It's time to head out to your local hardware store or Home Depot to pick up the components for your next antenna. AD5X shows us that it's not that hard and is a lot of fun.

How To Build Low-Cost Vertical Antennas For Your QTH

BY PHIL SALAS*, AD5X

In one of my previous articles ("Low-Cost Mobile Antenna Accessories From Plumbing Parts," *CQ*, June 1995, page 30) I described the ability to make low-cost HF mobile antenna accessories from plumbing parts available from your local hardware store. As it turns out, many of these same plumbing parts can also provide the means to build inexpensive base-station HF antennas.

This HF antenna effort started when I began looking into a low-cost 40 meter vertical antenna to help some new amateurs get on the air. Aluminum tubing is inexpensive and readily available from Texas Towers (800-272-3467 or 214-422-7306). However, I needed a simple way to build a base and base insulator, as well as a support bracket for the antenna. First let's look at a few characteristics of PVC pipe and aluminum tubing.

The PVC/Aluminum Tubing Connection

When we talk about PVC pipe, we talk about the inside diameter (ID) of the pipe. When we talk about aluminum tubing, we normally talk about the outside diameter (OD) of the tubing. For PVC pipe (schedule 40):

1. 1/2" PVC pipe has an ID of 0.6" and an OD of 0.85".
2. 3/4" PVC pipe has an ID of 0.8" and an OD of 1.1".
3. 1" PVC pipe has an ID of 1.05" and an OD of 1.3".

The Texas Towers catalog gives dimensions for all types of aluminum tubing. So now let's see how PVC pipe fits with standard aluminum tubing:

1. 1/2" OD aluminum tubing slides into 1/2" PVC pipe.
2. 1/2" PVC pipe slides into 1" OD aluminum tubing (0.884" ID).
3. 3/4" OD aluminum tubing slides into 3/4" PVC pipe.
4. 3/4" PVC pipe slides into 1.25" OD aluminum tubing (1.134" ID).
5. 1" OD aluminum tubing slides into 1" PVC pipe.
6. 1" PVC pipe slides into 1.5" OD aluminum tubing (1.384" ID).

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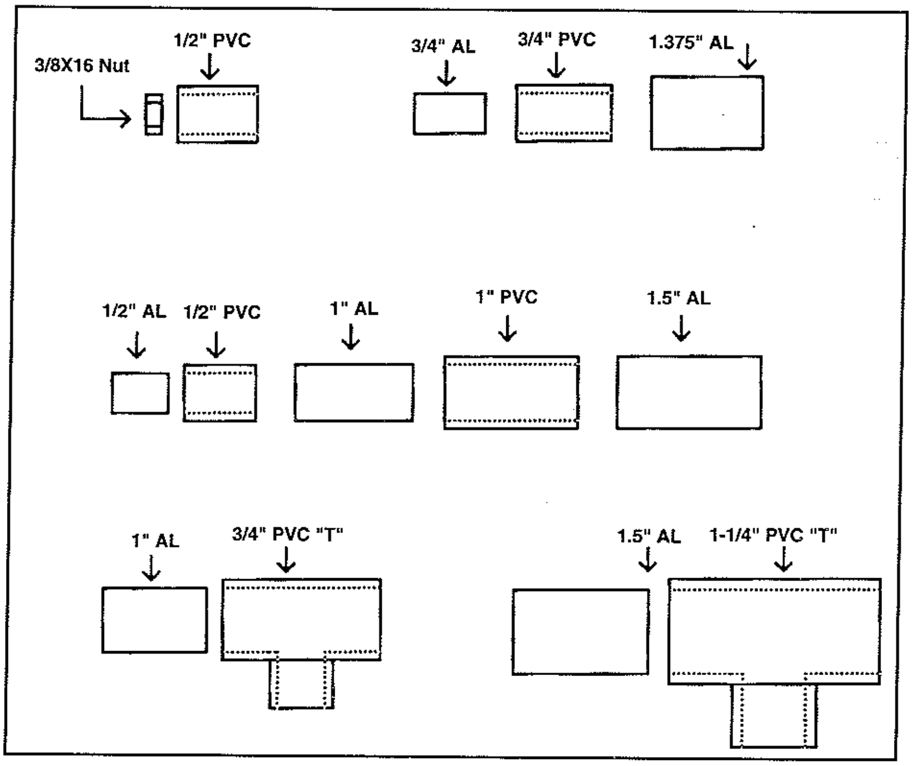


Fig. 1– Various aluminum-tubing/PVC-pipe combinations and configurations showing relative ID/OD relationships.

