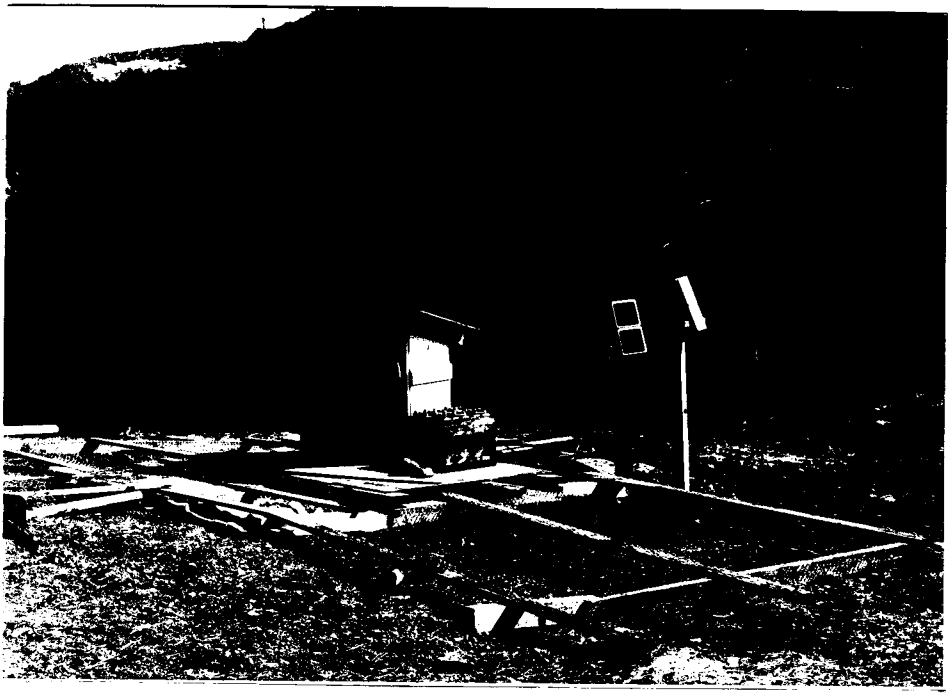
1: LF Engineering Company, Catalog No. 100/Fall 1985. 17 Jeffry Road, East Haven, CT 06512. See "Low Frequency Engineering Data" for equations and graph of radiation resistance. This material was credited to Antenna Engineering Handbook, by Henry Jasik (a classic text on the subject).

2: RF Design, a magazine puplished by Cardiff Publishing Company, Inc., 6430 South Yosemite Street, Englewood, CO 80111. (303) 694-1522. See the January/February 1984 article "Gain, Capture Area, and Transmission Loss for

Grounded Monopoles and Elevated Dipoles, Part II," by John W. Ames and William A. Edson of SRI International, Menlo Park, CA 94025. Shows "derivation" of equation for radiation resistance of monopoles (short vertical antennae). The title sounds insufferable, but it is really a simple article with equations that anyone with a calculator can put to use.

3: Radio Engineers' Handbook, by Frederick Emmons Terman, First Edition, 1943, published by McGraw-Hill Book Company, Inc. This is another classic and it has an excellent antenna section starting on page 770. Page 794 is especially useful if you can fill in all of the numbers in his equation!

4: Nautel, a Canadian NDB manufacturer located in Nova Scotia, has an excellent supplement that is included with every NDB instruction manual. They were kind enough to send me a partial copy of a manual and this supplement which is entitled "NDB Antennas." It is an excellent rule-of-thumb source of information. The formulae are simple enough to be worked out with pencil and paper, if not in your head. I will attempt to secure permission to plagiarize this document in the future.



SKY, August 1987 (see Page 41)

Optimizing The Part 15 Antenna

by Mike Mideke Z2

Early in 1986, my 30-ft. 1750m transmitting vertical was destroyed by high winds. Repair or immediate replacement was impossible, so I decided to make what I could out of the wreckage while gathering resources for a new and better antenna. During the months that followed, I built and tested a series of very short tophatted verticals. In the following paragraphs I will describe my progression back to a full-size antenna. In concluding, I will discuss some of the practical and theoretical implications of various tophat-to-vertical ratios. I apologize for not having gone Metric with this work. I have used the old measure of 50 feet as the allowable antenna dimension, while it is actually 15m, or 49.2 feet.

The Site is a narrow brushy ridge at 2,000 feet elevation. The ground system consists of around 150 insulated radials, most of which range from 30 to 60 feet in length. The earth connection is composed of 20 copper pipe grounds, each pipe being driven as deeply as possible into a treated posthole. Ground resistance measured at 165 kHz is around 10 Ohms.

Antenna No. 1 was an 8-ft. vertical with 20 tophat elements. Eight of these elements were 14 ft., 8 were 36 ft. and the remaining four were 30 ft. They were arranged in symmetrical pairs and secured to a pole and rigging support that surrounded the site. All tophat elements were essentially at 90° to the 8-ft. mast.

The large, low tophat produced a high antenna capacitance and in consequence, only 600uH of inductive loading was required to resonate the structure. Tuning was broad, current was high, and voltage on the vertical was low.

Looking more like a cartoon than a functional antenna, this stubby mushroom actually functioned reasonably well, being only 13 to 15 dB down from its 30-ft. predecessor. Copy of the CW beacon while mobile-in-motion was comfortable to about 30 miles and possible to 50 miles. At 100 miles, the copy was virtually impossible from casual roadside stops but at 110 miles on a March night the signal surfaced to copyable levels every 20 to 30 minutes despite moderately high levels of manmade noise. At 120 miles Jim Ericson's sampling recorder caught the signal many times during the weeks it was on the air, but rarely, if ever, at QSOable levels.

Antenna No. 2 was a 13-ft. vertical, produced by adding a 5-ft. mast section to the No. 1 version. Maximum tophat radius remained 36 ft. System Q increased. More loading inductance was required. Tuning became a bit sharper. A dramatic increase in signal strength was observed. The signal became marginally audible in Nevada, 280 miles to the east and occasional peaks to QSO levels were noted at 120 miles.

Antenna No. 3 extended the vertical to 18 feet. Tophat elements were pruned to keep overall length within Part 15 dimensions. The increase in height produced a further increase in signal strength, but the increment was smaller than that observed in the 8 to 13-ft. step. Signals were still generally marginal beyond 100 miles. By this time the season had progressed to the point where nights were largely clobbered by QRN, so evaluation was limited to groundwave performance.

Antenna No. 4 moved up to 23 feet, with a corresponding trim of the longer tophat elements. This step finally brought signals to a level where I could sustain conventional CW QSOs beyond 100 miles, but only when noise levels were low at the receiving site.

Antenna No. 5. The final step in this progression was a 36 foot vertical with 16 tophat elements, each 13 ft. long. Signals improved considerably (on the order of 6 dB) over the 3 ft. antenna. This large improvement may in part be due to fanatical attention paid to the electrical continuity of the final antenna.

Results—There are no surprises here. Taller antennas work better than shorter antennas but short antennas still radiate. Even the 8 foot tophatted vertical will exhibit performance superior to horizontal wire antennas of Part 15 dimensions at heights up to at least 30 feet. This result probably would not obtain if the vertical were obstructed or if the ground system was poor.

Tophats—The tophat plays an essential role in short vertical performance. To look at an extreme case: The 8-ft. vertical with no tophat will require a loading inductance on the order of 20mH. (Compare this to 0.6mH with the tophat). Coil losses will inevitably be high. If the coil is any good at all, the system Q will also be very high. This means that there will be high voltage on the antenna and that bandwidth will be extremely narrow. Tuning becomes very fussy in such a situation. In fact, remote tuning might be necessary since the presence of an operator within a few feet of the antenna would hopelessly detune the system. Worse yet, even if a perfectly tuned and completely lossless loading inductance were obtained, the effective height of the antenna would only be 4 feet. With sufficient tophat the effective height can be brought so close to 8 feet as to make no practical difference. This is to say that virtually all the available current will be flowing in the entire vertical element. The result will be a modest but useful amount of radiation.

Figure 1 illustrates the effective height obtained with various tophat-to-vertical ratios. Values of effective height have been calculated from the formula:

$$h_e = h\left(1 - \tfrac{1}{2}\left[\frac{C_M}{C_M + C_H}\right]\right)$$

h is height in feet

C_M is capacitance of vert in pF

C_H in capacitance of hat in pF

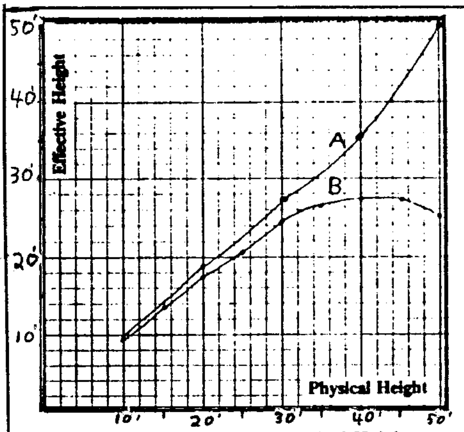


Fig. 1: Effective Height/Physical Height

In all cases Cm was assumed to be 4 pF/ft. Ch assumes 4 equally spaced horizontal wire tophat elements each having a capacitance of 2.5 pF/ft.

Curve A represents a vertical of from 10 to 50 feet having a tophat radius of 50 ft. in all cases. No configuration of curve A is acceptable under Part 15, though by the time the vertical is reduced to 25 ft. it is apparent that the excessive tophat radius buys very little advantage in effective height.

Curve B represents a "Part 15" antenna with tophat radius varying in proportion to height. As the tophat radius approaches and exceeds the vertical height, physical and electrical height become very similar.

Tophatted verticals in the 35 to 45 foot range appear to be optimum Part 15 antennas from an effective height standpoint. However, their advantage over a 50-ft. pure vertical seems, at best, to be minimal. The tophatted antenna may prove inferior to the vertical if the sacrifice in height results in a radiator that is lower than surrounding obstructions.

Since the electrical height of a pure vertical that is very short in terms of its operating wavelength is about half its physical height, the most a tophat can accomplish in this respect is a doubling of effective height. Even this will not be achieved for Part 15 antennas taller than about 30 ft. It would appear that such a doubling of electrical height will produce only a 6 dB increase in field strength. In actual practice, benefits are somewhat greater—and sometimes much greater. This is probbly because absorptive losses in the ground, vegetation, and surrounding objects rapidly decrease as the radiating conductor is elevated above the absorptive materials.

However, there are good reasons for increasing antenna capacitance beyond the point where electrical height approaches physical height. Loading inductance can be reduced, with a corresponding reduction in resistive and capacitive coil losses. System Q will be lower, resulting in broader bandwith, more stable tuning, lower voltage on the antenna and less stringent insulation requirements.

While we are, unfortunately, restricted as to tophat length, there is no limit to the number of tophat elements that may be employed. Thus, it should be possible to obtain some improvements over the cases illustrated in Figure 1 by increasing the number of elements. As more tophat elements are deployed, we begin to come up against diminishing returns. As the number of elements increases, the capacitance per foot of each element decreases. The 16 tophat elements on my final antenna are only contributing about 0.7 pF/ft; dismal in comparison to the 2 to 2.5 pF/ft that would have been achieved with 4 elements. In my case, this reduction in capacitance is due both to the large number of closely spaced elements and the fact that they form an angle of less than 90° with respect to the mast. I might have done better to concentrate my effort on 6 to 8 horizontal elements than the larger number of sloping tophat wires.

In any case, whenever a vertical of less than 15m must be used, it will be a positive advantage to employ the remaining available length in tophat—and the more the better, within reason. Verticals of 10 feet and less can be used to some effect on 1750 m and such antennas will reap maximum benefit from a massive tophat. However, they cannot be expected to perform very well in the absence of a well developed ground plane or if they are not in the clear.

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NOTES ON 1750 METER TRANSMITTING ANTENNAS/GROUNDS

by Vincent J. Pinto

I've [1]been doing a lot of experimenting with 1750 meter transmitting antenna configurations lately, and I figured I'll try to share some of what I and others have learned. To save you reading all the verbiage that follows, I'll give you a partial summary in a nutshell - the first two points a paraphrase of what Mike Meideke said some months ago in a Mailbag Letter - **GET THE ANTENNA AS HIGH AS POSSIBLE** - and **GET AS MUCH CAPACITY AT THE TOP END AS POSSIBLE.** Third point - **USE AS GOOD A GROUND SYSTEM AS HUMANLY POSSIBLE.**

First off, get your antenna as high as possible. If you can only go 28 or 30 feet high, that's OK, and it WILL radiate, but it just won't be as good as possible. If you want the best, every last foot counts. So that means 34 feet is better than 32 feet. And worth every bit of the effort. And 49 feet is better than 46 feet. And, again worth all the extra effort. Signal improvements due to height increases will be even more exaggerated than for ideal installations if your antenna is not in the clear, but, like mine, near houses and tall nearby trees. Here you not only get an increase from raising the effective electrical height of the antenna, but you get more of the current-carrying portion (which is what radiates your signal) of the tower above obstacles. I'm speaking from hardcore experience, not just theory.

If you can't put up a conventional free-standing or guyed tower, consider the cheap and easy way. Cap Hossfield was able to erect a decent vertical with tophat by throwing nylon rope over the tops of two nearby tall trees. At the "antenna" end of each thin rope, he attached a piece of wire with an insulator between the nylon line and wire. He then pulled up the two nylon ropes by the far end and the center wire became a horizontal tophat. The vertical antenna, about 31' long, drops down from the center of the tophat. So the two trees suspend the vertical and tophat between them on nylon ropes. Cap re-invented what is probably an ancient tool to do the job of getting a length of nylon rope over the tops, or near tops, of tall trees. Reasoning that, like me, he could never throw a weight with a rope attached high enough to make it over the branches, he used a very efficient sling to launch the thin rope. Cap ties a small weight (a brass plumbing elbow) to one end of the line, coils the remaining 100 feet loosely in large coils in his hand, and with the other hand starts to whirl the weight in a vertical circle (the weight is about 18" from his hand). When the spinning weight has picked up enough speed, it is released toward the target, carrying the rope behind it.

TOPHATS. I discovered the more tophat the better, at least to the point where the tophat radius is almost equal to the tower height. Of course, you have to stay within FCC part 15, but some tophat is better than none. In a clear area, where the tower is not surrounded by nearby obstacles that extend up an appreciable part of it's height, the most you can gain from a tophat is 6 dB. If your tower is surrounded by nearby obstacles, many at least 1/2 to 2/3 as tall as the tower, you can gain appreciably more by using a tophat, perhaps up to about 8 dB. Simply, an unhatted vertical (of the kinda lengths we use, and at these frequencies) has full current at the base, and zero current at the top. The current distribution from bottom to top is linear. This is the same as saying that one-half of the tower is carrying full current (the lower half), and one-half is carrying no current (the top half). When you add tophat capacity, you can make this distribution nonlinear, and "pull" more current into the top half of the tower. For a tower not shielded by obstacles, the most a tophat can do is "double" the tower effective length. (In a shielded situation, you gain more because you finally get a tower portion above the obstacles to radiate a significant amount.)

As so many articles have said before, it is not necessary to have horizontal tophats. This is ideal, but I have discovered that even sharply angled umbrella wires running from the top of the vertical, even to a point (well-insulated - of course!) near the ground and only ten - twelve feet from the base of the tower help a lot. If you are using wires as tophats, you'll find the point of "low return" appears when you go past about 15 spokes or wires in different directions. If using wire tophat radials, it is fairly important that they be equally spread over the compass. If a significant number tend to go in one direction, say East, horizontal circulating currents will get drwan into the tophat and be radiated. While this may look like an improvement on a nearby field strength meter, or even one 1/2 mile away, it's invariably a killer at further distances. At the kind of heights and lengths we use in our antennas on this band, horizontal radiation is only a loss factor. It never makes it to the horizon, much less beyond it!

