A High Efficiency Extended Length Mobile Antenna

By W5JGV

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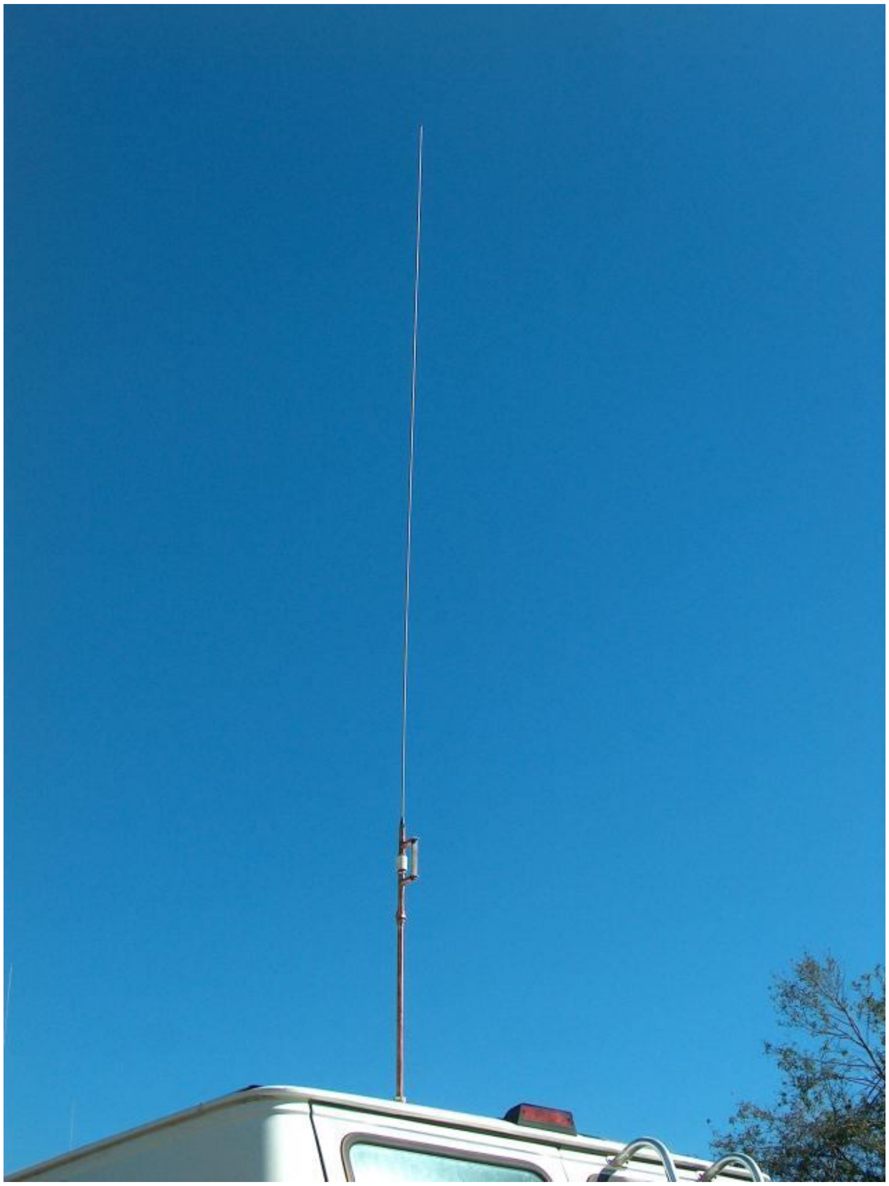
What amateur operator running mobile has not lusted for a bigger and better antenna? Well, so did I, and this is the result...

Much taller than the average Ham mobile antenna, this tree branch snapper tops out at 17 feet, 10 inches above the road.

