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COMPILED BY JEFF MORRISON APRIL 14, 2015

PANAXIS

ANTS – AM

MEDIUM FREQUENCY

TRANSMITTING ANTENNAS

CONSTRUCTION PLANS

BY

PANAXIS PRODUCTIONS

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COMPILED BY JEFF MORRISON ON APRIL 27, 2015

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CONSTRUCTION PLANS

MEDIUM FREQUENCY TRANSMITTING ANTENNAS

ANTS-AM

The principles and examples given in these plans are applicable to Marconi type (vertically polarized) transmitting antennas. Design criteria is applicable for frequencies between 300 KHz and 3000 KHz. This band of frequencies includes those of the Standard Broadcast Band of 535 KHz to 1605 KHz, commonly called the AM Band.

Although you can build an antenna to increase the range of a low or medium power AM broadcast band transmitter with these plans, it may be illegal to operate it. FCC Rules, Part 15, Subpart D, paragraph 15.111 sets forth the following limitations for transmitter operation in the AM Band:

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 (KHz)	distance (Meters)	Field Strength(uV)
10 to 490	300	2400/kHz
510 to 1600	30	2400/kHz

15.113 Alternative provisions for operation between 510 and 1600 kHz.

....

(a) The power input to the final radio stage does not exceed 100 milliwatts.
(b) The emissions below 510 kHz or above 1600 kHz are suppressed 20 dB or more below the unmodulation carrier.
(c) The total length of the transmission line plus the antenna, plus the ground lead (if used) does not exceed 3 meters.
(d) Low power communications devices obtaining their power from the lines of public utility systems shall limit the radio frequency voltage appearing on each power line to 200 microvolts or less on any frequency from 510 kHz to 1600 kHz.

....

The above are a stiff set of restrictions. Under 15.111 it works out to 24 microvolts per meter, at a distance of 30 meters (100 feet), with a transmitting frequency of 1000 kHz.

Of course most of us do not have a calibrated field strength meter. Even if we did we would find that 24 microvolts just barely gives reliable reception on inexpensive AM radios.

The alternate provisions are not much help either. An antenna only 3 meters long, about 10 feet, is extremely inefficient at these frequencies. Not only that but your transmission line (coax) and ground wire must be included in that 10 foot limit!

Of course you can get around the transmission line and ground wire by installing your transmitter right at your antenna. Of course a 10 foot long antenna probably would have to be outdoors so your transmitter would have to be weather proof as well.

The efficiency of a 10 foot antenna can be greatly improved however. By so doing you will undoubtedly have a field strength exceeding the FCC's limit under their paragraph 15.111.

The following principles and examples are presented for your information. Use your own discretion in applying them to your particular needs.

VERY BASIC PRINCIPLES

1. Any length of a conductor (wire, pipe, tower, etc.) is an antenna but is not necessarily an efficient antenna.
2. At medium and low frequencies ground conductivity is a very important part of your antenna system.
3. Field strength is dependent on the current flowing in your antenna
4. The shorter an antenna is related to its frequency's wavelength the lower is its feed impedance.
5. The lower the antenna's feed impedance the greater the current required to obtain a desired field strength.
6. The most efficient horizontal antenna is 1/2 wavelength long .
7. The most common vertical antenna is 1/4 wavelength long.
8. The physical length of an antenna is always less than its electrical length .
9. A vertical antenna with a ground plane, 1/4 wavelength long, has a feed impedance of about 35 ohms.
10. A vertical antenna shorter than 1/4 wavelength has capacitive reactance.

For the most part horizontal antennas are a problem at the medium and low frequency wavelengths. The following formula gives us an indication why:

$$\text{Wavelength (in meters)} = \frac{300}{\text{Frequency (in mHz)}}$$

Assuming a frequency of 1000 kHz (1 mHz) we find the wavelength to be 300 meters.

Rule # 6 says the antenna should be 1/2 wavelength long, or in this case 150 meters. This is about 500 feet long. It won't fit easily into many backyards. Not only that but it should be at least 1/4 wavelength above ground, in this case about 250 feet high! It is for this reason that most broadcast band and low frequency stations use a vertical (Marconi) antenna. The rest of this discussion will concern only vertical type antennas (Rule # 7).

A vertical antenna which is electrically 1/4 wavelength long is said to be resonant. This means that inductive and capacitive components cancel each other allowing maximum current to flow in the antenna. What remains in the way of opposition to current flow is called the antenna resistance. The antenna resistance consists of the radiation resistance of the antenna itself, the resistance of the ground (earth), and the resistance of loading coil wires and transmission line (coax).

Radio frequency currents flow on the surface of conductors, not through them, so RF resistance is always greater than the DC resistance in the system. It can't be measured with an ohmmeter!

In our example above we see that a 1/4 wavelength vertical for 1 mHz is about 250 feet high! This will be a bit impractical, but we can shorten the physical length and yet make it appear like it is electrically 1/4 wavelength long. Rule # 10 says an antenna shorter than 1/4 wave has capacitive reactance. If we introduce the proper amount of inductive reactance in series with the antenna we can cancel out the capacitive reactance! The antenna can be physically short, say 10, 30, or even 50 feet but we can make it appear to the transmitter like it is 1/4 wave long. The inductance we add is called a "loading coil".

By canceling the reactances of the antenna we are left with just its radiation resistance. The resistance of the ground is part of the overall antenna resistance however. It must be corrected as well.

Except along the sea shore and areas of high mineral deposits, the ground (earth) is not a very good conductor. The way to correct the problem is not easy however. The best method is to plant about 120 wires (radials) like spokes of a wheel, each 1/4 wavelength long, buried 6" under the surface, around your antenna (see Fig. 1). This can be expensive and a lot of hard work! There is a decrease in efficiency of the ground system as the radials are reduced to about 15 or so. Below 15 radials almost any random pattern and length is better than nothing (see Fig. 2). If radials are just plain impossible to do then use other grounding devices which are as close to the base of the antenna as you can get.

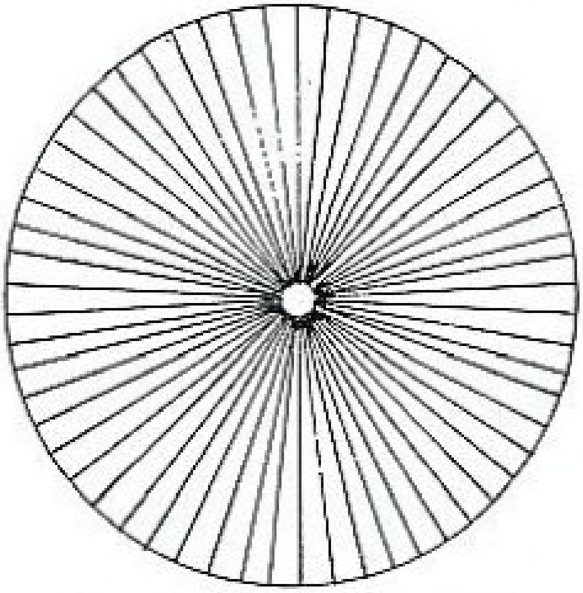


Fig. 1 Equally spaced radials

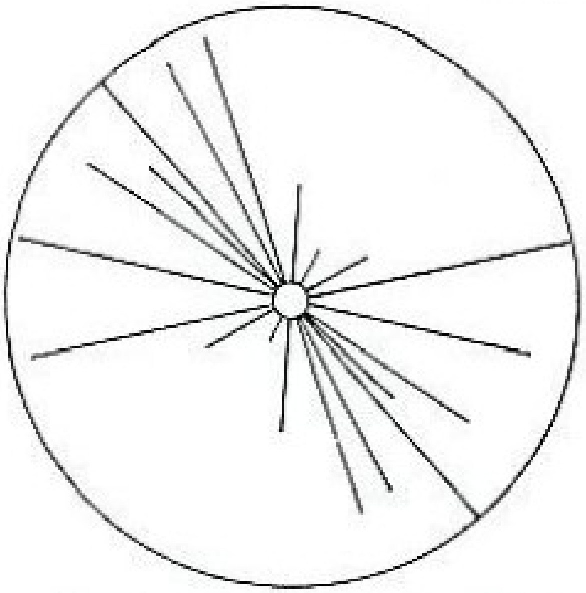


Fig. 2 Random spaced radials

Some simple grounding devices consist of:

One or more copper clad steel ground rods driven 8 feet into the ground near the base of the antenna. Connect all of them together for your "ground wire".