GROUND systems are highly important, especially if you live in an area with poor soil conductivity. Ground rods, at least two or three copper or copper clad rods a few feet apart and at least five feet deep, are a minimum necessity for lightning and static protection. They barely start to do the job as an efficient RF ground at 1750. Some ground radials are a must, and the more the better. Each radial should be at least as long as the tower height, and twenty radials are a good compromise between performance and hard work. By all means, if you're so inclined, put in more like 30 to 60. It WILL help. Radials work better if terminated in ground rods at their far ends. Terminating even a few is better than none. The radials may lie on the surface, or be buried one to a few inches in narrow slits cut in the soil with a sharp shovel. If you live in an area of poor soil conductiivity, or just want to get out better (and this method REALLY helps), consider buying a few rolls of galvanized hex chicken fencing, perhaps 2 ft. by 50 ft. each, or 3 ft.by 50 ft., and spreading these out near the base of the tower to make a ground screen. I recommend placing them over your ground radials. They can be held in place, (and below lawnmower blades) by making short hooked nails or staples in a J shape out of 12 or 14 gauge galvanized fence wire. Of course, attach each screen to the ground system central tie point at the tower base.

All GROUND CONNECTIONS should be soldered. When I finally did this, my signal gained 3 dB, and my ground system had only been exposed to the weather 8 months by that time. Many people use a square of heavy duty stainless steel plate about 1/4" thick at the tower base as a central ground tie point. I use an 18" length of tinned 3/8" diam. copper tubing, bent into a circle about the tower base, and suspended several inches off the ground to prevent the grungies. There are numerous small holes drilled thru the tubing, and thru each is a #6-32 machine screw and nut, each holding firmly several ground wires. The ground wires may be the near ends of ground radials, or wires to ground rods and old wells, and to the ground screens. All of my ground wires are at least #14 gauge insulated copper, and each is terminated in an uninsulated solder lug. After several solder lugs are mounted under one #6-32 screw, the connection is flow soldered with a torch (rosin solder please!). I have almost 9000 feet of ground radials buried, all as long as my tower height, and some up to 100 feet long. I have a number of them terminated in 6 ft. copper-clad ground rods at the far end. I also have a total of 160 square feet of galvanized chicken hex fencing lying on (stapled into) the ground within the first eighteen feet of the tower base. I have another 170 or more square feet (in small 2' x 4' pieces) of the same on the ground further out along the radails, each tied to the nearest radial(s). In addition to the 20 ground rods terminating some of my radials, I have 26 more 6' - 10' rods scattered throughout the back yard, each tied to the ground system. I've also tied into my town water system pipes about thirty feet away via a ground clamp. I have an old 168' deep well in my basemant, and two galvanized pipes going all the way down into the well are also tied into the ground system. I also have several wire fences tied into the gorund system.

For ground radials, and ground system tie-in wire, I used coaxial cable about the physical size of RG-58/U. I was able to buy a number of spools of this cable surplus for $12.00/1000 ft. The insulation quality is still good, and I simply strip some outer insulation to expose the braid wherever I need to attach a solder lug, or make some connection. The insulation is left on the remainder of the cable to protect the braid against soil alkalais and acids and abrasion. (I do not use the center conductor at all - the braid provides ample surface area at RF.)

BASE INSULATOR. For the tower, that is! I'm in danger of repeating what many authors in Lowdown have said before me - but use the best quality base insulator possible. As long a section as possible also helps. I use a fifteen inch bar (cylindrical) of solid G3 epoxy fiberglass at the base of my telescoping tower. About four inches at each end of the bar extend into the metal pipe sections above and below, leaving me with a 7 inch exposed section of insulator. Coke bottles work as well, but are a lot more fragile. Depending upon your antenna design and efficiency, the feedpoint impedance will be from several hundred thousand to several megohms at this point. An insulator resistance of 1 megohm at 180 khz might rob half your RF. A really lousy insulator can take 98% of your RF and you'll never know it without detailed measurements.

INSULATORS in general. Even if you use nylon or polypropylene rope for your guy wires os antenna support, you must still use at least one, prefferably two, high quality insulators next to the antenna, between the antenna and rope. Theoretically, clean fresh nylon rope, or any plastic rope does not conduct at d.c. However, it is far less predicatble at RF, and after a few months in the weather exposed to airborne contaminants and particluate matter, and picking up some humidity as a thin film of water vapor on it's surface, nylon rope, even a seventy foot length, is going to be a far from good insulator. Especially when we need literally many megohms to preserve the sanctity of our RF! So, insulate with solid insulators, or be sorry. This from direct experience. Ken Cornell, too, has numerous horror stories from correspondents on this topic.

ANTENNA COIL RESISTANCE. Much has been said about using the highest Q, lowest resistance coil for the antenna coil as possible. The idea behind this is simple (see Rich Brunner's article on antennas a few months back). Your ground system resistance and antenna coil resistance appear in series with your antenna system resistance. Your antenna system resistance is the only desirable one, i.e. - the one which radiates. It is, unfortunately, in our kinda installations often a tiny fraction of an ohm. So it's the smallest number by far, and yet it's the one which we'd like to develop as much voltage as possible across. Hence the continued insistence on improving ground systems, and (perhaps......... we'll see the reality in the next paragraph) on building gigantic antenna coils out of large gauge litz wire, to keep the RF resistance of ground and coil as low as possible.

ANTENNA COILS. Let's get some perspective on antenna coil RF resistance for a second. I won't talk in terms of Q, which is directly related but more abstract. Suffice it to say that the the lower a coils RF resistance as opposed to it's RF impedance, the better the Q. It's a direct ratio. A compact coil composed of about 500 turns of small gauge litz wire on a 1/2 inch fiberglass form, with about 7 layers of turns, (sealed with polystyrene "Q" dope) and about 3" to 4" in length will display an RF resistance of about 38 ohms at 180 khz. If you are using a small slug of ferrite to tune the coil, it's resistance will rise by about 40% to 80% to 60 to 78 ohms. (while on this topic, do not be mislead by pretty "Q" meter or RF resistance meter readings for ferrite slugs in the coil and etc.....these testing devices are not putting POWER in any quantity across the coil, and once you put POWER across a high Z circuit and put a piece of ferrite or iron powder in it, your losses go sky high!!) If you are using a long slug of ferrite in the coil, and running a watt or more, your coil RF resistance can go well above 100 ohms. The above figures assume you're keeping the coils from close proximity to any metal cabinet walls, etc.

The literature shows that coils with lowest RF resistance should have a large diameter, have only one layer of winding, and have length and diameter roughly equal (i.e. an eight inch long coil wound on an eight inch form). Ideally such a coil would be wound with thick litz wire. Furthermore, each adjacent winding should separated by a small gap, perhaps equal to 1/2 to 3/4 the wire diameter. (The recommendation for a small inter-wire gap, and the prohibition for more than one layer of windings both relate to eddy currents and associated losses. In reality, these eddy losses are nowhere near as prohibitive with litz wire, as when using solid wire.) To get on with our figures, a single layer litz coil wound on a 4" diam. form and about 12" long will have an RF resistance of about 15 ohms. A coil wound with large litz occupying about 10" on an 8" form will probably end up about 10 ohms. A coil on a 12" form, with equal length and diam., and wound with large litz, may have a resistance of about 6 ohms or better.

Cutting coil resistance increases the voltage across the antenna resistance, which is pitifully low to start with. But let's recall that coil resistance is in series with ground resistance. In many parts of the country, with a few ground rods, and a dozen to twenty 50' ground radials, and nothing else, it is possible to get a ground system resistance of 10 to 20 ohms. And with a bit more work, such as more rods and some screening and more radials, it is entirely possible to get a ground resistance of 5-6 ohms without backbreaking effort. In many parts of the lower Eastern seaboard, and in parts of the Southwest, including much of New Mexico, as well as in parts of California, such ground resistances as mentioned above are easily attained.

On the other hand, in large parts of New England and New York state, as well as portions of California, (and many other parts of the country which I'm too ignorant to know about!) the soil conductivity is terrible, and the soil very rocky as well. (Low water table often aggravates the situation.) I described my ground system a few paragraphs above. If anything, the description was on the conservative side - my ground system could easily be called overkill for a typical amateur installation. Nonetheless, my measured ground resistance varies from 140 to 290 ohms, depending upon the wetness of the ground, etc. This is not an error or fluke of measurement. Rich Brunner in Massachussetts uses a slightly less sophisticated ground system, and his ground resistance falls in the same range. When Dick Hilferty lived in Long Island, the picture was even worse! Apparently Jim White in New Hampshire faces an even worse problem with ground resistance. On the other hand, Dick Hilferty now lives in New Mexico, and with a relatively simple ground system, his ground resistance (RF) is down around 10 ohms.

If your ground resistance is fairly low, like below 35 ohms, it obviously pays to go berserk and spend some time getting the last bit of efficiency out of your antenna coil. On the other hand, if your ground resistance hovers around 150 - 190 ohms, shaving ten or twenty ohms off your coil resistance is not even one decibel in gain. Even bringing a 30 ohm coil resistance (easily attainable with even a modest effort in a compact coil) down to 1 ohm (impossible anyway for anyone without cryogenics) would not yield any appreciable improvement in signal strength. I am not saying you would want to be happy with a very tiny coil tuned by a ferrite slug for your high performance Lowfer beacon in an area of lousy soil conductivity, (it's resistance could easily be 140 ohms or more) but on the other hand be realistic in your efforts. It's hardly worth the expense and effort of building a 10" diam. single layer coil wound with heavy litz to get your coil resistance from 28 ohms down to 10 ohms in a system where your ground resistance is above 100 ohms. Better to spend the effort on improving your ground system. I would suggest a target of about 30 ohms for people with lousy soil conductivity (easily attainable with litz and a small, like 1/2 diam., 6 layer coil with perhaps a tiny piece of ferrite slug for fine peaking.) On the other hand, if your ground resistance is 10 to 25 ohms, or a bit more, go all out, and wind a 7" or 12" diameter single layer coil with heavy litz.

Now to ferrite for a minute. I hate ferrite for high Z (impedance) power applications such as this. At any kind of power and high impedance levels, ferrite or iron powder saturates immediately. This converts some of your power to heat in the core, and worse yet, (in my book.....) creates a nasty amount of harmonic energy by it's clipping action. Of course, this lost energy translates into higher coil RF resistance. I much prefer tuning my 1750 finals with multiple taps on the high end of the antenna coil, and then fine tuning with a 50 or 160 pf high voltage variable capacitor (the amateur transmitting type - make sure insulation is ceramic, porcelain or glass). Altho the capacitor will introduce a certain amount of circulating current which can't help but lose a bit of power at this high impedance, in practice tuning capacitors work a million times better than adjustable ferrite (ugh!) cores. Don't try using more than about 200 or 280 pf capacitance. (You CAN get away with more if your antenna has a very big tophat, and therefore has itself a large capacitance to ground.) You WILL start to get increasing losses at some point. One more nice thing about capacitors for tuning - not only don't they provide anything to saturate and generate harmonics, their very addition to to a high-Z final circuit like this (in my experience) seems to significantly drop the amount of harmonic energy radiated by the system as opposed to tuning only by adjustable coil taps. Of course, there is an explanation for this. The small amount of added capacity provides a new RF circuit at the higher frequencies, whereas before the harmonic energy had only to look at the capacitance of the tower to ground. This new tuned circuit seems to be especially effective at reducing the number and energy content of harmonics. On my antenna system, anything over about 50 pf of added capacity to ground has this very desirable effect. I now use capacitance tuning exclusively.

I am not totally agianst ferrite or iron powder rods. Especially for an installation that must be compact or very inexpensive or constructed with minimum time and effort, a small amount of ferrite in the antenna coil will not hurt matters much.

For power circuits at lower impedances, such as the drain tank coil of a VMOS FET (char. impedance 30 to 100 ohms) ferrite or iron powder tuning is actually a boon, and very desirable. My current VMOS final amp uses a multi-tapped tank coil of 50 turns enamelled wire wound on a T106-3 iron powder toroid core, and it is highly efficient. I have also used small slug tuned coil forms with good success for the tank coil. **Make sure your "slug" is really a good ferrite or iron powder for this frequency - one of those mu-metal or brass slugs will really wipe out your circuit!!**

TOP LOADING COILS. For years, much of the radio amateur literature devoted to electrically short vertical transmitting antennas has promulgated the idea that a short vertical can be made a more efficient radiator by "lengthening" it by adding a center loading coil or top loading coil (the top loading coil is usually under either a tophat, or below a 10 or 15 foot "whip" atop it). Theoretical gains over an unaided vertical of from three to ten dB have been claimed for this effort. It is notable that the authors of very few of these tomes actually tried the technique on electrically short (less than 1/10 th wavelength) verticals at low frequencies. (I use the word loosely here to connote frequencies up to 160 meters - 1850 kHz.) I have had the pleasure of discussing this topic with Gary Waldsmith (most recently) in California, and several other people who have actually tried a number of embodiments of this idea on 1750 meters and 160 meters. I have also reviewed some very interesting information that Ken Cornell forwarded me from one of his early Lowdown columns that pertains loosely to this topic and the one discussed below. Basically, the idea does not work worth a darn so far, and some even claim the loading coil hurts performance. I have never met or talked with one person for whom the conception worked on low frequencies using vertical antennas well below 1/10 or 1/20 th wavelength in height. Apparently the paradigm just falls apart somewhere, despite the often impressive theories and models and charts (mostly extrapolations!) quoted to prove it.

I can sum up the reaction of almost everyone who has tried the technique by paraphrasing Gary Waldsmith...... "it doesn't work worth a darn.....the loading coil, tho it's supposed to electrically lengthen the vertical radiator, actually seems to act like some kind of a high Q choke, isolating the radiator (or capacity hat) above the inductor and disconnecting it." I would note in this respect, before the textbook people start screaming (and heaven knows I myself use textbooks a lot - witness my sophisticated transmitting station), that no less an authority than M. F. (Doug) DeMaw, of ARRL/QST Technical dept. fame, and an excellent RF engineer in his own right, has made the same observation in several of his publications. He admits that there are the theories and charts on the one hand, but there is the hard data on the other hand!... He makes one interesting point. Some of these center or top-loading (coil) configurations do seem to increase local field strength, out to hundreds of yards or even a mile or two, but no one has ever been able to document the slightest improvement beyond the horizon on longwave, up thru 160 meters. These criticisms do not necessarily hold true for verticals appraoching a decent fraction of a wavelength. But for verticals that are a tiny fraction of a wavelength in height, they are perfectly valid. Doug Demaw also points out the incredible number of Amateur Radio and commercial radio engineering publications and texts in which these claims have appeared, despite lack of real proof. I'd say, if you're considering adding a loading coil in the vertical, spend the energy to put up a decent tophat instead. It works! Gary Waldsmith spent most of the spring (and there were many before him!) trying many variations on the loading coil theme with no success.

The above critique was not intended to condemn all methods of "lengthening" short verticals. Much of the amateur and experimenter literature seems to show that a more distributed "L" or inductance can make a difference, a positive one, in radiation efficiency. Thus, a vertical which is not a solid, linear wire or pipe, but a gentle spiral seems fairly effective an improvement over an unaided vertical. Such an antenna is often called a helical vertical, or helical antenna. There are several other takeoffs on this theme that are fairly effective, too. Years ago Ken Cornell published some stuff on this in his column, mostly regarding some work done by Keith Olson on the West Caost with models on 160 meters.

