

Report on measurements at NK7U
29-30 May 2009
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9 June 2009

On May 28th, George (W2VJN) and I (N6LF) drove over to Joe Rudi's (NK7U) QTH in Baker City, OR, to make some measurements on his 80m 4-square array. Joe has a contest station with multiple towers, some with multiple Yagis, in the immediate vicinity of the 80m 4-square. In October 2008 George and I had made a series of measurements on the array which clearly indicated that there was serious interaction between the array elements and at least one if not all of the towers on site. Figures 1 and 2 are samples of what we found at that time.

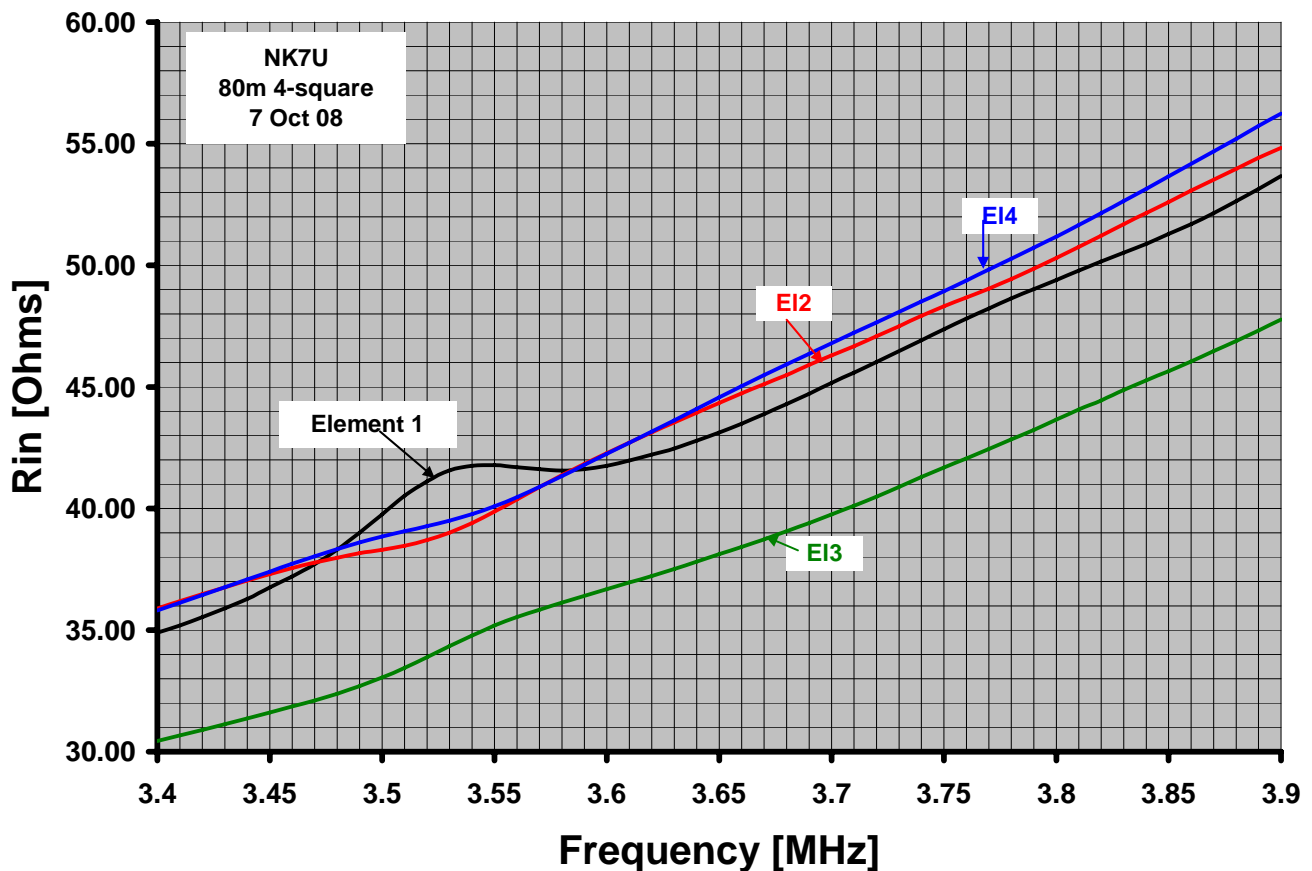


Figure 1, Rin for the four elements of the 80m 4-square array.
Each element measured with the other elements open-circuit at the base.

You would expect Rin to vary with frequency nearly linearly, without any bumps or dips. You would also expect all four elements to be almost identical because Joe had done first rate job in making the array and it's verticals very symmetrical. However, in figure 1 we see that there is hump or dip about 3.550 MHz and one element (#3) is very different from the other three.

figure 2 is a measurement of the mutual resistance between two of the elements (1 & 2) along with a graph of what NEC predicts for the ideal case. More graphs can be found in reference 1.

