Modeling the Choke Balun in NEC

Ward Harriman
AE6TY
1-Apr-21

Background

In February and March of 2021, the SimSmith discussion forum has been centered on the proper way to measure the 'common mode rejection ratio' of a balun. The discussion has centered on the technical mechanisms by which to make these measurements. The end result of those measurements as a single, scaler quantity referred to as the CMMR. The discussion is worth reading for the background of this paper.

Independent of the techniques involved with the measurement, I expressed concern that a scaler quantity is insufficient when discussing the utility of a balun when applied at the feed point of an antenna. Specifically, I pointed out that the reactance of the choke would affect the operation of the system, potentially causing unexpected resonances. If this was the case, the 'choking impedance' of the balun would need to be expressed as a complex number rather than a simple scaler. This phenomenon was easily demonstrated in NEC. The discussion then pivoted to how to determine the proper value for the lumped element introduced in NEC.

The traditional way to determine the proper value for the NEC element is to calculate the inductance using various equations or simply measure it using an inductance meter. The result of this measurement is radically different that that reported by measuring the 'common mode rejection ratio' of the balun. Reports in the SimSmith forum indicate a difference of a factor of four in one case. It was proposed that the traditional modeling of the choke balun in NEC was wrong.

I set out to decide for myself.

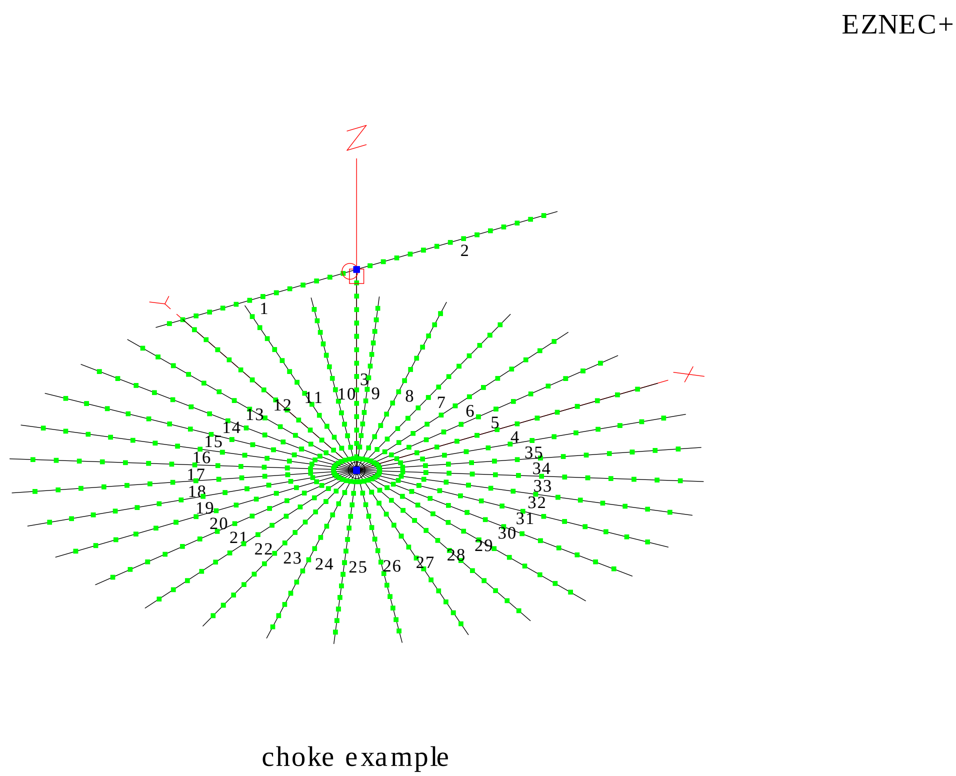
This paper is a report of a set of measurements of physical antennas and NEC models. The SimSmith forum discusses choke baluns constructed from twisted (or parallel) wires passing through ferrite cores. When measured as simple inductor, these baluns are quite lossy. The baluns I use in these experiments are NOT lossy. They are all air core baluns. I use these baluns so as to simplify the modeling in NEC and to maximize the effect of the reactance. The question to be answered is simply, "Is the simple inductance of these low loss baluns the proper value to insert into NEC as a simple load element?"