FOLDED VERTICALS AND "FOLDED MONOPOLES". In a word, these designs have been proposed several times as attractive, more efficient alternatives to base fed short verticals. The claim goes that (while just as physically short) the addition of tuned or loaded downleads to the vertical (and changing feedpoint technique and impedance) will yield very nice gains over conventional short verticals. Again, this arena is for verticals below 1/4 wavelength in height. Again, the claims sound great. And you can find any number of literature and text references which imply that such a system will have greater radiation resistance for it's size, (that's a goodie - it means you radiate more!) and lower feedpoint losses (lower impedance, so supposedly much less inductance needed to match antenna capacitance to ground - and therefore lower resistance and magnetic losses in the base loading coil.....or so the story goes...). Thats the claim.... Now for the reality. The theory seems to work great for verticals that are somewhat shorter than a 1/4 wavelength, and perhaps even 1/8 wavelength or less. But there is some undetermined crossover point at which other losses and other considerations begin to predominate. It just doesn't work for verticals that are 1/100 or 1/50 th or less of a wavelength (and remember 50' at 1750 meters is less than 1/00 th wavelength!) in height. As a matter of fact, I have never found anyone with hardcore experience (i.e. who really tried it!) who was able to get any such embodiment to radiate anywhere near as well as a basefed short vertical. I myself spent hundreds of hours in the springtime trying every conceivable variation to the folded monopole idea. The best single embodiment (which was ridiculously convoluted and complex and involved one dozen downleads on a 50' tower, - fed in a strange synchrony) was 11 dB below a conventional base insulated vertical of the same height in both local and 1000 meter and 1 mile and 5 mile field strength tests (for the same transmitter power output). My best guess is that I spent well over 300 hours on this one project, and I have a decent background in electrical engineering, antenna design, and low frequency RF (also microwave antenna design - from years ago). I also enjoyed frequent long-distance telephone consultations with antenna experts during this period - to no avail. Gary Waldsmith in California also spent at least the same amount of time this spring independently pursuing the same course of experimentation. (We compared notes only toward the end of our work.) Gary's experiences seem to duplicate mine. I have since learned from Ken Cornell and Dick Hilferty that this idea has been tried by several other Lowfers and experimenters in the past, (all individuals with an excellent background in the physical and engineering sciences, as well as in the low frequencies), and no one has been able to come up with a workable embodiment. The best answer seems to be that the models fall apart when the short vertical is less than something (just an educated guess!) on the order of 1/30 th of a wavelength in height. I am not saying positively that it can't work. I believe that most breakthroughs are made by ignoring the idea that something is impossible. However, much as I like to believe in the impossible, or at least allow as it might exist, I must admit that I am totally burned out on this idea. And I consider myself a fairly creative and imaginative person...... Take it from there.... and good luck!

I would like to acknowledge the help of several individuals. I also realize that a number of points I have made here were made before in this publication. They are however, points that I very painfully learned or re-learned from my own experience - and they are certainly worth repeating! My thanks to Todd Roberts, Rich Brunner, Dick Hilferty, Ken Cornell, Gary Waldsmith, Walt Glazar, Cap Hossfield, Bill Murr, Mike Mideke and Frank Wolfgram for discussions, correspondence, aid and insights in my experiments with antennas and grounds early this summer.

TUNED COUNTERPOISE

by

Keith Olson

In going back over the longwave literature since the turn of the century, it is apparent that series antenna tuning was used for both transmit and receive. My most successful tests use parallel tuned circuits in the final tank, with a Faraday shielded link and variometer tuned antenna.

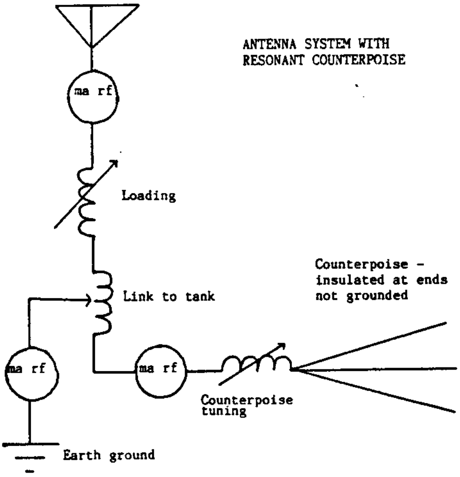
The Faraday shield can be constructed by wrapping the tank with about 1 1/4 turn of shim brass or copper. The tank coil should be wrapped with a good grade of cambric or other insulating tape. Insulate the end of the Faraday shield with a vertical strip of double sided tape, such as carpet layer's tape so as to prevent the shim from being a shorted turn. Ground the shim brass. On solenoids, the pickup link can be tapped to vary the coupling or mount it on a suitable form and slide it up and down the coil. With toroids, a tapped secondary will have to do.

I seem to get the best results with a tuned counterpoise. The null point of the link is grounded. This should be at or near the center of the pickup link.

To tune, resonate the antenna against the null point ground. Then resonate the counterpoise against the null point, with the antenna and loading device disconnected. Tune for maximum current in the antenna and minimum current in the lead from the null point to ground. The counterpoise should be several wires and, if possible, all wires should be the same length and approximately 6 to 8 feet off the ground. 7FS uses 4 wires 150 feet long arranged in a fan over an arc of 45 degrees. I intend to build three of these counterpoise assemblies, and use them separately or together to see if it will show any directivity.

It is very difficult to match the ground end of a short antenna to the hot end of a parallel tuned tank circuit unless the antenna is a half wave.

(Ed. Note- Comparisons between this counterpoise set up and earth ground showed quite different results for groundwave and skywave.)



ANTENNA SYSTEM WITH RESONANT COUNTERPOISE

NOTES ON ADJUSTING 1750 METER TRANSMITTING ANTENNAS

KEYWORDS: Antenna, transmitting, vertical, loop, polarization, field strength, measurements, remote measurements, coupling.

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[1] I have discovered that things are not always straightforward and simple when making adjustments on a 1750 meter transmitting antenna via field strength measurements. There appear to be several anomalies and errors introduced into certain such situations due to the extremely short electrical height (in terms of a wavelength) of the transmitting antenna. There may be other factors involved, too, such as inductive and / or capacitive coupling of the various physical devices involved, as well as less than omptimal ground systems in many amateur installations. Unintentional horizontally polarized radiation can also confuse the measurement picture. I am not the only person to have noted (and been stymied by...) these anomalies; there are several other Lowfers who have reported the same type of problem. Among others, I recently heard of experiences similar to mine from H.P. "Buddy" Morgan in Florida, who had to improvise to find a satisfactory way of measuring field strength. This article will attempt to outline some of the myths and fallacies of adjusting transmitting antennas on this band, as well as explore some satisfactory ways to measure relative field strength. For some of the problem areas, there are no outright answers, but some general precautions and caveats that we can talk about. We will first look at commonly used Lowfer transmitting antennas, and then at measurement problems.

Let's first define the field. We'll summarize the desirable properties of any short (i.e.: Part 15 compatible) transmitting antenna for the 1750 meter band. The following discussions assume electrically short antennas at low frequencies such as the 1750 meter band. Therefore, the words low frequency or electrically short may not always appear in the text - they are assumed.

First, the antenna should be vertically polarized. There is no place in the arena of very short low frequency antennas close to the ground (in terms of a wavelength) for horizontal polarization. Although such antennas might show impressive near-field field strengths due to capacitive or inductive coupling, the field strength falls off rapidly at any distance. The horizontal component tends to experience great absorption and loss from nearby obstacles and ground surface irregularities. If you can get a horizontal low frequency antenna long enough (at least a good fraction of a wavelength) and high enough (this one can be fudged if there are no nearby obstacles or terrain features) and positioned over a good ground plane (such as a lake or swamp), then you can realize fair field strength at a distance. However, such an antenna would not conform with FCC Part 15 requirements (due to length) unless you were to run reduced power. In general, horizontal components from a very short low frequency radiator tend to experience excessive absorption in the near field from nearby objects and obstacles. So the answer lies in making sure you radiate vertically polarized energy.

There are several commonly used configurations for this. We can use a base-fed vertical radiator. Or we can use a vertical radiator with a tophat. The tophat may be horizontal, or may be sloping as in an umbrella configuration. When vertical radiators are electrically short, the efficiency depends to a great extent upon the efficiency of the ground plane. In most areas, the soil alone will be nowhere near sufficient, and in addition to ground rods, an artificial ground plane must be used. The most common approach is to use radial wires, above, on, or in the soil to improve the ground. The rule with radials is the more the merrier, and each should be at least as long as the vertical is high. A quarter wavelength to half wavelength per radial is much better, but most of us cannot afford anywhere near that. Another method somewhat better than discrete radials is to install a ground screen of metallic mesh at ground level or a few feet above it for at least as far as the tower is high. Some practical installations use some screen on the ground near the tower with radials taking up the job beyond ten or twenty feet.

The radiation from a vertical (no tophat) will be purely vertical polarization, and the antenna becomes a pure E-field device. When you add a small symmetrical tophat, the radiation remains totally vertical, with E-field mode predominating. Since the radiation resistance will be a very small number, the greatest amount of antenna current will be dissipated in the necessarily greater resistance of the entire ground system. Nearby obstacles above the ground plane can absorb and dissipate an appreciable amount of near E-field energy, so foliage and bulidings can steal some power. Although a tophat can increase the radiation resistance and effective electrical height of a vertical, there are confounding factors. The tophat system becomes a giant capacitor plate with respect to ground (the other "plate"). Resistive obstacles between the two "plates", such as foliage and buildings will now have a greater negative effect on the picture. They will contribute more heavily to E-field losses. So, if your tophat vertical is in an area with no obstacles and vegetation, and an excellent ground system, the tophat is a real plus. A tophat is still a plus in a setup where there are foliage and buildings, etc, present, or where the ground is less than perfect (as in the real world of hobbyist communications), but some of it's gains will be offset by increased absorptive losses from obstacles in the "capacitor" area. A poor ground is also another loss factor. A perfect ground would have no resistance, and would simulate a large flat metal palte beneath the antenna. In the real world, with perhaps thirty radial wires on poor rocky soil, the ground acquires a certain depth into the soil. The soil is not a perfect conductor and the effective "ground" seen by the E-field includes a lot of losses from the poorly conductive, absorptive soil. So the ideal vertical should work over a perfect ground.

Let's talk about tophats for a minute. The ideal tophat is one that makes a figure T and extends in two or more directions. A less efficient version, but economical, uses a figure L arrangement - just one tophat wire in one direction. Ideally the best tophat for a short vertical should be a bit less in radius than the length of the vertical portion. In reality, especially with very short antennas, even tophats well longer in radius than tower height often seem to do very well. Ideally, the tophat should be composed of a number of radial wires or spokes, extending in different directions. Probably a good practical figure for Lowfer installations is 10 to 15 radial spkoes. Ideally the radials will be evenly distributed over all points of the compass.

If there is only one tophat spoke (an L - in one direction), or if the tophat wires are lopsided - that is, concentrated toward one direction, then a significant amount of horizontal radiation will take place. Altho the tophat may still afford some benefit over a hatless vertical, it's enhancement will be reduced by the introduction of the horizontally polarized energy. In many practical Lowfer installations with tophats, there is some horizontal radiation from the tophat.

There is another way of producing a vertically polarized wave. You can erect a loop antenna. The plane of the loop is vertical - perpendicular to the ground. The radiation from an electrically small loop is purely H-field. It is almost purely vertically polarized component if the shape factor is good. Two things to look at here. If the shape is not good - not a perfect square or circular loop - then there will be some horizontal components. Generally, as long as the thing looks roughly circular or roughly square, the radiation will be vertically polarized for all practical purposes. As long as the loop remains a small fraction of a wavelength in total length, the radiation is pure H-field. If the loop approaches an appreciable part of a wavelength in length, there will be increasing E-field radiation, and increasing components (at certain lengths) that will be horizontally polarized. The neat thing about the H-field is that it totally ignores nearby lossy or resistive obstacles. Due to the absence of E-field mode, there is no loss from poor ground either. The H-field radiator is basically oblivious to the ground plane, and any inefficiencies attendant. So you do not even need a ground system at all. The H-field device is totally oblivious to moisture and weather changes on nearby objects, too. About the only thing that could affect it would be a nearby, closely coupled loop. This H-field feature can make the loop an attractive antenna for an installation in an area of poor soil conductivity and / or lots of terrain and foliage obstacles.

For 1750 meter Lowfer work, the loop would ideally be at least 30 to 40 feet on a side. However the physical wire length of such a loop would be over 15 meters, and might possibly fall afoul of Part 15. Another way of interpreting Part 15's requirement might be to calculate theoretically the size loop needed to produce the same field strength as a 15 meter vertical over good ground, and go with that size loop. The necessary figures are in any good radio engineering handbook. Some people, too, interpret Part 15 as really including a volume of 15 meters, and not just a lineal length. The FCC has given conflicting and confusing interpretations to this 15 meter thing when presented with queries by experimenters. It is likely they are every bit as confused as we are. Whatever interpretation you decide it is fitting to go with, keep your radiated signal stable and clean from any harmonics or spurs, and it is unlikely you will hear further about the mattter. In any case, it has been proven that a loop that can be easily built by the average Lowfer, can, in areas of poor soil conductivity and / or lots of obstacles, easily surpass the performance of the best conventional vertical antenna. I would like to thank Dick Hilferty for making me aware of loops as a practical alternative, and for a terrific amount of information on the use and properties of loops on longwave.

The loop radiator will not figure much in the following discussions on field strength measurement. Loops are not in common use, their vagaries are fewer and simpler when it comes to field strength measurement, and they are not subject to the many configurations and ills that a vertical radiator might experience.

When I first put a beacon on the air, I used a passive field strength meter located near the vertical tower (about 22 feet away) to check changes in field strength due to power and transmitter adjustments, tuning the final coupling coil, and design changes in the tower and tophat. Experience has shown that as long as your ground system is fairly adequate (- lots of radials or screening), this method works fine for documenting changes due to transmitter adjustments, power changes and final loading coil tuning. In other words, relative changes on your meter will reflect true changes in your field strength that someone at a distance (over the horizon) would see. We are assuming that your final amplifier is located at the base of the tower, and that the cables carrying RF drive and d.c power to it are well grounded and shielded. (Radiation from these lines can play havoc with your measurements at any stage - so this type of interaction must be culled out.) By the same token, the field strength meter cannot be located in your shack either, unless your driver stages are well shielded and well grounded. Another bugaboo to the above formula would occur if you had a very poor ground system. Then every object in the near field takes on a life of it's own in a sense, and even small movements of your body or hand (or a tool) can produce gross, unrealistic changes on your field strength meter. As long as you had a fair ground system to begin with, a nearby (5 to 35 feet from tower) meter will also reflect fairly accurately changes in your ground system, such as improvements or addition of more radials. Again, a relative increase on the meter will correspond to an increase at a good distance.

You'll notice I specifically left out antenna adjustments and tophat adjustments as things that can accurately be monitored with the nearby field strength meter. There is a reason for that. Readings from the meter in response to such adjustments can be very misleading. In any real installation, there will be too much RF from the "wrong" sources coupled to the field strength mmeter to provide accurate readings realtive to true change in field strength at a distance. Some of the confounding factors are horizontal radiation components, ground field "loops", uneven ground currents, and electrostatic and inductive coupling to the radiator and tophat elements. In many cases it is possible to record a very nice local (nearby field strength meter) improvement due to an antenna/tophat change, only to discover that the power at a distance actually decreased. Bear in mind that any change to the antenna or it's tophat (or to obstacles nearby, such as moving them will result in a distortion of the terrifically complex fields local to the radiator, with often misleading results recorded on nearby equipment)

Thus you can make a change in tower height, or in size of tophat, or number of tophat wires (or in slope angle of umbrella tophat wires, or length of tophat, ...and so on) and can only expect a totally misleading reading from a nearby field strength meter. So, do we go out and build a small amplified field strength meter, and place it 100 yards away, using that for our readings? The answer is no, and for the same reasons that invalidated a meter at 5 to 50 feet. Even at 100 yards there are still plenty of stray fields and coupling effects that do not accurately reflect a true power change at a distance. So now we get in the car and try using a tunable voltmeter or receiver at a half mile or one mile distance. It's still no good! The readings can still be totally erroneous. Like a meter near the tower, the meter/receiver at a mile or half mile will accurately reflect changes in actual transmitter power or design, tuning the final coil, or improvements in the ground system (like adding more radials and lowering ground resistance), but there are still too many "strange" factors influencing the reading to make it useful for monitoring changes to the antenna or tophat. The only thing that's changed as compared to more nearby meter positions is the type of error. At any distance like a mile, freak effects due to "strange" ground current flow become less signigicant. Same is true for capacitive coupling to antenna elements. What really predominates at these distances to mess up readings is the component of horizontal radiation and some distortions of the antenna's pattern in the near field. Although horizontal radiation may make your antenna look better at a mile, that radiation will never make it to a receiving site 40 miles away.