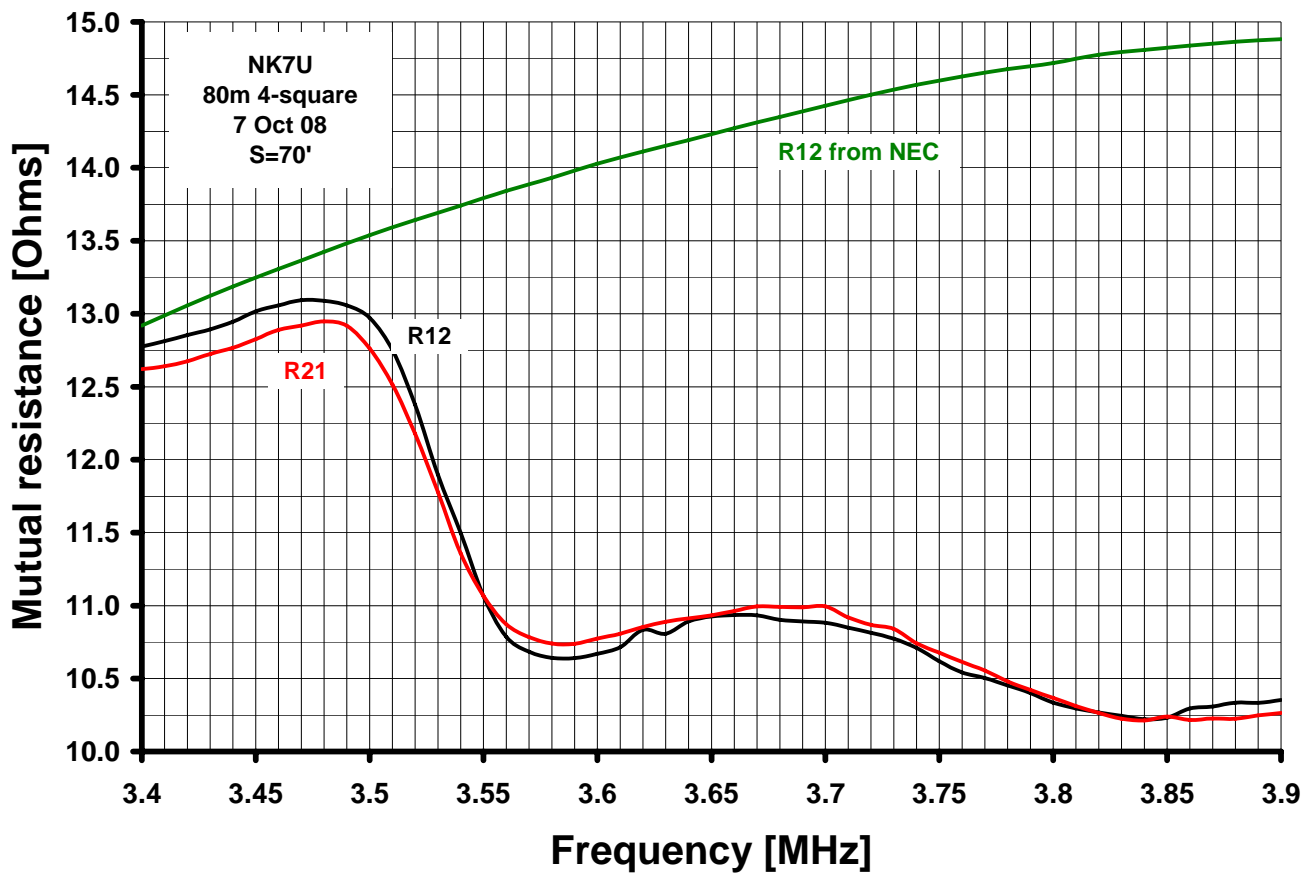


Figure 2, Measured mutual resistance between verticals 2 and 3.

Clearly there is something strange going on just above 3.5 MHz. At that time we were not able to sort out what was happening so we returned to investigate further.

Experiments at N6LF

In the interim between the two visits I had set up a test antenna and tower at my QTH in Cottage Grove, OR, to explore some of the problems associated with vertical-tower interactions. In particular I wanted a reasonable way to measure the resonances of a grounded tower which might have a large number of HF antennas attached to it, a means to measure the current induced into such a tower and finally to develop a means to accurately adjust a resonant sampling loop or "trap" attached to the side of the tower. I think I succeeded and I will describe this preliminary work in another note. In this report I'll only briefly mention how the measurements were made but mainly focus on the results.

Array and tower layout

Over the winter severe winds at NK7U had knocked down two of the verticals (V1 and V4) in the original 4-square but two others (V2 and V3) were still standing and the surviving pair were ok and perfectly adequate to explore the interactions. Over the summer Joe will be replacing all four

verticals with their bases located in the same positions so we can anticipate similar problems with interactions. Figures 3 and 4 are photographs of the antennas at NK7U. Figure 5 is a dimensioned diagram of the 4-square and tower layout. The elements of the 4-square are oriented E-W and N-S with a spacing of 70'. Keeping in mind that at 3.510 MHz $1/2\text{-wave} = 140'$, two of the towers (1 & 4) are within $3/8\text{-wave}$ of a vertical. Tower 2 is just a bit over $1/2\text{-wave}$ away from V1 and tower 3 is almost a wavelength away from V2 and somewhat further from the others. In any case all the towers are asymmetric to the array and will affect each element differently.

Tower descriptions:

- Tower 1 is a 72' crank-up with two large Yagis on a mast at the top. The lower end of one of the 160m dipoles attached to tower 3 is tied off to this tower.
- Tower 2 is 40' of Rohn 45G with three large Yagis on a mast at the top
- Tower 3 is 150' of Rohn 45G with 10' or so of mast at the top. The only antenna on this tower is a 160m 4-square using sloping, center-fed, dipoles.
- Tower 4 is 150' of Rohn 45G with eight large Yagis.



Figure 3, view looking NE of V2 and V3 and towers 1 and 2.



Figure 4, towers 3 and 4, looking a bit north of east.