Another interesting tidbit I found was that a 3/8 x 16 nut presses very nicely into a piece of 1/2" PVC pipe (using a vise makes this easy). And, PVC couplers and "T's" must pass the OD of the appropriate PVC pipe—i.e., a 3/4" PVC coupler has an ID of 1" (to pass the OD of a 3/4" PVC pipe), which means that a 1" aluminum tube will slide into it, and a 1 1/4" PVC coupler has an ID of 1 1/2" which means you can slide a 1 1/2" aluminum tube into it (you may need to read this a few times!). I have summarized these relationships pictorially in fig. 1.

A Simple 40/15 Meter Vertical Antenna

Now that we know all the above information, let's start out by building a vertical for 40 and 15 meters. A 1/4-wave vertical for 40 meters is approximately 33 feet long. This will also work well on 15 meters as a 3/4-wave vertical. This antenna length can be realized with either three 12 foot telescoping sections of aluminum tubing (1" OD, 0.875" OD, and 0.75" OD), or six 6 foot telescoping sections of aluminum tubing (1" OD, 0.875" OD, 0.75" OD, 0.625" OD, 0.5" OD, and 0.375" OD). The 6 foot sections may be more desirable for portable antennas. The dimensions of all antennas, traps, and

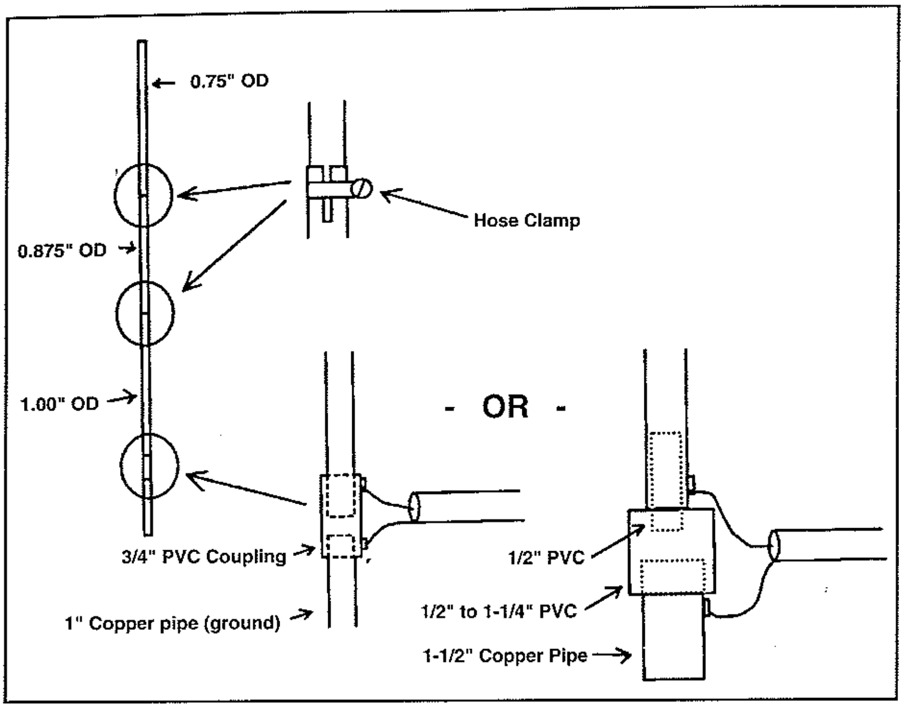


Fig. 2– Simple 40/15 meter vertical antenna construction details.

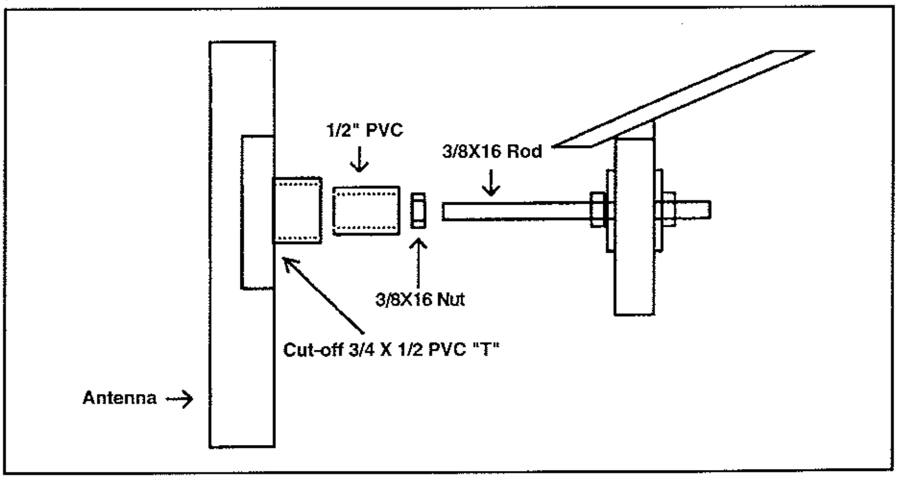
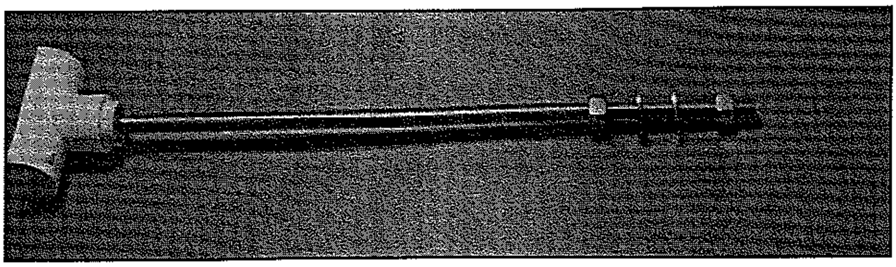