Nor are we really safe even at 3 or 4 miles. Effects due to horizontal radiation and freak field shape effects can still predominate. Another thing to beware of when making measurements with a receiver within the first five or so miles is power line coupling. If your immediate neighborhood is filled with power lines, and especially if you have some form of tophat on your antenna, you can couple a significant amount of your power into the power lines. Now, this gets reradiated mainly in the neighborhood of the power lines for the first few miles. This can produce highly amusing results. In one case, the addition of a long L tophat to a tower that previously had only a short round tophat yielded a 20 dB gain in power on a nearby (25 feet) field strength meter, and an impressive 26 dB gain at one mile away. A receiver at 4 miles recorded an improvement of 4 dB. The varmint responsible for the reading in the back yard was simple electrostatic coupling between the meter antenna and the nearby tophat wire. (A vastly increased local E-field did not help matters.) The culprit in the one mile reading was coupling from the tophat to a nearby power line, which reradiated the signal to nearby objects. The biggest single culprit at the 4 mile point was apparently the increased amount of horizontal radiation. It never made it much beyind the 4 mile mark, as we'll see in a moment. This particular change detailed above produced almost no effect as measured at a distance of 40 miles, and a slight negative effect at 75 miles. So we see that local measurements can be very misleading.

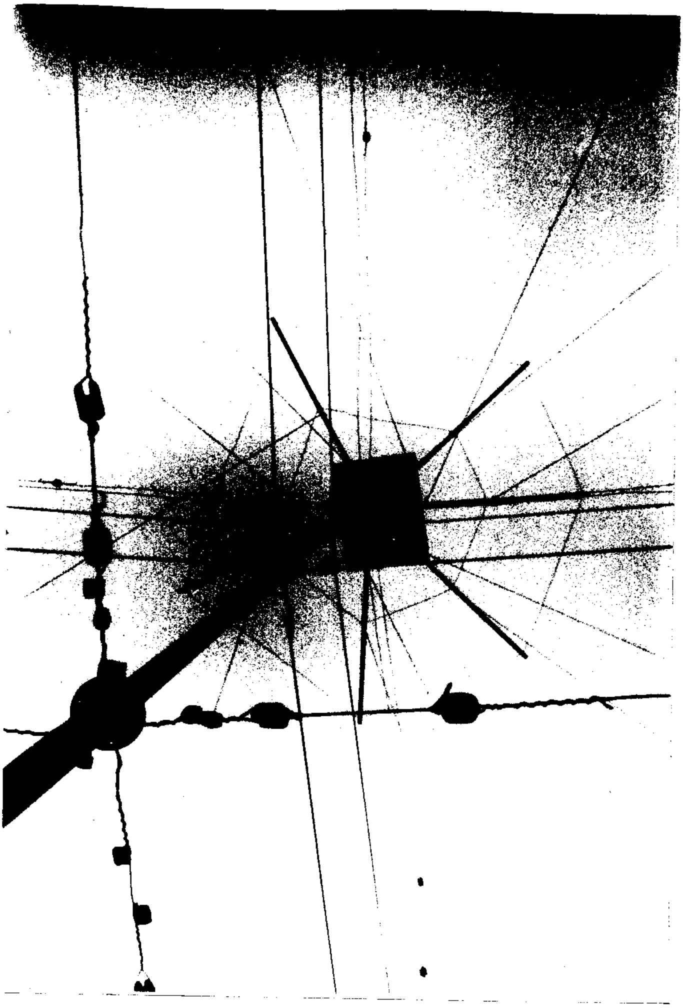
My own experience has shown that readings within the first ten miles are always suspect when recording changes in field strength due to antenna or tophat changes. Obviously, as you get even nearer, it gets worse. Some of these measurement errors would not occur if we were not using antennas that are such a tiny fraction of a wavelength in electrical height.

If you have to do near measurements, just remember that the farther the better. So 3 miles will usually be somewhat more accurate than a point 200 yards away. But the only sure method is to set up a repeatable observation point with a receiver at well over ten miles (or beyond.......). In any case, if you must compromise and do some work with a meter in the yard, at the very least keep the meter away from power lines, and out beyond the circle defined by the tophat. This will help some, but not a whole lot. Individual cases do have individual merits. You may find that in your situation one-half mile is perfectly adequate for monitoring most changes to the antenna. But just beware those misleading readings.

My experience has shown that the only really reliable field strength results come from beyond 35 to 40 miles. Now, at forty miles, as at 2 miles, we are no longer talking about using a simple amplified field strength meter. Measurements (accurate and repeatable relative measurements) at these distances must use a good, selective, stable tunable receiver or tunable RF voltmeter. The monitor receiver antenna must be vertically polarized and be totally nondirectional. I find a two and a half foot portable active whip to be the perfect field strength antenna for my receiver. If you happen to have a Lowfer friend at thirty five or forty miles or more with a very sensitive, narrow, metered receiver, and a suitable antenna, you can use him/her as your remote field strength meter. My ideas for a suitable antenna at your buddy's house would be an outdoor fixed active whip, or a large (like 4 foot diam.) fixed outdoor loop.

Even if your distant measurements and comparisons are made over a period of days and weeks, and your buddy does not have the best S-meter in the world, you will probably still be a hundred times better off than if you use a local meter to measure antenna changes. You will eventually learn to compensate for differences in readings due to outside factors such as recent rainfall (soaks the ground over the path yielding stronger signals) or day to day changes in the receiver. You'll still be a lot better off than trying to figure out why your backyard meter reads a thousandfold improvement in signal strength from lowering your tower to half height!!!

To record and document antenna modifications I made in the spring of 1983, I got in the habit of bringing my receiver and a portable active whip to work with me almost every day. I made a map of several points along roads near work at 23, 37 and 42 miles respectively from my tower. I then started keeping detailed daily records of field strength at each point. As I experimented with tower and tophat, I correlated these results with reports from Lowfers at 73 miles East and 70 miles South. I must confess that I sometimes ran up enormous phone bills to Bill Murr at 70 miles south in New Jersey, but I was able to sucessfully complete my antenna experiments and get predictable results. The difference between near field and distant measurements in some of these experiments was truly amazing, and I learned a very important lesson from it.



VP Antenna, 1985

1800 METER FIELD STRENGTH MEASUREMENTS

Richard G. Brunner

LOWFERS (Low Frequency Radio Experimenters) operating in the 160 to 190 kHz band under Part 15 of the FCC Rules and Regulations (1) are acutely aware of the alternatives for operation:

1. Field strength at 300 meters of $2400/f_{kHz}$ microvolts per meter.
2. One watt input and 15 meter antenna plus feedline length.

The more advantageous alternative is not obvious, and recent acquisition of an IM-109/URM-89 field strength meter gave me the opportunity to settle the question. For guidance I surveyed the available literature on field strength calculations, then made calculations and tests at 160 kHz for comparison.

Field Strength Formulas

A survey of the literature produced many field strength formulas, all assuming an infinitely conducting ground which is most assuredly not the real world. The effect of losses in the earth, upon the surface wave, depends in a relatively complicated way upon the frequency, dielectric constant, the conductivity of the earth, and the actual distance. The effect of the earth losses is not negligible, as we will see. Actual measurements may be half those calculated from the infinite conduction formulas.

The most convenient formulas I found were from Nilson and Hornung. (2)

(a) $$E_{\mu v/m} = \sqrt{P_{watts}}\ \frac{5870}{D_{miles}}$$

$E_{\mu v/m}$ = Received signal in microvolts per meter
D_{miles} = Distance in miles from transmitter to receiver
P_{watts} = Power in watts <u>radiated</u> by the antenna

(b) $$E_{\mu v/m} = \frac{1.25\ I\ f\ h_e}{d}$$

$E_{\mu v/m}$ = Received signal in microvolts per meter
I = Antenna current in amperes
h_e = Effective height of the antenna in meters
d = Distance from the radiating system in kilometers
f = Frequency in kilohertz

Second choice is from Reference Data for Radio Engineers. (3) It erroneously states that ground attenuation may be neglected for distances less than 10 wavelengths, but the answers come out about the same.

(c) $$E = \frac{377\, I\, h_e}{\lambda\, d}$$

E = Field strength in millivolts per meter
I = Current at base of antenna in amperes
h_e = Effective height of the antenna
λ = Wavelength, same units as h_e
d = Distance in kilometers

<u>Antenna Calculations</u>

The following brief study of the characteristics of short LF antennas is very enlightening, and will not much tax the students ability. Also see an interesting discussion by Ed Phillips. (4)

<u>Antenna System Resistance</u>

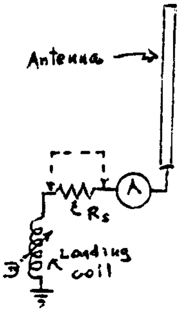
Antenna system resistance, including the loading coil, may be measured as follows.

a. With light loading to assure constant transmitter output (constant voltage source), measure antenna current (I).

b. Insert a known resistance, (R_s) retune for maximum antenna current if necessary, and measure antenna current (I_1)

(d) $$R_a = \frac{R_s}{\frac{I}{I_1} - 1}$$

R_s = Inserted resistance in ohms
I = Initial antenna current
I_1 = Antenna current with R_s inserted
R_a = Antenna system resistance in ohms



Antenna system resistance will be a few ohms for large commercial LF antennas, 20 to 40 ohms for LF aircraft beacons (Tee antenna: 30-60 foot vertical and 250 foot flat top) and 60 to 300 ohms for typical LOWFER antennas. (in New England) As antennas become smaller, they become more sensitive to ground and foliage losses due to higher E-field gradients. My antenna has 21 ground radials, and R_a varies from 100 ohms in mid-winter to 240 ohms in mid-summer.

Power in the Antenna

Power in the antenna is now:

$$P_{ant} = I^2 R_a \qquad \text{(e)}$$

P_{ant} = Power in the antenna, watts
I = Antenna current, amperes
R_a = Antenna system resistance, ohms

Radiation Resistance

Radiation resistance is a useful mathematical fiction. It is the resistance that would dissipate the same energy as is actually radiated from the antenna. At HF with large antennas, radiation resistance is high, and antenna ohmic loss is usually negligible. Thus, radiation resistance and antenna impedance are often used interchangably, and antenna efficiency is high. At LF, with very short antennas, the reverse is true. Radiation resistance is very low, almost negligible compared to ohmic resistance. Thus, antenna efficiency is very low.

For ease of calculation, my favorite formula for radiation resistance is from Jasik. (5)

$$R_{rad} = 160\,\pi^2 \left(\frac{h_e}{\lambda}\right)^2 \text{ ohms} \qquad \text{(f)}$$

R_{rad} = Radiation resistance in ohms
h_e = Effective height of the antenna
λ = Wavelength, same units as h_e

Power Radiated

Power radiated is proportional to the radiation resistance.

$$P_{rad} = I^2 R_{rad} \qquad \text{(g)}$$

P_{rad} = Power radiated, watts
I = Antenna current, amperes
R_{rad} = Radiation resistance, ohms

Field Strength Calculations

It is clear that field strength is directly proportional to antenna current and effective height from equation (b), and antenna current is inversely related to antenna system resistance from equation (e). For illustration, I have tabulated field strength versus antenna current and various values of antenna system resistance for 0.65 watt in the antenna. I assume a radiation resistance of 0.03 ohm and effective height of 8 meters as typical.

R_a Ohms	I_{ant} Amps	P_{rad} Watts	Field Strength $\mu v/m$	
			300 Meters	1 Mile
25	.161	.000777	875	163
50	.114	.000390	622	116
100	.081	.000196	441	82
120	.074	.000147	382	71
200	.057	.0000974	311	58
300	.046	.0000635	251	47

Field Strength Measurements

Field strength measurements on 160 kHz with 0.65 watt in the antenna were made at 300 meters and 1 mile. R_a was about 120 ohms.

Distance	Measured, $\mu v/m$	Calculated, $\mu v/m$
300 Meters	300	381
1 Mile	36	71

Measured field strength was 78% of the calculated value at 300 meters, and 50% at one mile. This does not follow the inverse distance relationship because the 300 meter distance is in the near field where simple formulas do not apply. (Rule of thumb: Near field is ten times antenna height, or one wavelength, whichever is greater.) These measurements having been made in New England with its thin rocky soil and low conductivity, it is reasonable to assume that installations elsewhere will have more favorable conditions, and field strengths will fall within these limits.

Other Field Strength Measurements

A sweep was made of the spectrum from 120 kHz to 18 mHz to log some field strength measurements for comparison. Since the field strength meter is only sensitive (and calibrated) down to 20 $\mu v/m$, only relatively strong signals could be heard. No carrier-current signals in the 160 to 190 kHz band were audible, so clearly they are all below 20 $\mu v/m$ here. A few near-by aircraft beacons were logged, the majority being barely audible, if at all. Not surprising, broadcasting stations are all quite strong. In the HF region in the daytime only one station was heard above 20 µv/m, and that with rapid fading which is characteristic of sky wave propagation, and made field strength measurement problematical. A sweep made late at night showed LF stations all slightly stronger, and many HF stations in the range 200 to 500 µv/m.

Frequency kHz	ID	Field Strength µv/m	Commentary
123	CFH	130	RTTY
133	CFH	170	RTTY
194	TUK	1800	Nantucket Is. 78 m.
201	FLR	76	Fall River, 22 miles
227	TAN	80	Taunton, 16 miles
236	NZW	35	S. Weymouth, 16 m.
251	SKR	40	Hanscom Fld. 28 miles
257	PYM	58	Plymouth, 27 miles
382	LQ	295	Lynn, 29 miles
397	OW	34.5	Stoughton, 6 miles
550	WGNG	3700	Pawtucket, RI
850	WHDH	6400	Needham, MA
1460	WBET	4850	Brockton, MA
1600	WUNR	480	Brookline, MA
3.44 mHz	CHU	280	night
17.5 mHz	-	3000	day

Conclusions

Clearly the power and antenna alternative is less restrictive than the field strength limitation, typically by 20 times, and the fellow with a low resistance antenna system and some top loading can make an additional dramatic improvement.

From field strength measurements, and from experience, LOWFER signals are very weak indeed; 36 µv/m at 1 mile, 3.6 µv/m at 10 miles, and 0.36 µv/m at 100 miles. I estimate carrier-current signals in the 160 to 190 kHz region at 3 to 6 µv/m, and LOWFER signals from any distance over 10 miles are invariably weaker.

REFERENCES

1. FCC Rules and Regulations Part 15, Subpart D.
   Unlicensed operation is permitted from 10 to 490 kHz limited by field strength at 300 meters of $2400/f_{kHz}$ microvolts per meter. In the 160 to 190 kHz region the alternative of 1 watt input and a 15 meter antenna plus feedline length is permitted.
2. Practical Radio Communication, Nilson and Hornung, 1935, page 267
3. Reference Data for Radio Engineers, Fifth Edition, 1968, page 25-6
4. "Coupling the VLF Antenna to the Transmitter," Ed Phillips, W6IZJ
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5. Antenna Engineering Handbook, Henry Jasik, 1961, page 19-6

LF Skywaves and 1750 Meter Skywave Antennas

by Michael Mideke

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In an earlier article (*Lowfer DX 1985-86: A Western Report*) there was some discussion of LF propagation from the standpoint of 1750 Meter reception over paths on the order of 500 to 1,200 miles. It was assumed that the mechanism for such propagation is essentially a single hop or reflection from the ionospheric E layer at altitudes of 60 to 80 miles. While the precise circumstances for optimum occurrances of such propagation of weak LF signals are somewhat unclear as yet, there can be no doubt that this type of propagation is anything but a normal and relatively predictable manifestation of solar/geophysical interactions.