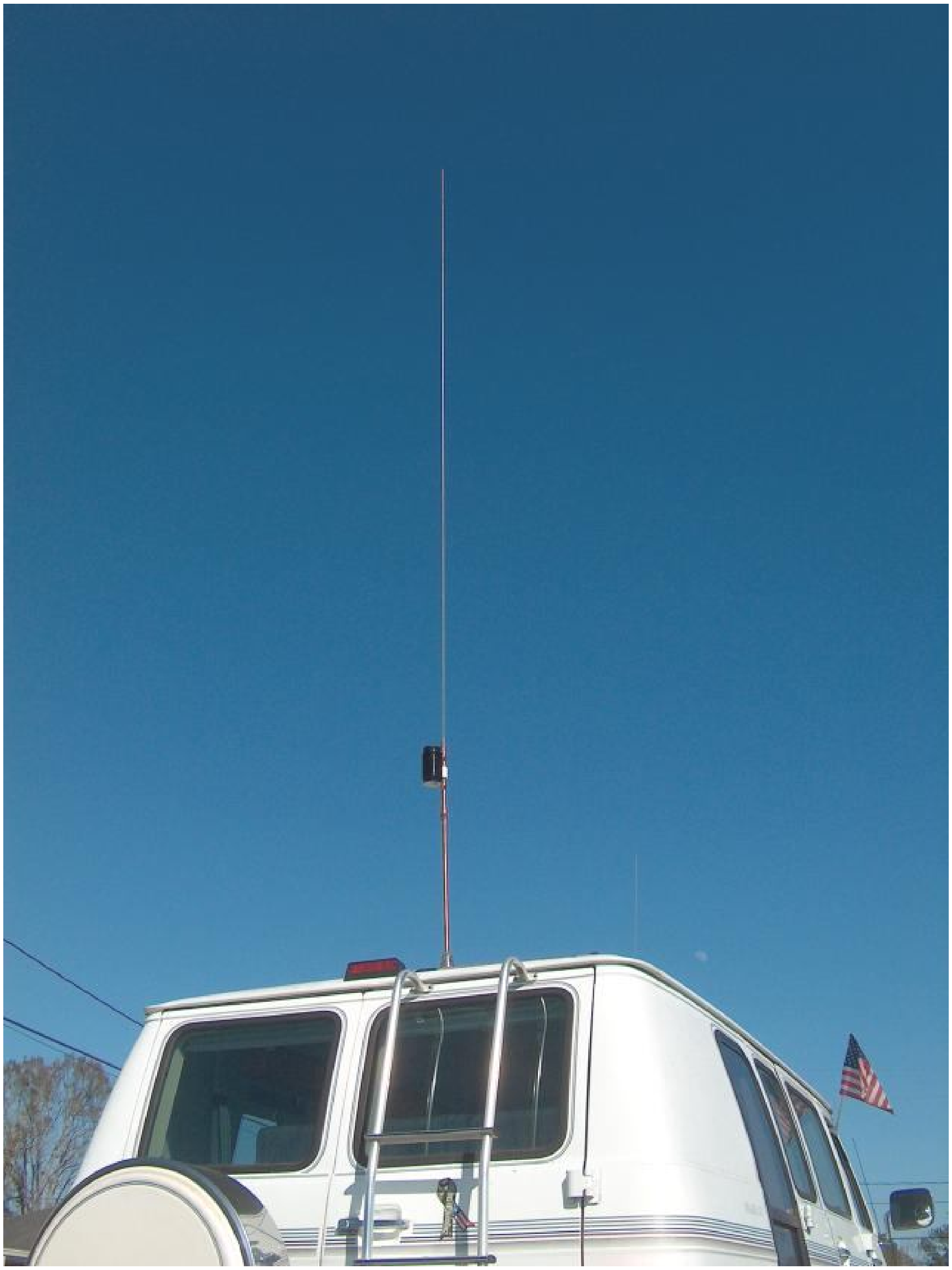
The antenna itself is 3.42 meters or 11 feet 2 inches long from the top of the mounting spring to the tip.

In this picture, the 40 Meter loading coil is in place.



A rear view of the antenna shows the antenna with the shunt strap in place.

This strap is used for operation on the 10, 12, and 15 Meter bands.



The 40 meter loading coil installed on the antenna.

Yes, I do have to stop the vehicle and get out and change loading coils when changing bands.

The original antenna was designed as a moderately short antenna for the 10 meter band.

I originally wanted an antenna that would not hit everything overhead while driving, since it was to be installed on a van. I came up with an antenna that extended only 1.65 meters or about 5 feet 4 inches above the top of the vehicle. It had a calculated efficiency of 42% when compared to a half-wave dipole. It was my hope to be able to install a series of different loading coils to be able to operate on the other HF bands. However, calculations indicated that the antennas was simply too short to work well as the frequency was lowered. Something better was needed.

The Evolution of the Antenna Design

My first thought was to increase the length of the antenna below the loading coil. My reasoning was that since that portion of the antenna carries the highest RF current, then adding more length there would increase the radiation efficiency of the antenna more than would adding the same length to the antenna above the coil. Unfortunately, since the antenna is mounted on top of a van which is a rather high vehicle, that would place the coil at a dangerous height with regard to tree branches and the like. Since the loading coils were going to be rather heavy due to their sturdy construction, placing a heavy coil high up on a flexible support did not seem like a good idea. I decided to investigate what increasing the length of the upper portion of the antenna would do to the radiation efficiency.

It quickly became apparent that very good results could be obtained by increasing the top whip length. As it turned out, this was due to two factors. First, the antenna was center loaded, and second, increasing the top whip length greatly reduced the coil losses due to the smaller number of turns required. This also meant that I could use larger wire for the coils, which further reduced the losses. It was almost like getting something for nothing!

Since I had once a standard CB-length whip plus the magnetic mount and base spring installed on the van, I knew that a total height of 3 meters was workable, even though it did hit quite a number of overhead obstructions. I ran calculations to determine how it would work. The results were very encouraging, and I promptly set out to build the antenna. I still had the CB whip, and figured that I could simply cut the top end off of it to get the total length of 3 meters for the completed antenna.

While laying out all the parts on the ground to see how they would fit together, I looked at the CB whip and realized that I would only have to cut off about 17 inches. That seemed like a waste, and I really hated to cut that small amount off of a perfectly good antenna.

