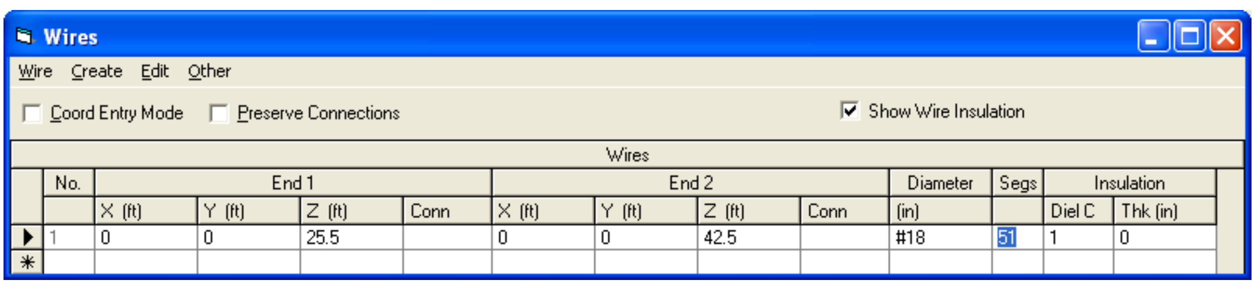
Feed Line Currents for Neophytes.

This paper discusses the sources of feed line currents and the methods used to control them. During the course of this paper two sources of feed line currents are discussed: ‘conducted’ and ‘induced’. These two sources are almost entirely independent. While most antenna projects address ‘conducted’ feed line currents, most do NOT address the ‘induced’ currents. Thus, in many cases, the traditional ‘cookbook’ solutions often result in antennas that do not perform as expected and may even be unsafe!

Getting Started, the Half Wave Vertical Dipole

The modeling of antennas for this paper is done using EZNEC by Roy Lewallen. EZNEC is an extremely easy to use tool and highly recommended. A ‘student’ version of EZNEC is available with the ARRL antenna handbook.

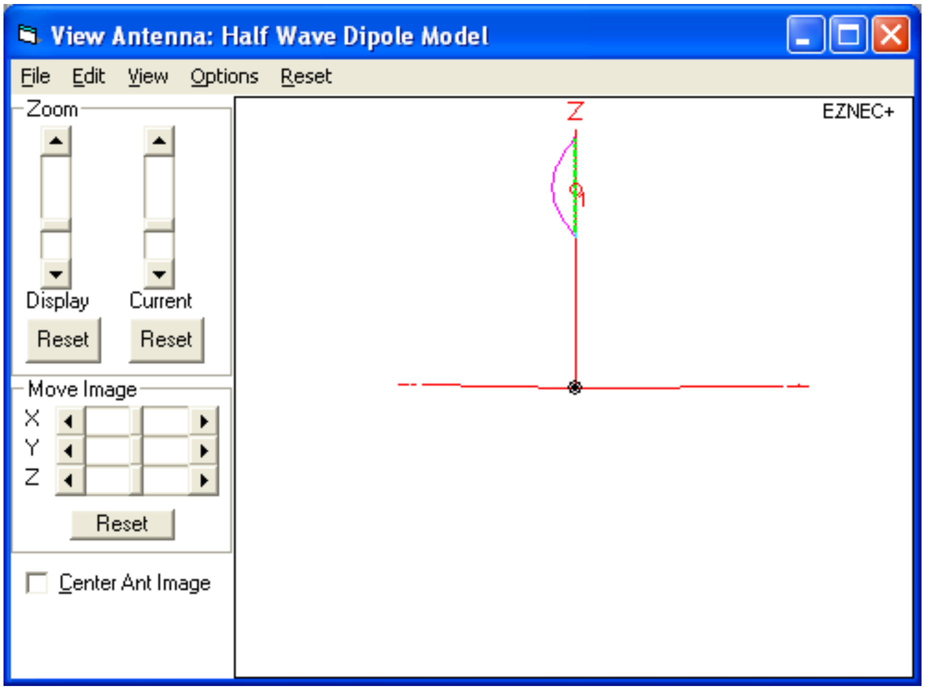
EZNEC allows the user to model a wide variety of antennas. For the purposes of this paper, only simple wires, impedances and drives are needed. EZNEC allows the user to specify the wires, impedances and drives using familiar ‘spread sheet’ style forms. Simple models can be entered in a few minutes and complete simulations take only seconds. For example, the very first model will be a single wire. It is entered as:



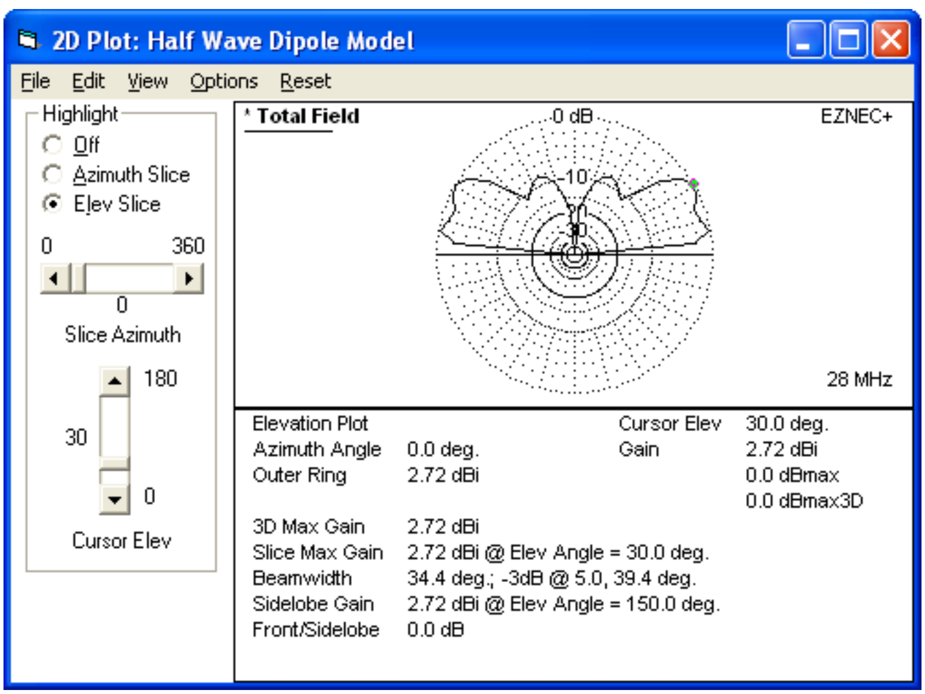
	Wires											
No.	End 1				End 2				Diameter	Segs	Insulation	
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)		Diel C	Thk (in)
1	0	0	25.5		0	0	42.5		#18	51	1	0

This single wire is the starting point of the exploration of feed line currents. It is a 28 MHz, resonant, vertical dipole antenna placed 1 wavelength above ground.

The output of EZNEC is largely graphical in form. Three graphs are typically used: the View Antenna, the 2D plot and the SWR plot. Examination of each of these graphs follows:

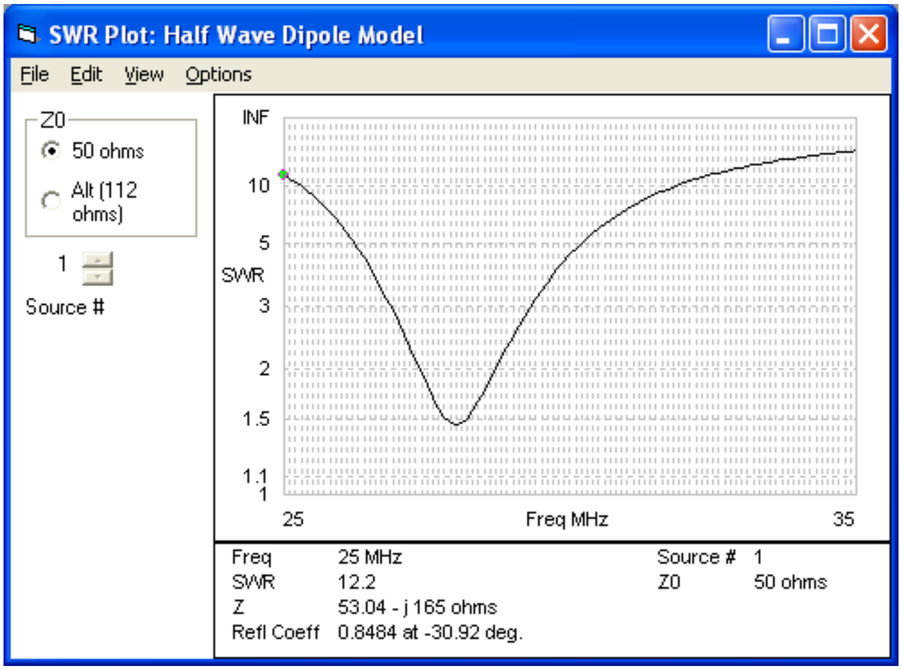


View Antenna:
Antenna wires are shown in green, drives are shown as red circles.
Loads such as inductors, capacitors and resistors will be shown as red squares.
The red arc shows the current distribution on the antenna wire. Phase of the current is not shown but available in the 'currents' file available from EZNEC.