This article will review some of the considerations basic to LF 'skip" or skywave propagation and tentatively explore a few of the ways in which Lowfers and LF DXers may attempt to take advantage of its peculiarities.

Normal LF propagation is largely tied to the behavior of the two lowest layers of the ionosphere—the D layer at 40-50 miles and the E layer at 60-80 miles. These designations are somewhat arbitrary. It is important to remember that the layers are not hard-edge, fixed phenomena; rather, they are amorphous zones having particular types of predominant qualities. Their densities, depths, altitudes, and angles, with respect to the surface of the Earth, are all in a state of constant flux. Solar, geomagnetic, and atmospheric effects all modify the characteristics of these ionospheric layers.

The D layer is reflective at VLF (3 to 30 kHz) and absorptive on LF and MF. Since the D layer is "charged" by sunlight, absorptive effects are greatest during the day, decreasing rapidly around sunset. By the same token, D absorption is greater in summer than winter. Since reflected signals must traverse the D layer twice, it is clear that best results will be obtained when absorption is lowest.

The E layer is reflective at LF and MF, providing us with the medium for most of our distant reception of LF signals. At low and medium frequencies, daytime skywave propagation is limited by D absorption, ordinarily (but not always) restricting signals to the groundwave perimeter.

At night, the D absorption drops sufficiently to allow single and multi-hop skywave propagation. When D absorption is low enough and E reflectivity, high enough, even our tiny Lowfer signals can survive that single ionospheric hop with sufficient field strength to be copied and QSOed at distances of several hundred miles.

The most effective penetration of the D layer will occur at relatively high angles of radiation from the transmitting antenna. This is because the signal path will be shorter in the absorptive region when it has an acute angle of attack, whereas oblique angles of attack will result in longer paths within the D region, with greater absorptive attenuation as a direct consequence. Since the angle of reflection more or less equals the angle of incidence in the fuzzy medium of the ionosphere, D layer penetration will be easiest both coming and going for signals arriving at a high angle.

On the other hand, "skip" distances and E reflection may both be diminished for high angle signals, making low angle radiation look more appealing for distant work. However, our allowable ERP and the radiation angles achievable with our antennas very much favor the acute angle "short skip" mode. This has been demonstrated to be a viable option in that it allows reception well beyond groundwave range.

While it is natural to think of skip propagation in terms of its potential to extend our radio horizon, we cannot ignore the fact that ionosphericly reflected signals also return to Earth everywhere within the groundwave zone. Such local skywave returns are readily observed as nighttime fading on signals which normally manifest stable daytime levels. This type of fading results from the different lengths of groundwave and skywave paths between transmit and receive antennas causing signal components to arrive out of phase to produce varying degrees of signal cancellation and distortion.

It is interesting to note that, insofar as it exists only in the receiving antenna, such fading is more apparent than real. The fields travelling in space are quite independent of one another and it is only the accident of their arrival times that gives us problems. With multiple antennas and a switch or, better yet, a goniometer or other phasing unit, most of its effects can be cancelled by an agile listener.

Short range LF skywave is at best a mixed blessing, making copy of local signals more difficult while at the same time providing "holes" in local interference that permit reception of weaker distant signals. In addition, it presents us with a convenient tool for investigating skywave propagation in general.

Depending upon one's objectives, nighttime fading problems of this type can be minimized by an appropriate choice of receiving antennas. I recently conducted a series of tests in which the carrier level of the NDB S-322, Point Sur, California, 49 miles distant, was monitored on a continuous chart recording. During numerous trials with several antennas, I found that horizontal wire antennas always exhibited nighttime fading to levels below the daytime average. Vertical antennas showed frequent fades to levels above the daytime average. This would seem to indicate that a horizontal antenna is desirable when listening for weak signals through local interference, while a vertical is better for nighttime copy of groundwave Lowfers.

Not all fading is a product of skywave/groundwave interference. As the characteristics of the ionospheric layers change in response to the many varibles which determine their moment-to-moment condition; layer height, depth, density and angle all shift. This shifting is reflected in a continuous complex movement of optimum paths and null-paths across the Earth's surface and we experience fading.

In addition, multiple reflective paths can create fading similar to that encountered in the case of mixed groundwave and skywave. No matter how we look at it, fading is the inevitable signature of skywave propagation.

As if this were not enough to keep us happy, there appear to be a good number of exceptions and anomalies that creep into our receivers to confuse the issue. On a few occasions during the winter of 1985-86, strong nighttime enhancement of several Lowfer signals was noted at 100 to 200-plus miles. These events tended to produce signals considerably stronger than daytime levels and more stable than the usual nighttime signal. Vigorous, fast-moving weather fronts in the signal paths appeared to be closedly associated with the phenomenon. Enhanced propagation was clearly not reciprocal in all instances but it may have been in some. More observations of these transient events are required.

Similar enhancement over paths of several hundred miles have been observed both day and night, in apparent conjunction with cold fronts and shifts in the jet stream.

The mechanism behind such propagation is as yet somewhat unclear. It seems possible that physical disruption of the D Layer takes place, reducing its absorptive qualities either over the whole path or over one or both ends of the path. If such disruption does occur, evidence may be found by observing VLF signals propagated via Earth-D Layer waveguide mode. On the other hand, perhaps the LF enhancements are evidence of ducting between parallel thermal boundaries or between thermal and ionospheric layer boundaries. There can be little question but that weather has at times a major influence on LF propagation and it must be taken into consideration when we become involved in any kind of weak signal work.

In any case, it is clear that these occasional events offer both Lowfer and LF DXer unique opportunities to accomplish things which would be more difficult or even impossible under normal conditions. The experimentally-inclined can devise any number of studies and procedures to develop a better understanding of these events now classified as exceptions and anomalies.

While such unusual events may be difficult to anticipate, the vast majority of propagation is cyclical. There are Earth-based cycles, which are diurnal, seasonal, and annual. Obvious solar cycles relate to the solar rotation period of approximately 28 days and the 11-year sunspot cycle. On a microcosmic scale, fading shows distinct minute-to-minute patterns which can provide valuable clues to prevailing conditions while giving the patient listener numerous opportunities to fish out the weak signals.

Skywave Antennas

The question perennially arises in Lowfer circles as to whether there is a practical skywave antenna which would be more effective than our typical top-hatted verticals for launching high-angle radiation. The concept is very appealing. What fun to have an antenna that produced little or no local impact (thanks to its absence of groundwave radiation) while laying down usable nighttime signals at 300 to 1,200 miles or perhaps even further. Also appealing is the idea of a simple backyard antenna that would produce results for all the would-be Lowfers who are unable to put up a vertical.

Personally, I am afraid we are pretty well stuck with what we already have. However, I would love to be wrong about this! Since it seems a fairly easy matter to test, we might as well look into the possibilities.

Conventional wisdom has it that vertical antennas such as those used by Lowfers and most NDBs are predominantly low-angle radiators like AM broadcast stations and the verticals of HF DXers. However, these latter antennas are large in terms of their operating wavelength and their ground planes are comparably scaled. The Lowfer's vertical and ground plane are both miniscule in relation to the working wavelength. Such electrically small systems tend to generate more high-angle radiation than is really desirable for groundwave operation. While there is a "cone of silence" directly over the vertical, the antenna still functions very much as a high-angle radiator. Inarguably both Lowfers and NDGS *do* generate usable skywave signals, so the question has to be whether some other type of antenna will do as well or better for skywave generation.

Horizontal antennas operating less than a wavelength above the ground are known to generate a healthy amount of high-angle radiation. Such antennas have always proven quite effective for single-hop communications in the amateur bands. In attempting to extend the concept to 1750 Meters we immediately run afoul of a couple of serious difficulties.

Our horizontal antenna will have to be *very* close to ground in terms of the 1-mile wavelengths we use. Thanks to the restrictions of Part 15 of the FCC rules, our low antenna will also be very short in terms of its operating wavelength. So we find ourselves in the position of a 160 Meter operator who has to work DX with a five foot antenna he can only get two feet off the ground! (Let us not forget that he can only run 1 watt as well.) To put this dismal prospect in other terms, our radiation efficiency will be very low and what little radiation we do produce will be almost entirely spent warming the ground under the antenna. Still, this is only a slightly worse case of what we face quite successfully with our verticals. A little radiation in the right place can work wonders on longwave.

Results can be tested quite easily. If a horizontal antenna is heard much better at night than by day at the relatively close ditance of 20 to 50 miles and if nighttime signals are heard at 50 to 150 miles with the daytime signal very weak or non-existant, we can pretty well assume a skywave mode is operating. Supposing the experiment has been successful to this point it will be useful to determine the quality of the signal relative to that from a conventional top-hatted vertical. Ideally, a comparison vertical should be located at the horizontal transmitting site, with due care being exercised to avoid mutual coupling between the two antennas. Observations may be simplified by using a phasing unit to null the daytime groundwaves then watching strength and fade patterns of nighttime signals as the skywave comes into play.

The ultimate test of any Lowfer skywave antenna must be its performance at several hundred miles. However, it seems unlikely that any antenna which fails to exhibit easily detected skywave properties within 100 miles will perform any better at greater distances.

Implementation

The simplest antenna will be a horizontal end-fed wire, 15 Meters long and as high as possible, inductively loaded at one end and insulated at the other. Loading losses will be high, antenna current will be low, and there will probably be more effective radiation from the downlead to ground than from the antenna proper. This will be vertically polarized radiation, tending to obscure the experimental objective. Efficiency of this version can be improved somewhat by replacing the single wire with a wire cage or parallel "flattop" type wires, or a narrow fan or something really massive like 16-inch culvert pipe, but all the basic problems will remain. Still, it is an easy antenna to build and something might be learned from playing with it.

Some of the problems of the simplest antenna can be overcome by going to a loaded dipole configuration. This will consist of two horizontal elements 7.5 Meters long with loading coils at the midpoint. This antenna should be somewhat independent of ground and the problem of unwanted vertical polarization should be reduced. Unfortunately, we are now bringing our 15 Meter antenna to one-half wave resonance so the combined center inductance and associated losses become very large indeed. Short of going to superconducting coils, about all we can do is make the radiating elements as massive as possible. In order to keep the system within the letter of the rules, the transmitter (or at least the final amplifier) will have to be mounted in the center of the dipole. Unless this central feedpoint is accessible to the operator, tune-up is going to be a real problem. Adjustment of the coils will be critical and it will vary with small changes in antenna height. A cut-and-try procedure might be practical, with final fine-tuning done by adjusting the height of the antenna while watching field strength and supply current to the final amplifier.

Various loop configurations might also be considered though, once again, allowable antenna dimensions make prospects for success rather dim. In working with loops, losses should be minimized by using the largest possible diameter material.

Alternatively, experiments along these lines might be pursued under FCC Part 5 experimental license to eliminate the artificial constraints on antenna dimensions. Given a horizontal antenna producing groundwave levels comparable to a 1750 Meter vertical, what will the skywave comparison be at 1,000 miles?

SKY EXPERIMENTS

by

Michael Mideke

After completing the above article I established a new transmitter site (designated SKY) and implemented several premutations of the horizontal transmitting antenna. The experiments included center-fed dipole, end-fed wire against ground and end fed wire against various counterpoise configurations.

As earlier tests with very short verticals have demonstrated, even a few feet of vertical RF current flow will generate quite a groundwave. One of the major challenges at SKY was the exclusion of vertical RF conductors. I'm not sure that my efforts were ever completely successful in this regard.

Power was adjusted to produce antenna current equal to that in the vertical antenna at the Z2 site, some 700' above SKY and 1/4 mile to the NW.

In all instances, SKY produced weak groundwave signals that were audible to about 40 miles and useful to perhaps 20 miles. (Z2 groundwave ~300 miles.) In no instance was daytime copy of SKY achieved at 100 miles, but possible traces of the signal were heard on a few occasions. No trace of the signal was ever heard at night at 100 miles.

Later, the horizontal system was replaced with a suspended tophat vertical over a chickenwire and radial groundplane. Higher antenna efficiencies than Z2 were achieved but groundwave from this antenna remained 6 to 8 dB below Z2 (identical current in vertical elements of the same height). This differential appears to be a consequence of terrain and vegetation absorption. It remains to be seen whether the skywave potential of the site is limited in a similar fashion.

As far as the horizontal antennas at SKY are concerned, it appears that the radiated signal was orders of magnitude too small for the production of a detectable skywave. However, the horizontal effort was hampered by lack of height; the best that could be achieved was around 25 feet. Had it been possible to suspend antenna and transmitter at 50 or 100 feet results would surely have been a bit better. But such installations get us rather quickly out of the area of feasible "backyard" installations, especially if incidental vertical radiation is to be excluded. Overall, results are inconclusive but suggestive that useful horizontally polarized LF transmitting antennas are not easily produced within the constraints of Part 15.

Effects of Moisture on Insulated and Non-insulated ground radials

By Les Rayburn, XMGR

For several years many Lowfers have noticed that the ERP and antenna current from their transmitters drops during periods of rain, snowfall or other moisture. It was decided late in the 1985-86 season that the MGR site should be used to investigate this occurence and to document the extent of the losses caused by ground moisture on various types of ground systems.

The I.D. cycle for the MGR beacon was modified to include periods of long key-down (20 seconds in length) during which times measurements were taken from a antenna current meter at the site, a local F/S meter at the site, and a calibrated F/S meter located onboard the USS Ulysses S. Grant SSBN 631 which was undergoing overhaul at a distance of 1.3 miles.

Three types of ground systems were evaluated; a system of buried bare wire ground radials, insulated wire radials laying on the ground, and a small elevated counterpoise ground system. The testing period lasted for two (2) months and over 400 readings were taken at various, random times. The weather during the tests ranged from a long, dry period of about two weeks to heavy rainfall, and a light snowfall.

The ground systems performance differed radically as follows:

Buried Wire Radials: Losses as great as 4 db were noticed when using this type of ground system during periods of high moisture. Morning dew could cause losses as great as .5 db!

Insulated Wire Radials: This system was a better performer, with losses of only about 2.2 db under worst case examples. Morning dew had little effect on the output and the system seemed to "recover" more quickly than the buried wire radials from moisture.

Elevated Counterpoise: This system was unaffected by moisture and also resulted in the highest antenna current despite being the second smallest system erected.

**In fairness to other lowfer installations, all of the above ground systems were quite small and enlarging all of the systems resulted in less loss from moisture. Those with large ground systems may not notice losses that are this great.

From this study, it seems logical to assume that the elevated counterpoise ground system will result in a greater ERP for a given installation, year round. Those lowfers in the New England area will benifit greatly from this type of system due to the weather conditions that exsist throughout most of the year. (Snowfall on a two day period resulted in losses as great as 4 days of rain!)

The reasons for these losses is not entirely understood but an effect of antenna de-tuning was noted at the MGR site during the tests. Re-tuning the antenna always resulted in a .2 to .8 db improvement in the output during periods of moisture loss. It is assumed that the loss is caused by the return or image current from a vertical antenna having to pass through a greater resistance in order to complete its flow.

Mike Mideke, Z2 has also studied these effects and has noticed that improvements to his ground systems (length) have not reduced his losses. While others have reported that losses can be reduced to almost nothing by improvements...this may depend on the soil under a given lowfer installation.

Mike Mideke has also indicated that his losses are not related to de-tuning of the antenna through this was clearly noted at MGR. Though this effect did not cause the major loss, it was a factor in the overall losses caused by moisture.

Soil analysis is available from most state universitys and this may prove to be a worthwhile project for lowfers and result in further investigation of this occurence. For those mainly interested in imrpoving their ERP, this adds to the evidence that the elevated counterpoise ground system is the best ground systems for those lowfers who can erect one, with the insulated wire radials laying on top of the ground being the next best choice.

REFERENCES:

1750 Meters Western Update #21, Mike Mideke, December 1985.

Effects of Moisture on Insulated/Non-insulated/Elevated Counterpoise Ground Systems, Low Frequency Experiment #003, Les Rayburn, March 1986.