Just for fun, I decided to repeat the calculations to see what would happen to the gain if I left the extra 17 inches on the antenna. I was surprised to find that the antenna efficiency increased between 19 and 31 percent, depending on frequency. The trade off, of course, was that I knew the antenna was going to hit a lot more objects overhead than if I trimmed the 17 inches off of it. As a test, I assembled the antenna full length and drove around with it for a few weeks to determined how much of a problem it would be. I decided that I could live with it, as a necessary price for the increased signal strength.

This table shows the results of the calculations. Notice the large jump in gain between the original short antenna and the 3 meter antenna. Longer IS better! <G>

Computed Radiation Efficiency of Center Loaded Mobile Antenna vs. 1/2 wave Dipole Antenna

TEST FREQUENCY, MHz	Original 1.65 Meter Antenna	Proposed 3.0 Meter Antenna	Actual 3.42 Meter Antenna	% GAIN INCREASE 1.65 > 3.0 Meters	% GAIN INCREASE 3.0 > 3.42 Meters
1.95	0.09	0.3	0.4	333	31
3.9	0.5	1.5	1.9	300	26
7.3	2.0	5.5	6.9	275	22
10	3.9	10	12.4	256	23
14.2	7.6	18.8	22.8	247	22
18.15	12	27.7	33	231	19
21.2	15.7	34.6	40.6	220	19
24.9	20.3	40.6	40.6	200	0
28.4	24.7	40.6	40.6	164	0

Construction Details

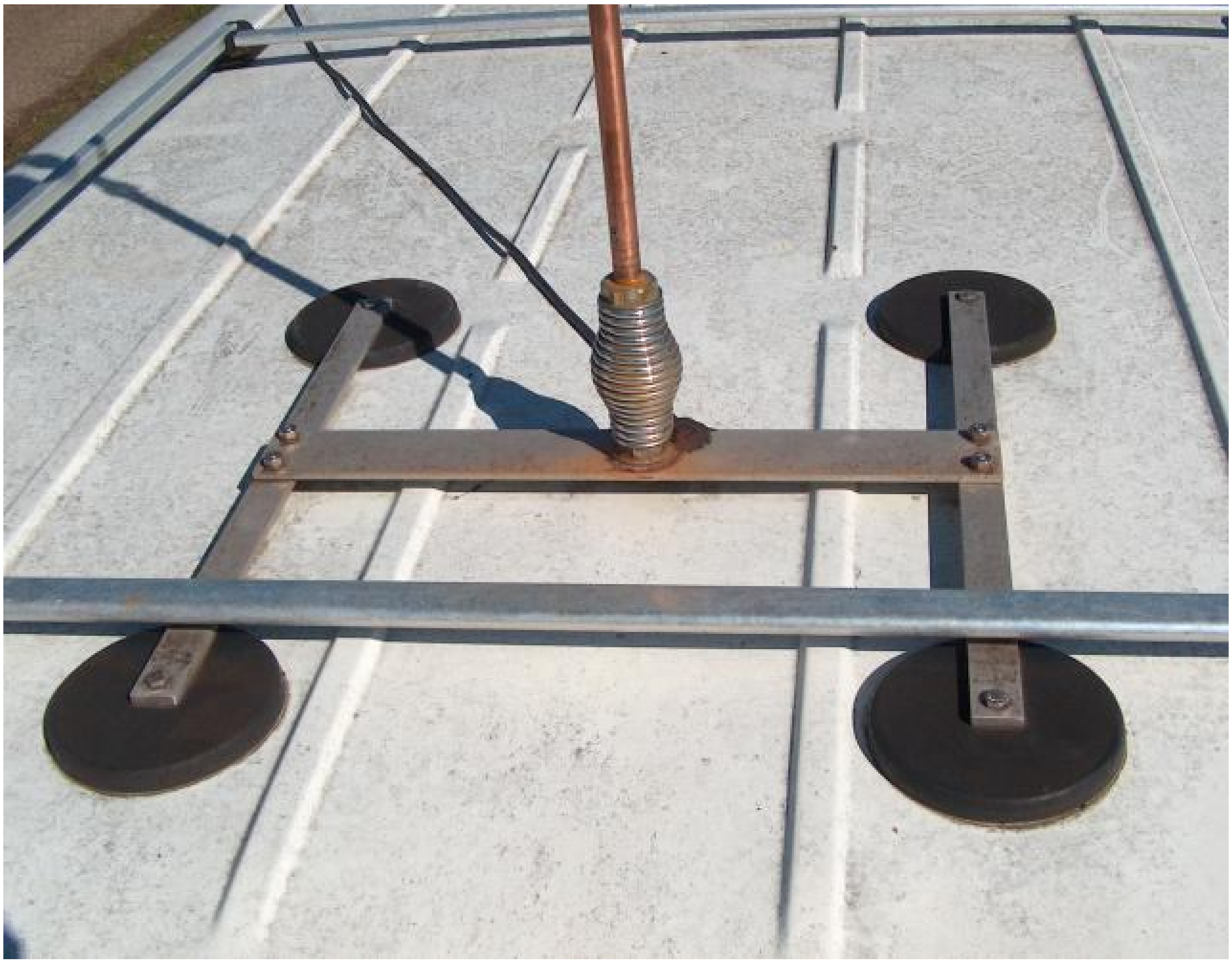
I was able to make use of the basic antenna design and most of the parts when constructed the final antenna. I'll show you in the following pictures how I did it. This is a very easy antenna to build, and you can do it with some simple tools and parts from the local home improvement or hardware store.