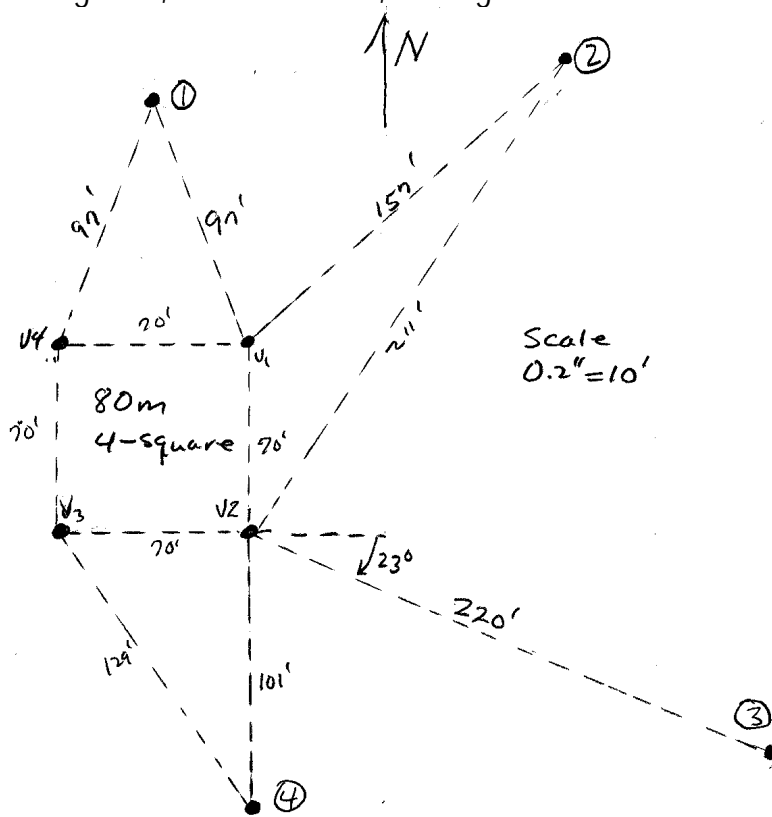


Figure 5, NK7U array and tower layout.

Just looking at the spacings, at least three of the towers (1, 2 and 4) are candidates for interaction with the array.

Tower resonance measurements

The first step was to see if we could determine the resonant frequencies of the towers by measuring the phase of the impedance at a sampling loop on the tower (for more details see reference 2). We did this for towers 1, 2 and 4. There wasn't enough time to do tower 3 with WPX operation but then it is the most distant one. Keep in mind that in these measurements V2 and V3 were open-circuit except as noted. Also the sampling loop was placed either at the base or at most 5' above the tower base.

Tower 1

Figure 6 shows the phase of the impedance measured at the bottom of the sampling loop (1' X 20') with tower 1 at full height (70', blue trace) and also with the height reduced 15' to 55'.

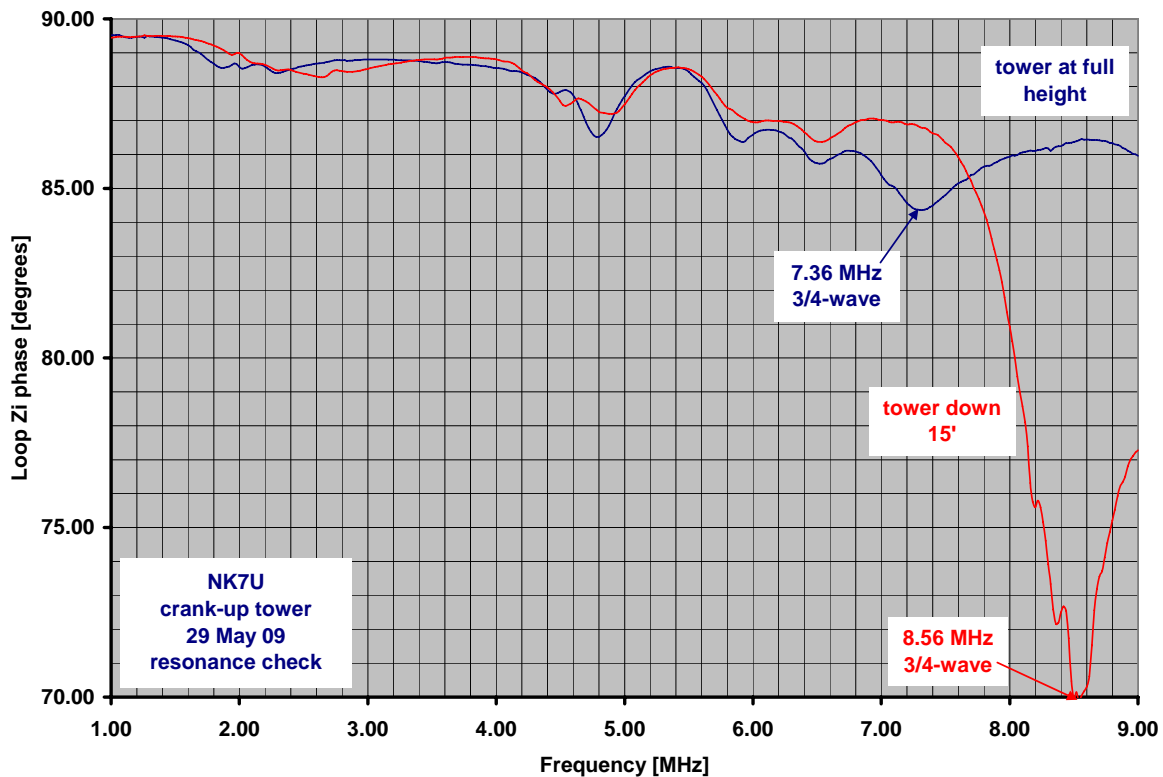


Figure 6, phase of Zi at the base of the sampling looping for the tower at full height (blue trace) and reduced to 55' (red trace).