Fig. 3– A roof overhang antenna support system.



The completed roof overhang vertical support assembly as depicted in fig. 3.

coils used in this article assumes that the above three 12 foot tubes are used, however.

To attach the sections together, cut a 1 inch long slot in the end of the larger tubes with a hacksaw, and then use a stainless-steel hose clamp to compress the slotted tubing over the smaller tubing that slides into it. Always use stainless-steel hardware on aluminum tubing and brass hardware on copper tubing. Fig. 2 shows the antenna construction with two different ways to make the base.

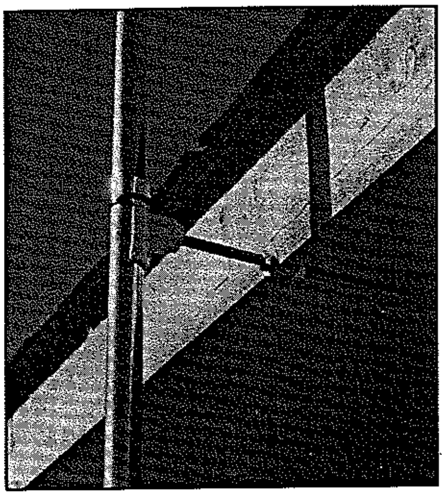
Now how do we support the antenna? Actually, the antenna can be self-supporting if the base is made strong enough. The first base shown in fig. 2 can be self-supporting if the ground pipe is strong enough. In the second base shown a 1/2 inch wood dowel treated with outdoor varnish can be inserted into the 1/2 inch PVC base pipe to provide the necessary strength for self-support. In my case, the antenna was to be mounted close to the house, so I elected to support the antenna from the roof overhang. For this I used a 3/4" × 1/2" PVC "T" as shown in fig. 3. Remember that a 3/4" PVC coupling or "T" will encircle a 1" OD aluminum tube. I cut the 3/4" PVC "T" section lengthwise so that the 1" OD aluminum tube would rest in it. A tie-wrap can now be used to hold the aluminum tube to the sectioned "T." Next I cut off a one inch length of 1/2" PVC pipe and pressed a 3/8 × 16 brass nut into it with a vise. I added a little epoxy just to make sure the nut would stay put. Then I glued the 1/2" PVC pipe into the 1/2" "T" section as shown. I used a carpenter's level on the antenna to determine where to drill a 3/8" hole in the overhang. Finally, I used a 3/8 × 16 threaded brass rod, two 3/8 brass washers, and two 3/8 × 16 brass nuts to hold the assembly to the roof overhang as shown. I used the carpenter's level again to determine the adjustment length of the rod.

Preliminarily assemble the antenna by telescoping the three sections together and install the combination on the base. Use the stainless-steel hose clamps to keep the sections from completely sliding into each other. Rest the antenna in the cut PVC support and hold it in place with a tie-wrap. Finally, I wanted a DC connection from the antenna to ground to bleed off any static charges on the antenna. I built an RF choke using 41 turns of #16 enameled wire wound on a T200-2 torroid. This has a high enough impedance so that operation all the way down to 160 meters will eventually be possible.

That's all there is to it. Now all you need to do is put in all the radials you can, attach your coax, and adjust the antenna length for best VSWR in the middle of the 40 meter band. The VSWR on 15 meters should be good at this same antenna length. With the vertical resonant at 7.15 MHz, I achieved full 40 meter band coverage with a VSWR of less than 1.5:1, and full 15 meter band coverage with a VSWR of less than 2:1. Incidentally, check out the electrical section of your local hardware store for radial wire. I found 18-gauge stranded copper wire for 4¢/foot, or $14 for 500 feet. Also, I found a product called "Plasti Dip," which is made for coating tool handles. This stuff is great for weather-proofing your coax connection to your antenna as well as your coax connectors. I also used it to coat and seal the toroidal choke.

