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Modeling the K9AY Loop

The first K9AY Loop was designed and built in the fall of 1996 — more than 18 years ago. From the beginning, the issue of modeling this antenna in NEC-based programs was a matter of concern. Its small size, loop configuration, and a connection to real ground are all factors that collide with recommended practices for NEC simulation. It took several years to develop and confirm a reliable antenna definition in *EZNEC* (or your preferred modeling program). This article shows the parameter setup I use for the K9AY Loop and other small receiving antennas. The final step in its development came in the summer of 2013, when I built and tested several new antenna structures that were developed and refined though modeling. They successfully matched the predicted performance, validating the modeling method. One of the new designs is presented as an example.

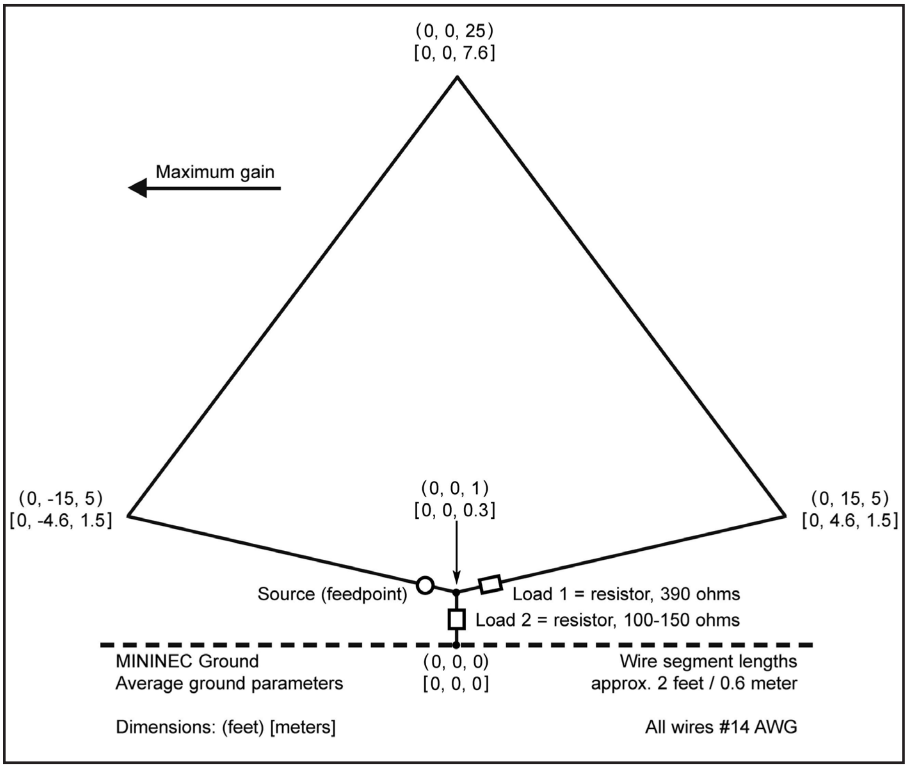

Figure 1 — The basic K9AY Loop with dimensions and parameters for NEC modeling.

It's All About the Loop

Figure 1 is a diagram of a single K9AY Loop. Physical construction is defined by the *x-y-z* coordinates of the wire ends, along with the locations of the feed point ("Source") and termination ("Load 1"). Modeling setup parameters are noted on the diagram, and there is an additional resistance in the ground wire ("Load 2") that I will explain below.

The height of the loop is 25 feet [7.6 m], and its width is 30 feet — or 15 feet [4.6 m] from center to each of the outer corners. The bottom wires have feed point and terminations connected to a common point at the top of a 1 foot high [0.3 m] grounding wire. Maximum radiation is toward the side with the feed-point connection, in line with the loop wires.