Several copper or iron pipes buried near the antenna base. Connect all of them together for your "ground wire".

Connect your ground wire to underground water pipes (or a water faucet in your yard).

DESIGNING YOUR PARTICULAR ANTENNA

The design of your antenna depends on:

(a) The frequency of operation
(b) How high you are permitted to build it
(c) The capacitive reactance of the antenna

This means you may have to do some calculations for your particular installation. You may need to calculate the capacitive reactance of your antenna, the inductive reactance necessary for a loading coil, the number of turns required by that coil, and how to match the impedance of the finished antenna to your transmitter.

Formula for finding capacity (in picofarads) of your antenna

f = frequency in MHz
h = height of antenna in feet
d = diameter of antenna in inches

$$C_A = \frac{17h}{\left[\left(2.3 \log_{10} \frac{24h}{d}\right) - 1\right]\left[1 - \left(\frac{fh}{234}\right)^2\right]}$$

Click to view formula

The examples in the following pages assume the use of a TV mast as your antenna or a part of your antenna. Examples are based on 10, 30, and 50 foot heights. For other heights you may want to calculate the capacity yourself, or you may select the appropriate value from the following table:

Typical Capacity of TV Masts at Frequencies of 535 kHz to 1605 kHz

	10 feet high	30 feet high	50 feet high
1" diameter mast	38 pF	93 pF	140 pF
1.5" diameter mast	42 pF	100 pF	150 pF

……

Interpolation of the above table for other heights will probably be close enough to complete other calculations for loading coils, etc. A 20 foot high, 1" diameter mast would have a capacity of about 65 pF (picofarads), by interpolation.

Formula for finding required inductance of the loading coil: (Formula B)

L = Inductance in Henrys
f = Frequency in Cycles (Hz)
C = Capacity in Farads
Pi= 3.1416

$$L = \frac{1}{4\pi^2 f^2 C}$$

Click to view formulas

Formula for finding number of turns required to make the loading coil: (Formula C)

N = Number of turns of wire
a = Radius of coil form
b = Length of coil
L = inductance in microhenrys

$$N = \frac{\sqrt{L\,(9a + 10b)}}{a}$$

Formula for finding number of turns using an Amidon T-184-41 toroid core: (D)

N = Number of turns of wire
L = Inductance in microhenrys

$$N = 100\sqrt{L/1640}$$

Formula for finding inductive reactance of coil: (Formula E)

Pi = 3.1416
f = Frequency in Cycles (Hz)
L = Inductance in Henrys
X_L = Inductive reactance in Ohms

$$X_L = 2\pi f L$$

NOTE: T-184-41 core can be obtained from AMIDON, 12033 Otsego St
North Hollywood, CA 91607
(213) 760-4429

EXAMPLE # 1

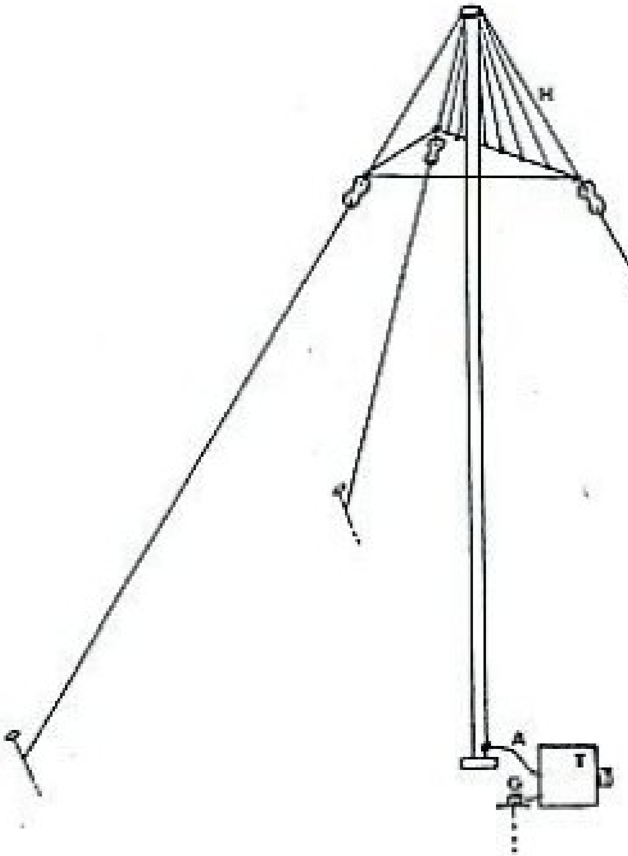


Fig. 3 Simple 10 foot mast with Capacitive Hat loading

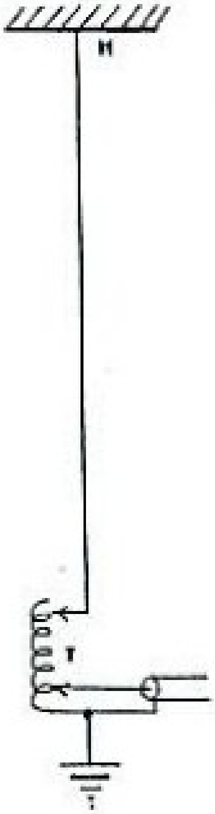


Fig. 4 Schematic

The mast is held in place with three guys of 3/16th inch Nylon rope. If regular guy wire is used instead then insulators must be installed between each guy and where it connects to the capacitive hat. The capacitive hat is made from regular guy wire (H) as shown in the drawing. A three sided pyramid is made in which each side consists of a number of wires, or screen wire, or pieces of sheet metal. The length of each side (H) is about 2 feet. The apex of the hat is electrically connected to the top of the mast.

The base of the mast is insulated from ground. The mast may be placed on top of a pvc pipe cap, a short beer bottle, or some other glass or plastic insulating material. The loading coil and transmitting matching unit is installed at the base of the mast as shown. The antenna wire connects to the mast, the ground wire connects to the ground system (radials, rods, pipes, etc.) very close to the base of the mast.

See Fig. 16 for details on the construction of the toroid loading coil and matching unit (T). The coax connector of the unit connects to the transmission line from the transmitter.

(Example # 1)

The antenna can be constructed without the capacitive hat but it will not be quite as efficient. Additional capacitive loading at the top end of the antenna assures a more even flow of current through the antenna. Fig. 15 shows that capacitive loading appears along the entire length of the antenna. More current flows in the bottom of the antenna and is shunted back to ground by the capacitive effects. As the capacity to ground decreases with height so does the shunt path - hence more current flows at the bottom. The capacitive hat having more capacity due to its larger size becomes the larger governing factor in the flow of current up through the entire mast.