2D Plot:
This shows the azimuth gain for the above single wire antenna. Key features of the 2D Plot are the outer ring gain (shown in the text at the bottom) and the little green dot which is the cursor. The cursor may be moved around. The gain of the antenna at the cursor is shown on the lower right of the text area.

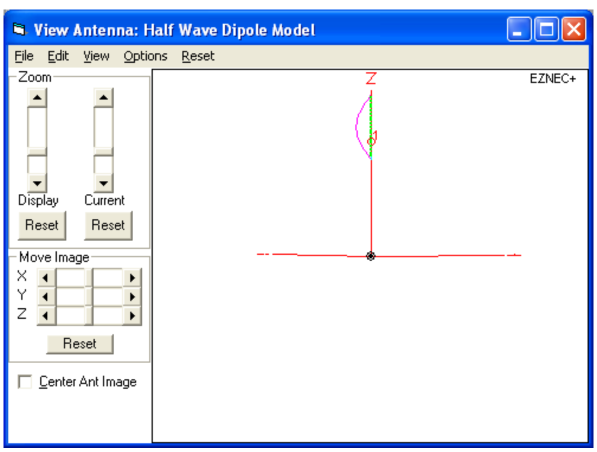
And the SWR plot (representing impedance) is:

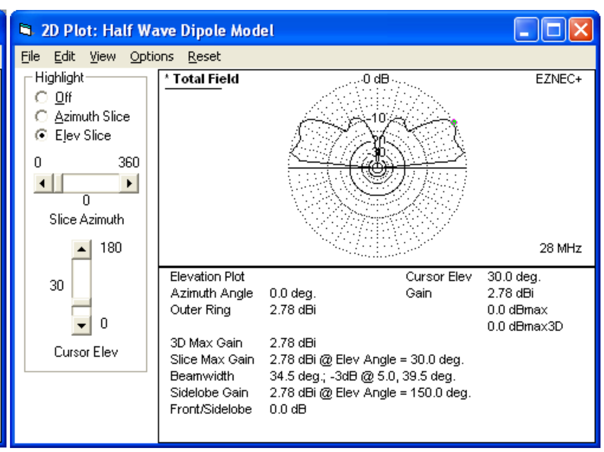


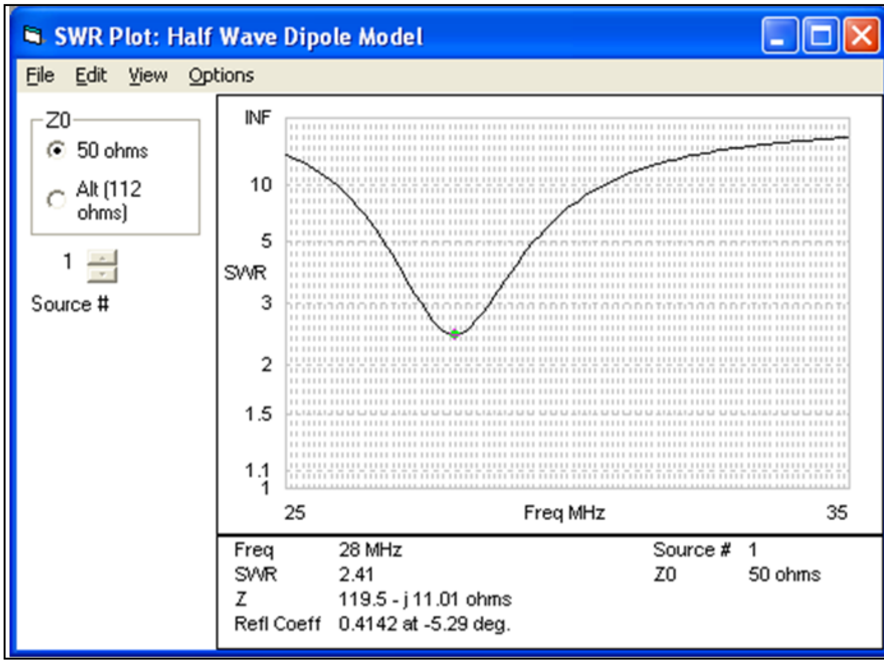
SWR Plot:
This graph shows the SWR for the modeled antenna. The SWR is relative to a specified impedance which is shown on the left hand side. The minimum in the graph generally represents resonance. The green cursor can be moved and the antenna characteristics at the cursor are listed in the text at the bottom of the graph.