As usual there are a large number of dips which require some interpretation (also known as a wild ass guesses!). Taking into account the height of this tower, which is very close to 1/4-wave at 3.510 MHz, and the significant top loading, we would expect the first resonance (1/4-wave) to be well below 80m. I assumed that the two large dips on the right are the 3/4-wave resonances (7.36 and 8.56 MHz). I then expanded the region from 1-3 MHz as shown in figure 7.

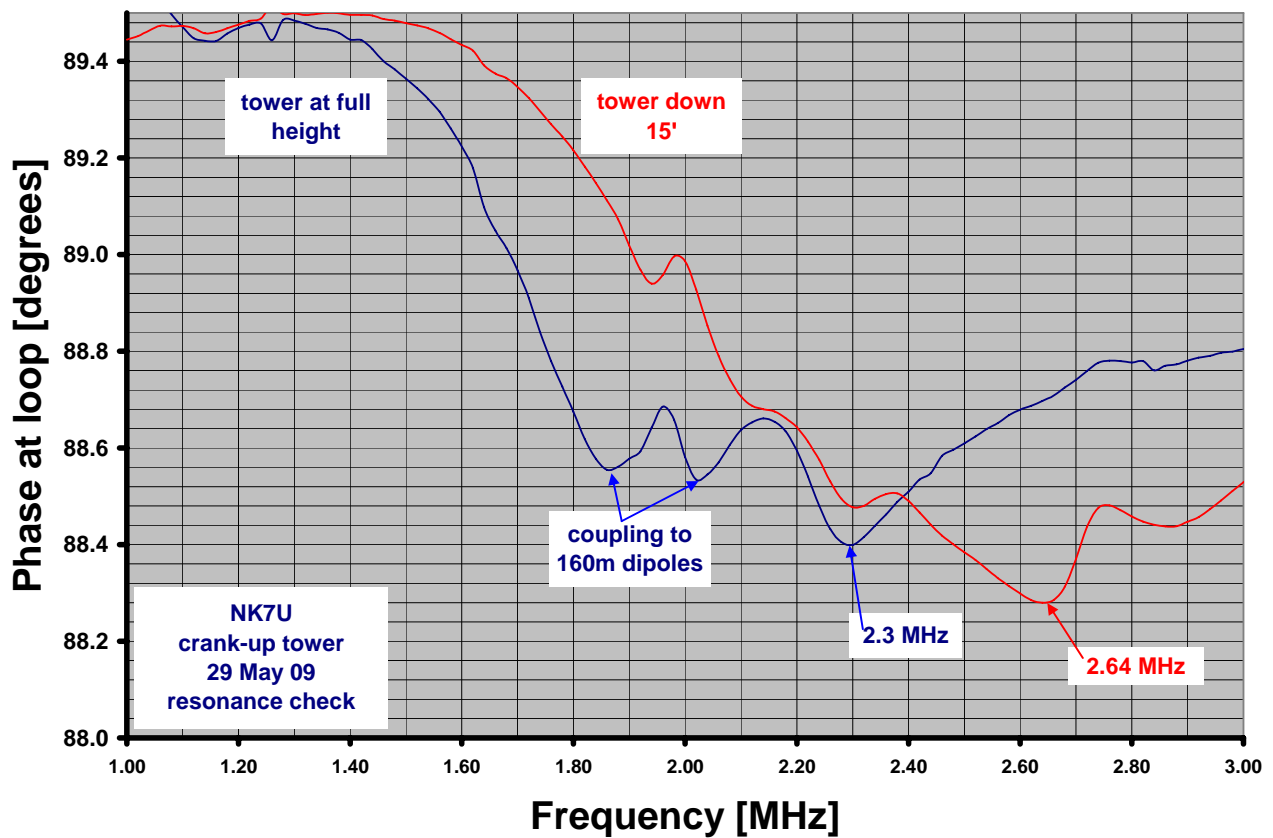


Figure 7, expansion of phase plot for Zi at sampling loop base.

If the 3/4-wave resonances are at 7.36 and 8.56 MHz, then we would expect to see the 1/4-wave resonances at 2.46 and 2.85 MHz. Looking at figure 7 we see dips at 2.30 and 2.64 MHz. This is a reasonable correlation. I think the basic 1/4-wave resonance is about 2.4 MHz in the full up position.

What about all the other bumps we see? As mentioned before, the lower end of one of the 160m dipoles is tied off to the tower. The end of the dipole is 30-40' from the tower but there could still be some coupling. Looking at figure 7 we can see what appears to be a couple of dips associated with the 160m 4-square. As we lower the height of the tower, moving its resonance higher, the 160m coupling appears to go down. As for the rest of the dips in figure 6, I don't have a clue.

Tower 2

The sampling loop Zi phase plot for tower 2 is shown in figure 8.