Resonance On Other Bands

How about other bands? Well, you can use this vertical on bands other than 40 and 15 meters with an antenna tuner, although you should use low-loss coax and/or a very short run of coax to keep from losing too much power in the coax when the VSWR is high (as it would be on 160, 80, and 20 meters). When the antenna is fully collapsed (around 12.5 feet total length), it works great on 17 meters with a VSWR of about 1.2:1 or less! The antenna length can be adjusted for 3/4-wave operation



The vertical antenna is shown mounted to the roof overhang. Notice that the antenna is secured to the mount by a simple tie-wrap.

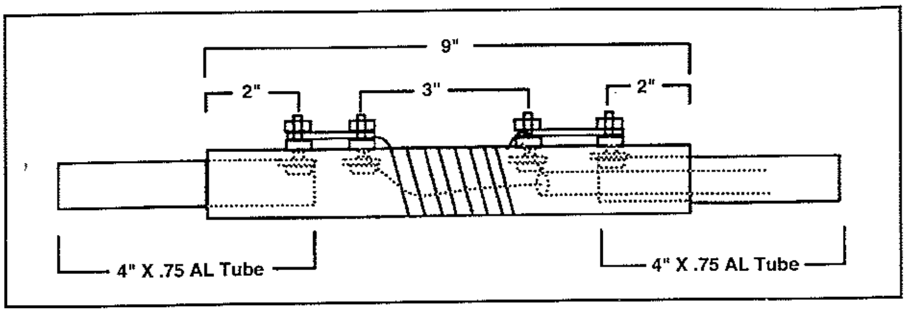


Fig. 4– Mechanics of assembled 14 MHz trap.

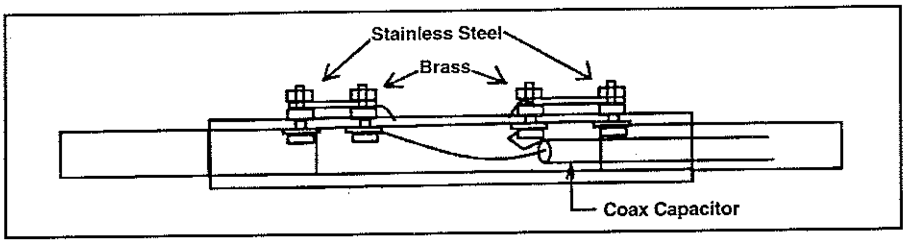


Fig. 5– Cutaway view of the 14 MHz trap showing the coax capacitor.

on 15, 12, and 10 meters and 1/4-wave operation on 40, 30, 20, and 17 meters. Finally, you easily can resonate this antenna on 160 meters without an antenna tuner with the Butternut 160 meter coil kit (around $60), and it will still also operate on 40 and 15 meters. This is too easy though. What else can we do?

A 40/20 Meter Antenna

Because of the current low sunspot activity, I decided to trade off 15 meters for 20 meters by adding a 20 meter trap into the vertical. A trap consisting of a 4.7 μH inductor in parallel with a 27 pF capacitor resonating at 14.1 MHz should do the trick. However, how could I build an inexpensive trap that could be inserted into the vertical antenna? After a little thinking, I came up with the design shown in figs. 4 and 5. This trap is made from two 4 inch pieces of 3/4" OD aluminum tubing removed from one end of the 12' 3/4" section, a 9 inch piece of 3/4" PVC tubing, some #18 stranded and insulated speaker wire, a piece of RG-58 coaxial cable, and some #8 stainless-steel and brass hardware. I used a standard nibbling tool to notch the two pieces of 3/4" OD aluminum tubing about a quarter inch so that they would fit over the stainless-steel screws as shown.

The 27 pF capacitor is made from an open-circuited piece of RG-58 coax. RG-58 has a capacity of 28.5 pF/foot. Take a one foot piece of RG-58, strip 1.5 inches of insulation off it, separate the inner conductor and braid, and solder the center conductor and braid to the head of #8 brass screws that are spaced 3 inches apart. With a little patience, you can fish the screws through the PVC pipe at the locations shown.

This will give you a capacitance very close to 27 pF. I used an Autek RF-1 SWR analyzer to trim the length to exactly 27 pF. Dip the open end of the coax cable in Q-dope or "Plasti Dip." This RG-58 capacitor will work fine for power levels up to 100 watts.

The inductor consists of 23 turns of #18 stranded speaker wire (Radio Shack) wrapped close wound over 2 1/2 inches of the PVC pipe with the ends connected to the brass screws from the coax capacitor as shown in the drawings and the photographs. After winding the inductor, I adjusted the turns spacing slightly so that the trap resonated exactly at 14.1 MHz as indicated on my old trusty Heathkit grip dip meter (I have a counter output on my grid dip meter to ensure accuracy). "Plasti Dip" was used to firmly hold the coil windings in place.