The Effect of Off Center Feed Point.

Many antennas are driven 'off center'. In general, the more off center the drive the higher the impedance. Consider the off center feed point at 30%. Notice that everything is essentially the same except for the impedance at resonance:

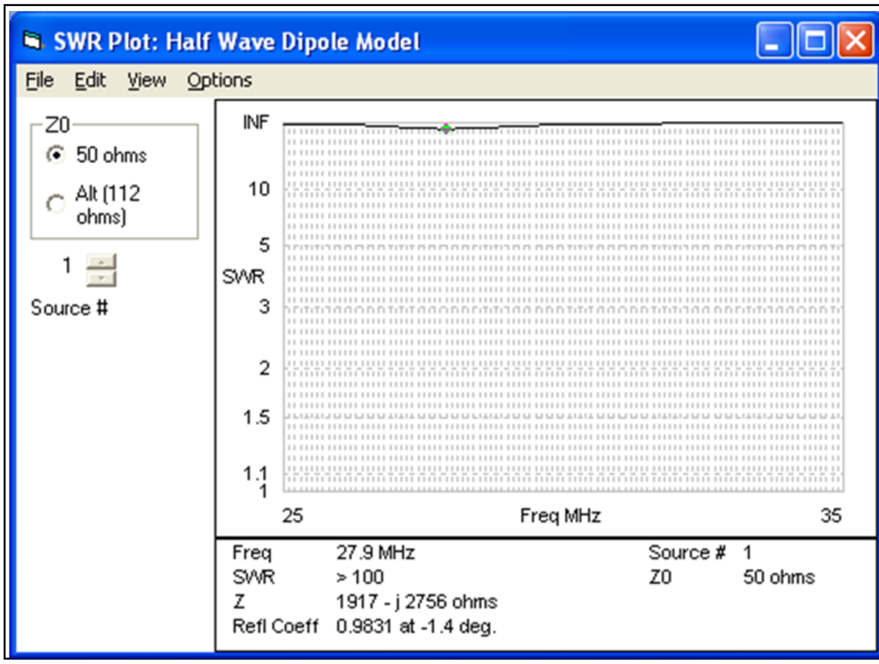






While the gain pattern and current distribution do not change as the feed point is moved, the impedance does. Here the impedance has risen to about 120 ohms.

Next we drive the antenna from the 3% point. Again, the current distribution and gain patterns do not change and so are not shown. And again, the feed point impedance changes significantly:



The SWR of a vertical dipole driven at the 3% point. Note the impedance has risen dramatically. Here it is nearly 2k ohms AND has a significant capacitance.

This last point should be emphasized. The drive impedance of a resonant dipole near its endpoint is very high. Consider a simple calculation. Suppose the antenna is expected to carry 5 watts. To drive 5 watts into this antenna will require a voltage of V = sqrt(P*R) or V = sqrt(5*2000) = sqrt(10000) = 100 volts. Even higher voltages can occur if the feed is even nearer the endpoint.

As can be seen, this very simple antenna model is extremely useful. It can be used to show the effect of moving the feed point as was done above. Other simple experiments are informative but not done here. Two other experiments suggest themselves: moving the dipole vertically and making the antenna horizontal with both will affect the gain pattern. These experiments are left to the reader.

In summary, a single wire model can tell a great deal about how the antenna will perform in an ideal environment. However, the goal of this paper is to understand how the antenna will perform when actually deployed. The major missing item in this model is the presence of the feed line.

