Some Design Notes on MF /LF Antennas for Small City Lots

By W5JGV

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For those experimenters, myself included, who are faced with operating from restricted space lots, the choice of proper antenna design becomes critical to the success of operating on MF or LF frequencies. After gathering a lot of information about low frequency antennas, I set out to analyze the available options. I needed to take into consideration such things as antenna gain (actually antenna loss, since any reasonable sized antenna constructed under such circumstances will have a negative gain value) and mechanical construction difficulties. After all, if you can't physically construct it, or can't afford it, then it doesn't matter how good the antenna is; it's not the one for you!

My QTH is not unlike many urban locations. A large house, a small lot, and very close neighbors. In my case, the lot measures about 110 feet deep by 50 feet wide. The house occupies all but the rear 25 feet of the lot and a small front yard. A driveway exists on one side of the house, but that space is not obviously usable for antennas. The front yard is about 25 x 50 feet. Power lines running across the edge of the street make antennas in the front yard dangerous to build and noisy to use.

I wanted to be able to erect an antenna which would be suitable for operation between 150 - 500 KC. It must fit in the small space I have available, and be as efficient as possible. As the old saying goes, "You can't get there from here!" Well, I'm going to give it a good try!

I have a guyed mast on top of the house which rises to a height above ground of 15 meters, and a tower in the back yard which is 20 meters high. The tower supports a TH3-jr tri-band beam and a 2-meter Yagi. Strung between the tower and the mast is a sloping three-section W9INN style loaded wire dipole. Any additional antennas for LF/MF must go between the tower and the mast or up the side of the tower, or both.

The grounding system for the tower consists of a 1" diameter ground rod, 10' long, driven into the moist earth (it's ALWAYS moist here in south Louisiana!). All three of the tower legs are connected directly to the ground rod with sections of 2-0 welding cable. In addition, there are other ground rods connected to the steel support base of the tower. I planned to mount the LF/MF antenna tuner cabinet to the base of the tower so the tower ground would be close to the tuner.

The measured earth resistance at various frequencies is:

166.5 KC = 50 Ohms

480 KC = 18 Ohms

1800 KC = 35 Ohms

Everything MUST fit between the tower and the roof mast!

The left side of the house is 5 feet from the lot line, and the right side of the driveway is the other lot line.

At this QTH, it is almost impossible to construct anything which resembles a real ground radial system. The tower itself is mounted a steel frame which is bolted through the concrete driveway slab, with ground rods driven through the slab into the earth. The distance from the tower base to the property boundaries in three directions is only 20 to 25 feet. The house covers the lot in the fourth direction. The city water supply pipe is, of course, on the other side of the house, so I can't connect to that, even if it were legal to do so. In this case, unless I can pull the proverbial rabbit out of the hat, I'll have to depend on the existing ground rod system under the tower and its base support.

Previous experiments with using the tower as a shunt fed antenna for 160 and 80 meters did not work out as well as I had hoped they would, so I did not give too much hope to using the tower as a radiating element at lower frequencies. (The problem was traced to the very low radiation resistance (Rrad) of the tower combined with the earth resistance which caused most of the transmitter power to be wasted in hearing the earth.)

The available literature and reports by other experimenters and operators on these frequencies seem to support the use of either some form of top loaded short vertical antenna or some form of a vertically oriented single turn loop antenna. Since it appeared reasonable to construct some version of either of these two types of antennas at my QTH, I began a series of antenna simulations using EZNEC antenna modeling software.

Running the software against a series of known antenna systems verified that the software was producing good results when given reasonable input data.

To make a three-week long story very short, just let me say that I investigated a seemingly endless number of different antenna designs, all of which would have to fit in the space I have available.

I considered shunt feeding the tower, but I rejected that idea due to the very low value of radiation resistance (Rrad) and the resulting poor efficiency.

I also modeled various designs of single and multiple turn loop antennas of differing sizes, heights, wire diameters and feed methods, but I eventually rejected them due to the poorer radiation efficiency caused by the fairly small loop size possible. If I had about twice the existing space available to construct a loop, calculations indicate that a loop might very well have performed as well as or better than a top loaded vertical.

I then looked at using single and combinations of vertical wires of varying diameters running up the outside and inside of the tower, both with and without a horizontally strung top loading wire of varying diameters suspended between the mast and the tower. A simple single vertical wire with top load eventually proved to be the most workable solution for the task at hand.

As it turned out, there were so many trade-offs to be made that it would have been almost impossible to do the job in a reasonable amount of time without the use of the computer software. For instance, I found that the optimum diameter of the vertical portion of the antenna which runs parallel to the tower varies depending on the frequency of operation, the distance of the wire from the tower, and the amount of capacitive top loading. Virtually every other component of the antenna system interacts in much the same way. Luckily, it turned out that it was possible to design an antenna configuration which seems to be able to provide acceptable performance throughout the range of 150 to 500 KC which will require only adjustments to the matching network at the bottom of the antenna.

One other thing should be noted here. When you have a fairly high ground resistance, in this case 50 ohms, then the difference between the best antenna design and the worst differs by less than 2 dB. If your ground system has a lower resistance, then the difference in antenna performance between best and worst design increases. In that case, the best design comes much closer to the performance of an antenna operating over a perfect ground system.

What I eventually decided upon was a fairly simple single wire top loaded vertical antenna in the shape of an inverted "L".