Now we need to mount the trap. Cut the 0.875" OD aluminum tube in half (the center tube), slot the ends of the tube with a hacksaw, and mount the trap at this point with stainless-steel hose clamps. Since the trap has the effect of electrically lengthening the antenna on 40 meters, I had to remove an additional 12 inches of tubing from the top 3/4" 12 foot tube (I had already removed 8 inches for the trap tubing end pieces). Now adjust the antenna so that the trap is 15'2" above the base of the antenna and the total tubing above the trap is 10'1/2". With these dimensions my measured performance was as follows:

Resonance/VSWR	Worst VSWR Across Band
7.13 MHz/1.3:1	1.8:1 @ 7.3 MHz 1.5:1 @ 7.0 MHz
14.2 MHz/1.1:1	1.3:1 worst case across entire band

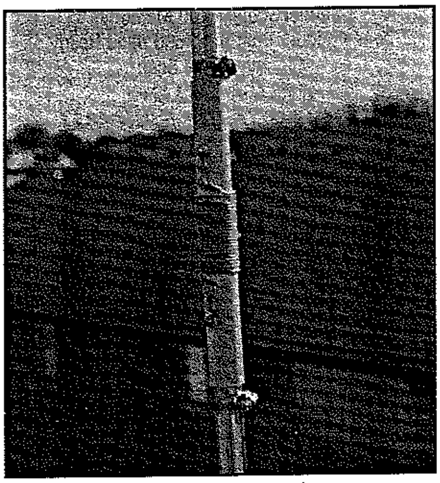
If you want the 40 meter performance to be optimized over a different part of the band, adjust the top section (above the trap). Lengthening it will lower the 40 meter resonant frequency, and shortening it will raise the 40 meter resonant frequency. The 20 meter band will be unaffected. For those who prefer building coax traps, I rebuilt this trap as a coax trap by winding 10 turns of RG-58 close wound on the same form (refer to the photo). After a little adjustment of the turns spacing to get it to resonate at 14.1 MHz, I fixed the coax turns in place with "Plasti Dip."

160 Meter Antenna

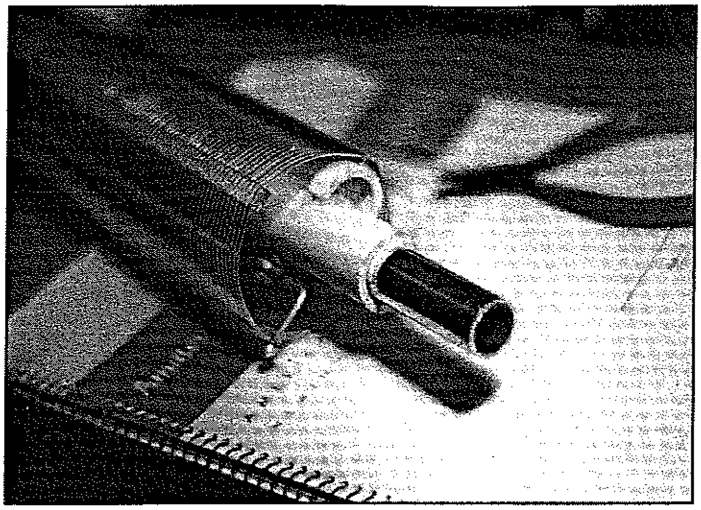
I mentioned earlier that you can make the untrapped 32 foot vertical operate on 160 meters with the Butternut 160 meter coil kit. However, I wanted to build a more optimum antenna for 160 meters. One better way of building a short efficient antenna is to center load it instead of base loading it the Butternut way. Why center loading? Because center loading increases the radiation resistance 2.25 times over a base loaded antenna. And since a short antenna has a low radiation resistance, we should see an increase in efficiency with center loading. At a 32 foot overall length, our antenna is only about 1/16th of a wavelength long on 160 meters. From the *ARRL Antenna Book*, the radiation resistance of an antenna shorter than 1/10th wavelength can be calculated from:

$$R = 273 \times (lf)^2 \times 10^{-8}$$

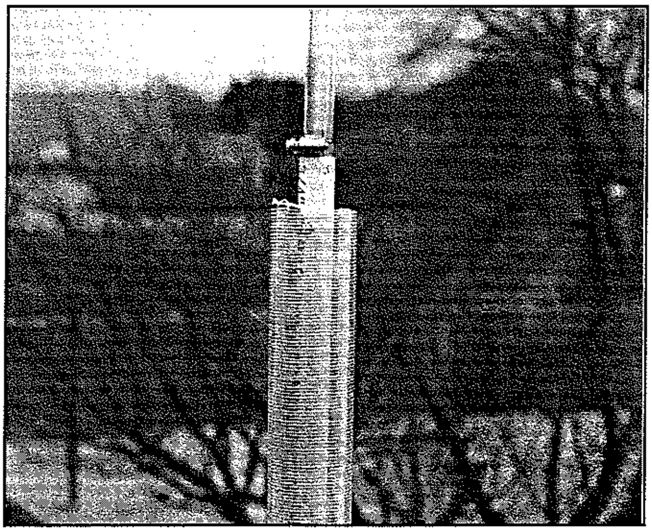
where: l = length in inches
f = frequency in MHz



This is what the 20 meter trap looks like when it is installed on the vertical antenna.



A close-up view of the 160 meter coil showing the coil support system. The brass rod holds the coil secure on one side and the small piece of PVC the other.



The 160 meter coil is shown installed on the antenna using stainless-steel hose clamps.

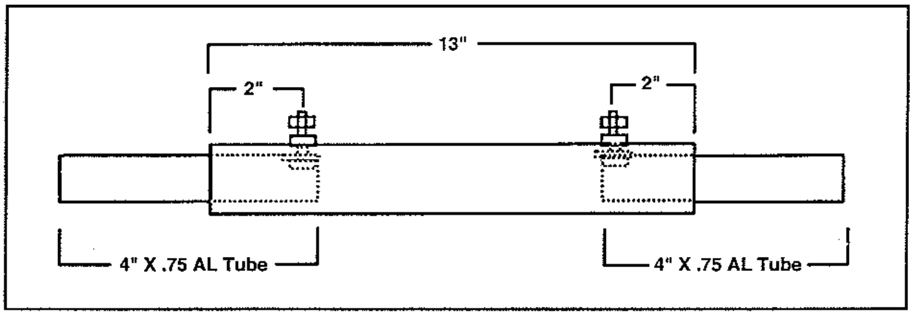


Fig. 6– Mechanics of the 160 meter coil assembly. The coil is not shown in this view.

This calculates out to only 1.3 ohms of radiation resistance for this antenna! Center loading will increase this to 3 ohms, which can help considerably with the antenna efficiency. As an example, assume you have a pretty good radial system consisting of 20 radials. This should give you about 10 ohms of ground loss. Now assuming that you can match perfectly to the total radiation resistance plus ground loss, let's see what improvements in efficiency can be achieved with center loading.

First remember that there will be loss in the loading coil. Because this is an air-wound coil with a fairly large diameter, a Q of 500 is assumed for the 140 µH center loading coil used in the final design. The loss of a coil is:

$$L_{loss} = 2\pi f L/Q$$

A center loading coil has twice the inductance of a base loading coil and so will have twice the loss for a constant Q. Finally, antenna efficiency in dB relative to a lossless antenna is:

$$\text{Eff (dB)} = 10 \log (R_{rad}/[R_{rad} + L_{loss} + R_{gnd}])$$

Refer to the following table for the results.

	R_{rad}	R_{gnd}	L_{loss}	Eff.
Base Loaded	1.3	10	1.5	–10 dB
Center Loaded	3.0	10	3.0	–7.3 dB

As you can see, center loading gives about a half S-unit improvement over base loading. For higher ground losses the difference becomes greater. For lower ground losses the difference becomes less. The lower you can reduce your ground losses (more radials) and coil losses (higher Q), the closer your antenna will be to "perfect."

I selected my center loading coil based on equations in the *ARRL Antenna Book* which indicated that a 130 µH coil mounted at the center of the antenna would resonate it on 160 meters. I used the equations for inductively loaded physically short antennas originaly derived by Jerry Hall, K1TD, and modified them for a center loaded vertical antenna as shown below:

$$X_L = (106/34\pi f)\{[\ln 24((234/f - H/2)/D) - 1][(1 - fH/468)^2 - 1]/(234/f - H/2) - 2[\ln(12H/D) - 1][(fH/468)^2 - 1]/H\}$$

(Yes, this is simplified!)

where: f = frequency in MHz
H = vertical antenna height in feet
D = antenna diameter in inches

I used the average tubing diameter of 0.875 inches in calculating XL. The required inductance can now be found:

$$L = X_L/2\pi f$$

where: L = required coil inductance in microHenries
f = frequency in MHz

I found that a B&W 3031 coil (2¹/₂" diameter, 10 TPI, 10" long) has an inductance of 140