Calculations: (For operating frequency of 680 KHz)

(1) Find total capacity of antenna: (Formula A)

From table....10 foot 1 " mast = 38 pF
Capacitive hat (approximately) = 50 pF
Total antenna capacity.... 88 pF

(2) Find inductance of loading coil: (Formula B)

$$\frac{1}{4(3.1416)^2(680\times10^3)^2(88\times10^{-12})} = 622\,\mu H$$

Click to view the formulas

(3) Find turns for loading coil: (Formula C)

Assume 3" diameter pvc pipe 6 " long but coil covering just 4" (Air wound coil)

$$\frac{\sqrt{622[(9\times1.5)+(10\times4)]}}{1.5} = 129 \text{ TURNS}$$

(4) Find turns for toroid loading coil: (Formula D)

Use Amidon T-184-41 toroid core

$$100\sqrt{\frac{622}{1640}} = 62 \text{ TURNS}$$

(5) Find inductive reactance of coil: (Formula E)

$$2(3.1416)(680\times10^3)(622\times10^{-6}) = 2658 \text{ OHMS}$$

(6) Impedance ratio for finding 50 ohm tap point:

$$\ldots\ldots\frac{X_L}{50} \qquad \frac{2658}{50} = 53$$

(7) Turns ratio to 50 ohm tap point:

$$= \sqrt{\text{IMP. RATIO}} \qquad \sqrt{53} = 7.28$$

(8) Turns from ground end of coil which is the approximate 50 Ohm matching point

Air wound coil

$$\frac{129}{7.28} = 18 \text{ TURNS}$$

Toroid coil

$$\frac{62}{7.28} = 8.5 \text{ TURNS}$$

NOTE: Although a toroid loading coil/matching unit is shown in Fig. 3, it can be replaced with the air wound loading coil/matching unit calculated above. A different operating frequency will require new calculations.

EXAMPLE # 2

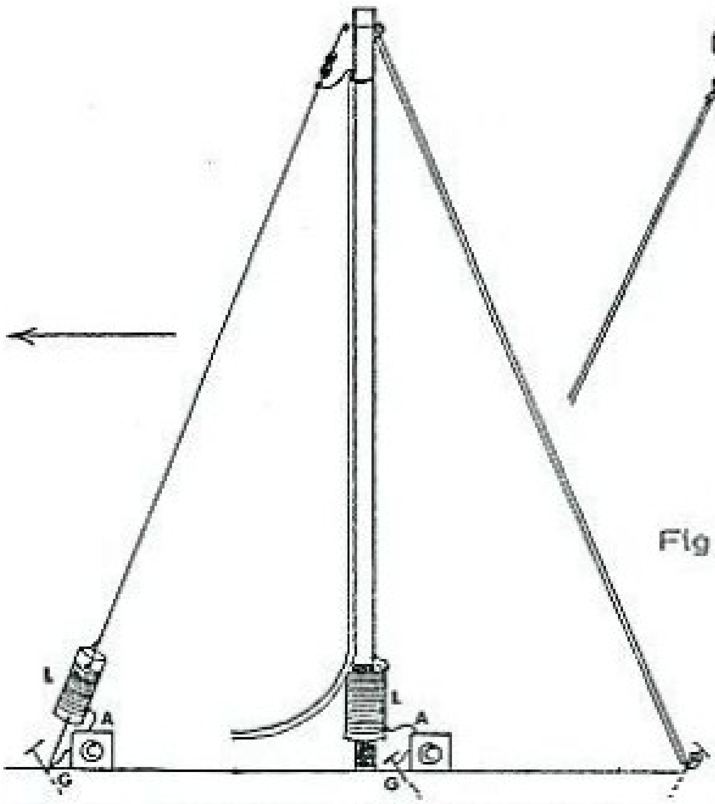


Fig. 5 Half-Sloper with bottom loading

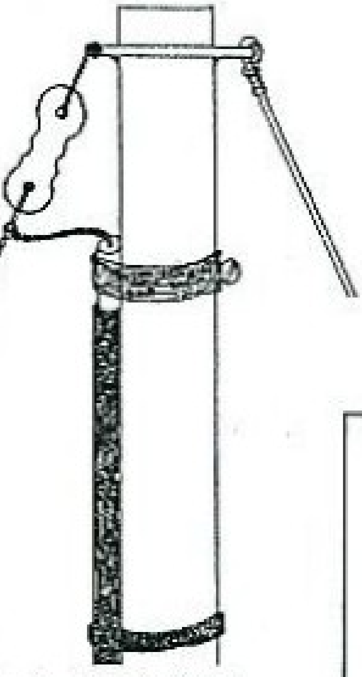


Fig. 6 Feed detail

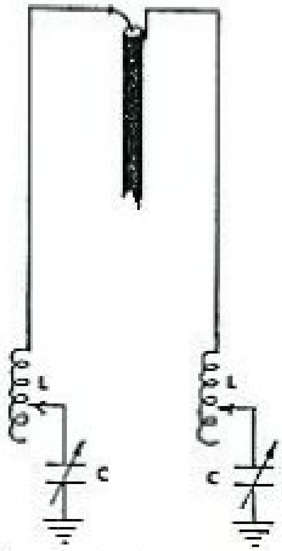


Fig. 7 Schematic

The Half-Sloper is a modified inverted vee type antenna. The feed point is at the top rather than at the bottom. When properly adjusted the feed impedance is between 35 and 70 ohms (nominal 50 ohms). Standing wave (SWR) should be less than 1.5 to 1 after adjustment. It's somewhat directional (arrow) with a power gain of 2.

The mast serves as one leg of the system. One of the guy wires is the other leg of the system. All other guy wires should be 3/16th inch nylon rope. In this example the mast is 50 feet high. This requires Nylon guys at the 50', 30', and 10' levels at least.

The system uses additional capacity tied directly to ground. This results in a smaller loading coil for each leg. Both coils are of the same inductance. The coils may be tapped if desired for tuning, however tuning may be accomplished by the loading capacitors instead. The loading capacitors are receiver-type air variable tuning capacitors of about 360 pF each. Fig. 9 shows how they can be installed inside of a weather tight box. Fig.10 shows the details for construction of the loading coil for the guy wire leg of the system.

Fig. 6 shows how the coax is connected. The shield is electrically connected to the mast with a hose or mast clamp. Tape the coax to the mast every few feet. The base of the mast is insulated from ground.

(Example # 2)

Calculations (50' mast, 1.5" diam. , 50' slope guy , .0525" diam.
Operating frequency of 1000 kHz)

(1) Find capacity of each leg:
(Formula A or table)

	Mast cap.=150	Sloper cap. = 90 pF
	Var. cap.=230	Var. cap. =290 pF
Total cap each leg......	380 pF	380 pF

(2) Find inductance of loading coils:
(Formula B)

(Both coils are the same inductance)

$$\frac{1}{4(9.87)(1\times10^{12})(380\times10^{-12})} = 67\mu H$$

Click to view formulas

(3) Find turns for loading coils:
(Formula C)

(Both coils have same # of turns)
(Assume2" diam pvc pipe, coil 2" long)

$$\frac{\sqrt{67\left[(9\times1)+(10\times2)\right]}}{1} = 44 \text{ TURNS}$$

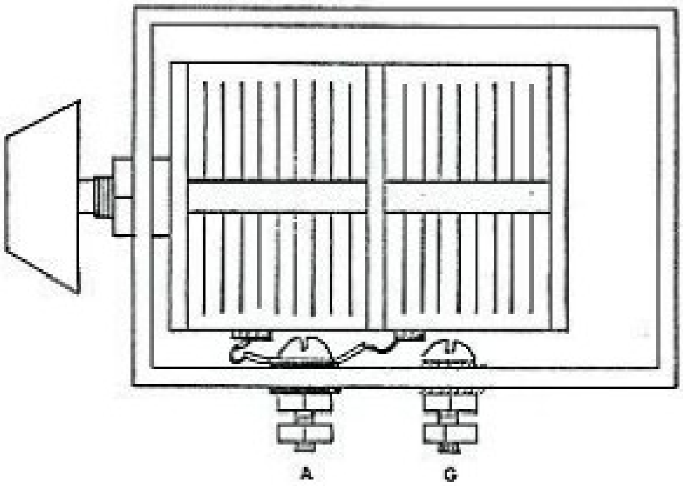


Fig. 9 Capacity tuning box

A 360 pF or dual 180 pF variable capacitor is mounted in a small metal box. The ground screw is connected directly to the box. The capacitor is also grounded to the box. The other capacitor lead is brought out with a screw and nut through insulating shoulder washers.