The Basic Feed Line

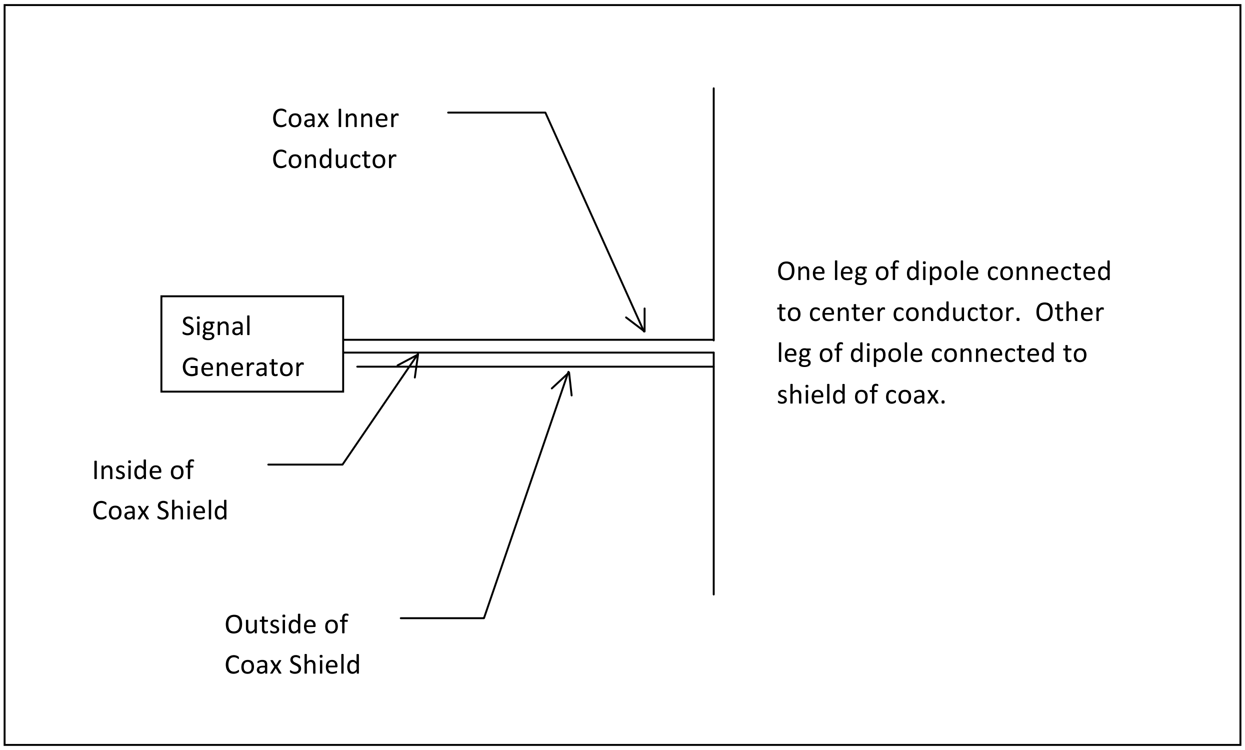
> Author's Note: as will be shown, the feed line can have tremendous impact on the characteristics of the antenna. In some cases the effect can be positive and in some cases negative. Here we try to discuss these effects without regard to their merit.

Most feed lines are coaxial cable or 'ladder line'. As one would expect, there are advantages and disadvantages to each. Generally speaking, coaxial feed lines are easier to deploy. Unfortunately, coax also introduces some unique problems.   For these reasons, this paper only discusses coaxial feed lines. It should be remembered, however, that 'ladder line' can have essentially all the same problems discussed below.

For the purposes of this paper the feed line is modeled as a single conductor wire. There is significant precedent and extensive experimentation which justifies this model. A short explanation of why this model is valid goes as follows:

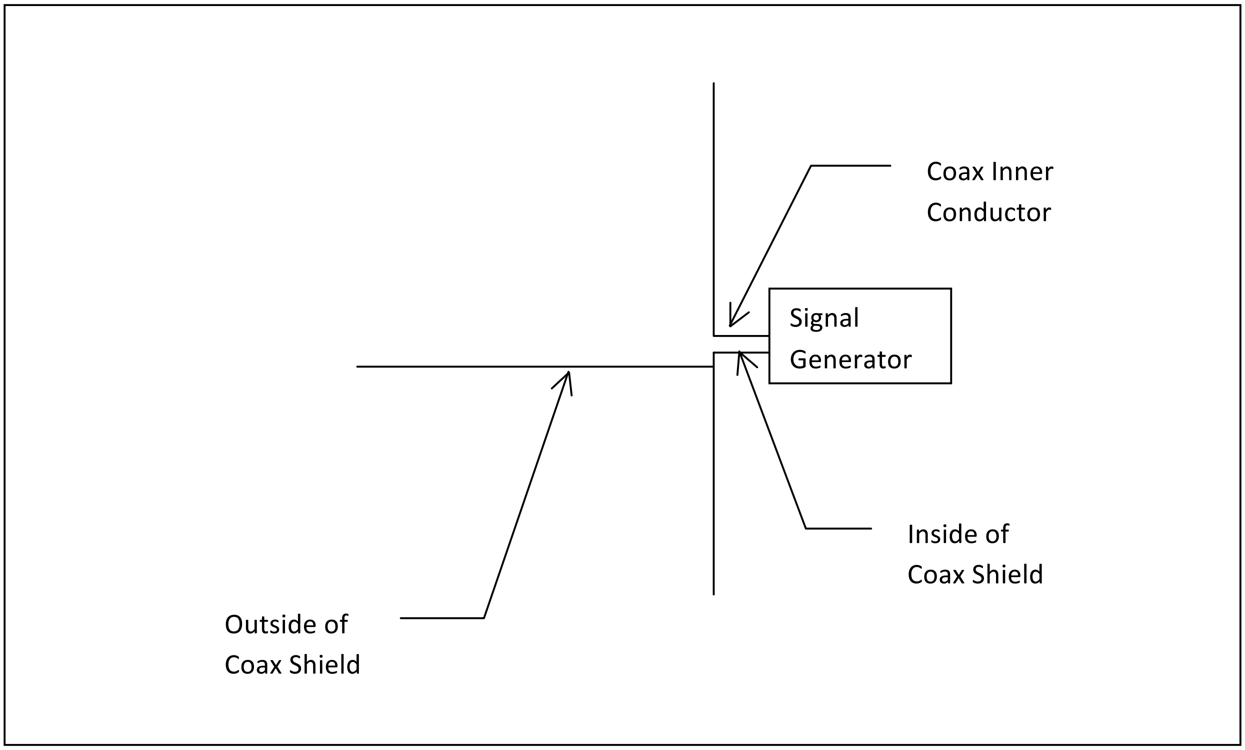
At RF frequencies electricity actually flows on the surface of conductors. Thus, for RF frequencies coax actually has three different conductors. The first is the center conductor and the current flowing on this conductor flows on the outer surface of this wire. The second is the 'inside' surface of the shield (also called the 'braid'), and the third is the OUTSIDE surface of the shield.   For all intents and purposes of this paper, the current on the inner surface of the braid is completely independent of the current flowing on the outer surface.

Now consider what happens when the signal generator is connected to the antenna through a coax feed line. At one end the transmitter is connected to the shield and the center conductor. At the other end, one leg of the dipole antenna is connected to the center conductor and the other leg is connected to the shield.



Now consider the currents which flow on the three conductors. Under normal circumstances the current flowing on the coax center conductor and the current flowing on the inner surface of the shield balance each other out: they are equal and opposite. All the current flowing on the center conductor is conducted onto the connected dipole leg. The current flowing on the coax inner surface, however, splits when it reaches the dipole. Some of the current will flow onto the connected dipole leg and some will flow onto the coax outer shield. The current flowing onto the outer coax shield is one type of ‘feed line current’. Specifically, it is called a ‘conducted’ feed line current.

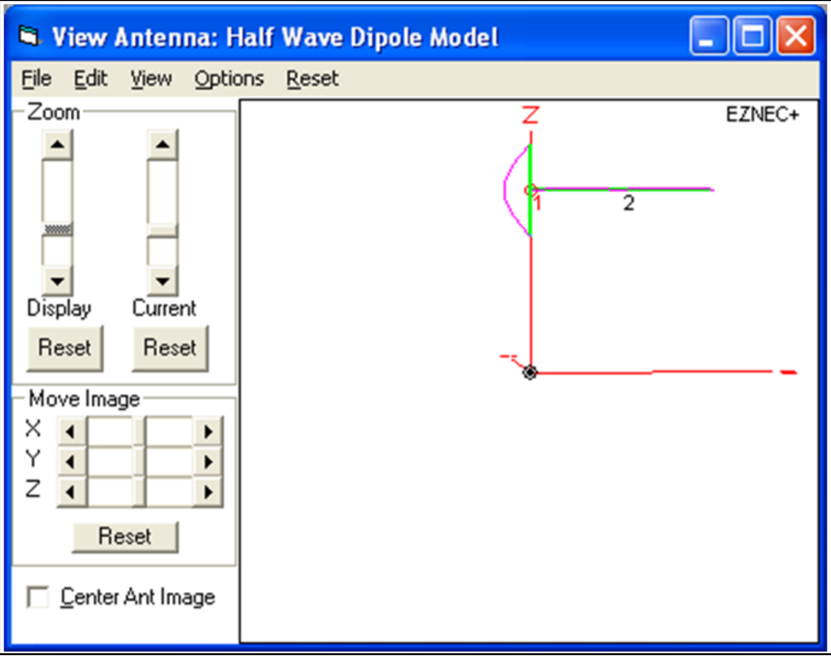
The next step in modeling this system is to eliminate the coax inner conductor and inner surface of the shield. Doing so results in a new drawing as follows:



Thus, the coax feed line can be modeled as a single conductor and the signal generator can be placed directly on the dipole.

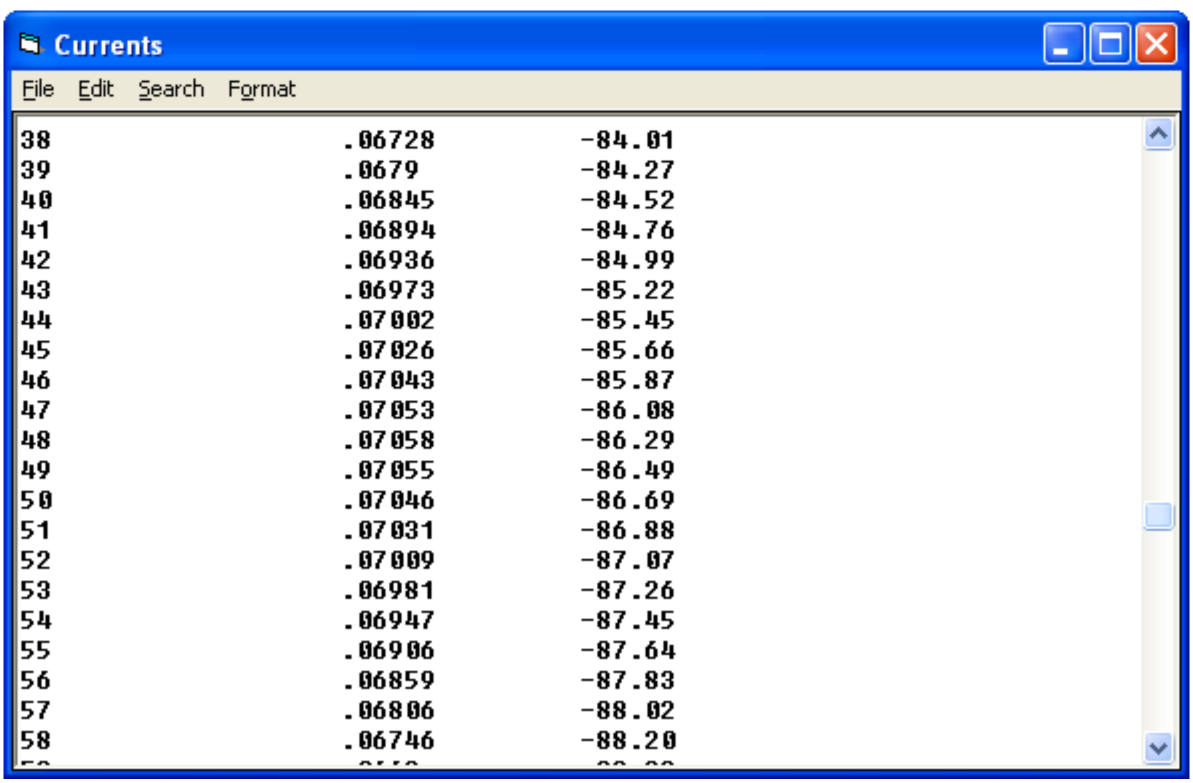
"Ideal" Feed Line, 90 Degrees from Center

The very first experiment with feed lines is to connect the coax feed line to the center of the dipole and run this coax directly away from the center of the dipole. This is the general recommendation made in every discussion of this topic. In this first experiment the length of the feed line is purposely chosen to be 1 wavelength long.   The feed line is connected to the center of the antenna and the feed point is connected just below it.