What I did….

I built and modeled three different, 200 MHz antennas. I measured the physical antennas and compared them to the NEC predictions. I reached a conclusion.

The NEC Model

Below is a picture of the NEC model. It consists of a dipole being driven by a NEC source and a single wire modeling the feed line connected to one side of the dipole and connected to a radial system. There is no NEC ground. Here is a picture:



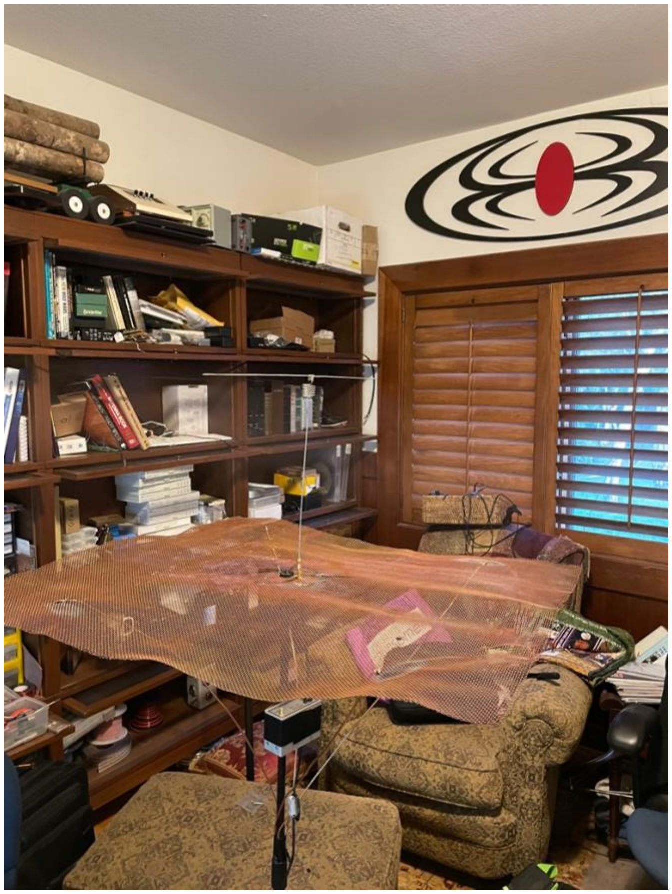
The small circle on the dipole is a NEC source and the small square is an inductor which is used to model the choking impedance of the balun. Initially, the inductance is set to 0. The model was simulated, and the dimensions were fine tuned to match the measurements to establish a starting point.

The Physical Antennas

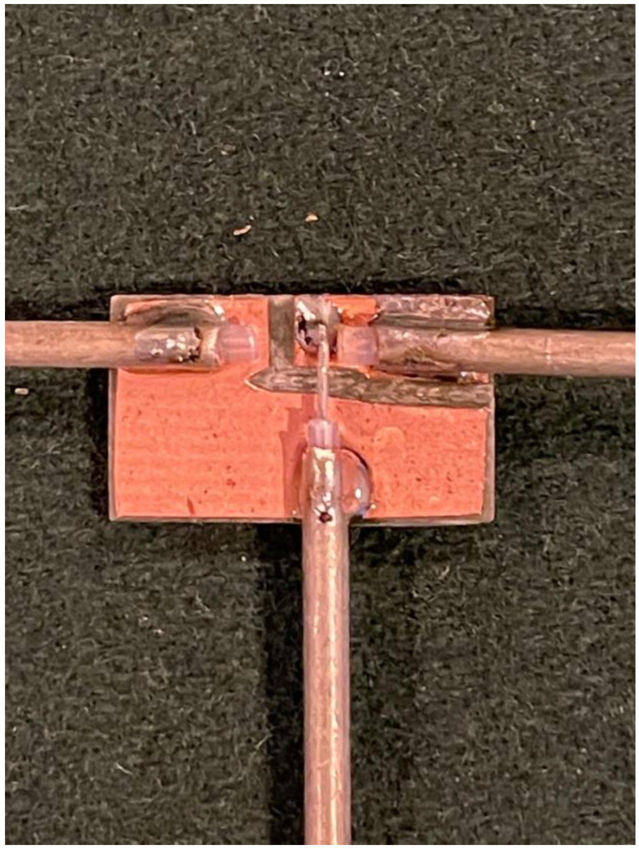
The antennas were constructed using 50 ohm ‘hardline’ coax purchased at the local electronics surplus store. It has a .087” outside diameter and is tinned. All connections were made using either solder or SMA connectors. The operating frequency turned out to be 207 MHz.