Mideke note, Dec. 1987

Ground resistance at Z2 was reduced to around 10 Ohms through a combination of radials and treated grounds (see P. 47). De-tuning caused by changing soil moisture does in fact occur at Z2. This problem was only slightly alleviated by ground system improvements. However, de-tuning is a correctable condition while moisture related variations in ground resistance are considerably more intractable.

In my experience at Z2, system efficiency is highest when the ground is very dry to a depth of 4 feet or more. Even with careful re-matching, antenna current reductions of 30% to 40% are observed when the upper few feet of soil becomes saturated.

Due to the difficulty of making precision measurements and the uncertainty as to how various related loss factors can be isolated, it is hard to say how important such seemingly large ground variations really are. Climate, the nature of the soil and the antenna site itself will all play a role in determining whether this is an important phenomonon....or whether it can be observed at all.....

FERRITE LOADING

Ferrite core loading coils WILL work. There are a few things that are important to remember about using ferrite. Ferrite losses increase exponentially as power is increased, so what may seem excellent from a receiving standpoint may be worse than useless when called upon to handle even a little power. All ferrites are not the same. The wrong material can make a bad situation worse- use high permeability, LF materials and avoid things like salvaged BCB loopsticks. Salvage material from TV high voltage supplies instead.

A ferrite loaded coil that has a slug that is either calibrated or lockable is very useful when it comes time to construct a large air-core coil for an existing antenna installation. Simply resonate the antenna with the ferrite coil and measure the coil's inductance. This won'" be perfect but it will provide a perfectly good target value for designing a custom coil.

SITE FACTORS AFFECTING PERFORMANCE OF 1750 METER TRANSMITTING VERTICALS

by

Michael Mideke

Over the years I've attempted to radiate LF signals from a number of sites. The most important lesson learned from a number of fairly serious installations has been the virtue of putting the antenna in the clear.

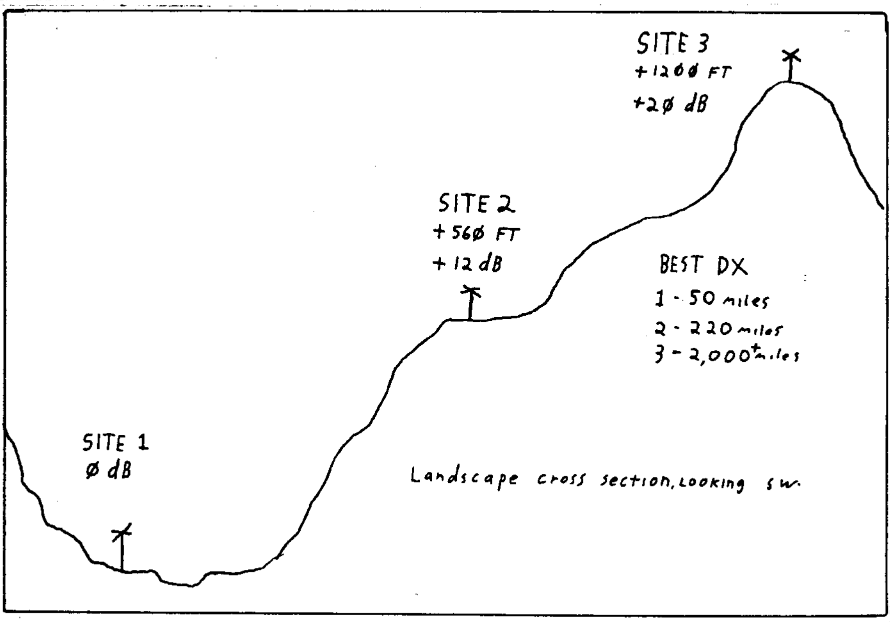
The accompanying drawing illustrates 3 real installations, each consisting of a 32 to 36 foot vertical with substantial capacity tophat and identical current in the antenna base. The relative signal levels are for groundwave at distances from 25 to 220 miles. Site 1 has never been heard beyond about 50 miles. Only Site 3 has generated a verifiable skywave signal, though it seems likely that Site 2 has skywave potential. Site 1 is wooded, Site 2 mostly brushy with scattered oak and pine trees. Site 3 is surrounded by brush ranging in height from 2 to 8 feet. However, except for a narrow ridge rising to the West, the ground drops away very steeply from Site 3, leaving the antenna essentially in the clear.

This suggests two main points:

1 - Given 1 watt input efficiently utilized, the EFFECTIVENESS of that power can vary by a factor of at least 100, depending almost entirily upon where the antenna is situated.

2 - Antennas in the clear have an overwhelming advantage over antennas that are obstructed.

Not much seems to have been done with high level LF transmitting sites. In view of the potential performance, such sites seem well worth considering. There are drawbacks also worth considering: effective ground systems don't come easily on rocky peaks, remote control becomes almost essential and lightning hazards are increased in high, exposed places.



Landscape cross section, looking sw.

TRANSMITTING GROUNDS FOR 1750 METERS

by

Michael Mideke

The following material is drawn from early issues of the WESTERN UPDATE and from numerous unpublished notes.

The explanations that begin this section probably leave much to be desired from an engineering standpoint but they should at least point fairly clearly to the kind of situations which must be addressed by ground systems to be used with radiators that are electrically very short.

Ground systems for electrically short radiators need to accomplish two things: they must establish a low-resistance connection with the earth and they must screen the intense electrical field from the lossy ground surface in the immediate vicinity of the antenna.

Short verticals are electrically lengthened by inductive loading to behave in many respects as if they were a full 1/4 wave long. In effect, the radiating element is made to look like half of a 1/2 wave dipole; the ground system provides the other half.

In a dipole, equal current flows in either half. In the case of the dipole formed by our short radiator and its ground system, the resistance of the ground half is invariably higher than that of radiating half. The current that flows in the antenna is limited by the higher resistance. So the more the ground resistance can be reduced the more nearly the antenna system will approximate a vertical dipole and the more efficiently it will perform as a radiator.

A simple ground system consisting of a ground rod or two and perhaps some connection to local plumbing may be more or less satisfactory at high frequencies but on LF it is of dubious value. Ground resistance may be 100 ohms or more, and it is clearly desirable to improve the situation. If ground resistance cannot be brought to a low value, there are real limits as to how far it is worthwhile to go in reducing the resistance of other parts of the system.....1" Litz wire and a gold plated antenna will be a waste of effort if the ground is no good.

PRACTICAL GROUND SYSTEMS -

Several measures may be undertaken to reduce ground resistance. What approach or combination of approaches will be most valuable or practical will depend on site, available resources and the ambition of whoever has to do the work.

THE OPPORTUNISTIC APPROACH is to run a 'radial' to every grounded [or just massive] metal object within reach - plumbing, fences....buried metal of all sorts. Each wire should lead to only one earth connection and all wires should be brought to a central point near the base of the antenna. Assuming enough metal can be found, this process can continue until further additions produce no measurable change in antenna current or tuning. Wherever possible, connections should be soldered. Otherwise, use brass, copper or stainless steel clamps and connectors. Avoid aluminum and iron. If you need to make connection with a rusty (or rustable) iron pipe, an oxy-acetylene welding torch can be used either to bond heavy copper wire directly or to braze on bronze connecting hardware.

Where connections must be strictly mechanical, try to make them accessable for future cleaning and polishing.

When adding opportunistic grounds, it is a good idea to monitor both transmitter performance and signal level. (Best if signal is monitored from a few wavelengths away.) Some grounds or combinations of grounds turn out to be counterproductive; more is not always better. As grounds are added, antenna current SHOULD increase while loading inductance and/or capacitive trimming should decrease.

RADIAL GROUNDS - A more formal approach to the ground system is to construct a mat of radial wires centered under the vertical. Where, as is the case with Lowfers and most NDBs, the antenna is very short in terms of operating wavelength; it appears there is little advantage in using long radials (on the order of 1/4 wavelength). This is especially true if the operator is unwilling to install at least 100 such radials! In practice, radials 20% to 50% longer than the vertical itself will work very well. If one has a mile of wire to invest in radials, it will probably be better to cut it into many 35 to 70 foot sections than to use it all for three or four very long radials.

Obstructions such as buildings, trees and property boundaries can render the realization of a symmetrical radial mat impossible. In these situations one must just concentrate on doing what is practical. Make radials long where you can and try to spread their ends apart so that distribution is more or less even within the constraints of the location.

It is better to have radials on the surface than buried and better to have them above the surface than lying on the ground. If radials are buried or in contact with the surface, they should be insulated; otherwise contact with the lossy surface or immediate sub-surface will lead to unnecessary losses and exagerate the de-tuning that results from varying soil moisture conditions.

It is often totally impractical to elevate the radial system. Sometimes radials are buried just to get them out of the way. A practical alternative to burial is to "staple" radials to the ground. Just make a bunch of 'U's of heavy (10ga to 12ga) solid wire, an inch or less wide and 2 to 4 inches long and use them to pin the radials down every few feet. This will permit lawn mowing and un-tripped foot traffic while minimizing maintainence.

RADIAL WIRE SIZE - If we view all of the radials as parallel conductors each carrying a roughly equal share of the RF current, it would appear that once there are a dozen or more radials the resistive losses in the radial system become quite small. Any wire that is heavy enough to be durable will be plenty big enough to handle the current.

However, it won't hurt a bit if you DO use massive radials. Early in 1987, Lowfer Jerry Parker (OWR) hoisted a modestly tophatted wire vertical above a groundplane that consisted of 109 pieces of CATV hardline. The lengths of hardline varied from 250 to 400 feet! This installation was an outstanding success. Would results have been as good had the radials been shorter or made of something like #22 hookup wire?

There is no virtue at all in having radials that are either not connected or are poorly connected. Again, SOLDER WHEREVER POSSIBLE and take special care with purely mechanical connections.

CHICKENWIRE - Wire mesh reallly works. In a portable installation I had a tophatted wire vertical which initially was suspended over 12 thirty foot radials. There were four short ground rods and a couple of connections to plumbing and fencing. At 1 Watt input the antenna current was a discouraging 60 ma. When 60 sq. ft. of mesh was placed directly beneath the antenna and connected to the ground system, antenna current doubled and loading inductance was reduced to a coresponding degree. An additional 180 sq. ft. of assorted mesh material produced only minor improvements.

In a subsequent installation at another site, a more refined approach was taken. An 8' x 20' wooden framework was constructed from planks and 2x4s. 160 sq.ft. of 1" mesh was attached to the upper side of the framework and flooring was nailed over the screen to provide workspace and a platform for the transmitter, battery, etc. Radials (some with ground terminations), were extended from the edges of the screen rectangle. No earth connection was made immediately under the antenna. This arrangement has proven quite satisfactory. In comparison to a conventional radial mat laid on the surface, this system seems to be relatively immune to tuning changes caused by variations in soil moisture.

CHICKENWIRE ON THE ROOF - Sometimes roof mounting offers the best way to get an antenna into the clear. And sometimes the roof is the only available antenna site... Chickenwire mesh can be used to advantage here - either on top of the roof, tacked to rafters immediately underneath or simply laid out on the ceiling joists. Elevated radials or downleads tosurface radials and ground rods can be run from sides and corners of the building.

RADIAL TERMINATIONS - It is probably more helpful to provide numerous ground rod terminations for radials than to attempt a massive earth connection directly under the antenna. A case in point is the transmitter installation at Z2. The initial configuration consisted of around 120 thirty to sixty foot radials and a central ground consisting of copper pipe penetrating about 12 feet in a treated pit. Later, another 20 radials 40 to 70 feet long were added. These radials were each terminated with a treated copper pipe ground. This change resulted in a substantial increase in antenna current. Furthermore, the central ground no longer drew measurable current or made any other apparent difference to antenna system performance. I believe the ideal objective here is to make the effective diameter of the earth connection about the same as that of the radial mat.

DIMINISHING RETURNS - One of the sad facts about ground improvement is that the more you do the less return you get for each hour of labor. The first 3 or 4 radials or ground rods produce immediate and impressive results. The next few will produce measurable but less impressive results. After that you have to really work to see that anything at all is being accomplished. A rough but practical rule of thumb for this sort of work says that, for a useful result, it is necessary to at least double the number of elements already in place. If you have a dozen radials down, adding one or two more is not likely to show a measurable improvement (if it does, stop right there and figure out what was wrong with all the OTHER radials!) but the addition of another dozen should have some positive effect. The next step calls for a minimum of 24 more. How much is enough? My own feeling is that if a person manages to put out 30 to 60 radials and 10 to 15 ground rods, he has earned his rest. Its time to sit back for a few months, see how it works and seriously consider just what the next level of improvement is really worth.

GROUND RODS - Beware of the cheap "copperclad" rods intended for use with TV receiving antennas and the like. Not only are they rather short, the thin copper layer is more like paint than plating. What doesn't scrape off when the rod is driven will vanish in a few months and you will be left with nothing but rusty iron in the ground. Use heavy duty copperclad ground rods, 6 feet long if you can possibly get them that deep. Or use copper pipe. Even the thin 1/2"material can be worked down to considerable depths if one is patient.

PLACING GROUND RODS - I've found a posthole digger to be most helpful in placing ground rods. Using the posthole digger and a tamping bar, dig out a 6" to 10" diameter hole as deep as you can conveniently make it. 2 1/2 to 3 feet is usually fairly easy. Then place your ground rod in the center of the hole and drive it in as far as you can. With the right soil and a bit of luck you can get the top of the rod all the way to the bottom of the hole. While you can still reach the top of the rod, securely solder a length of #14 or heavier copper wire to it so that you will have something on the surface to make connections with. Best to do the soldering after the pounding is all over. This is propane torch work; soldering irons won't hack the job. Sandpaper all surfaces, tin the rod if you haven't already done so, take several snug turns of wire around the rod and flow solder over the whole thing.

TREATED GROUNDS - A further bonus of the posthole technique is that it leaves you all set to make a treated ground. Once the ground rod has been driven as deeply into the hole as it is going to go, the hole can be refilled with a mixture of dirt and rocksalt or copper sulphate. (The salt blocks sold for livestock consumption are inexpensive and can be broken up to provide slow-disolving hunks.)

As the crystals dissolve in rain or irrigation water, a conductive solution begins to spread through the hole, extending both deeper and outward. This increases the effective volume of the earth connection, reducing the resistance of that connection. If aesthetics and safety permit, don't completely fill in the postholes. Shallow depressions left in the surface will gather rainwater and focus it on the soil (and rod) underneath.

The treated hole technique can be further elaborated by digging a bigger hole. Make a pit that is large enough to climb into. Take care that you are not digging into material that can collapse around you, and go down 6 or 8 feet. Drive one or more rods into the bottom of the pit. Then line the pit with chickenwire to provide a nice conductive armature to support about a 2" thickness of clay. The clay work can be done in stages of a foot or so. Fill in each level with soil and chemicals as it is lined. This procedure is a LOT of work but it does result in a large diameter, deep treated ground. The clay limits dispersion of the conductive solution. There is no need to buy expensive potters' clay. Find a claybank and dig out what you need. Discard large rocks and ignore the small ones.

All treated grounds will tend to improve over time, especially if provision is made to renew their treatment every year or two.

HAZARDS - Both copper sulphate (which is marketed as root killer for septic systems) and rocksalt can be destructive to plant life. Massive injections of chemicals into the ground should not be performed without due consideration for potential damage to vegetation or groundwater contamination. While copper sulphate is supposed to be most effective in increasing conductivity, salt is nearly as good and consequences of contamination may be less serious. Diminishing returns apply in this area as well - there are real advantages to enhancing conductivity immediately around your ground rods but going on to saturate the neighborhood won't make all that much difference to your signal.

TAKE ADVANTAGE OF CIRCUMSTANCES - Whenever there is construction or an excavation around the place, make sure you have some copper at the bottom before the hole gets filled in. Do good soldering and build for permanence; you never want to see the bottom of that hole again!

POSTSCRIPT ON GROUND SYSTEMS

The reader will note that the expositions of ground systems found in this volume are somewhat at odds with treatments of the subject in HF and Broadcast Band literature. This is not entirely due to the myths of Lowferdom- The real point is that our antennas are VERY short, E-field generating devices which are plagued with different kinds of losses than those incurred by more current oriented radiators.