The vertical radiating portion of the antenna runs up the side of the tower, and is held away from the side of the tower at a distance of 2 meters. The top loading wire - there is only one, I don't have any place else to fasten more than one - stretches between the top of the tower and the roof mast, some 20 meters away.

This means that the top loading wire slopes down slightly, from an elevation of 20 meters at the top of the vertical wire of the antenna to a height of 15 meters where it meets the roof tower. Note that this horizontal wire serves to add tuning capacity to the vertical section of the antenna, and does almost nothing to radiate energy usefully. After much calculation and considering the various trade-offs, I decided on using #14 copper house wire for both the vertical part of the antenna and the top loading wire.

This is electrically a very short antenna at low frequencies, and it was determined by calculation that adding loading coils in the middle of the antenna resulted in almost no additional gain, If the antenna were about three times as long, then loading the antenna in the middle would result in an improvement. Accordingly, all the antenna loading and tuning will be done at the bottom of the antenna.

Although the tower is a part of the radiating structure, since it is so short in terms of electrical length, it does not have a great effect on the actual antenna. The tower itself has a low resistance compared to a thin wire, and calculations indicate that the loss introduced by the tower is only about 1.3 dB. Most of the additional loss is due to the reduction in Rrad caused by the close coupling of the tower to the antenna wire making the antenna system "think" the wire is of larger diameter than it actually is. (Thicker wires have a lower radiation resistance than do thin wires.)

Factors affecting the overall antenna gain in order of their importance and general effect are:

1) The earth resistance - probably 95% + of the antenna system loss in most cases

2) Distance of the vertical wire from the tower

3) Diameter of the vertical wire

4) Number to top loading wires

5) Diameter of the top loading wires

EARTH (GROUND) RESISTANCE - Do whatever you can to bring it to the lowest possible value. This is by far the largest source of loss on your antenna system.

DISTANCE OF THE VERTICAL WIRE TO THE TOWER - The closer to the tower, the lower the Rrad and the larger is the reactance. This makes tuning the antenna more difficult.

The calculated antenna gain goes down rapidly after you get closer to the tower than about 1 meter. This happens because the Rrad decreases rapidly as the wire approaches the tower and the ground resistance becomes a much larger part of the total antenna system resistance.

I chose to use 2 meters as a tower-to-wire space distance for mechanical reasons and the fact that moving the wire out to 3 meters gave only another .05 dB antenna gain improvement. A 1 meter spacing is inadvisable, since moving the wire back towards the tower to 1 meter spacing causes a loss in gain of about 1.5 dB.

DIAMETER OF THE VERTICAL WIRE - A larger diameter wire results is decreased resistance loss in the wire, but at the same time the larger diameter also reduces the Rrad of the antenna. Since the earth loss stays the same, a lower Rrad means more of the power gets used up in heating the ground instead of being radiated.

In the case here, with a 2 meter tower-to-wire spacing, the calculated optimum vertical wire diameter is about 2 mm. Using #14 (1.6 mm) copper house wire will work quite well and is inexpensive.

For a 3 meter tower-to-wire spacing, the calculated optimum vertical wire diameter is about 13 mm / 1/2 inch. I have a nice length of 1/2" hardline coax cable that would work just fine, or a length of 1/2" OD copper tube would also work great. Since calculations show that dropping back to plain old #14 copper house wire even in this case will result in a loss of only about 0.22 dB, using wire instead of copper tube is still acceptable.

NUMBER OF TOP WIRES (and length) - More and longer is better, but I can only manage to fit one top load wire on my lot here.

Note that calculations show that changing the diameter of the wire from 1.6 mm (#14 wire) to a wire cage array of measuring 1 meter in diameter gives less than .05 dB gain improvement.

Using parallel wires closer than about 1 meter from each other also results in very little gain improvement.

Spreading the far ends of the wires apart by 45 degrees or more increases the gain much more than using a series of parallel top loading wires. In other words, an "umbrella" top hat. As you change the length and number of top load wires, the optimum diameter of the vertical wire will also change.

TOP LOAD WIRE ELEVATION - Drooping the far ends of the top loading wire (guy wire top hat) causes the antenna gain to decrease rapidly. If I could manage to get the far end of my wire up to a height of 20 meters instead of the available 15 meters, I would get an additional 1.47 dB gain increase. But raising the outer wire end even higher than the top of the vertical portion of the antenna does not gain a proportional amount. For instance, If I could elevate the outer end of the wire from 20 meters to 25 meters, the antenna gain would increase by only an additional 0.17 dB. It would be far better to increase the height of the vertical part of the antenna if you can.

SUMMARY -

A reasonable cost, medium performance, restricted space LF/MF antenna may be constructed using ordinary #14 copper house wire for the vertical radiating element and the top loading wire. The wire is run upwards from the antenna loading unit at the base of the tower, parallel to and 2 meters away from the tower.

The vertical wire is run to a height of 20 meters from the tuning unit. It then continues on slightly below the horizontal plane out to a distance of 20 meters away from the tower where it is attached to an insulator connected to a support point which is 15 meters above the ground.

This antenna, when combined with the ground loss resistance of 50 Ohms at 166.5 KC, gives an effective radiation gain of -26.3 dB below a perfect antenna .

This antenna, when combined with the ground loss resistance of 18 ohms at 480 KC, gives an effective radiation gain of -13.9 dB below a perfect antenna.

Note that these figures do not include losses incurred in the antenna matching networks, however, with reasonable care in construction, these losses may be minimized.

I'll update this page as construction progresses

73, Ralph W5JGV

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