When I made the 10 meter coil for the first 1.65 meter long antenna, I used 1/4" OD copper tube for the coil. I inserted the ends of the coil into a short length of 3/8" OD copper tube and then flattened the ends of the tube. I then drilled a 1/4" diameter hole through the flattened ends so they could be attached to the antenna posts. This coil should have had one more turn on it. That way, the turns would have been spaced a bit further apart. This would have lessened the coil losses somewhat. However, the calculated loss in power was not enough to worry about, so I never bothered to make a new coil for the antenna.

See that length of clear plastic between the ends of the coil? When using a self-supporting coil like this one, you MUST use an insulating brace like the plastic strip shown here or the white insulator between the two antenna sections will fracture when you hit a big tree branch with the antenna!

This is a close-up picture of one of the ends of the loading coil.

You can see the coil tube inside the larger flattened copper tube. The larger tube added structural strength to the ends of the coil and provided a larger area for drilling the mounting bolt holes through the coil ends.

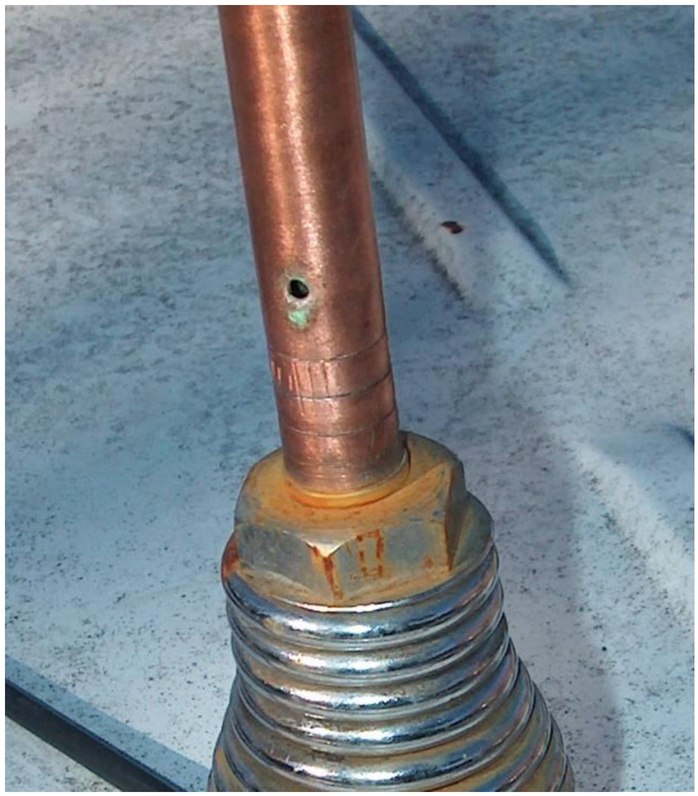


A big antenna needs a serious mag-mount!

I purchased this magnetic mount for my mobile antenna years ago over the Internet - I don't remember where I got it - but it holds to the roof like a barnacle on a ships' hull. You can fold the antenna over until it touches the roof of the van and the mag-mount stays put. It requires two hands and a short pry-bar to get it loose.

See all that rust on the horizontal bar? That's from a cheap steel quick disconnect I used for several years. It finally rusted to then point that it made intermittent contact and I decided to get rid of it. So far, I have not found anything strong enough to replace it. I have broken two fairly heavy brass quick disconnects so far. So, for now, I just either tie the antenna down to the roof of the van or unscrew it when I have to go into a low garage. Needless to say, I strongly favor outside parking spaces!

This picture was taken before I installed the quick disconnect. It shows the lower end of the bottom section of the antenna. The antenna mast sections are constructed from hard wall copper pipe, 1/2" in diameter. A brass plug with a 3/8" x 24 threaded hole was pressed into the end of the copper pipe and hard-soldered into place. To hold the plug in place during the soldering process, I rolled several grooves around the outside of the copper pipe as seen here. I was careful not to roll them too deeply and weaken the pipe.



A small "weep hole" is drilled through the pipe wall just above the upper end of the brass plug that was soldered into the pipe. The hole allows water to drain out of the antenna and not sit inside and corrode the mounting bolt. Water WILL get into the antenna - you can't prevent it - so you might as well make provisions to allow the water to drain out.

