Some notes on measuring tower resonances

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First the disclaimer: these are very preliminary notes. This is still an experiment in progress with a long way to go. These notes will be expanded and modified as the work proceeds. I'm throwing this out so other hams can see what I'm about and perhaps try it for themselves. Who knows, there may be an even better way to handle this measurement.

The problem

I recently encountered a severe case of tower interaction with a new vertical array belonging to a friend. I discovered the problem after the array was up, while making impedance and coupling measurements prior to feed-network adjustment. In this case there were three towers within one wavelength of the array due to the restricted size of the property. Unfortunately I had not seen the installation before I arrived. My first "uh-oh" reaction was quickly confirmed. The array element and coupling measurements were really crazy even though the construction of the array was first rate and mechanically very symmetric.

The first order of business was to determine which tower(s) was the culprit and the mode of the resonance(s): i.e. 1/4, 3/4 or 5/4-wave. Each tower was solidly grounded and had a large bundle of cables and control lines running up it. The towers also had multiple stacked Yagis, etc. This brought me to the problem of how to determine the tower resonances for this kind of grounded structure.

The desired solution

Ideally what I wanted was to be able to walk up to a grounded tower and without climbing it (or at least not up more than a few feet!) to accurately determine the multiple resonances typically present in ham towers. I wanted a setup that was light weight to take into the field and mechanically simple, with a minimum of fiddling with attachments to the tower. It would be best if it took no more than half an hour for the full procedure per tower and of course I would like to do it with simple instrumentation.

My solution

My present solution does achieve most of the goals stated above. The major exception was that the instrumentation required was not simple: a network analyzer or at least a good impedance bridge like the AIM4170. In addition you have to have enough experience to understand what the instrumentation is telling you.

The first thing I tried was a quick experiment on a bare tower using the "standard" technique: i.e. installing a short arm at the top of the tower and dropping a wire down to measure resonance with a dipper. This method has been in all the ham antenna books since the beginning of time but I couldn't get it to work even in a very simple and carefully controlled arrangement. Even when I substituted a VNA (N2PK) for the dipper (Boonton model 59) no dice. In any case I have no enthusiasm for climbing 150' towers to drop a wire down!

A tower is a form of resonator, rather like a tank circuit but with multiple resonances. My idea was to couple to the tower with an un-tuned loop. In principle this is much like using a link to couple power out of a transmitter tank circuit. In an early experiment I tried a loop as shown in figure 1.