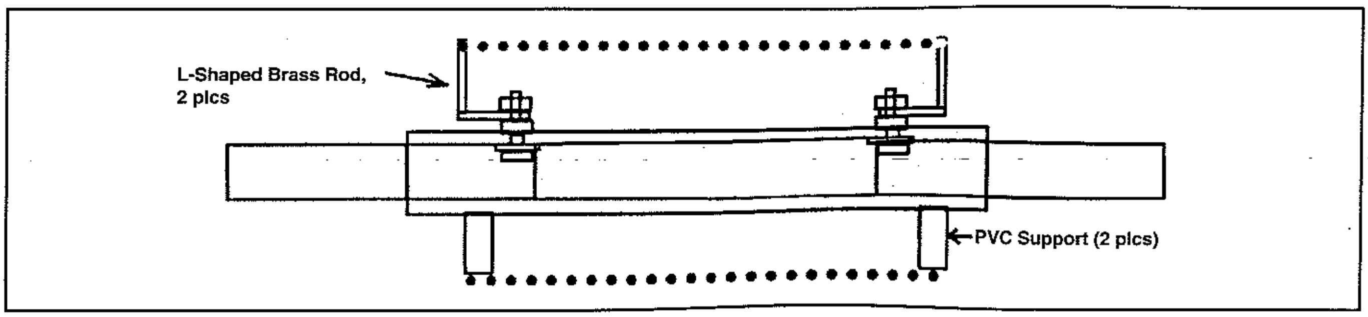


Fig. 7– A cutaway view of the 160 meter coil assembly showing the coil support system.

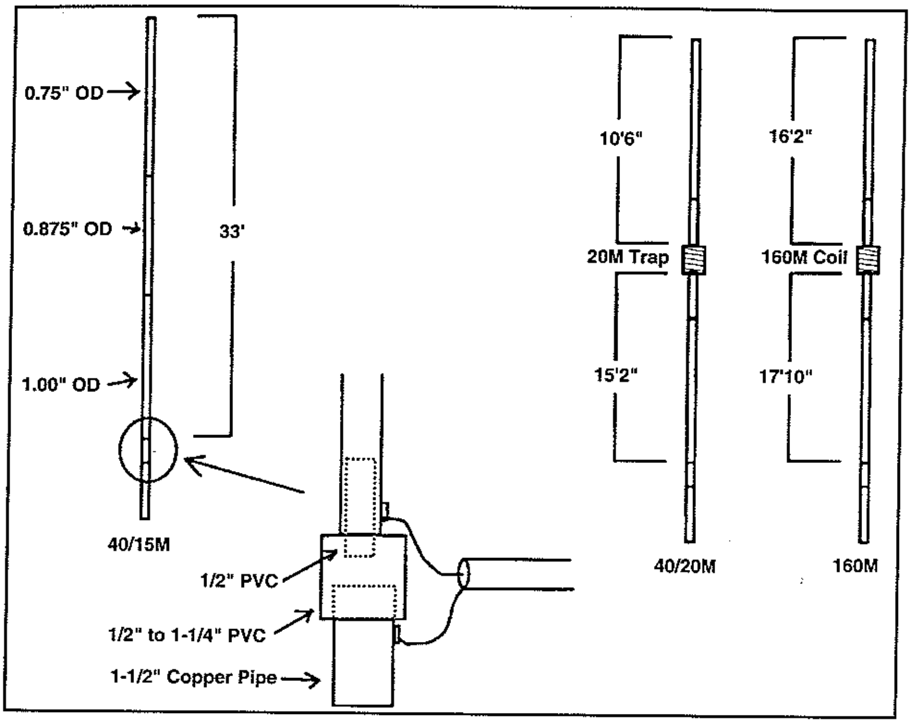
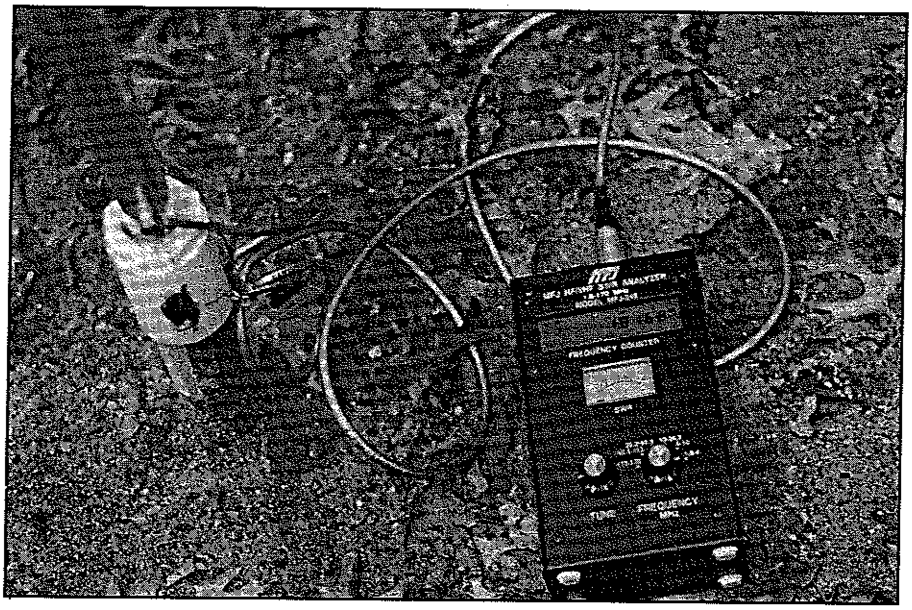