To hold the antenna to the base spring, I used a length of threaded steel rod cut from a stainless steel bolt. After making sure that the threaded rod was the the correct length and that everything fit properly, I removed the mounting bolt from the base of the antenna and the base spring and used thread locking compound (OK, I used Super Glue, if you must know) to retain the bolt in the base of the antenna. That way I would not misplace the bolt when I had to remove the antenna from the base spring.

The Center Insulator and Coil Mounts.

The lower section of the antenna is a 1/2" diameter copper pipe about 60 cm (24 inches) long that extends upward to the lower coil support.

The support itself is made from a 1/2" sweat "T" fitting, a 2" length of 1/2" copper pipe and a 1/2" sweat cap.

The bolts holding the coil in place are 1/4" diameter x 1-1/2" long stainless steel bolts. A 1/4" hole is drilled through the center of each pipe cap before soldering it in place, and the bolts are temporarily held in place by gently tightening the nut visible in this picture.

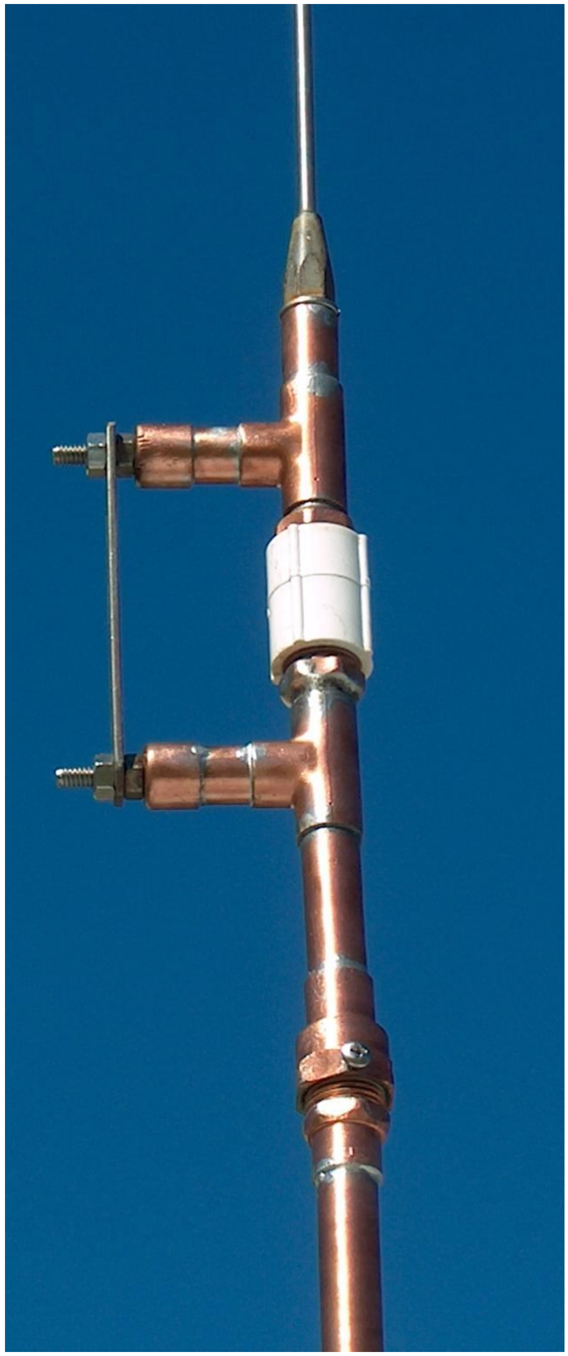
The plastic center insulator is a 1/2" female-female threaded PVC coupler.

Each end of the antenna sections that thread into this coupler has copper adapters that go from 1/2" OD copper pipe to 1/2" iron pipe. These fittings have a male thread on them so they will screw into the plastic coupler which then becomes the antenna center insulator.

Using plumbers hard solder (not rosin core radio solder) and the proper cleaning flux, the copper components are soldered together.

Next, the interior of the copper sections is thoroughly washed with clean water to remove any soldering flux residue and then placed in the sun or some other warm place to dry.

When everything is dry, the nuts on the coil mounting bolts are firmly tightened, and the sections may be screwed into the center insulator.



The coil support posts shown with the 10 - 12 - 15 meter shunt strap in place.

Note that with this shunt strap in place, the plastic strengthening strip is not needed. This is because the shunt strap is made from a length of heavy silver-plated copper stock.

The top support for the loading coil is fabricated in the same manner as the bottom support.

To hold the top whip, a 2" long length of 1/2" OD copper pipe is soldered into the "T" fitting. Another female threaded brass plug is inserted into the top end of the 2" long pipe section and soldered in place.

Hey! What's that extra set of pipe fittings doing, and why are they there? (Keep reading for the answer!)

A (very) close up photo of those extra pipe fittings.

I always had a problem getting the antenna loading coil lined up "just so" on the mount. When you screw the antenna into the mount, you never know where the loading coil will be pointing when the mounting screw is tight. With coaxial mounted loading coils, this is not a problem, but this antenna has the loading coil mounted off-center from the mast. Provision needs to be made to adjust the coil position. How come?