LOW POWER ANTENNA CURRENT & POWER METER

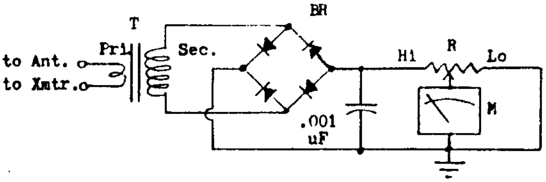
Dave Johnston, 9HDQ

This meter is a relative indication device sensitive enough to measure the antenna current generated by a CMOS chip.

Calibrate it for Power by using a non-inductive load resistor and measuring the load voltage with a 'scope or RF voltmeter.

$$P\ (\text{watts}) = E^2/R\ (\text{Ohms})$$

Set full-scale deflection sensitivity with potentiometer R.



T - - T50-6 (substitution OK).
Pri.- 10t #24 (Ant/Xmtr may be interchanged).
Sec.- 20t #24 (May be increased for greater sensitivity).

BR - bridge rectifier, use four 1N914 or equiv.

R - - 5 k Ohms pot.

M - - 50 uA full-scale meter. A less sensitive meter will require more secondary turns in T.

SO239 receptacles can be used at input.

1750m RESISTANCE BRIDGE

by Mitchell Lee

When designing filters, matching transformers, and antennas for 1750m, it is sometimes necessary to measure resistance at the operating frequency. An excellent low frequency noise bridge has been described by Stirling Olberg (page 17, December 1984 LOWDOWN), but a few simplifications can be made. The toroid chosen was a T200-3, and it required 88 trifilar turns of wire. In addition, a variable 365pF capacitor was added to null any reactive component. The utitlity of this capacitor at 1750m is questionable considering that its reactance is roughly 100 times the resistive component of a typical 1750m antenna system.

The adjacent page shows a simplified bridge configuration than can be built from a small, inexpensive FT50B-77 toroid (looks more like a sleeve to me), and a 250-ohm carbon pot. It is worth spending money on a good, solid potentiometer because the nulls are narrow and require a precision touch. The toroid is wound with 10 bifilar turns of small, insulated hook-up wire (26 to 30 gauge). Bifilar wire is nothing more than a twisted pair. Two 2' lengths of hook-up wire and a hand drill will produce professional-looking bifilar wire. Try to keep these turns bunched up to one side of the toroid. The inside edge of an FT50B-77 is rough and will cut through enameled wire so ordinary, jacketed wire is preferred. When the winding is complete connect the two individual windings in series to form a center-tapped winding. Add 10-turn winding to the opposite side of the toroid for the oscillator/noise input.

As far as the center-tapped winding: the centertap goes to your receiver, one end connects to the unknown, and the other end connects to the 250-ohm carbon pot. Solder the toroid to suitable connectors to match your receiver and oscillator/noise source. Note that one end of the oscillator winding is connected to ground. A banana post is optimum for "unkown" terminal, although I used a BNC. A small aluminum box with pot attached will serve as a foundation for the bridge and connectors.

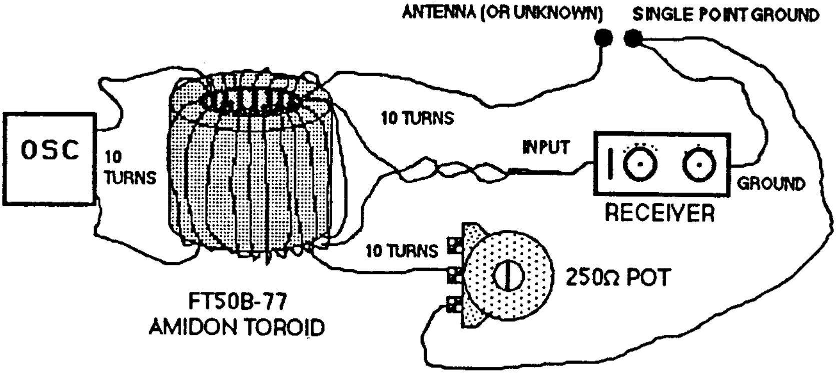
The oscillator/noise source can be a signal generator or a loud noise source. 10mV rms or more is recommended. If the generator is particular about load impedance, solder a 51-ohm resistor across the oscillator winding.

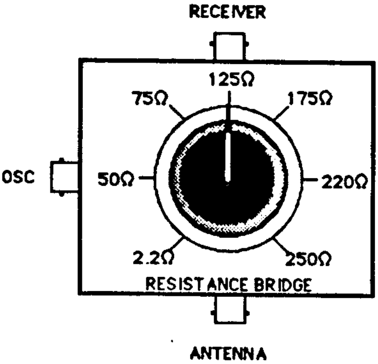
The bridge must be calibrated. The easiest and most accurate method is to collect an assortment of carbon resistors in the range of 2.2 to 250 ohms. Connect a signal source and a receiver and tune them both to 175kHz. Now attach each resistor, one at a time, and adjust the 250-ohm pot for a null as observed at the receiver. Mark the position of each null and write down the value of the resistor next to this mark. The resistors can be double checked with an ohmmeter. If a resistor assortment is unavailable, the pot's DC resistance can be measured with an ohmmeter at several positions. Mark this measurement at each associated position. I have found the resistor method to be superior to the ohmmeter method since circuit parasitics can throw off the potentiometer null point such that the pot resistance does not correspond to its DC resistance.

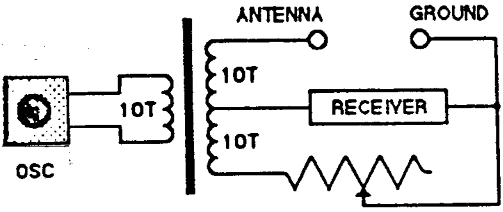
Now tune the receiver and signal source to your transmitting frequency. Let's measure the antenna and find out what its resistance is. Connect the bridge "unknown" terminal to the bottom of the loading coil (don't forget to ground the bridge, too), and then tune the loading coil and 250-ohm pot for a null in the received signal. The null will be quite narrow and deep, and signals on the antenna often overpower the bridge signal source. The resistance will represent the sum of the coil, antenna, and ground. An antenna resistance measurement is not intended to substitute for transmitter tuneup, but rather to give a ballpark figure for total resistance and system efficiency.

LOW FREQUENCY RESISTANCE BRIDGE

Tune oscillator and receiver to desired frequency. Calibrate with fixed carbon resistors of 2.2 to 250Ω. Adjust carbon potentiometer for a null with each different resistor and record value on scale. To measure an antenna, tune antenna to resonance and attach to bridge. Alternately adjust pot and antenna tuning for null. To check loading coil losses, replace antenna with dual-365pF variable capacitor and retune to resonance. Adjust bridge for null.







RF AMMETER FOR 1750m TRANSMITTING ANTENNAS

by Mitchell Lee
172 North Twentyfourth Street
San Jose, CA 95116

The key parameter in any 1750m beacon is antenna current, yet a means of measurement is often very hard to find. Typical 1W antenna currents range from 50mA to over 300mA, but RF ammeters in this current range are extremely rare. Often, when one does find such an ammeter some amateur radio operator has beat him to it; the irreplaceable thermocouple has long since vaporized because it was used to measure the antenna current delivered by a 100W HF transmitter! A better way is to build a simple RF current probe.

Shown in Figure 1 is an RF current probe suitable for measuring 50 to 500mA full scale deflection (FSD). The circuit consists of an E-core current transformer, shunt load resistor, diode voltage doubler, and 1mA DC meter. The RF current is sampled by the E-core assembly. The primary is a single turn (passing through each E-core void once), and the secondary is 25 turns of #24 or smaller magnet wire. The current is transformed by the inverse square of the turns ratio, so 1/25 of the actual RF current flows in the secondary. The current transformer reflects less than an ohm into the primary when adjusted for 50mA RF FSD. Another way of stating the insertion loss is say that less than 10mW is consumed to operate the ammeter.

A load resistor (500 ohm pot) terminates the secondary. The voltage developed is rectified and doubled by a pair of diodes and capacitors. The second capacitor, used to smooth the rectified RF waveform, is located at the terminals of a 1mA FSD DC milliammeter. The meter can be located remotely, if desired. Use shielded cable between the current probe and the meter.

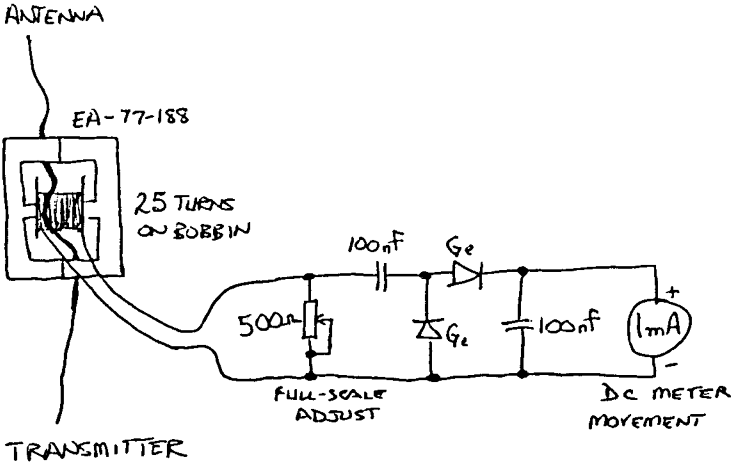
The diodes are general purpose germainium types. The E-core is a special item (substitutions are easily made), available from Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91607. Order part number EA-77-188; it includes a nylon bobbin.

As with any measuring device, the ammeter must be calibrated. The 500-ohm pot is adjusted for the desired reading while a known RF current is passed through the primary. The "known RF current" might be the output of a meter calibration source, a random antenna current simultaneously monitored by an RF ammeter of known calibration, or a known RF voltage and load resistance. If none of these are available, calibrate the ammeter at midscale with your own particular antenna current, whatever that might be. The meter can then be monitored for changes in antenna current. Even though the current is unknown, you can still watch for relative changes when various transmitter, antenna, or ground improvements are made. Be sure to adjust for constant input power, otherwise "improvements" might be the result of loading changes.

The easiest place to measure antenna current is at the bottom of the loading coil, but this is not the true antenna current. The coil will exhibit some capacitance to ground and that will shunt away some of the current before it reaches the antenna. Another method is to place the meter at the top of the loading coil, or at the base of the antenna. However, caution must be excercised. This is a voltage node and stray capacitance contributed by the meter and RF current probe will shunt some antenna current away, thereby decreasing the actual antenna current. If the meter is attached directly to the voltage node, a small meter movement should be used right at the current probe to minimize stray capacitance. In this case DO NOT locate the meter remotely as previously suggested.

This current probe uses a small E-core so that it can be clamped on to the antenna system in various places without interrupting the circuit. It can even be clamped on to ground radials to get comparative readings of radial efficiency. Larger E-cores or toroids can be substituted with little or no effect on the circuit values shown. An appropriate toroid for actually threading over the antenna mast itself is an FT-240-77, with a 1.4" inside diameter.

If an E-core is used as a clamp on ammeter, be careful to not chip the mating faces of each half. While the current probe is relatively insensitive to alignment, it is extremely sensitive to small gaps caused by dirt or dust trapped between the mating faces. The two halves of the EA-77-188 can be held together by a rubber band or clothespin.



RF AMMETER. COMPONENTS CAN BE MOUNTED ON BACK OF METER.

LF DIPPER AND RESONANCE CHECKER

by

David Johnston

This is a DIP meter I have used for about a year now with great success. I have used it to check resonant frequency of my VLF antenna with no loading coil (just tophat radials), to check resonance of the antenna with the loading coil in place, to check resonance of the loading coil itself, and to check tuned circuits when building transmitters and converters. This instrument gives a nice sharp dip at resonant frequency, the depth of the null depending on the Q of the circuit under test. Normally a two turn link from the dipper wound around the coil under test gives a nice pronounced dip with little loading effect.

Most of the parts used are not especially critical. Lots of junk box parts were used in the prototype. L1, C1 and C2 are chosen to resonate over the band of frequencies desired. As a bandspread cap I have used a broadcast band 25 to 365 pF variable for C1. C2 is a 680pF fixed capacitor. This gives me a tuning range of 156 to 218 kHz. A switch can be added to change values of capacitors to raise or lower the tuning range. If you add more capacitance, you will be able to tune lower in frequency, but your high frequency end will be lowered accordingly.

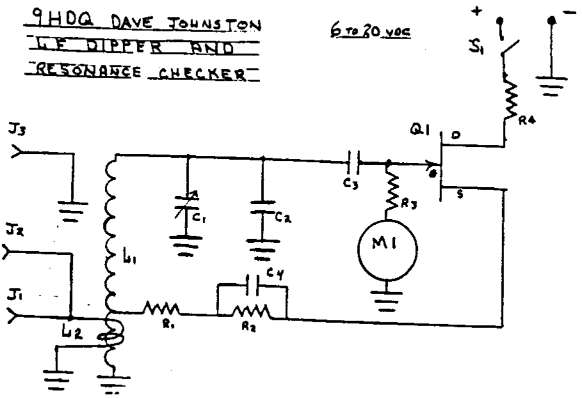
L1 is approximatedly 1MH. (a miller 9015 coil with one pie removed).

M1 can be any sensitive meter you have lying around, the more sensitive the meter the more pronounced the dip will be. My prototype uses a 100 microamp movement with good success. A 1 ma movement could probably be used with a transistor meter amplifier.

I used a 4 turn link around L1 running one side to ground and the other end out to a terminal. This is where the high side of the link going to the circuit under test is connected. The other side of that link is connected to a ground terminal on the rear of the chassis.

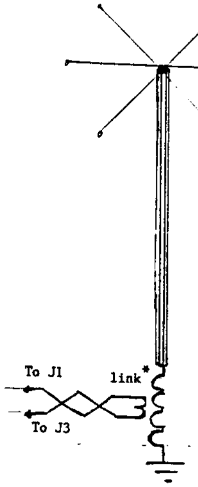
This unit also serves as a signal generator in the LF range. I have another terminal (J2) on the rear of the chassis into which I connect a frequency counter for very accurate readout. Most of the time my calibrated front dial works nicely.

I am an electronics instructor at ITT Technical Institute, and, as I tell my class, this circuit is "student proof". You really have to try for it not to work.

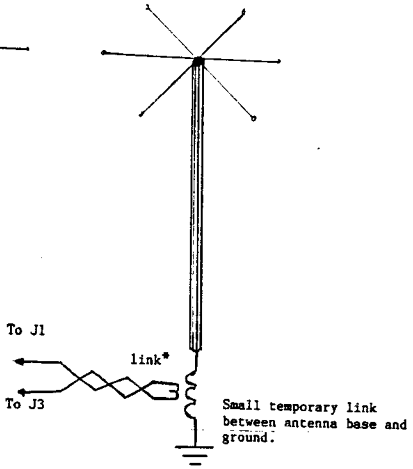


PARTS LIST

R1 - 22 Ohm, 1/4w
R2 - 1 K, 1/4w
R3 - 100K, 1/4w
R4 - 220 Ohm, 1/4w
C1 - 25 to 365 pF variable
C2 - 680 pF
C3, C4 - .47uF
J1, J2, J3 - any type EXCEPT SO239
L1 - around 1 mH (see text)
L2 (link) - A few turns around L1.
Q1 - MPF 102, 2N4416, etc
M1 - 100 uA or whatever junkbox has.