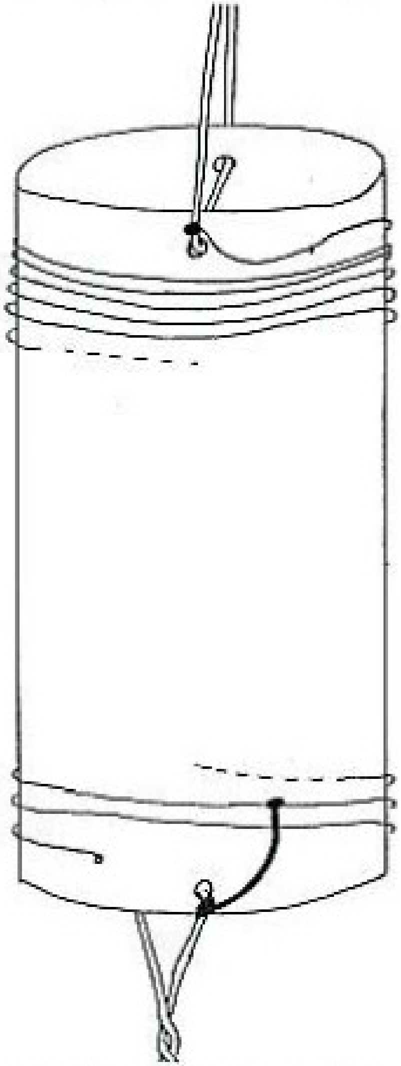


Fig. 10 Detail of guy leg loading coil

EXAMPLE # 3

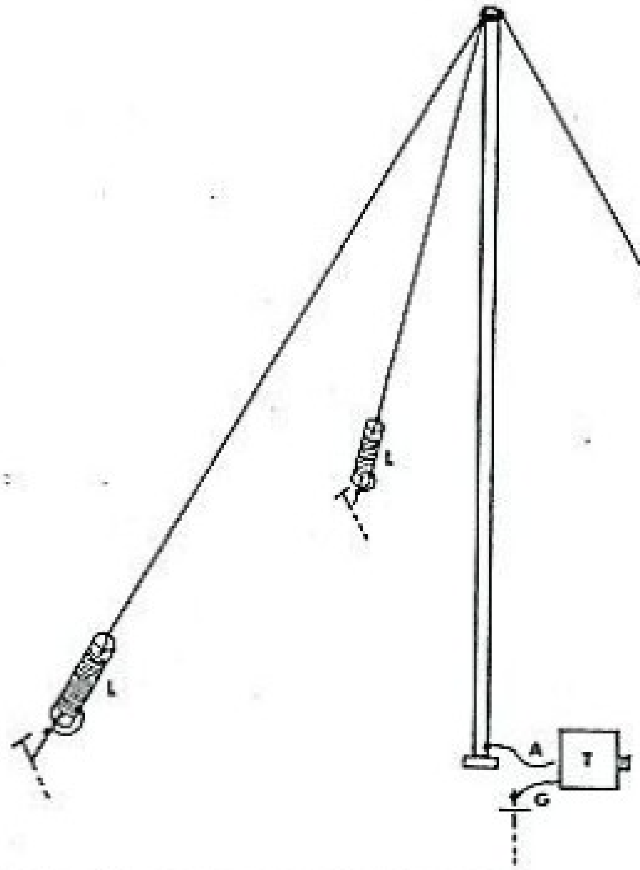


Fig. 11 Multi-element Vertical

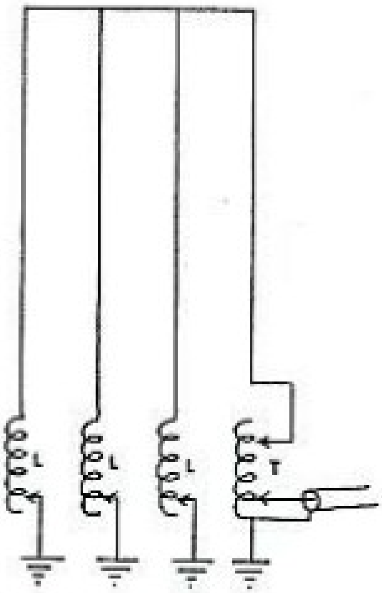


Fig. 12 Schematic

The multi-element antenna is used extensively in low and very low frequency communications (10 kHz up through 300 kHz). Antenna current flows in each leg of the system as if it were one single antenna section. Because each section radiates energy the overall efficiency is approximately 4 times that of a single antenna of the same length.

The mast is one current path, and each of the guy wires is a current path. The 3 guy legs are in parallel with the mast leg and are fed from the high impedance point at the top of the system. The mast section is fed at the bottom with a combination loading coil and matching transformer. Each of the guy wires are electrically connected to the top of the mast. The base of the mast is insulated from ground.

Each guy leg is terminated with a loading coil which is connected to ground. When properly adjusted each guy, and the mast, are resonant. In other words, each loading coil is adjusted to cancel the capacitive reactance of the antenna section to which it is attached. Although a toroid type unit is shown in Fig. 11, it could be replaced with an air wound (pvc pipe) equivalent. Guys at the 10 and 20 foot levels must be 3/16th " Nylon rope.

(Example # 3)

Calculations (30 foot mast, 1" diam., 3 guy wires 35 feet long, .0625" diam. Operating frequency of 1400 KHz)

(1) Find the capacity of each leg: (Formula A or table) $C_{mast} = 95$ pF $C_{guy} = 73$ pF (all same)

(2) Find inductance of loading coils: (Formula B) (all 3 guy coils are the same inductance)

$$\frac{1}{4(3.1416)^2(1.4\times10^6)^2(95\times10^{-12})} = 136\,\mu H$$

MAST COIL

$$\frac{1}{4(3.1416)^2(1.4\times10^6)^2(73\times10^{-12})} = 177\,\mu H$$

GUY COILS

(3) Find turns for loading coils: (Formula C) (all 3 guy coils have same # of turns)

Click to view formulas 1 - 3

$$\frac{\sqrt{177[(9\times1.5)+10\times4]}}{1.5} = 56 \text{ TURNS}$$

(4) Find turns for toroid (mast) coil: (Formula D) (use Amidon T-184-41 toroid core)

$$100\sqrt{136/1640} = 29 \text{ TURNS}$$

(5) Find inductive reactance of coil: (Formula E)

$$2(3.1416)(1.4\times10^6)(177\times10^{-6}) = 1557 \text{ OHMS}$$

$$2(3.1416)(1.4\times10^6)(136\times10^{-6}) = 1200 \text{ OHMS}$$

TOROID

(6) Impedance ratio for finding 50 ohm tap point: $\frac{X_L}{50}$

$$\frac{1557}{50} = 31 \qquad \frac{1200}{50} = 24$$

(7) Turns ratio to 50 ohm tap point:

$$\sqrt{31} = 5.58 \qquad \sqrt{24} = 4.9$$

(8) Turns from ground end of coil which is the approximate 50 Ohm matching point.