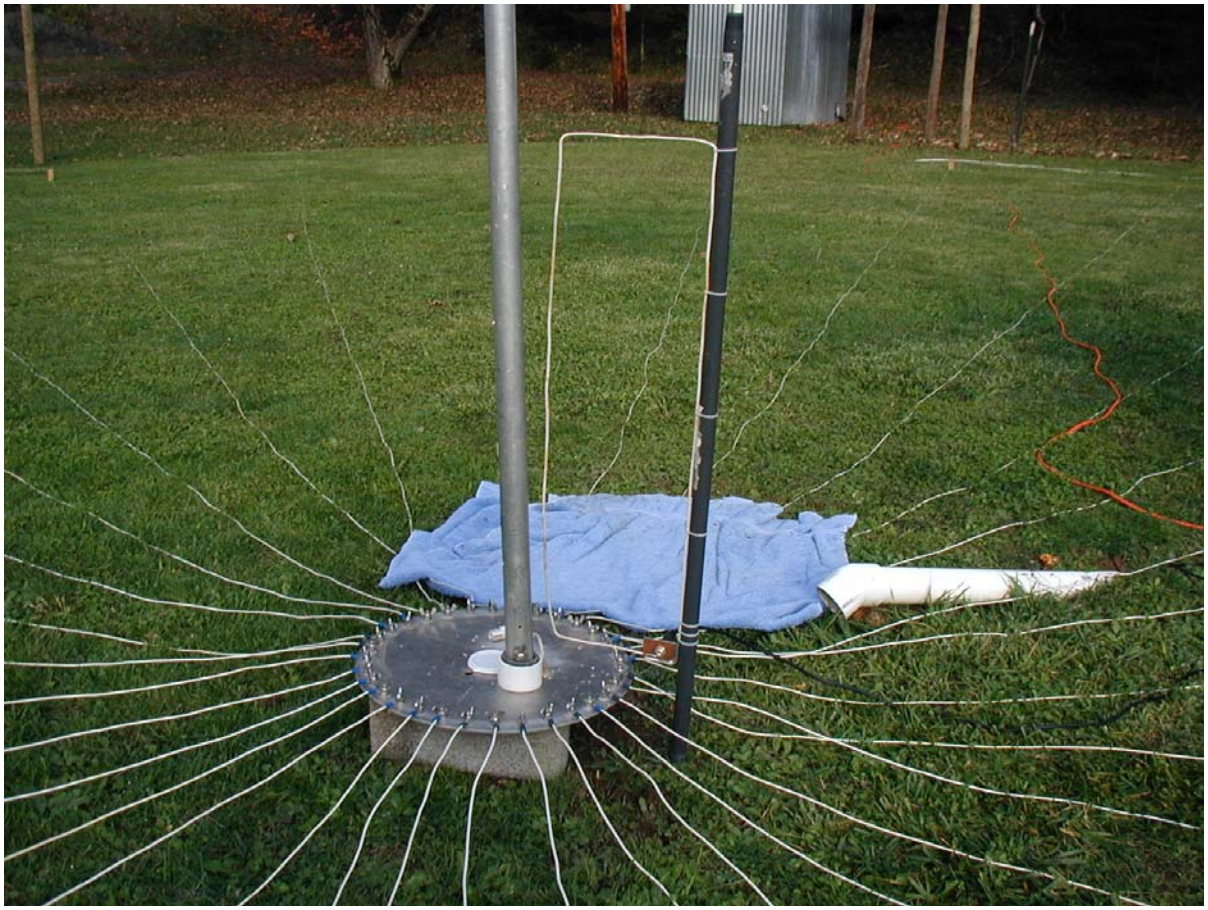

Figure 1, coupling loop next to a 40m 1/4-wave vertical.

This worked just fine and I could easily determine the 1/4 and 3/4-wave resonances. But this small is loop proved to be insensitive and scaling it up would result in a large loop which would be hard to work with or transport. It quickly became apparent that using the tower as part of the loop by attaching a couple of brackets with a shunt wire between them, was a whole lot more practical. The two approaches are identical electrically, they just differ in the mechanical arrangements. An example of a typical bracket-shunt wire assembly, mounted on a tower, is given in figures 2 and 3. At the base of the shunt wire there is a BNC connector to which the VNA is connected.

I tried several variations of loop length (up to 20') and width (up to 24") as well as shunt wire size from #12 to the 2" diameter tubing shown. Larger loop sizes and larger shunt wire diameters gave better sensitivity but there is an important limitation on loop size. When the loop length starts to approach 1/4-wave at the highest frequency of interest you begin to see transmission line resonances which can be mistaken for actual tower resonances. For this reason and also because I like to work standing on the ground (especially in the winter!) I kept the loop length relatively short.

Another possibility to increase sensitivity would be to use several turns in the sampling loop. I tried that but the problem with that approach is that stray capacitances within the loop cause it to be self resonant, often at too low a frequency.

The tower is a resonator and so is the sampling loop. The two together form a multi-tuned coupled network. To improve the sensitivity you have to improve the coupling but when you do that you introduce new resonances and also shift the original tower resonances as I will show shortly. The VNA has the advantage that it can give useful readings even with very loose coupling.

I used 28' of Rohn 25G for the test tower. This gave me a resonance just above the 40m band so I could add a variable shunt inductor at the base to tune the tower resonance from above to below the band edges for some future tests on decoupling between verticals.

Figure 2, view of the shunt loop at the base of the test tower (28' of Rohn 25G).

Figure 2, close-up of the bottom of the shunt wire showing the insulator and the BNC connector where the VNA is connected.

The tower in the photo was put up just for test purposes and has an insulated base. The idea was to measure the tower resonance directly at the base (with the BNC on the shunt wire shorted) and then short the tower base connector and see if I could get the same results by measuring at the bottom of the shunt wire. Before taking this show out into the world I wanted to be sure that impedance measurements with a VNA at the base of the shunt wire would actually correlate with the measurements made at the base of the tower.

I quickly realized that the phase of the input impedance was the variable of interest. The impedance magnitude is not nearly as sensitive an indicator of resonance. For this reason most of the graphs to follow are for the phase of Z at the base of the tower or at the base of the shunt wire.