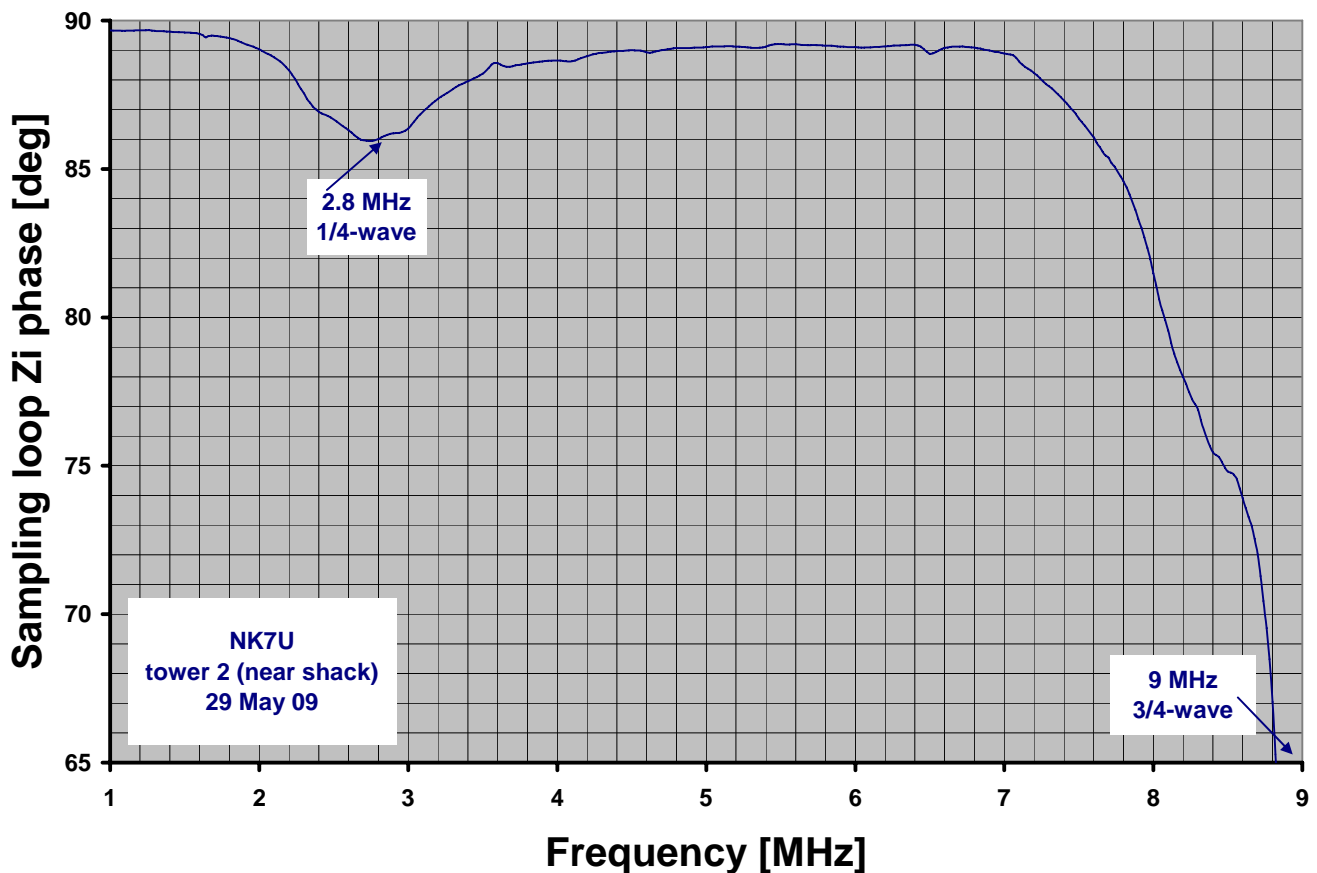


Figure 8, Zi phase of sampling loop on tower 2.

For some reason this one doesn't have nearly as many humps and bumps as figures 6 and 7 and is much easier to interpret. The 1/4-wave resonance seems to be about 2.8 MHz and the 3/4-wave resonance about 9 MHz. Given that the tower is 40' high but has three very large Yagis on top it is reasonable that the first resonance could be below 80m.

This is a point to reflect a bit on what these kinds of phase plots are telling us. With a given size of sampling loop, the coupling to the tower will be small at lower frequencies and increases as we go up in frequency. If we had really tight coupling to the tower we would expect the dips to go right down through zero phase and even lower. But we don't have very good coupling, especially down at 1-2 MHz so the phase dips are very small. I've noticed in all of the tower resonance measurements I've made this way, that the lower frequency dips are consistently low in frequency if we divide down from the higher frequency dips. I think that the 1/4-wave resonance for tower 2 is probably more like 3.0 or even 3.1 MHz which is more reasonable given the height of the tower even with the heavy top loading.

I thought it was at least possible that this tower could be coupling into the verticals so I ran some additional tests. The first was to expand the view of the dip at 2.8 MHz with the base of $\sqrt{2}$ o/c and then s/c. There was a very small change between the two states but that really didn't tell me much.

The next test was to measure the coupling between tower 2 and V2 and also between tower 2 and V3. This involved exciting the vertical and sensing the resulting current in the tower with a clamp-on current probe on one leg of the tower. I did this with the sampling loop s/c and then with the loop tuned to 3.525 MHz. Figure 9 is a graph of $|S_{21}|$ between V2 and tower 2 for the two cases using the current probe on the tower leg.