Air wound coil	Toroid coil
$\frac{56}{5.58} = 10$ TURNS	$\frac{29}{4.9} = 6$ TURNS

Click to view formulas 4 - 8

EXAMPLE # 4

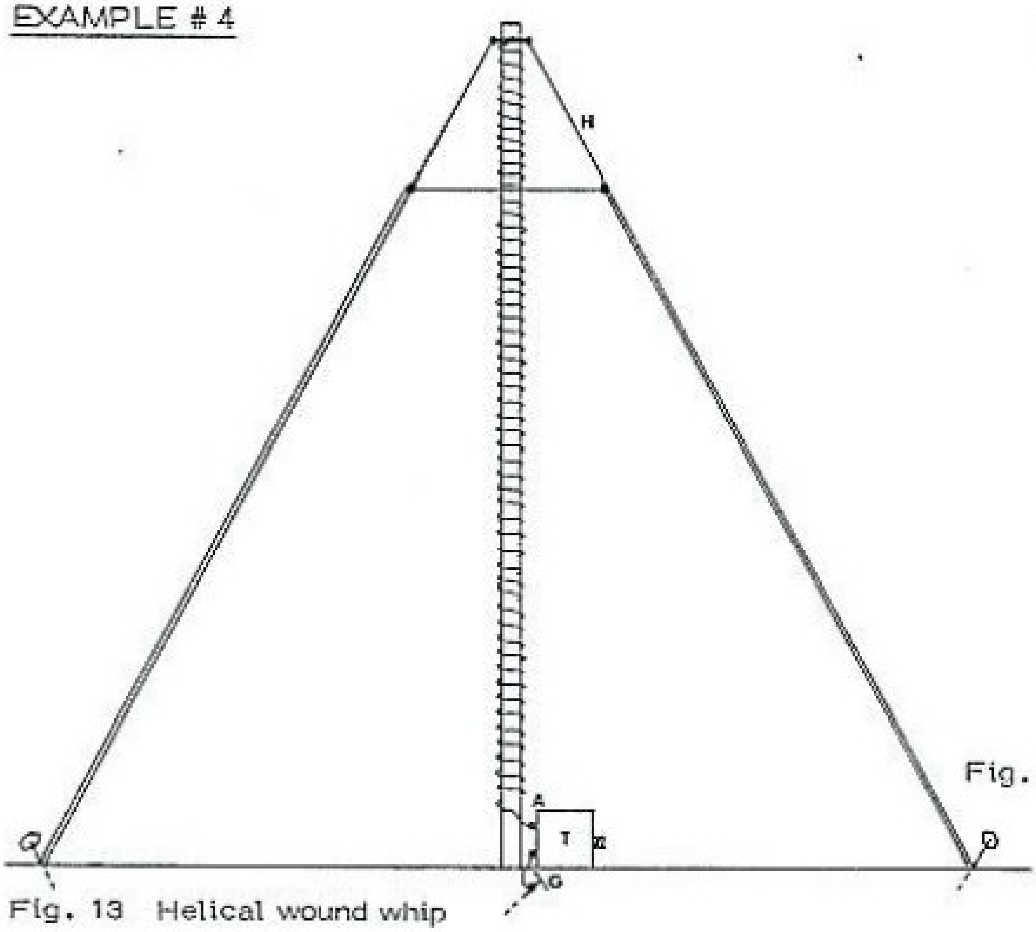


Fig. 13 Helical wound whip

Fig. 14 Schematic

It is also possible to distribute the necessary resonating inductance over the entire length of the physically short antenna. The wire of the coil also has capacity to ground just as if it were the mast in previous examples. To assure a good current distribution through the entire antenna it is wise to also include a capacitive hat. The hat in this case(H) is the same dimension as the one in example # 1 and has the same effective capacity. The guys are all 3/16th inch Nylon rope.

The wire consists of a little less than 1/2 wavelength, uniformly spaced turns, wound over the length of a 1" diameter pvc pipe. The top end of the winding is electrically connected to the capacitive hat. The bottom is connected to a small value of loading coil with matching provisions.

Unfortunately the value of the small loading coil and matching section is best found by experimentation. The only calculations that can be done with certainty is the finding of how much to use and how many turns you'll wind up with.

Assuming an operating frequency of 800 kHz, then:

① $\frac{300}{.8}$ = 375 METERS

② $\frac{375}{2}$ = 187 METERS (1/2 WAVE)

③ 187 METERS ≅ 600′
USE ONLY 500′

④ 500′ = 6000″

⑤ INCHES/TURN = πd = 3.1416/TURN

⑥ $\frac{6000''}{3.1416}$ = 1910 TURNS!

CONCLUSIONS

You have seen four different ways of constructing fairly efficient vertical antennas useful for experimental broadcasting on the AM band. It is difficult to recommend any one over another, each having its own characteristics. You must be the one to decide which might serve your needs best.

Some last things to consider

Since the RF currents flow over the surface of a conductor instead of through it, it would appear that the larger the wire the better. This is true but reaches a point of impracticability. For power handling up to 100 watts or so a # 16 wire should be alright. For higher powers you might go to a # 14, 12, etc. Loading coil wire may be varnished, plastic insulated, or even bare if the turns are spaced apart. If the coil will be subject to heavy weather conditions it would be wise to coat them with a clear varnish to hold down oxidation.

When winding a loading coil you should provide 10% more turns than your calculations. This is because there will always be some error, not in the mathematics, but just due to the surroundings. Walls, trees, cars, people, and poor ground connections are all affecting your antenna system just because they are close. The effects are unpredictable. The best you can do is calculate as close as you can and then leave some room for error. By having more turns on the loading coil than you are supposed to need you have extra adjustment you may need!

TUNING THE ANTENNA

Of course this is best done with expensive equipment which most of us don't have. But, with a little trial and error, patience, and lots of luck you can tune your antenna pretty close.

Connect your transmitter to the antenna. Set up a simple field strength meter using any sensitive dc meter with a diode across it. Put the meter where you can see it easily a few feet away from the antenna. Connect one lead of the meter to ground by just poking the wire into the earth. Connect a short length of wire, a couple of feet or so, to the other lead of the meter to act as a pick-up antenna. Turn on your transmitter. If the meter reads backward, reverse the diode. It is assumed here that you have connected your loading coil(s) and have your coax connected to the approximate 50 ohm tap point.

Move the tap at the antenna end of the loading coil until you find a point on the coil which gives the maximum reading on the meter. If you have more than one loading coil do this with each coil. If you built the half-sloper then you should also adjust the variable capacitors for the highest meter reading.

When you have obtained the very best field strength reading on your meter you can adjust the transmitter tap. This is best done with an SWR meter connected in the transmission line. The transmitter tap is adjusted up and/or down the turns to get the best (lowest) SWR reading with the highest field strength reading.

If you do not have an SWR meter, or your power is too low to operate one satisfactorily, you'll just have to hope your matching point is near correct. Adjust the transmitter tap point up and/or down the turns to obtain a maximum reading on your field strength meter. Go back and recheck for best tap on the loading coil. Repeat each adjustment several times until you are sure you have the best field strength obtainable from the system.