Fig. 8– A summary of antenna lengths for the three antennas.



The proof is in the pudding. Here at the base of the 160 meter center loaded vertical you can see the mica capacitor, and at the rear a portion of the RF choke described in the text. You will also note that the resonant frequency is 1.8168 MHz.

μH, so I ordered one from Surplus Sales of Nebraska for $19. To actually build the coil assembly, I used the same tricks I came up with for the 20 meter trap described earlier. The 3/4" PVC insulating form length needs to be 13 inches long, and the entire B&W 3031 coil is used. Refer to figs. 6 and 7 and the photographs for the details. You should strengthen this PVC pipe, since it is not only longer than that used in the 20 meter trap, but there is a longer length of aluminum tubing above it than above the 20 meter trap. To strengthen the PVC pipe, assemble one of the 4 inch long aluminum tubes onto the PVC pipe, and then drop a 9 inch long 3/4" diameter wood dowel that has been dipped in varnish into it. Then assemble the second 4 inch long piece of aluminum tubing onto the other end of the PVC pipe.

I used 1/8" diameter brass rod to both support and provide electrical contacts between the coil and the antenna as shown. One end of the brass rod is bent into a circle so that it can be mounted on the screws as shown. The remainder of the brass rod is bent into an L-shape as shown to support the coil. For the PVC coil supports that are shown opposite the bent brass rods, I cut a short piece of PVC pipe lengthwise as can be seen in the photograph. I attached the PVC support between the main PVC pipe and the coil with a spot of hot glue to hold it while a liberal amount of epoxy was curing. Again, this antenna consists of 12 foot telescoping lengths of 1" OD, 0.875" OD, and 0.75" OD aluminum tubing. The 0.875" OD section is cut exactly in half, and the coil is mounted at this point.

Well, we've resonated the antenna, but the antenna impedance (radiation resistance plus ground loss), while now totally resistive, is still lower than 50 ohms as described earlier. As most HF mobile operators know, a shunt capacitor at the antenna base can be found which will transform the impedance of short coil loaded antennas to 50 ohms. I found that 2500 pF of capacitance to ground at the base of this antenna transformed the impedance to close to 50 ohms. I realized this capacitance with a 1500 pF and a 1000 pF silver mica capacitor connected in parallel. These capacitors are rated at 1000 VDC. It is better if you can find higher voltage capacitors, especially if you run more than 100 watts and are using an antenna tuner to move much beyond the antenna resonant frequency. I resonated my antenna near the bottom of 160 meters since I operate CW there. My antenna resonated at 1817 kHz when the bottom of the coil was exactly 17'10" above the antenna base, and the tubing above the top of the coil was exactly 16'2". To raise the resonant frequency of the antenna, shorten the tubing above the coil. At resonance my SWR is 1.2:1. The 2:1 SWR bandwidth is only 10 kHz on this antenna! This implies that the antenna is pretty efficient—i.e., most of the driving impedance is transformed radiation resistance and not ground losses. A higher percentage of ground losses would broaden the bandwidth of the antenna but lower the efficiency. To wander much beyond your resonant frequency, you'll need an antenna tuner. Fig. 8 summarizes the antenna lengths for the three different antennas discussed (40/15, 40/20, and 160 meter).

More Bands?

You don't have to stop here. You can build a center loaded antenna for 80 meters that will outperform standard commercial base loaded short verticals as well. You can build a seperate 80 meter coil (25 μH required) or just short out turns on the 160 meter coil to reduce the inductance for 80 meters, although shorting turns may reduce the coil Q. Don't forget to change the shunt capacitor at the antenna base between 80 and 160 meters!

Conclusion

I have shown simple ways of building for yourself very effective antennas that can be used on several different bands (although usually one at a time). The total cost of the tubing for this antenna is around $30. The total cost of all the different traps was about another $30 (due to the cost of the 160 meter coil). Obviously, you can make this antenna work on many different bands with a few design changes. Go ahead and build an HF antenna. You'll have fun, learn a lot, and best of all you can use the final product on the air! ■