Instead of using 32 physical wires, the ‘radials’ were constructed using a piece of copper screen scrounged from my garage. The screen is 29” wide and 36” long. Here is a picture of the test setup in my back yard.

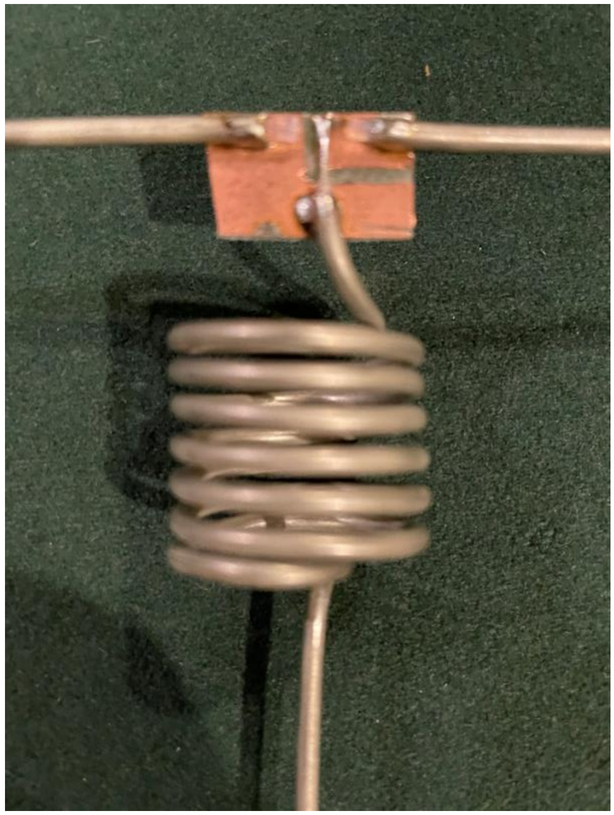
NOTE: measurements were NOT made in my back yard. My VNA is connected to a PC using USB and I have no portable PC. As a result, measurements were made in my study. My study is definitely NOT an anechoic chamber; the house is stucco, and my study contains a great deal of metal. Here is a picture of the test setup in my study. I know, it's a mess.



The feed line and dipole are both constructed from the hardline. The junction between the feed line and the dipole looks like this:

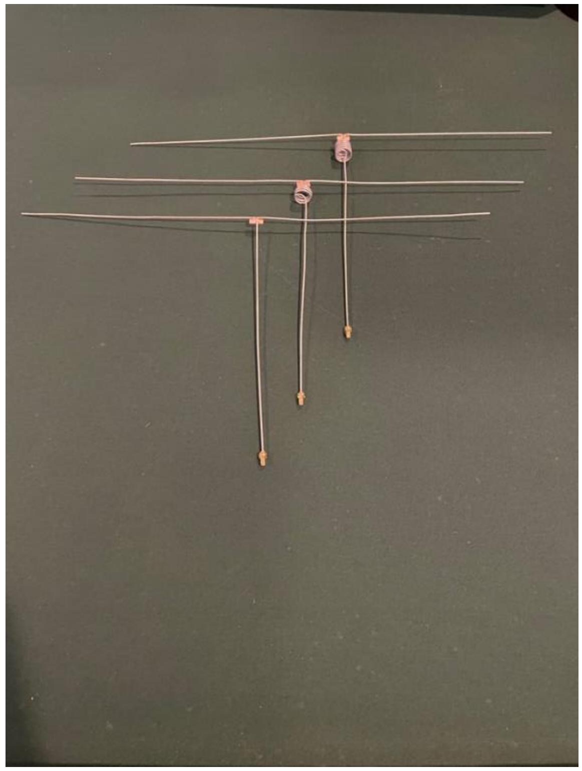


The baluns are simple ‘coax coils’ constructed by bending the feed line:



The coils are approximately 2 cm in diameter. A ‘six turn’ inductor is roughly 2 cm long. An online calculator indicates an inductance of .58 uH. A ‘four turn’ inductor is about 1.5 cm long and the online calculator says the inductance would be .27 uH. I also used my “Almost All Digital Electronics” inductance meter which delivered answers essentially the same as the calculations.

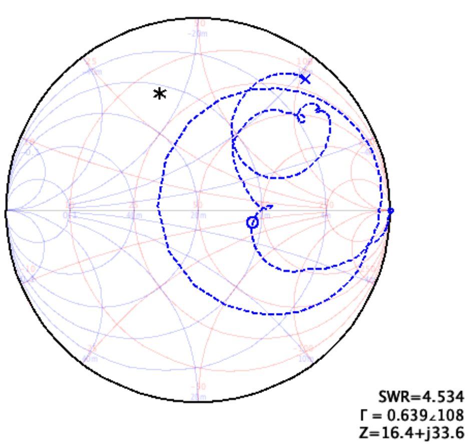
Here is a picture of my three test antennae:

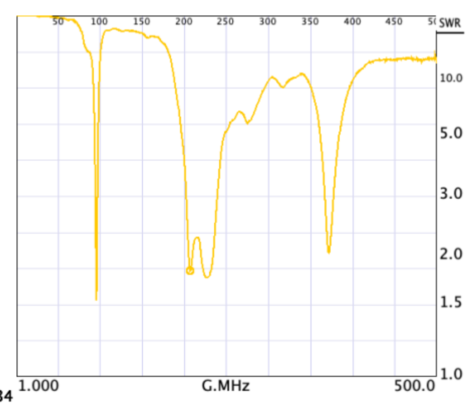


Measurements

To make measurements I started by calibrating my VNA. The reference plane was the base of the feed line immediately above the screen. The frequency range was 1 to 500 MHz using 2000 steps.

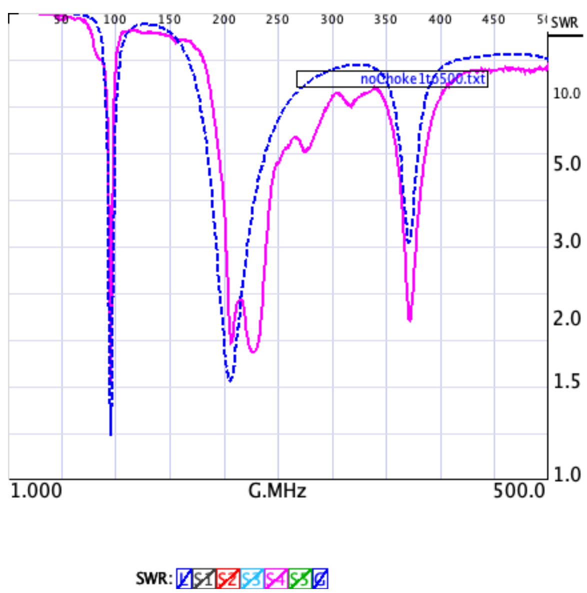
The 'no balun' antenna was measured. Here is the resulting Smith Chart. SimSmith was used to subtract out the feed line length:





The coils also add additional rotation of the traces in the Smith chart and these rotations make direct comparison of the traces cumbersome. The SWR charts, on the other hand do not reflect the angle of the impedance and so provide a more convenient medium for comparison. As a result, the SWR charts will be used for comparison for the rest of this paper.