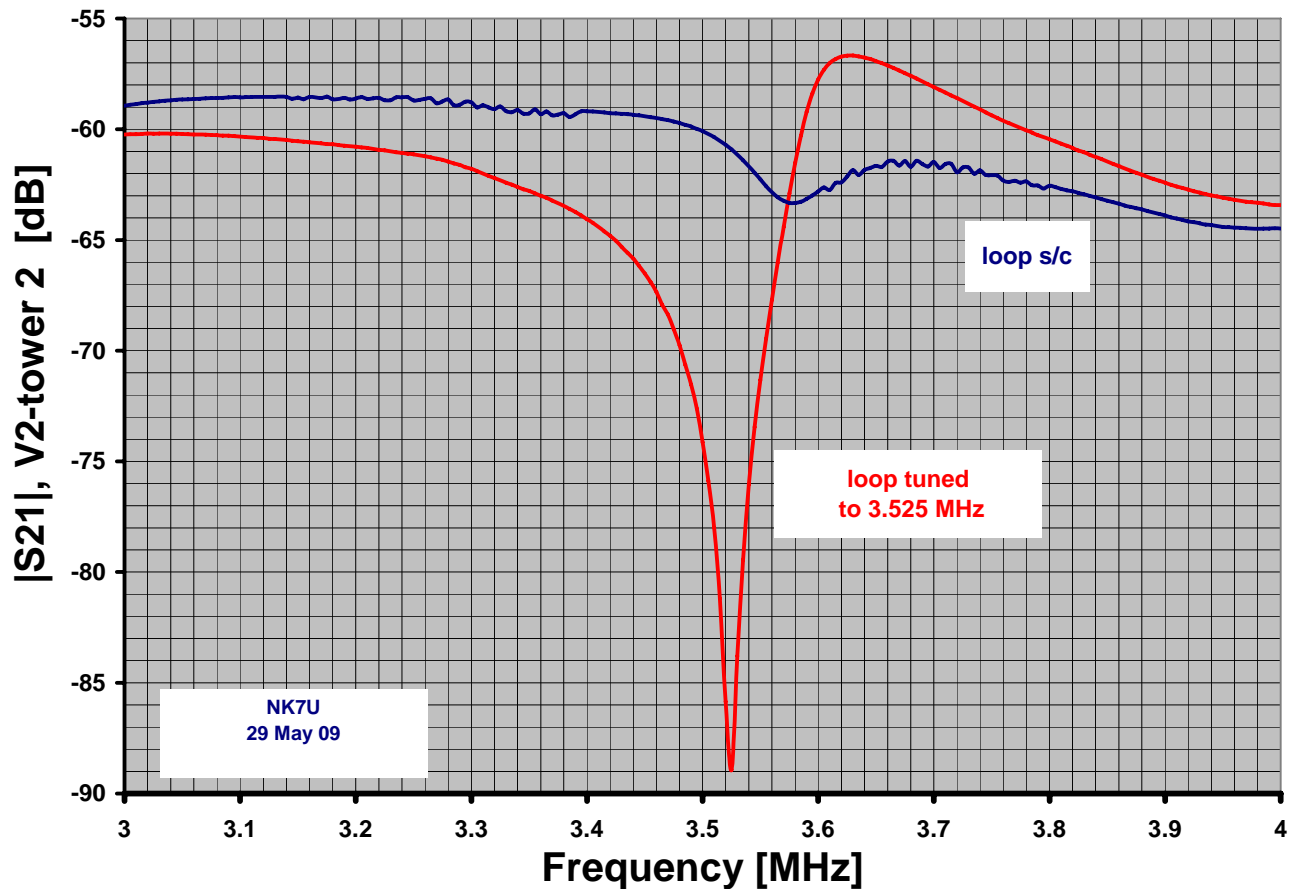


Figure 9, $|S_{21}|$ between V2 and tower 2 with the loop s/c and tuned to 3.525 MHz

The plot for the case where the loop is s/c looks very much like the data I got from the experiments on 40m with the tower resonance close to the vertical resonance with one exception: I have not seen a dip like that just above 3.5 MHz. You would think if anything you should get peak not a dip?? My guess is that this is due to a third element, perhaps tower 4. The tuned loop plot is very typical showing the action of the tuned loop or "trap".

Still this not very definitive, so I measured Z_i at V2 and V3 (separately) with and without the trap on tower 2 to see if I could see anything change. Figure 10 is a graph of R_{in} for V2 with and without the trap. These measurements were taken on Saturday during the WPX contest. I was getting some interference in the N2PK VNA from the 20m transmissions, but I wanted the data so I pressed on given my limited time. The same graph for V3 looks very similar.