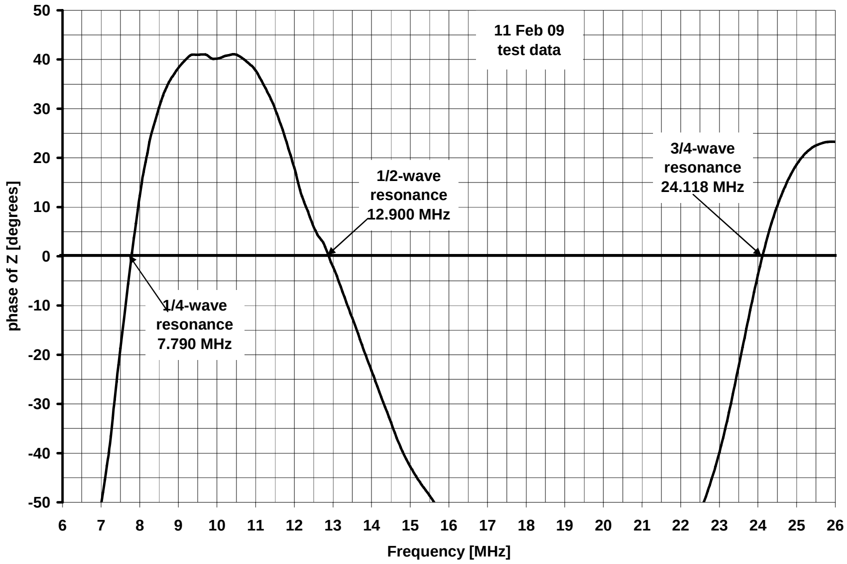

Figure 4, Zin phase at the base of the tower with the shunt wire BNC shorted.

A typical graph of Zin phase at the base of the bare tower (no shunt wire or brackets) is shown in figure 4. The first resonance, at 7.790 MHz, is the 1/4-wave mode. The 1/2-wave mode resonance is at 12.900 MHz which is quite a bit less than double 7.790 MHz. This lower frequency is due to the large shunt capacitance from the base to ground. This is no surprise. The 3/4-wave mode resonance is at 24.118 MHz. This is a bit more than triple 7.790 MHz and is what you would expect in a real vertical as apposed to an infinitely thin wire.

Ok, now we know where the tower is actually resonant. What does the impedance measurement at the base of the shunt wire show (with the tower base shorted to ground)? Figure 5 is a graph of the phase of Z for three different sampling loops: 6" X 48" # 12 shunt wire, 12" X 72" #12 shunt wire and 12" X 84" 2" shunt wire. Clearly we do not see anything like the large phase swings with well defined zero crossing in figure 4. All we get are a couple of small phase dips at 1/4 and 3/4-wave points. Note also that the frequency of the phase minimums shifts a bit between the different sampling loops.