There are several options for small antennas that operate similarly, including the EWE, flag, and pennant designs. This configuration was selected, because it has the following key characteristics:

♦ Support at a single point for ease of installation

♦ Direction switching at a single point, enabling simple four-way switching with two orthogonal loops

♦ The largest size that meets guidelines for a "small loop" at 80 meters and lower frequencies, usually considered to be a maximum of 0.1 λ diameter or 0.3 λ circumference

♦ The ground connection results in approximately 3 dB higher signal level than the same sized flag or pennant

A model that simply replicates the antenna's construction, including connection to real, high-accuracy ground, does not conform to NEC recommended practices. First, the antenna connection to real ground is a known problem in NEC-2. Even in NEC-4 the results are variable. Next, using the recommended number of segments to accurately model a loop makes them shorter than the recommended minimum segment length. My first model had variations in the results for different numbers of segments. After some study, these variations were identified as changes in currents in and out of ground; from erroneous computations, not actual physical behavior.

To try to identify the antenna's true performance, I modeled the antenna in free space, replacing the ground connection with a mirror-image of actual wires (see Figure 2). After adjusting the termination resistance for best results, the gain and the location of the nulls correlated well with the modeling parameters and segmentation that were my best guess for the grounded

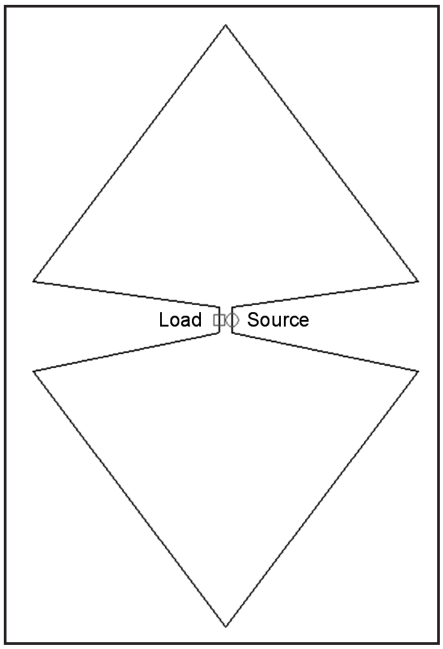

Figure 2 — Free-space configuration of the loop for evaluation without a ground connection.

loop. At this point, I set aside my doubts about the accuracy of NEC simulation and built the antenna. It worked well, and its behavior — pattern shape, terminating resistance value, and feed-point impedance — were just as predicted. Trial-and-error adjustment of the terminating resistance ended up returning to the original value.

Figure 3 shows the pattern plots — vertical pattern (a) and horizontal pattern (b) at 30° elevation. There is a single null in the direction toward Load 1, which is 35° above horizontal for this loop configuration, so the horizontal plot does not show the deepest null. Also, the top of the horizontal plot corresponds to the direction of maximum signal, off the end of the loop. My initial model showed antenna gain to be –26.2 dBi. Comparisons with the transmit antenna and 1.0 λ Beverages confirm that the gain is in this range.

A More Reliable Modeling Method

The troublesome connection to ground kept bothering me, especially after I'd begun to study a number of alternative sizes and shapes, elevated installation, arrays, and other new configurations. Then I remembered a passing comment from Roy, W7EL, when first discussing how to properly model the antenna. He said something like, "...well, at least *MININEC* ground is stable." So, I changed the ground type and placed a resistance in the ground lead to represent all system losses, including ground loss (Load 2 in Figure 1). This is an example of the *equivalent circuit* technique that is common in computer simulation. *MININEC* ground uses perfect ground for current and impedance calculations, while far-field pattern calculations use real dielectric ground. Load 2 was adjusted to a resistance value that resulted in gain and pattern shape that matched the earlier model, which is known to agree with measured results. Using this procedure, I determined that setting Load 2 resistance to 100-150 Ω provided the best agreement.

The value of Load 2 may also be inferred from the free-space configuration of Figure 2. The optimum termination of a K9AY Loop is about 400 Ω, so the mirror-image free-space version would be expected to have a value of twice that, or 800 Ω. Instead, the optimum termination is near 1000 Ω, which suggests that the total resistance in the ground-mounted loop is actually 500 Ω, comprising the 400-Ω terminating resistor at Load 1 plus 100 Ω of loss resistance at Load 2.

To summarize, *MININEC* ground is used, with the Source, 400 Ω termination (Load 1), and 100-150 Ω system loss resistance (Load 2) placed as shown in Figure 1. Wire segments are approx. 2 feet long, so the bottom wires have 9 segments each, while the upper wires have 11 segments each. With this modeling setup, I have continued to explore different loop configurations. A bonus is that computations are executed faster with *MININEC* ground than with real ground, which is nice when analyzing large arrays and complicated multi-loop designs.