Well, the loading coil must always "trail" the antenna mast; that is, the coil must be directly behind the antenna mast when the vehicle is moving. The reason is rather obvious - after you hit the first big low-hanging tree branch! If the coil happens to be in front of the antenna mast, the coil may become snagged on the tree branch and instantly becomes part of the local roadside litter. When the coil is mounted behind the mast, the mast simply slides harmlessly beneath the tree branch, the coil does not get hit, and all is well.

In order to accomplish this alignment without resorting to the use of shim stock, various thicknesses of washers, and all sorts of other chicanery, I decided I had to have a way to be able to rotate the coil around the mast in some way. Since everything was soldered together, I came up with the idea of using a pair of threaded mating fittings that I could simply twist to get the alignment exactly correct. I drilled and threaded a pair of holes through the outside (female) fitting so I could use a pair of stainless steel screws to lock the fittings in place after after the adjustment was complete.

The 40 Meter loading coil in place on the antenna.

Notice the stainless steel nut at the bottom of the coil. This nit, and another one at the top of the coil holds the coil on the antenna. Changing coils is easy. Simply remove the nuts at the top and bottom of the coil, swap coils, and replace the nuts. Tighten firmly - but not excessively - and the PVC plastic acts as a lock nut to keep the coil in place. Still, it's a good idea to carry a few spare nuts in the vehicle in case you drop one while changing coils.

The complete Coil Set for the antenna.

From left to right -

Top Row: coil form made from 2" OD schedule 40 PVC pipe; old self-supporting 10-meter coil made from 1/4" copper tubing; plastic support spacer, used with self-supporting coils; copper shunt ring, used to tune loading coils.

Bottom Row: loading coils for 160-meters, 75-meters, 40-meters, 20-meters, and 17-meters.

The 160 and 75-meter coils are wound using #14 AWG Nylon insulated wire; all the rest of the coils are wound with #10 AWG THHN insulated wire. Note that no terminals are used on the coils - the wire ends are simply wrapped around the mounting bolts. When the coil is attached to the antenna, the wire loops are pressed against the copper coil mounts to make the electrical connection by the coil form when you tighten the 1/4" nuts from the inside of the coil form.

General Coil Construction

The coil form is made from a length of 2" OD PVC pipe. I cut each coil form about 3/4" longer on each end than the spacing between the mounting bolts. NOTE: Make sure that each coil form fits easily over the mounting bolts before winding on the wire or you'll have problems changing coils.

After winding the wire on each coil, an application of epoxy adhesive (J-B Kwik) was used to keep the coil turns in place. A coat of black spray paint was applied for appearance and to make the white plastic coil form less noticeable. NOTE: Apply the epoxy AFTER you have adjusted the coil to resonance.

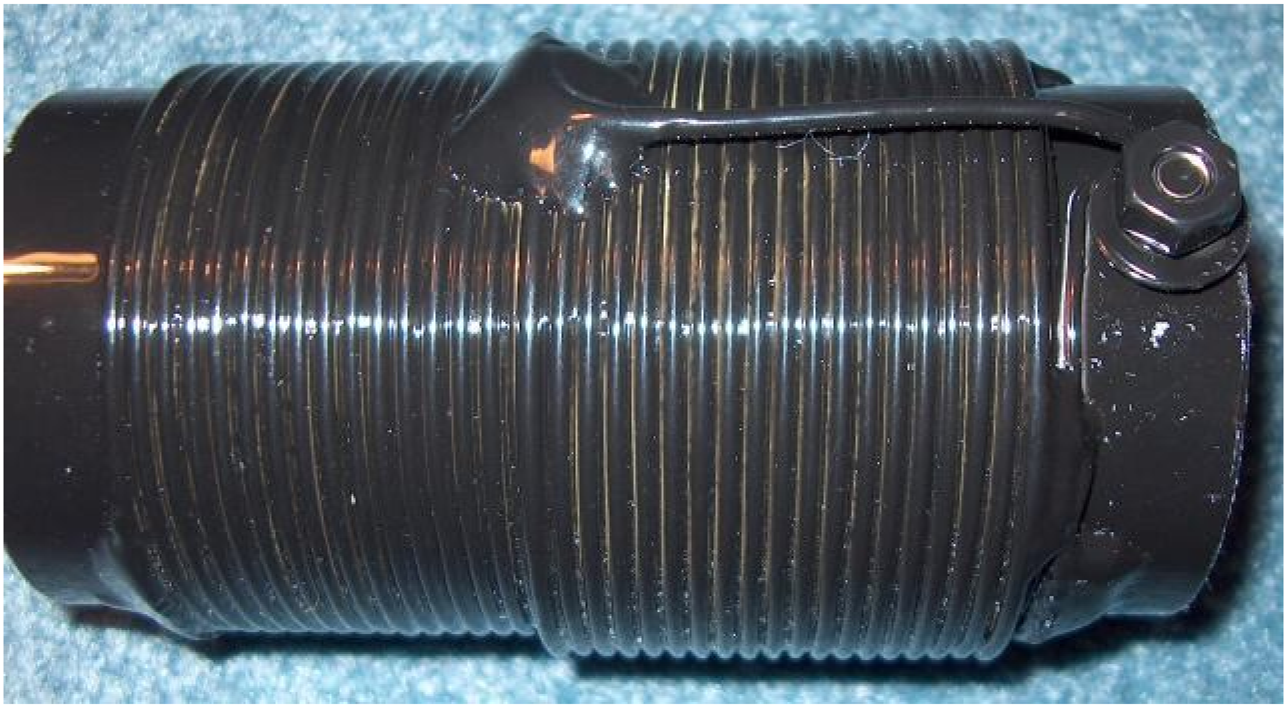
If you just wind the wire on the coil forms directly, this will result in the coil "springing back" and becoming loose on the form when you release the wire after winding it. I wound several extra turns on each coil as I wound it on the form, then removed the coil from the coil form and then squeezed it down around a slightly smaller form (actually a spray can of insect repellent.) I then removed the now slightly smaller diameter coil and gently screwed it onto the coil form, where it remained tight enough to stay in place properly.