After this initial measurement was made, the NEC model was dimensioned so as to deliver results consistent with the above SWR chart. The double minimum and various resonances are affected by my environment. I did try several different orientations and the dip and resonances changed. Ultimately, I picked a convenient placement and moved on. Here is the tuned version of NEC compared to the ‘no balun’ measurement. (Remember, I tuned the NEC model to match here.)



There are three features of the above plot that should be noted. The first is at 207 MHz which is the target operating frequency. At that frequency the impedance looking down the feed line is extremely high. This is because the length of the feed line plus the length of the radials is half a wavelength. One would not expect the choke to have any substantial impact at this frequency.

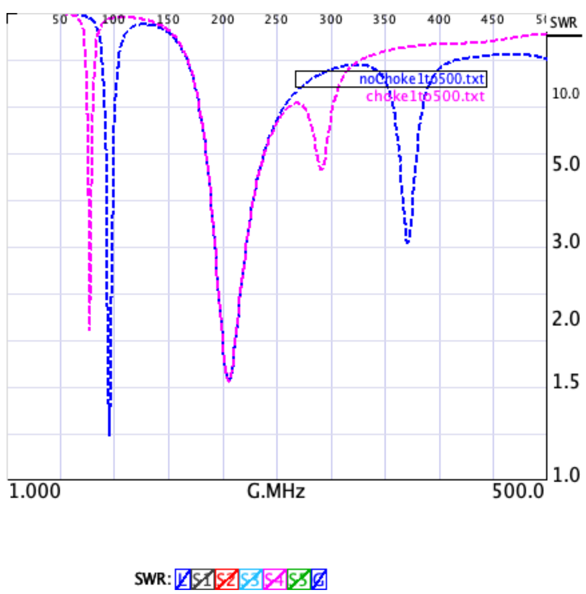
The second feature of note is that resonance down around 70 MHz. This is the fundamental resonance of the system. If the choke balun reactance were to have an effect, it should show up as a change of this frequency.

The third feature is the resonances up around 330 MHz. It would be expected that these resonances would also be affected by the presence of a choke on the feed line.

Having aligned the NEC and measurement model I proceeded to the next step.

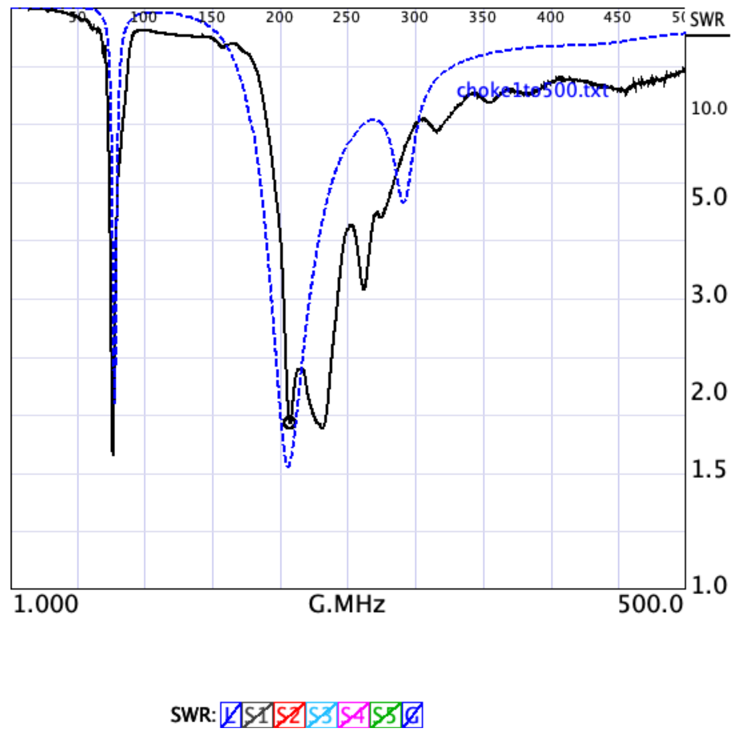
Comparison

As indicated above, I construct two antennae with 'choke baluns'. The first was four turns with a calculated and measured inductance of .27 uH. Here is a comparison of two NEC models, one without a balun and one with a balun modeled as a simple inductor of .27 uH inductor on the feed line:



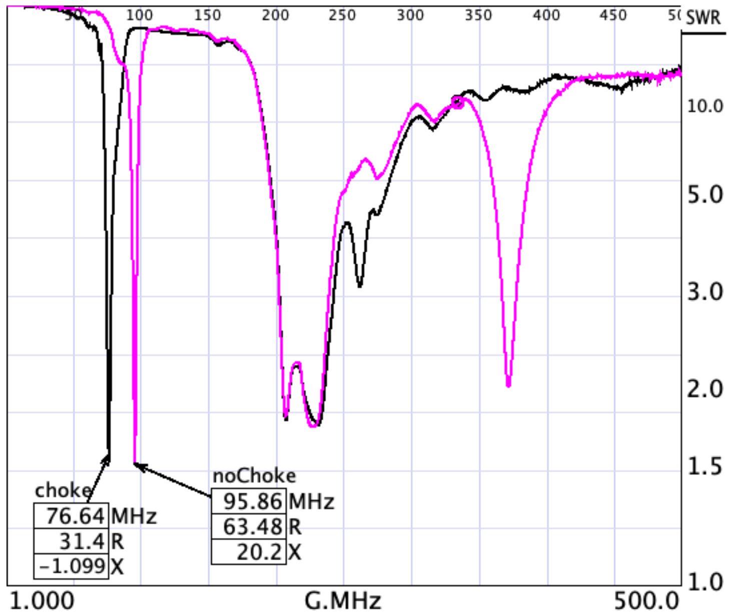
NEC clearly shows that the feature at 70 MHz has moved downward, that the feature at 207 has not changed much, and the feature a 330 MHz has moved downward.

We have arrived that the moment of truth. How does this measurement compare to that of a NEC model with a .27uH inductor inserted as indicated above? Here is the resulting comparison:



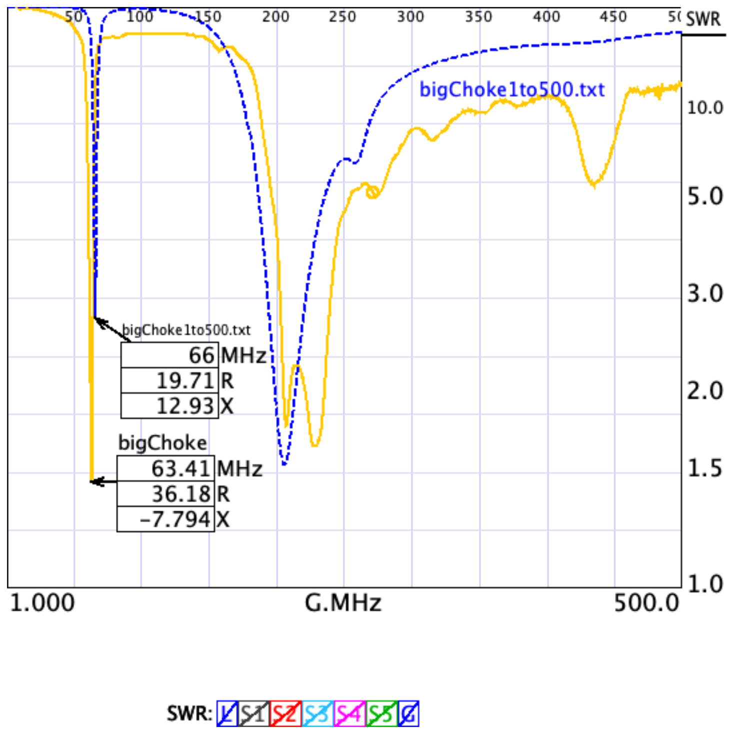
As can be seen, the lower resonance as precited by NEC and as measured align perfectly. The feature at 207 has moved down slightly from that predicted and the resonance predicted at around 290 has moved down even more than predicted. These movements may be due to the self-resonance of the choke which has not yet been measured. This is an avenue for further exploration.