Example of a New Loop Concept

In the summer of 2013, I finally set aside time to construct and test some ideas that had been developed as long as 15 years earlier. In particular, I wanted to confirm that a number of multi-loop configurations worked as predicted by NEC simulation. One of those new designs — a 2 turn loop — is presented here as an example.

Figure 4 is the *EZNEC* view of a 2 turn loop. With two turns cutting the magnetic field (***H***) lines, the contribution from that part of the antenna's response is increased by 6 dB. The antenna also has a contribution from the electric field (***E***) component of the arriving wave front, which is increased by an uncertain amount due to the additional length of wire in the second turn (perhaps 3 dB?). To achieve the deep rearward null, these two responses are balanced by the terminating resistor, with the net result that the 2 turn loop has approximately 5 dB gain over a single loop with the same cross-section area.

As the old saying goes, "There's no free lunch." The extra inductance lowers the maximum frequency of operation. For example, the original loop will no longer cover 80 meters, if extended to 2 turns. Also, a 2 turn loop is a more complicated structure, although there is little increase in the required space, since it only needs 6 inch spacing between turns.

This technique is most useful for en-

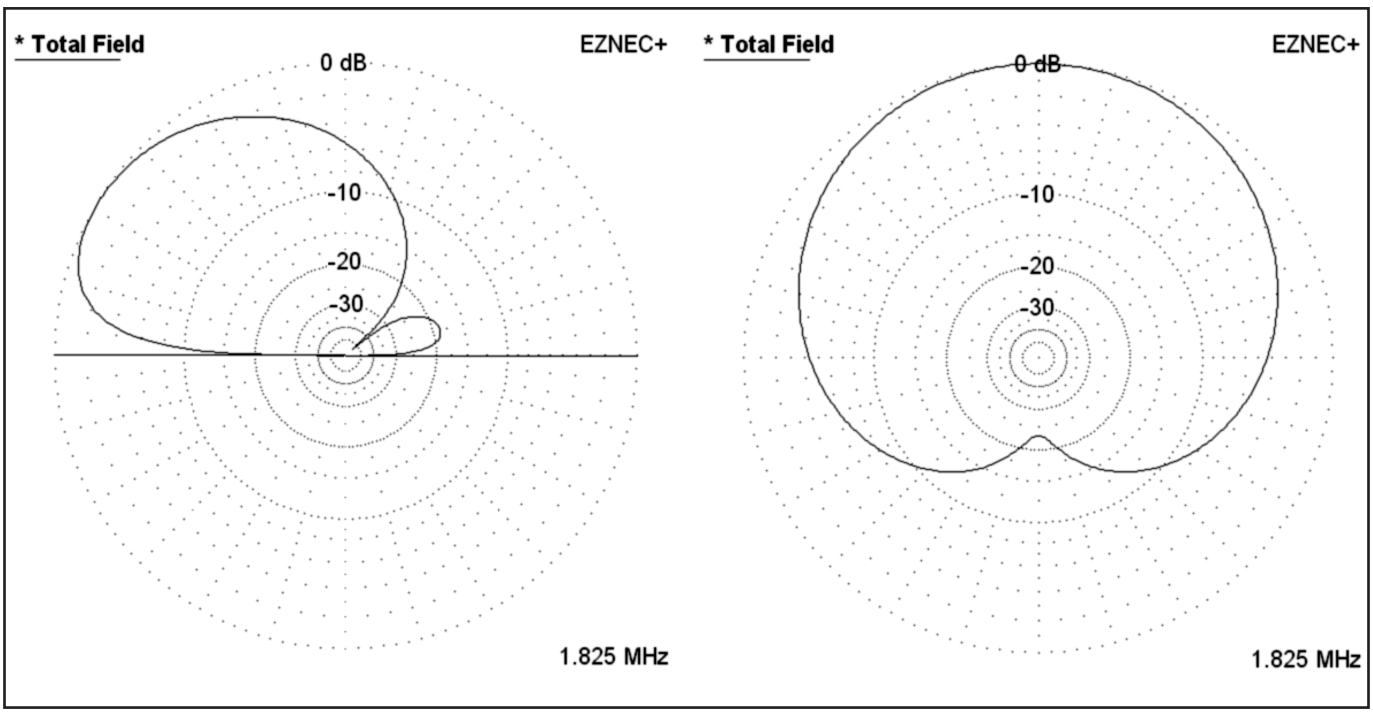

Figure 3 — Vertical (a) and horizontal (b) pattern plots of the K9AY Loop.