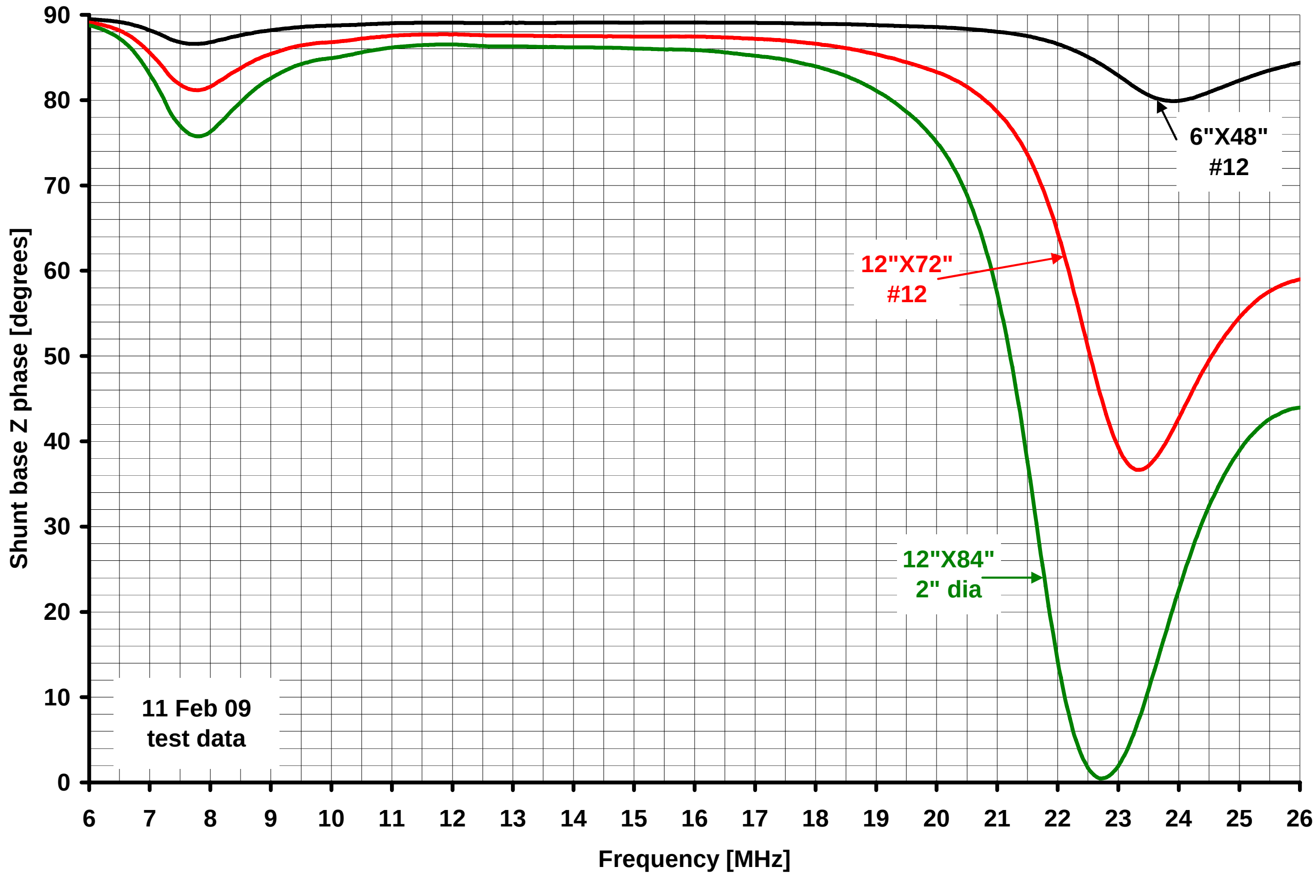

Figure 5, phase of Z at the base of the sampling loop.

To demonstrate the effect on the tower resonances from adding the sampling loops, I measured the resonant frequencies at the base of the tower with and without the sampling loops. The BNC on the loops was shorted. The results are shown in Table 1.

Table 1 tower resonant frequencies with and without the sampling loops.

sampling loop	1/4-wave resonance	1/2-wave resonance	3/4-wave resonance
none	7.790 MHz	12.900 MHz	24.118 MHz
6" X 48"	7.835 MHz	12.650 MHz	24.193 MHz
12" X 72"	7.900 MHz	12.500 MHz	23.998 MHz
12" X 84"	7.970 MHz	12.350 MHz	23.818 MHz

Table 2, tower resonances from the sampling loop measurements.

sampling loop	1/4-wave resonance	3/4-wave resonance
6" X 48"	7.800 MHz	23.910 MHz
12" X 72"	7.805 MHz	23.998 MHz
12" X 84"	7.855 MHz	23.818 MHz

If we measure the frequencies of minimum phase in figure 5 by reducing the sweep widths and increasing the frequency resolution we get the results in table 2. Note that the 1/2-wave resonances do not show up in this test where the loop is at the base of the antenna. But then it is the odd quarter-wave resonances that give us the interaction we're worried about. I don't think that in a grounded tower the 1/2-wave resonances are a problem.

Comparing the entries in table 2 to the first row in table 1 for the bare tower, the correlation is not perfect but is more than close enough to identify a problem tower. I repeated this exercise with both the tower and also a 1/4-wave 40m vertical with good correlation in all cases.

Time for a real tower

Emboldened by my success with the test tower and also some of my own towers which however, only have single Yagis on top, not a complex of Yagis and other antennas, I went over to see George, W2VJN. George has a 150' Rohn tower with a 15 mast added at the top. At the very top is a 2-element 40m Yagi and down from there a long stack of Yagis on different bands. In addition there is a pair of 80m inverted V's at 140' (these are at right angles to each other) and a set of four 160m slopers for his 160m 4-square.