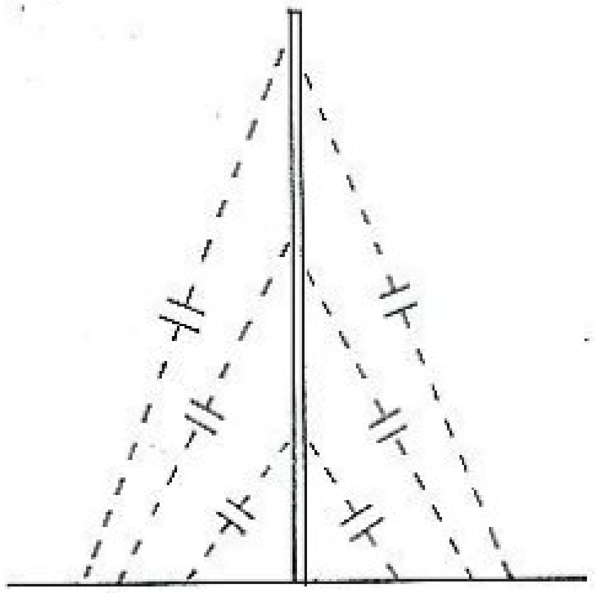


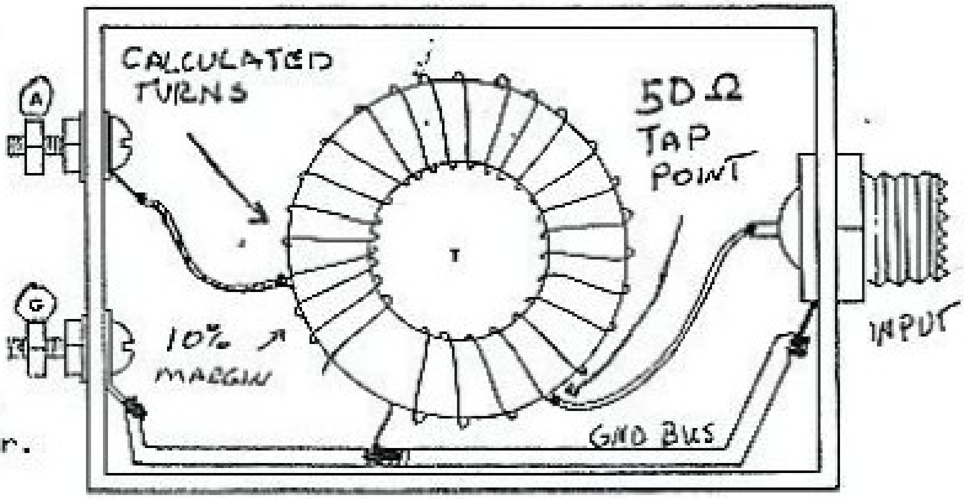
Fig. 15 Capacity distribution

The capacitive effect is greatest near the base of a vertical antenna. This is due to its closeness to ground. Any higher point must be progressively less as that distance is increased.

Because of this greatest current flow is near the base of the antenna. To assure current flow through the entire antenna, and thereby getting maximum radiation , additional capacitive loading can be employed at the top of the antenna.

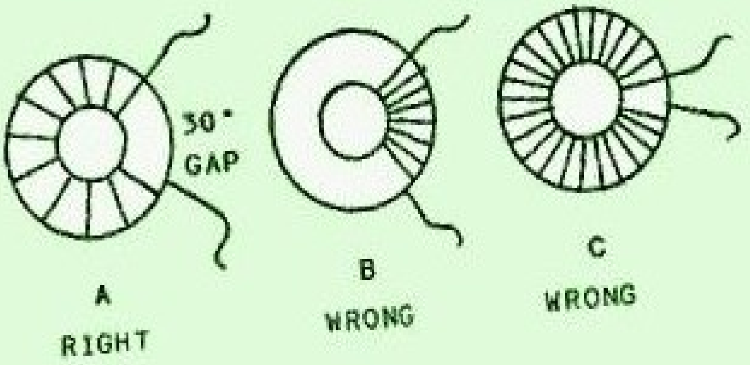
Fig. 16 Detail of a toroid loading coil installation

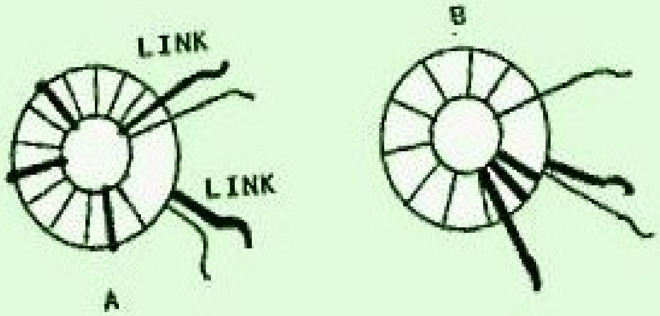
The box protects the unit against the weather. It may be metal or plastic. If it is metal the "A" screw must be insulated from the box with fibre or plastic shoulder washers. The tap nearest the ground end is for matching the transmitter to the system. It is connected to the coax by way of your choice of connector.



Appendix

WINDING and USING TOROIDS





Appendix: Winding and Using Toroids

Page 01: Basic Principles

Page 03: Winding Toroids

Page 04: More info

WINDING and USING TOROIDS

Do not be afraid to work with toroids. Think of them as donut-shaped coils that have magnetic cores. Compare this to slug-tuned coils that have adjustable iron or ferrite cores. The major difference is that a toroidal coil has a donut shape, while the slug-tuned coil has a cylindrical shape. The core material provides high inductance with a small number of coil turns, whereas an air-core coil of equivalent inductance would have many more turns than a toroid or slug-tuned coil. The latter assembly permits us to change the inductance when we vary the position of the slug within the coil. A toroid coil is also adjustable, but over a small range of inductance. This is done by spreading or compressing the turns of the winding. An ideal toroidal coil has its winding spread over 330 degrees of the core. This leaves a 30° gap at the ends of the winding.

There are two advantages when using toroids. (1) The coil Q (quality factor) is high, owing to the small number of turns. This is true only if the right core material is used for a specified operating frequency. (2) A toroidal coil or transformer is self-shielding. No metal enclosure is needed in order to keep the field of the coil confined to a small area.

FERRITE VERSUS POWDERED IRON CORES

You may be confused about when to use ferrite as opposed to powdered iron. This simple rule may be adopted for most amateur work: use powdered-iron cores for circuits that require high Q in narrow-band (tuned) networks. These include RF amplifiers, mixers, IF amplifiers, oscillators and RF filters. The charts and tables found in the manufacturer's data sheets indicate the best powdered-iron core for a given frequency range. Powdered-iron cores are sometimes used for audio inductors. These cores have high permeability. An example of an iron-core audio inductor is the popular 88-mH telephone toroid.

Ferrite toroids may also be used for narrow-band RF circuits up to, say, 10 MHz. I do not use them above this frequency if high Q is a criterion. Again, you must select the proper core mix (recipe) for high Q at the frequency of interest. Check the manufacturer's charts.

Ferrite cores are used mostly in broadband inductors and transformers. By this I mean RF chokes, baluns and matching transformers in solid-state circuits and antennas. Ferrite toroids of a specified size (diameter and thickness) have far greater permeability (u or mu) than equivalent-size powdered-iron toroids. This means that far fewer coil turns are required. But, the greater the core mu the lower the Q of the coil or transformer at a particular frequency. This rule applies also to powdered iron cores.