hancing the performance of smaller loops, which was one objective of my summer 2013 tests. Those multi-loop experiments used an 8 × 12 foot rectangular loop. A wooden frame (Figure 5) supported wires for a number of multi-loop configurations, which were evaluated by comparing them to a nearby loop built according to the originally published design.

A single 8 × 12 loop has about 10 dB lower gain than the original loop, since this smaller loop has an enclosed area of just 96 square feet versus 360 square feet for the original design. The gain achieved by using 2 turns restores some of the loss, so it is just 5 dB down from the original loop. The higher signal level has the benefits of lower noise floor, less preamp gain, and reduced susceptibility to common mode problems. Testing verified the relative gain predictions in *EZNEC*, using several AM broadcast stations and 2.5 MHz WWV as signal sources. Front-to-back tests showed that the deepest rearward null was achieved at the expected value of terminating resistance.

The 8 × 12 size was chosen, because it is the largest size where a 4 turn loop will still cover 160 meters. The 2 turn loop described above can be used on 80. Recently, I built and evaluated a rotatable 5.5 × 10.5, 4 turn loop. At this size, the loop performs well on 160 and has 10-12 dB F/B on 80, but no deep null (3 turns would be better for 80). This 4 turn loop has 7.4 dB gain over a single loop, so despite its small size of 58 square feet, it is just 6 dB down from the original loop.

Summary

Until a number of different configurations were built and tested, I was not fully confident that my method of modeling these small loops was accurate. With that work now done, the modeling setup shown in Figure 1 has been verified. Loops having different sizes and shapes can be modeled with confidence that they are represented properly in NEC-based antenna programs.

The above 2 turn loop example is just one of my recent experiments to improve the efficiency of smaller loops that are easy to deploy and have less visual impact than the 25 foot high, 30 foot wide original K9AY Loop. I am currently preparing a detailed description of those loop experiments and expect to have it published in the near future.

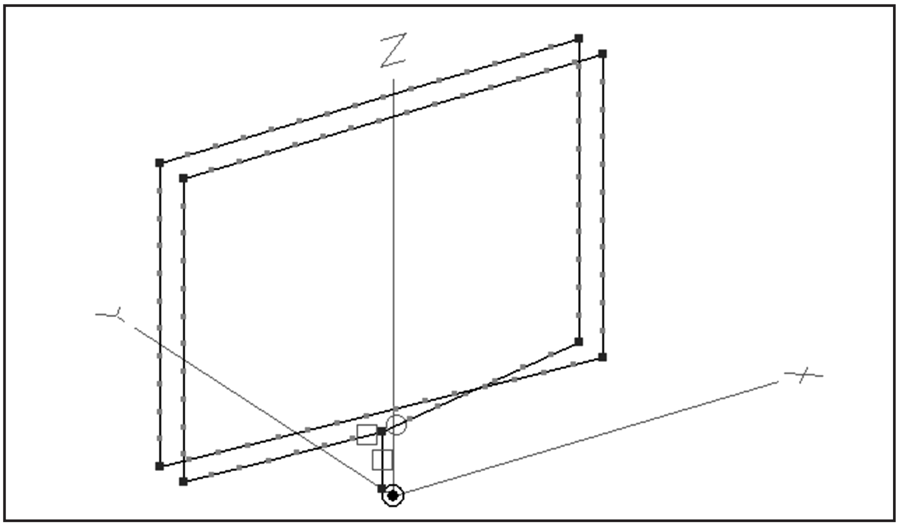

Figure 4 — A 2 turn K9AY Loop, which has ~5 dB gain versus a single loop.

Figure 5 — Test setup used to evaluate several 8 × 12 multi-loop configurations. [Gary Breed, K9AY, photo]