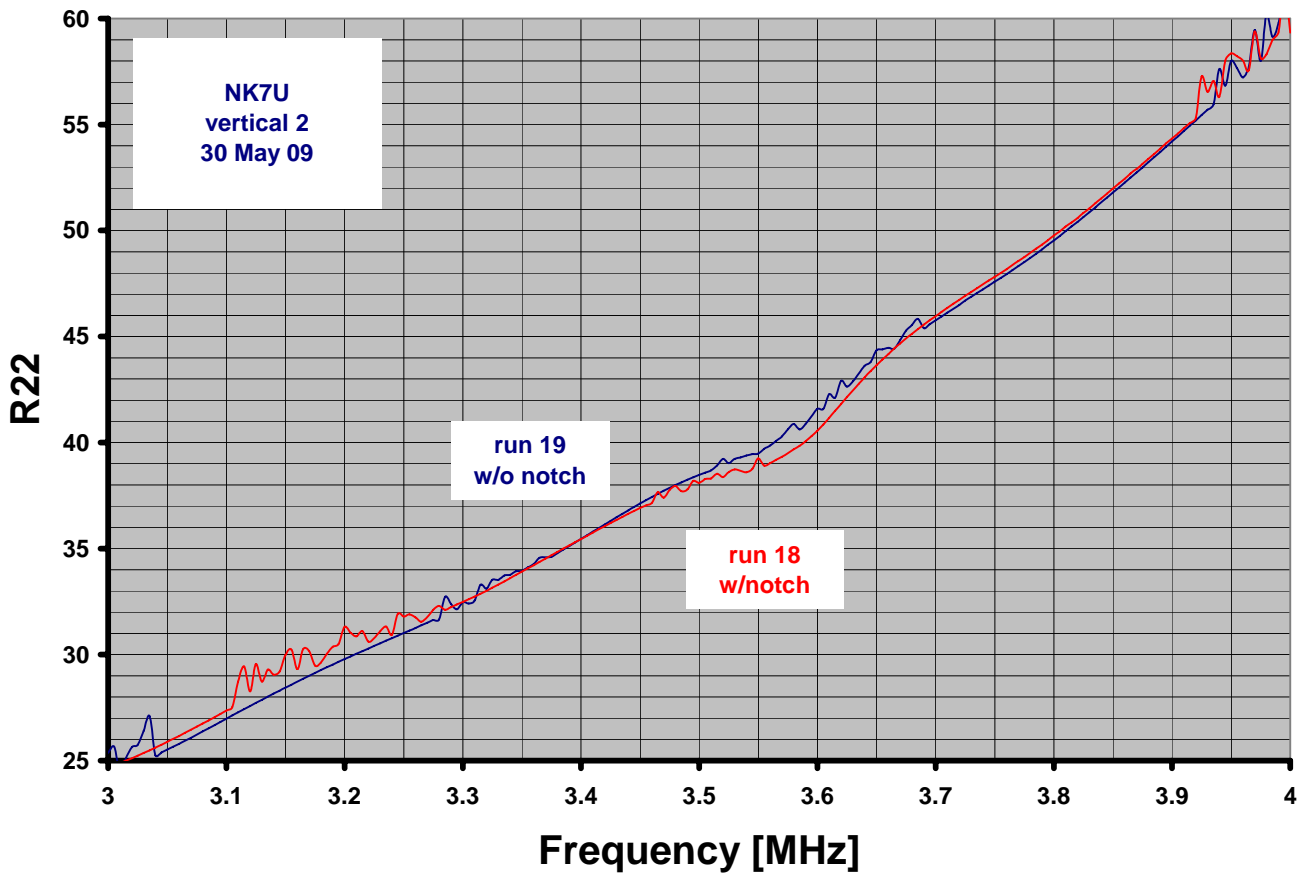


Figure 10, Rin (R22) for vertical 2 with and without the trap on tower 2.

Despite the fact that the trap does radically change tower 2 as a vertical radiator (the trap extends over half way up the tower), we see some effect but not all that much. This implies to me that tower 2 is probably not a major player in the effects we see in V2 or V3. It may have more effect on V1 and V4 when they are reinstalled because they will be much closer to tower 2.

Tower 4

On Saturday (during lunch!) there was a break in the contesting so I ran some quick tests on tower 4. Figure 11 shows the loop Zi phase plot for tower 4. The bottom of the loop was about 5' above the base and the loop was 1' X 20'. There appears to be a resonance at about 3.860 MHz (5/4-wave) and another at 2.360 MHz. This is close to the frequencies of the bumps on figures 1, 2, 9 and 10, so maybe tower 4 is the major player in this drama.

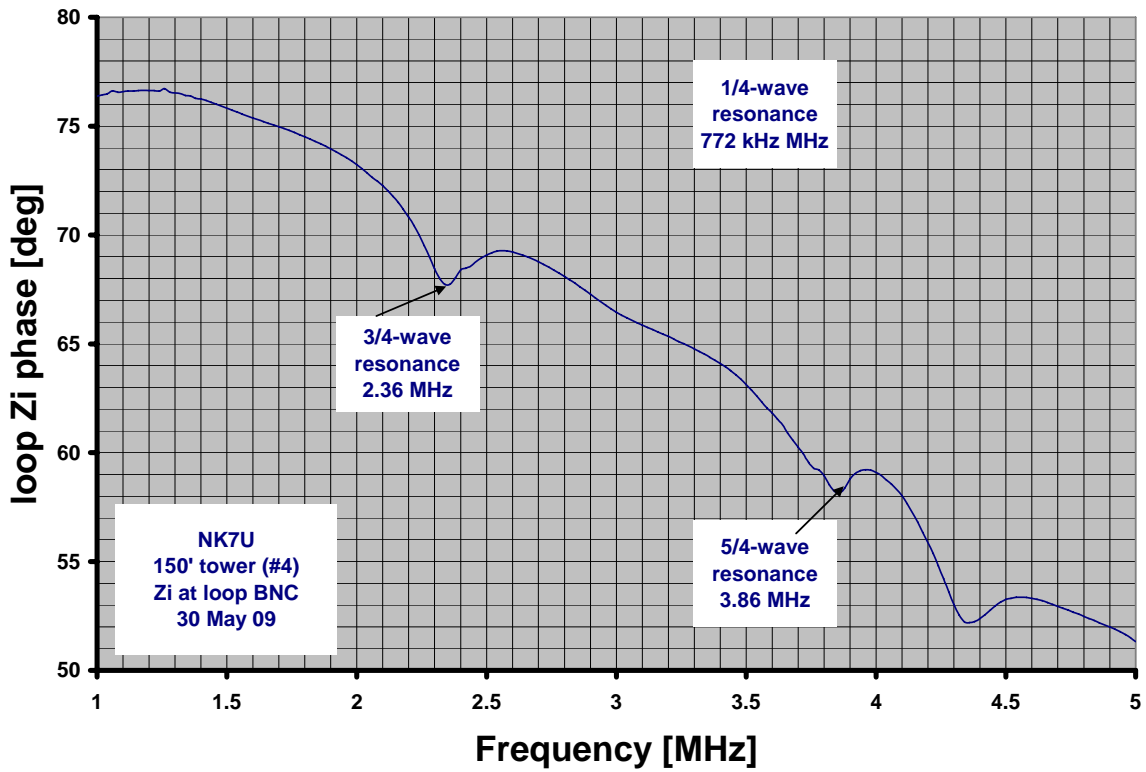


Figure 11, sampling loop Zi phase for tower 4.