Ferrite is brittle because it is made from a ceramic material that is actually a semiconductor. It breaks easily when stressed, and may even break or shatter when used in a circuit that generates more power than the core can handle. This is not true of powdered iron. Both types of core will overheat if subjected to excessive power. Powdered iron will return to its rated mu after cooling.

Ferrite will not. The core may become permanently damaged from overheating. The mu will decrease and render the winding useless from insufficient inductance. Many antenna baluns are destroyed in this manner when high power is applied to an antenna that does not match the feed line (high SWR).

WHAT IS SATURATION?

The matter of overheating that we just discussed is an example of core saturation. All magnetic cores have a gauss rating that relates to how much power they can handle before saturation occurs. This is a function of "flux density" in an operating circuit. The greater the cross-sectional area of a core the greater the power it can handle before saturation occurs. Equations exist for determining the core capability (gauss) for a particular circuit application. In-depth treatment of this subject is contained in **The ARRL Handbook** and in my Prentice-Hall book, **Ferromagnetic Core Design & Applications Handbook** (1).

Saturation is based on the core size, the number of coil turns and the voltage and current in the windings. It is too complex a subject to discuss here. I encourage you to read the aforementioned references if you wish to learn more about selecting the proper size core.

Another side effect from saturation is the generation of unwanted harmonic currents. As the core goes into saturation the sine wave (RF or audio) becomes distorted and degenerates into a square wave. Square waves are rich in harmonic energy, and this distortion can ruin an audio circuit or cause TVI and RFI in an RF circuit or antenna. This nonlinear operation can be avoided by making certain that you select a core than can handle the job. If a core is quite warm or hot to the touch during operation, chances are that the size is inadequate or marginal. Substitute a larger core if this happens.

CORE NOMENCLATURE

The numbers assigned to toroids may confuse you. Micrometals cores are the ones used most frequently by hams, so I will mention the numbering system that relates to those components. Powdered-iron cores have a T prefix (toroid). By way of an example, suppose you have a T68-2 core. T stands for toroid and 68 indicates the core diameter (0.68 inch). The no. 2 in the suffix tells you what the core mix is. The color code for no. 2 cores is red. The Colored powdered-iron cores are manufactured by Micrometals Corp.

Ferrite cores have a slightly different numbering system. For example, assume you have an FT-50-43 toroid. The "FT" indicates ferrite toroid. The 50 means that the diameter is 0.5 inch. The number suffix, 43, tells you what the core mix or permeability is. All OF the ferrite cores are gray (uncoded), so it is important to keep them separated in your workshop. I like to use spray paint to color-code my ferrite cores when I receive them. This saves many headaches later on!

THE RIGHT WIRE SIZE

Micrometals catalog contains charts that suggest the proper wire gauge versus the required number of coil turns for a given core size. Try to use the largest wire diameter practicable, consistent with ease of winding. This will help to ensure minimum circuit losses and highest Q. Enamel-covered magnet wire is used for most toroidal coils and transformers. Use care when winding ferrite toroids, because most of them have rough edges. These sharp surfaces can scrape the insulation from the wire and cause shorted turns. Shorted turns kill the Q of the circuit and ruin performance. I like to wrap the larger ferrite cores with 3M glass tape or strips of masking tape before I apply the windings. Damage to the insulation can be avoided when doing this. Most powdered-iron toroids have been tumbled. Therefore, their edges are smooth and do not present a hazard to the wire. Do not tension the wire too much when winding a powdered-iron core. These cores will break in half if too much pressure is applied.

WINDING YOUR TOROID

We tend to waste magnet wire when we wind toroids. This is because we guess at the required length for X number of turns. You can avoid this waste by first determining the necessary number of turns. Next, wrap one turn around the toroid, remove it, then measure its length. Multiply the length by the required number of turns, and allow two extra inches of wire for the leads at the end of the winding.

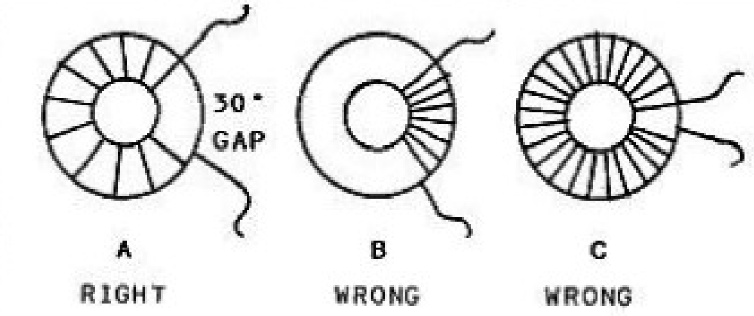


Fig 1 -- Right and wrong methods for toroid winding. The example at A is the recommended technique. Note the 30° gap between the ends of the winding. This minimizes unwanted capacitive effects and inductance cancellation. Compressing the turns (B) increases the inductance. Spreading the turns (C) decreases the inductance.

Fig 1 illustrates the right and wrong ways to wind toroid cores. However, at a moderate sacrifice in coil quality you may compress or spread the coil turns (B and C) to vary the effective inductance. This is a useful method when tweaking a tuned circuit that contains fixed-value capacitance.

COILS THAT HAVE LINKS

There seems to be confusion concerning placement of the link on a toroid that has a main winding. There are two philosophies we can embrace in this regard. (1) The link can occupy the same area on the core as the main winding. This appears to provide the greatest efficiency (reduced losses) in coupling. I prefer this technique for broadband transformers. See Fig 2.

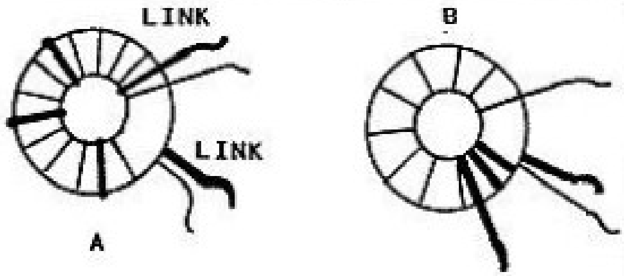


Fig 2 -- The dark lines represent the link winding at A and B. Example A shows the link winding spread over all of the main winding. In drawing B is a link that is crowded at one end of the main toroid winding. In both examples the link should be wound in the same sense as the main winding.

For narrow-band transformers, such as those in RF amplifiers, mixers and oscillators, I use method B of Fig 2. The link is wound over the grounded or +V end of the main coil, whichever may apply. This minimizes unwanted capacitive coupling between the windings. Harmonic currents are not so easily passed through the link when method B is used. In any event, wind the link with the same sense (clockwise or counter clockwise) as the main winding. This will ensure that the polarity of the windings is the same at the start of each winding. The black dots that you often see above the windings of a toroidal transformer are there to show that the tops of the windings have the same polarity or phase, as indicated in the circuit diagram.

TAPPED WINDINGS

You must be careful when placing a tap on a toroidal winding. It is easy to damage the wire insulation and cause a shorted turn or turns. I use the method shown in Fig 3 when I need to tap a winding. It consists of keeping track of the coil turns during the winding process, then allowing excess wire at the tap point. This excess wire is twisted into a small loop (two or three tight twists). The remainder of the winding is then placed on the core. I next scrape the insulation from the loop with a hobby knife or Moto Tool with an abrasive bit. The bare wire can now be tinned with a soldering iron. An alternative and neater looking technique results from scraping the insulation from the wire at the tap point, but not making a loop. The bare section is tinned and a short piece of bus wire is wrapped around it and soldered in place. This serves as a connection point. A thin piece of meat-wrapping paper or glass tape is placed around the tap area (U shaped) and the winding is continued until completed. The insulating material prevents shorted turns.