The 75-Meter coil

The calculations indicated that I would need to use #22 AWG wire to get enough turns on the coil in the space I had available. The losses would have been quite high, if I used that small size wire. So, this coil is wound with #14 AWG wire. Since using larger wire would not allow as many turns in the same length, I could either use a larger diameter form (too much wind resistance and negative "eye appeal",) or a longer form, continuing the extra turns below the lower mounting bolt (wind resistance, and higher RF losses.) Something better was needed.

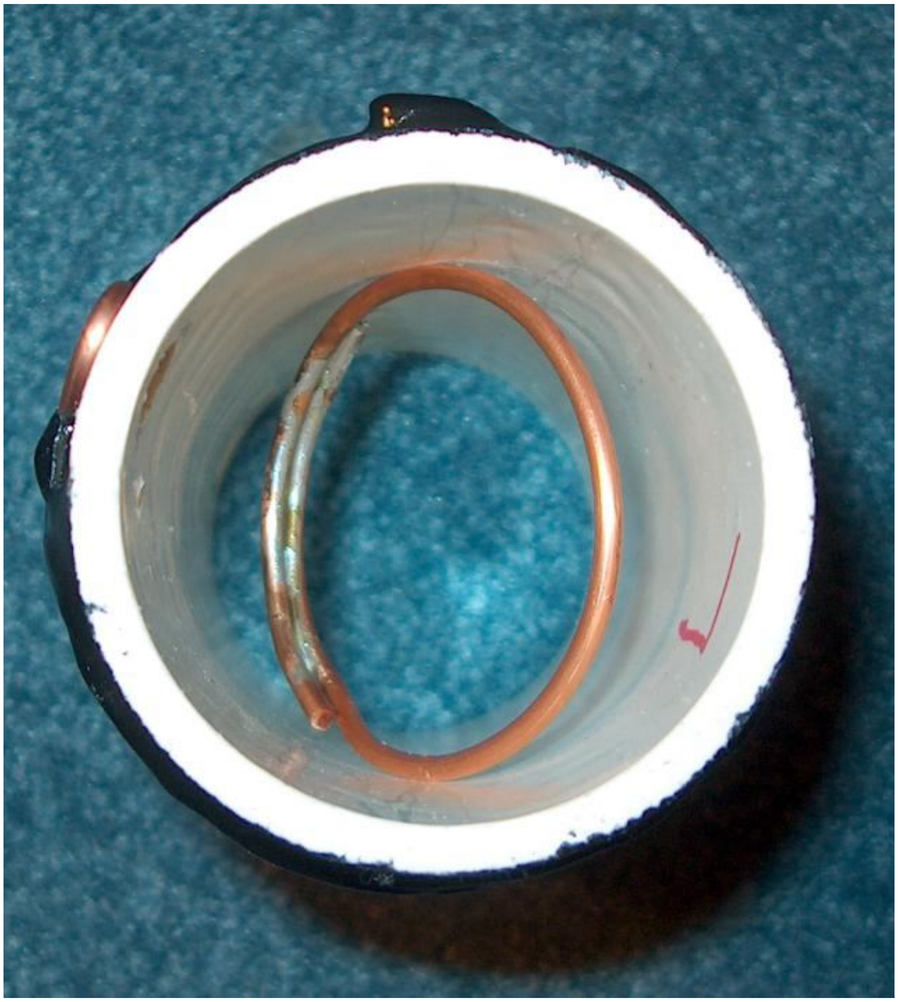
Remembering my switching power supply transformer winding experience, I decided to try winding the loading coil for the antenna in the same manner, that is, complete the first layer of the winding in the usual manner, then "jump" the winding end back up towards the start of the first layer and then continue the second layer of the winding towards the end of the first layer of the winding. This is sometimes referred to as a "Z" winding.