I then went back to V2 and measured its Zi without the trap and with the trap tuned to 3.510 MHz.

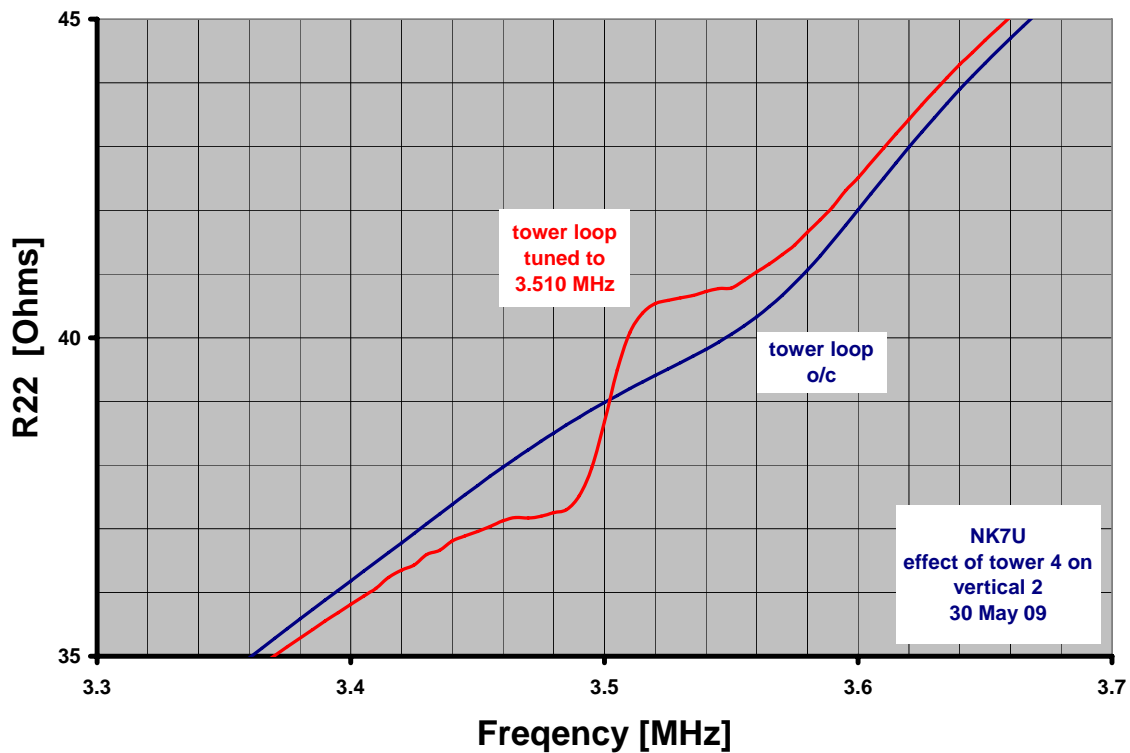


Figure 12, Rin for V2 with and without the trap on tower 4.

Figure 12 is a graph of R_{in} for V2 expanded around 3.5 MHz. Finally, we see something happening! I'm not sure that putting a trap near the base of tower 4 is an improvement, it may actually make things worse but it definitely has very demonstrable effect. I ran a similar test between tower 4 and V3 with similar effect only reduced in amplitude. V3 is further from tower 4 than V2.

Summary comments

Looking over all the measurements, I don't see any gross effects from towers 1 and 2 but tower 4 definitely is interacting with the array. Another item which I haven't mentioned to this point, is that the anchor points for one set of guys for tower 4 are within 15' of V2. The lower portions of the guys are galvanized steel cable broken up with egg insulators. However, some of the guy sections, which are close to V2, are nearly 60' long. These guy sections are floating so in theory they should not have a serious effect. However, we have still recommended to Joe that he break these up further. I want to do some modeling of these guys and a vertical to see what the effect is on a vertical very close to them.

Mostly due to advancing senility and but also from past experience where NEC was grumpy modeling antennas where part of the antenna was a parallel wire transmission line, I have been doing very little modeling of towers with traps. Instead I've been spending days and days and, doing experiments in the field! I recently saw some of Greg Ordy's (W8WWV) work on modeling a vertical with a trap which looked like it worked just fine. So I did it myself and sure enough, with a bit of care, it works great. I have a lot of experimental data which I can now try to correlate with NEC modeling.

In fact at this point I think modeling will be much more effective a sorting out what's going on at NK7U than further measurements. There are a lot of questions which will be much easier to answer with modeling than measurements. for example, just how wide is the effective bandwidth, in terms of pattern distortion, of a given trap, on a given tower? George and I have been puzzling over that for a while. I think modeling is the only practical answer and that will now be my focus.

[1] www.antennasbyn6lf.com, NK7U array tests 7 Oct 08

[2] www.antennasbyn6lf.com, Some notes on measuring tower resonances