To see the extent of the movement, here is a comparison of the measurements of the ‘no choke’ and the ‘.27uH choke’ antennae:

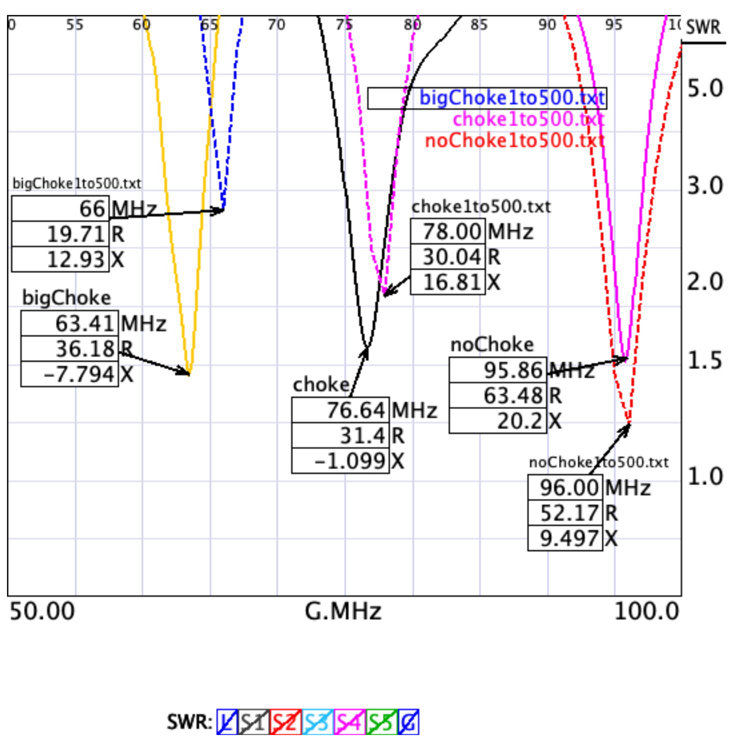


There is a clear movement of approximately 19 MHz predicted by NEC and verified by measurement.

As confirmation, a second choke balun was constructed with a calculated and measured inductance of .58 uH. Here is a comparison of the NEC prediction and the measurement:



Note that this is a small difference between the measured and the simulated results. Presenting all six measurements results in very messy chart:



There are three areas of interest. The first is at about 95 MHz. The 'no choke' case. These frequencies align by construct and there is nothing much to be learned there.

The second area is around 78 MHz. These two traces compare the NEC prediction using a .28 uH inductor and the four-turn balun. There is some divergence but there is general agreement that the .27 uH inductor is quite close to the right model for NEC.

The third area is around 65 MHz. These two traces compare the NEC prediction using a 5.8 uH inductor and the six-turn balun. Again, there is good agreement between the NEC model and the physical measurement.

Conclusions

The goal of these experiments was to determine how to model low loss feed point baluns in NEC. Three antennas with different baluns were constructed and measured. The inductance of the baluns was measured directly and inserted into the NEC model as simple inductances on the feed line. The results of the measurements and the NEC simulations were compared. There was good agreement between the antenna measurements and the NEC simulations.

Conclusion: low loss feed point baluns can be modeled in NEC as simple inductors whose values can be determined through calculation and/or the use of simple, low-cost inductance meters.

Remaining Work

The self-resonance of the choke baluns has not been measured or modeled.

The measurement of feedline currents has not been done. This might be necessary IF there is reason to believe that it is possible for NEC to correctly predict feedline impedances and yet NOT correctly predict currents in the feedline and/or radial system.