You can see the black painted bolt in the right of the photo that holds the end of the first layer of the winding. From that bolt, the wire that begins the second layer "jumps" back to the left of the second layer of the winding. The end of the second layer is brought out to one of the mounting bolt holes. You can see the epoxy that holds the windings in place.



The 160-Meter Coil

Wound in the same manner as the 75-meter coil, the 160-meter coil required only 60% of the number of turns as would be needed if the windings were in a single layer. The trade off is that there are several stray resonances of the antenna system using this coil, but none of them cause any problems with normal operation. Since less wire is used in this coil than would be used in a single layer coil, the copper losses are less, but the dielectric losses are slightly higher due to the overlapped windings. However, the use of the "Z" winding method minimizes the dielectric losses as much as possible. The measured Rac loss of this coil is less than the originally calculated coil using #22 AWG wire.



Tuning Ring in place inside the 40-Meter Coil

As it turned out, I didn't need to use it, but I found that I could insert a shorted copper ring inside the coil and adjust the antenna tuning plus or minus a turn or so on each coil. I also tried using various types of ferrite and iron tuning slugs, but found that the copper ring produced less extra loss in the coil than did the ferrite core. When the ring is placed parallel to the turns on the coil, it acts like a shorted turn and reduces the inductance of the coil. The ring fits in place by friction, and after adjusting it, it may be permanently attached with some epoxy. Further minor adjustments may then be made by bending the ring slightly.

ADDITIONAL LOADING COIL DATA

(This loading coil data was added on 24 July 2010)

Since this article went on-line, I have received quite a few questions about the exact construction of the loading coils. Although it is possible for a careful observer to look at the photos posted on this page and deduce the construction of the coils, it is probably a good idea for me to post a more complete description of the construction of the coils so the reader can more easily build them.

In the chart below, all the coils are wound on lengths of Schedule 40 white PVC pipe. The actual end-to-end length of the coil windings is shown in the chart. Due to the thickness of the insulation on the THHN wire, the actual diameter of the finished coil will be close to 2.5 inches. The inductance values are what I measured on my completed loading coils.

FREQUENCY BAND	INDUCTANCE	WIRE GAUGE	NUMBER OF TURNS	COIL LENGTH	COIL DIAMETER	COIL FORM
18 MHz	1.5 uHy	# 10 THHN	5	3.5 Inches	2.5 Inches	2" PVC sch 40 Pipe
14 MHz	3.8 uHy	# 10 THHN	9	3.5 Inches	2.5 Inches	2" PVC sch 40 Pipe
7 MHz	16.5 uHy	# 10 THHN	22	3.5 Inches	2.5 Inches	2" PVC sch 40 Pipe
4 MHz	55 uHy	# 14 THHN	Layer 1 = 34, Layer 2 = 6,	3.75 Inches	2.5 Inches	2" PVC sch 40

			overlaps layer 1			Pipe
2 MHz	100 uHy	# 14 THHN	Layer 1 = 34, Layer 2 = 20, overlaps layer 1	3.75 Inches	2.5 Inches	2" PVC sch 40 Pipe

Note that the coils for 160 and 75 meters have overlapping coil windings. This can be avoided by using smaller diameter wire or using a longer length coil form. Depending on where you place the top layer of wire on the first layer (near one end or near the center of the first layer of wire) the inductance of the coil will vary somewhat, and you may need to adjust the number of turns on the coil. Tuning on the lower frequency bands will be more critical, so you should expect to do some tuning as needed.

Please note that these exact coils may NOT work for you in your particular situation. Factors such as whip length, height above ground, size of the vehicle, etc., will require tuning the antenna, either by tweaking the number of turns on the coils or adjusting the length of the antenna's top whip slightly. In my case, "close enough" was good enough, because I planned to use an antenna tuner in my mobile station. In any case, the dimensions given in the chart above should get you "in the ball park", as it were.

Tuning the Antenna

A center loaded vertical antenna will not present a pure resistive load at the base of the antenna. Usually, a matching network is added at the bottom of the antenna to cancel the reactance and transform the lower than 50 Ohm feedpoint resistance to something close to 50 Ohms. Since this antenna was designed to operate over several HF bands, a single matching network is impractical. Instead, I chose to connect the antenna through a length of low-loss coaxial cable to an automatic antenna tuner (ATU) inside the vehicle within reach of the operator and out of the weather.

To make the best use of the antenna with this set-up, the loading coils for the antenna should be tuned to resonance at the high end of each band. The antenna will then look electrically "short" to the tuner, which will then be able to tune the antenna to the desired operating frequency. If the loading coil in the antenna is tuned to a frequency below the top of the band, then operation above that critical frequency will cause the antenna to look electrically "long" to the RF. The loading coil will begin acting as a choke and effectively reduce the length of the antenna, causing a severe loss of gain.

Final Notes:

The top whip represents a (measured) capacity of 17.5 pF. This value changes by about 0.75 pF as the mast is moved +/- 60 degrees from vertical in any direction.

The tuning of the antenna stays fairly constant as the whip sways, so compensation for bending of the antenna while driving is not necessary, at least not on this vehicle.

73, Ralph W5JGV