We began the test using the 12" X 84", 2" shunt wire, sampling loop and got reasonable results but the lowest tower resonance was about 850 kHz where that size loop is not very sensitive. So we moved the loop bracket up to 20' and tried both a #12 wire and 20' of 1" aluminum tubing. Both of the longer shunt wires gave much better resolution. The test results are shown in figure 6.

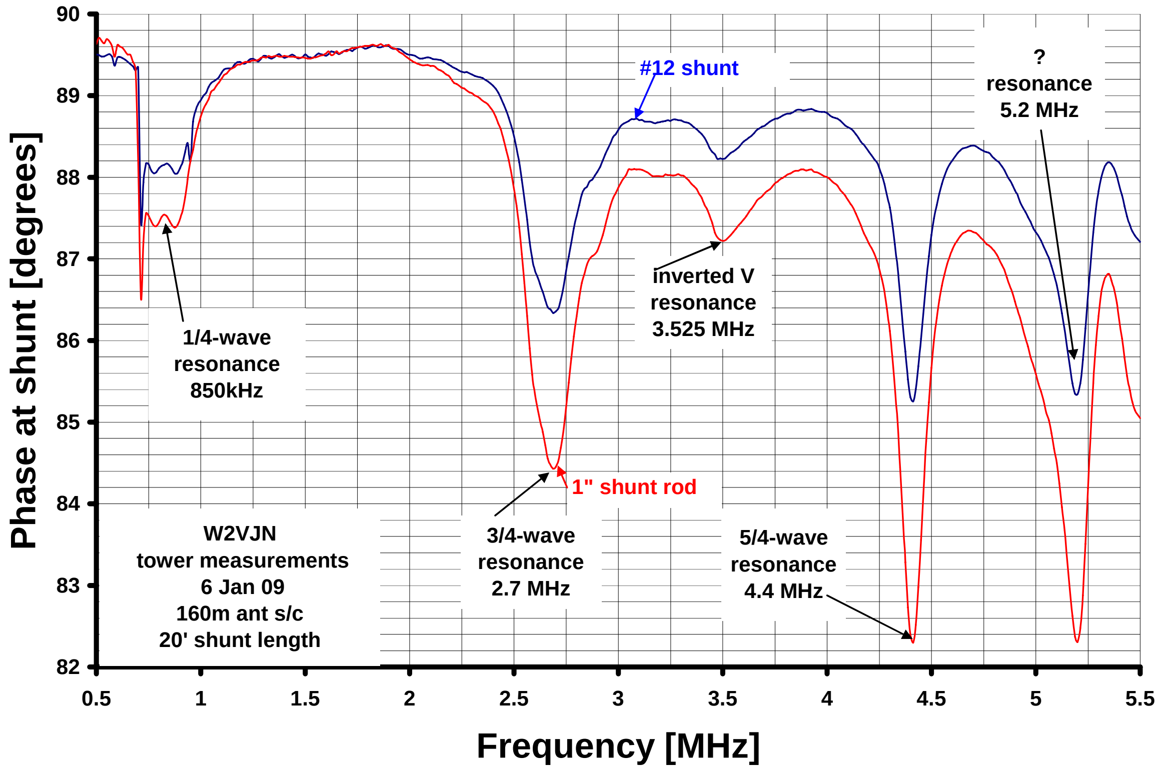

Figure 6, phase of Z for the W2VJN tower system using a 20', #12 wire and a 20', 1" aluminum tube for the shunt wire.

The broad resonance around 850 kHz was a puzzle until we shorted and then opened the ground ends of the coax going to the 160m array. With the coax short circuited we got the result you see. With the coax open circuited the phase dip became a single dip at 850 kHz. The dip at 5.2 MHz is still a mystery because it is too low to be the 7/4-wave resonance which should be above 6 MHz. We explored this with another test run at higher frequencies which showed a phase dip at 6.4 MHz which is most likely the 7/4-wave resonance. I have no clue what the 5.2 MHz dip is from.

Since the measurements at W2VJN, I have done a number of other towers and the results all appear to be reasonable. In addition whenever there have been slopers or inverted V's on the tower these show up in the measurements. This is not a surprise since these antennas are partially vertically polarized and can couple into the tower.

Summary

I think I have a viable way to measure tower resonances. It's not perfect, it takes relatively good instrumentation and a knowledgeable user. I suspect I have a lot to learn yet but I hope this information will be useful to others working on a similar problem.

That's it for now. I have a lot more data and will be doing many more towers so this write-up will be expanded sometime in the future.