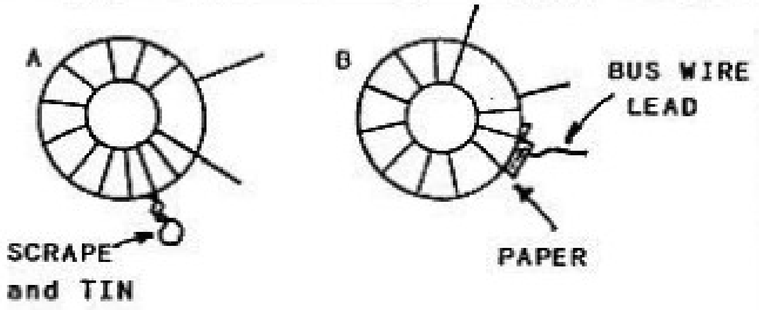


Fig 3 -- Two methods for placing a tap on a toroidal winding. Method A involves twisting a loop in the winding for the tap point. At B is a technique that requires scraping the winding and using a piece of bus wire for the tap (see text).

A third method for making a coil tap is to cut the winding at the tap point. Allow a 3/8-inch pigtail. Scrape off the pigtail insulation and tin it. Create a similar pigtail with the wire for the remainder of the winding. Twist the pigtails and solder them. This becomes the coil tap.

FINDING THE CORRECT NUMBER OF COIL TURNS

Each toroid has what is called an A_L factor. This relates to the resultant inductance for a specified number of turns. The A_L factor varies with the permeability of the core being used. The Amidon Assoc. catalog lists the A_L factors for powdered-iron and ferrite toroids. This information is available also from Micrometals Corp. (powdered iron) and Fair-Rite Corp. for ferrites (3).

Let's examine an example of how the A_L formula works. Suppose you need a toroid inductor that is for use at 14 MHz and the required inductance is 1.2 uH. A T50-6 (yellow) core will, according to the Amidon charts, provide high Q at this frequency. We check the A_L rating in the Amidon catalog. It is listed as 40.

$N(\text{turns}) = 100\sqrt{L(\text{uH})/A_L}$, thus $N = 100\sqrt{1.2/40}$ or 17.3 turns.

We will use 17 turns in order to avoid the impracticality of a fractional part of a turn.

The equation for ferrite cores is similar. But, owing to the high mu of ferrites, the formula is expressed in mH rather than uH. For example, suppose you need a coil that has an inductance of 10 uH for use at 7 MHz. We will use an FT-37-61 core. The A_L for this core is 55.3. Hence,

$N(\text{turns}) = 1000\sqrt{L(\text{mH})/A_L}$, hence $N = 1000\sqrt{0.01\ \text{mH}/55.3}$ or 13.44 turns.

I have changed uH to a decimal value of mH. This makes the formula easier to use when working with uH.

CHECKING TOROID RESONANCE

If you do not have access to an inductance bridge or a Q meter, try the following technique for finding the approximate resonance of a toroidal tuned circuit. It involves the use of a dip meter. Details are given in Fig 4.

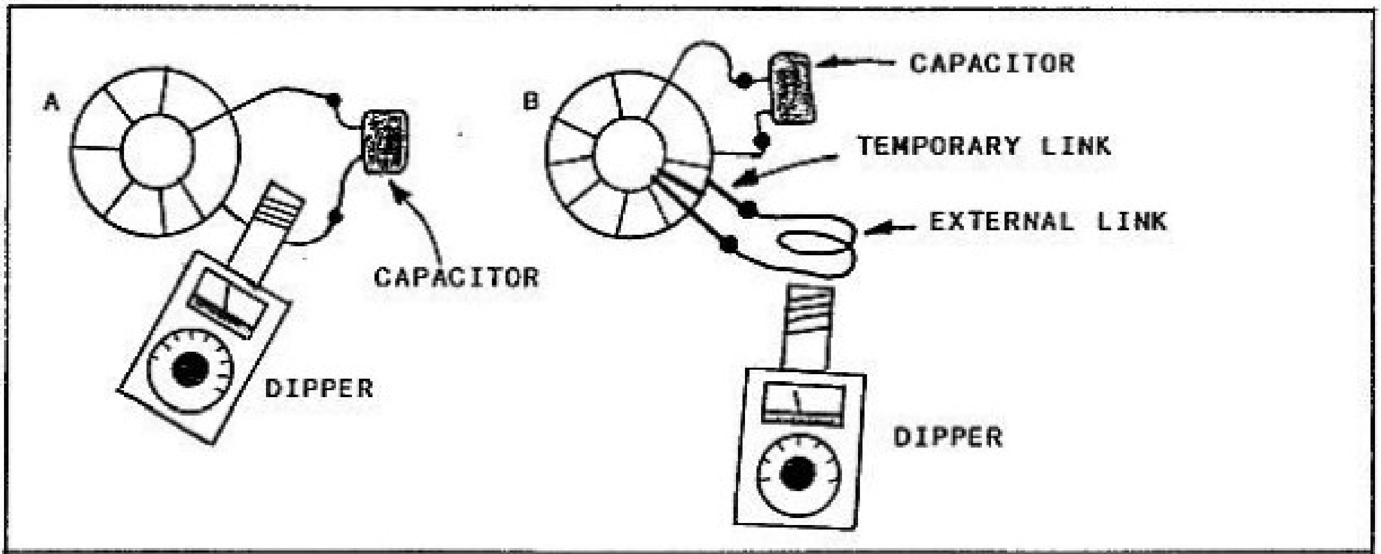


Fig 4 -- Two methods for checking toroids for resonance. Method A shows that the dipper coil is inserted in the loop formed by the winding and capacitor leads. At B is a technique that requires adding a temporary 1- or 2-turn link to the toroid coil. A similar external link is joined to the first one, as shown. The dipper coil is placed in the external link to sample the resonance. The inductance of the toroid may be checked in this manner if a known value of capacitance is used in parallel with the toroid coil. The coupling methods at A and B are necessary because of the self-shielding properties of toroids. They cannot be dipped like conventional coils.

TOROID DOPING AND AFFIXING

Toroidal coils may be used in VFOs and other frequency-critical circuits, but they can cause drift problems. The drift is related to changes in ambient temperature, which causes changes in core permeability. These shifts in mu cause the coil inductance to vary, and hence frequency shift. No. 6 powdered iron seems to be the most stable of the core mixes for use in VFOs. After you wind the VFO coil, coat it and the toroid with polystyrene Q Dope. As the layer dries, add another until three coatings have been applied. This helps to keep the winding securely in place on the core, and hence improves frequency stability. Q Dope is available.

Completed toroidal coils and transformers should not be supported by their leads when they are mounted vertically on a PC board. Vibration will cause the leads to break when small-gauge wire is used. Place the vertically mounted toroid in its position on the PC board. Next, put a generous dab of quick-setting epoxy cement between the bottom edge of the toroid and the PC board. When the cement has dried the toroid will be held firmly in place. This can be done also to flush-mounted toroids if better stability is desired. You may also use Dow or GE silastic compound for this purpose. It will be easier to remove later.

SUMMARIZATION

I have covered the subjects that appear to confuse most builders. You may want to place this file in a notebook for future reference. I have prepared similar files on other subjects of interest to builders. They are available from Oak Hills Research.

If you break a ferrite toroid or rod, don't throw it away. You may glue the pieces together by means of epoxy cement, and the core will work properly. Be sure to interface the broken pieces firmly when gluing them together. This technique has not proven practical when I have broken powdered-iron cores.