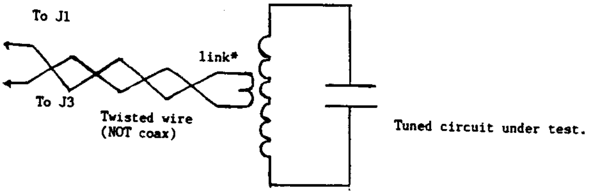


Checking resonance of
1750 M loaded antenna



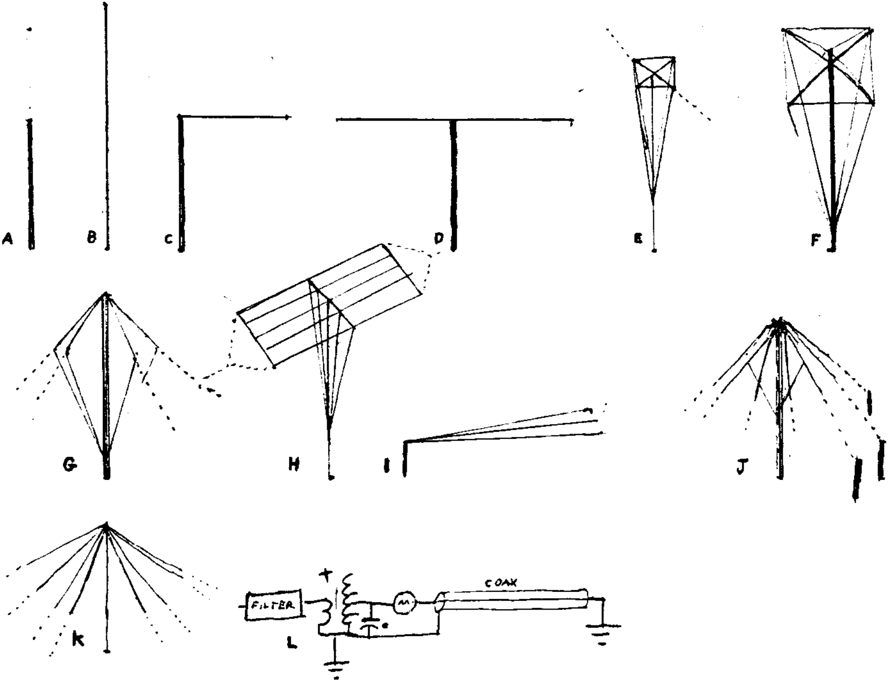
Checking resonance of
antenna plus tophat

*Link consists of minimum usable number of turns (2 or 3 should be plenty) wrapped around coil.



ONE DOZEN 1750 METER TRANSMITTING ANTENNAS

WCUD # 9 P 3



A- 26 ft tubular steel vertical. Reference ant- 0db. Just distinguishable at TYP, 120 miles.

B- 50 ft suspended vertical, RG58 U, center and braid tied together. +5 db, 120 mi

C- 26 ft vertical with 24 ft "L" section. +2db at 120 mi, +6db in near field (1/4 mi).

D- 26 ft vertical with two 24 ft top hat sections for "T". +6 db at 120 mi.

E- 35 ft suspended wire cage, 4 wires forming 8 ft square at top, 5th wire runs down the center, all wires meeting 6 ft above feedpoint. +8 db at 120 mi.

F- 36 ft steel mast supporting 4 wire cage, rigid support members at top form 16 ft square. Cage wires connect to mast at 8 ft. + 10 db at 120 mi. A structural nightmare- not recommended.

G- "Eggbeater" wire cage suspended from and attached to 36 ft steel mast, guys tensioning the cage elements. (more guys needed to support mast) +8 db at 120 miles. Could be very good with more cage wires.

H- Suspended five wire flattop with 5 downleads meeting 8 ft above feedpoint. Height-35 ft, each tophat section 15 ft, tophat width 8 ft. + 12 db at 120 mi.

All of the above antennas were erected in quick progression at my Zebra 1 site; far field evaluation was done by the late Art Child, TYP.

I- 6 ft vertical with 3 element asymetrical tophat of 44 ft. High clear location over a good ground plane. -3 db but readily copyable at 60 miles.

J- 30 ft vertical with 12 16 ft tophat elements and 3 cage downleads meeting mast at about 12 ft. Tophat elements secured to fenceposts. Approx +13 to +15 db, hard to tell as this antenna is in superior location and has far better ground (150 radials, 20 gnd rods) than any above except I.

K- 30 ft suspended wire vertical with 8 20 ft tophat elements. Performs much like J above but because it is located at my canyon-bottom home it is more than 20 db below J in far field.

L- Underground "antenna" Transmitter output goes through filter and matching transformer T. Transformer tap and parallel capacitance C are selected for maximum current measured at RF ammeter M. The coax is buried and runs about 200ft to a remote ground system. Probably 24 db below J but it has been copied at 33 miles.

SAN SIMEON TO SAN JOSE
"Z" WOGEER — "TYP"
PATH DX= 120 AIR MILES.

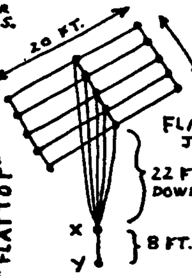
1750 METER LONGWAVE XMTG AERIALS

160 —— 190 KC
1875 — 1579 M

L O W F E R
- L — Low
- F — FREQUENCY
- E — EXPERIMENTAL
- R — RADIO

"LICENSE·FREE·BAND"
MILE LONG WAVELENGTH
ONE WATT INPUT & 50 FT. ANT. MAX.
(OUTPUT ≈ ONE MILLIWATT)

GAIN: +13db
20x PWR.
MULTI·WIRE·CAGE "FLATTOP"



10 FT. USING (3) 10'x 1" P.V.C. SPREADERS.
FLATTOP (5) #12 WIRES JOINED TOGETHER 15 PLACES.
22 FT. (5) #18 WIRE DOWNLEADS
TOTAL APPROX. 260 FT. of WIRE.

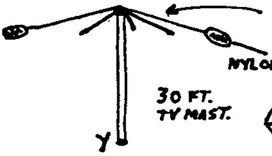
I_{ANT} = 200 MA.
L_{BASE} = 2.8 mh.
E.R.P. 800 MICROWATTS.

+10db
10x PWR.
TOP HAT·CAGE "CONICAL"

(5) 8 FT. WHIPS OR EQUIV. RADIALS ON TOP of 30 FT. TV MAST.
22 FT (5) #18 WIRE DOWNLEADS

I_A = 175 MA.
L_b = 3.2 mh.
ERP 400 µW.

+8db
7x PWR.
UMBRELLA



(5) 10 FT. TOP RADIALS #12 WIRE.
NYLON GUYS
30 FT. TV MAST.

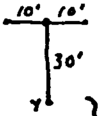
I_A = 150 MA.
L_b = 3.5 mh.
ERP 280 µW.

+6db
4x PWR.
PURE VERTICAL

15 METERS 50 FT. TV MAST.

I_A = 120 MA
L_b = 4.5 mh
ERP 160 µW.

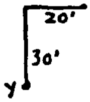
+3db
2x PWR.
"T" ANT.



#12 WIRE OR 5-CONDUCTOR ROTOR CABLE

I_A = 90 MA.
L_b = 5.7 mh.
ERP 80 µW.

+2db
1.5x PWR.
INVERTED "L"



I_A = 75 MA.
L_b = 5.9 mh.
ERP 55 µW.

0 db
REF. ANT.
24 FT. WHIP

7-"TANK ANTENNA" MAST SECTIONS.

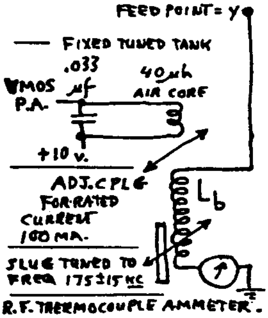
I_A = 45 MA
L_b = 6.6 mh.
ERP 40 µW.

NOTES: X — Y = 8 FT.

X = DOWNLEADS JOIN HERE, THUS MINIMUM CAPACITY TO GROUND IS REALIZED IN THIS AREA; MAXIMUM CAPACITY AS HIGH AS POSSIBLE ABOVE GROUND, WITH THESE 1% OF A WAVELENGTH ANTENNAS.

(IF APPROPRIATE L/C NETWORK INSERTED AT X, SYSTEM CAN BE MADE RESONANT FROM BCB to 10 METERS)

#18 WIRE INCREASES INDUCTANCE of MID-SECTION.



ADJ. CPLG FOR RATED CURRENT 100 MA.
SLUG TUNED TO FREQ 175±15 KC
R.F. THERMOCOUPLE AMMETER.
(NO COIL PERMITTED IN ANT. — L_b IS A "COUPLING COIL" AND PART OF XMTR P.A. CKT.)
PWR IN L_b IS HALF WATT.

0 db	7 RADIALS ea. 50 FT.	+ GROUND STAKE.	POOR SOIL MOUNTAINTOP GROUND SYSTEMS.
+3.5db	57 RADIALS ea. 50 FT. PLUS LONG COUNTERPOISE WIRE	+ 4 GROUND STAKES.	

YEAR·LONG TESTS to 12/82
— W6TYP

Kerrigan Lewis Wire Products

K&L Manufacturing

Everything You May Want To Know About Litz Wire ...But Might Never Have Asked.

The term "litz wire" refers to a type of conductor peculiar to the electronic coil industry. Its multi-strand construction of small gauge, precision twisted, film insulated wire minimizes the power losses related to the "skin effect" of current at radio frequencies.

The skin effect of RF current in a solid conductor is its concentration in a thin layer at the periphery. The effect results from the internal and external distribution of flux lines. If the solid conductor is assumed to be made up of a number of elements in parallel, then those in the interior, surrounded by more flux lines, will have greater reactance; hence less current will flow in these elements than in those in the exterior. As a result the current is crowded to the surface or skin of the conductor.

The above analogy can be translated into reality if one substitutes parallel, but insulated, strands for the imaginary elements described. In this instance, and for the reasons given, the strands at the core will carry little or no current; rather, most of it will be concentrated in the outer skin of the wires on the surface of the parallel-strand bundle. Such a cable construction frequently has only slightly less RF resistance than an equivalent area solid conductor.

However, if a relatively few insulated strands are twisted together in a precision pattern and with a precise minimum lay, the theoretical requirements of a high frequency conductor are met. With such twisting each strand in the conductor occupies corresponding positions in the cable for equal distances; these positions ranging uniformly from the center outward to the periphery and return. The strands will thus carry equal currents, for each is surrounded by the same amount of flux per unit length.

Equal transposition of a great many strands is impossible to accomplish in a single twistng operation. Accordingly, these cables are made by twisting together several previously twisted component cables. For example, a forty-strand cable might be made by twisting together eight pretwisted cables of five strands each or four of ten strands.

Even in a properly twisted litz cable there is still some skin effect. This is due to the finite size of the strands themselves, each having an appreciable skin effect at high frequencies. Therefore, a litz conductor made with many strands of very fine gauge wire can be expected to produce higher Q coils than another equal in area but having larger and fewer strands.

The methods used by Kerrigan Lewis to fabricate litz cables are completely in accord with the above theory and reasoning. Standardized fabricating procedures, designed to effect precision strand transposition, are closely followed. Conductors having few strands are formed in a single twisting operation, multi-strand cables are built up from twisted submultiples in one or more succeeding operations. The cables thus fabricated are soft and free from work hardening and springiness. Most important, an unusually high degree of spool-to-spool and lot-to-lot uniformity is thereby attained.

Polyurethane film insulated wire is most commonly used for the cable strands because of its low electrical losses and solderability. Strand gauges usually range from #30 through #50, and the number of strands, from as few as three to as many as a thousand. The litz cables are available with conventional single and double servings of teflon, celanese or nylon, single nylon space-wrapped servings, and unserved.

There are no American military or wire industry specifications for litz wire. In their absence, Kerrigan Lewis closely follows its own long established manufacturing practices. The cables are fabricated as described above and, when conventional servings are applied, their builds approximate those of magnet wire. The polyurethane insulated wire from which litz is most commonly made conforms to specifications MIL-W-583 and MW2.

KERRIGAN-LEWIS WIRE PRODUCTS

4421 W. Rice Street • Chicago, IL 60651 • (312) 772-7208

FCC RULES AND REGULATIONS
(Abridged)

§ 15.111 Operation below 1600 kHz.

A low power communication device may be operated on any frequency between 10 and 490 kHz or between 510 and 1600 kHz subject to the condition that the emission of RF energy on the fundamental frequency or any harmonic or other spurious frequency does not exceed the field strength in the following table.

Frequency (kilohertz)	Distance (meters)	Field strength (microvolts per meter)
10 to 490	300	$\frac{2,400}{F(kHz)}$
510 to 1600	30	$\frac{24,000}{F(kHz)}$

§ 15.112 Alternative provisions for operation between 160 and 190 kHz.

In lieu of meeting the requirements of § 15.111, a low power communication device may operate on any frequency in the band 160–190 kHz provided it meets all the following conditions:

(a) The power input to the final radio frequency stage (exclusive of filament or heater power) does not exceed one watt.

(b) All emissions below 160 kHz or above 190 kHz are suppressed 20 dB below the unmodulated carrier.

(c) The total length of the transmission line plus the antenna does not exceed 15 meters.

§ 15.131 Certification required for devices that are marketed or built in a quantity greater than 5 and not marketed.

(a) A low power communication device manufactured between December 31, 1957 and October 1, 1975 which is marketed or which is built in a quantity greater than 5 and not marketed, shall be self-certificated pursuant to the provisions of §§ 15.135–15.136.

(b) A low power communication device manufactured after October 1, 1975 which is marketed or built in a quantity greater than 5 and not marketed shall be certificated pursuant to Subpart B of this part.

§ 15.133 Certification and identification required for home built device.

A person who constructs not more than five low power communication devices for his own use, and not for sale, need not meet the requirements of § 15.131 and § 15.132. In lieu thereof, he shall attach to each such device a signed and dated label that reads as follows:

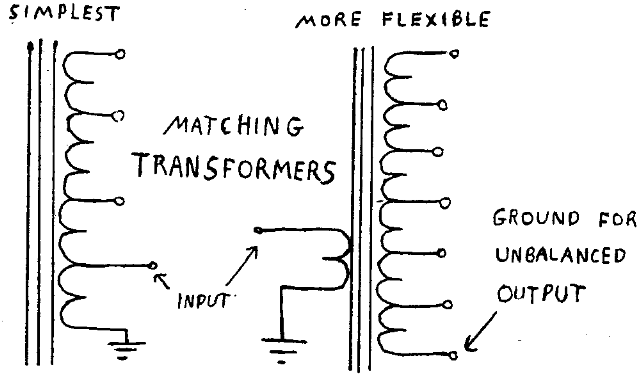
I have constructed this device for my own use. I have tested it and certify that it complies with the applicable regulations of FCC Rules Part 15. A copy of my measurements is in my possession and is available for inspection.

------------------------	------------------------
(Signature)	(Date)

ART 13 GOODIES

The ART 13 WWII vintage aircraft transmitter has at least two items that are very nice to salvage for LF antenna service. The feedthru insulator (which may be either ceramic or composition material) is a low-loss, water-shedding "bubble" having sufficient diameter to make a relatively lossless way to route high impedence RF through the walls of a coil doghouse or other structure.

The ART 13's RF ammeter comes equipped with a shunt which allows a 5 amp full scale reading. With the shunt removed, the meter reads 250 ma full scale. The GE meters (a DW 68 movement) generally preserve their calibration without the shunt, so fairly accurate readings may be obtained by dividing the numbers on the dial face. The meters made by Westinghouse tend to read high...more like 150 to 200 ma at full scale.



FERRITE MATCHING TRANSFORMERS

A tapped matching transformer between transmitter (or filter) output and the antenna loading inductance can be a great convenience. This is particularly true when design factors dictate that the output stage see some specific load impedence. The matching transformer is also invaluable for experimentation with counterpoises, balanced antennas and the like.

Use a fairly large (1.5" or bigger) toroid of high permeability ferrite material. Wrap the core with fiberglass tape. Wind with #18 or heavier enameled wire. Or you can use Litz, but this is not really essential since only a little bit of wire is needed.

Several configurations are possible. My favorite employs an independent 10 turn primary and a 25 to 30 turn secondary, tapped every 3 or 4 turns. Balanced or unbalanced loads can be driven with this arrangement. Adjust for maximum output and minimum DC supply current.

If efficiency is still improving when you get to the last tap, either build a wider range transformer or modify the characteristics of your load.

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