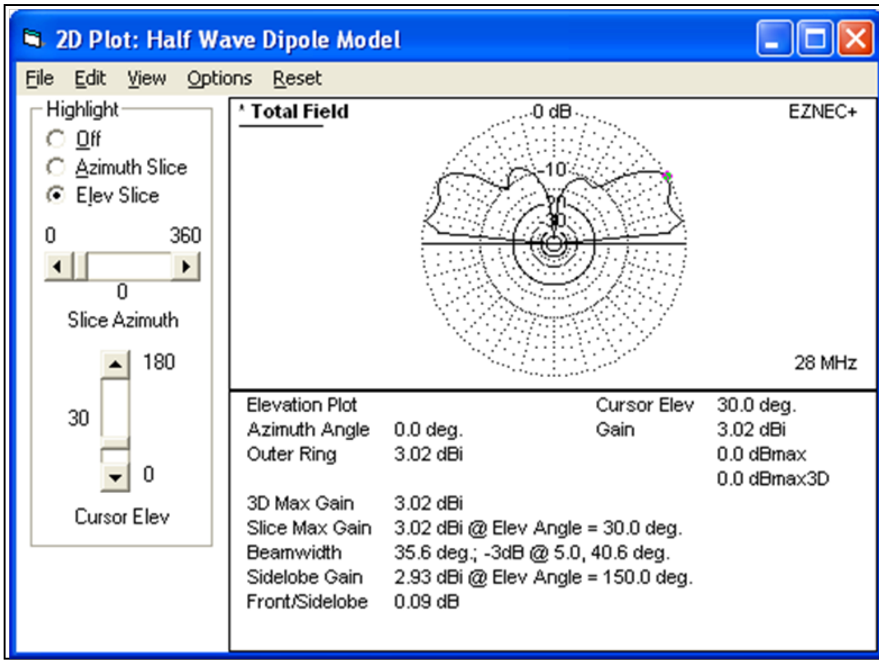


A horizontal feed line 1 wavelength long. Coax feed line connected at center with feed point immediately below the coax. This models having the coax shield connected to the top half of the dipole. Note that little current is flowing in the feed line.

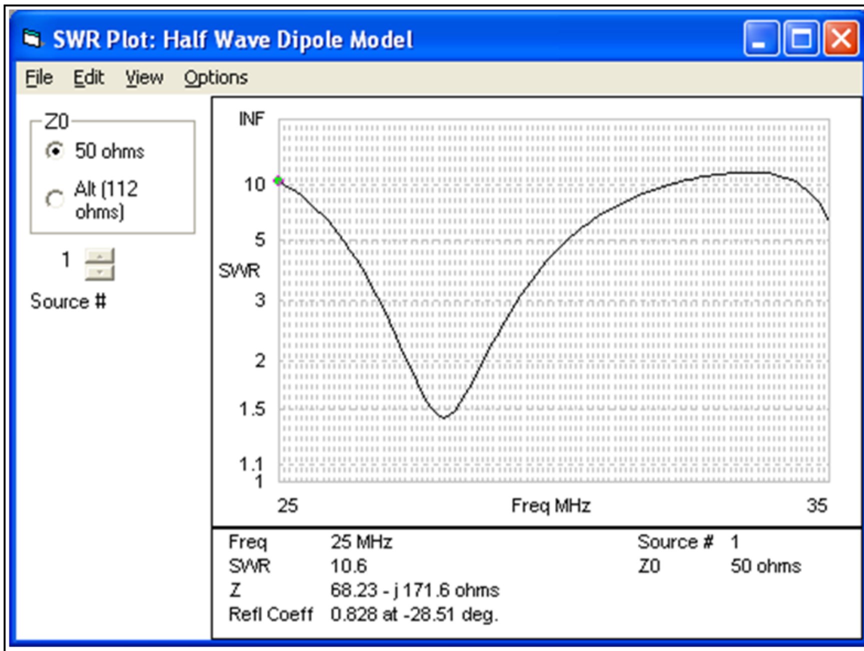
To look more closely an examination of the 'currents' file is in order. Here is a piece of the 'currents' file for the feed line (wire 2 above). Note that there is, in fact, some feed line current but that it is quite small. While wire 1 has peak currents of 1 amp (the specified drive), the feed line has peak currents of only .07 amps.


Currents
File Edit Search Format

38	.06728	-84.01
39	.0679	-84.27
40	.06845	-84.52
41	.06894	-84.76
42	.06936	-84.99
43	.06973	-85.22
44	.07002	-85.45
45	.07026	-85.66
46	.07043	-85.87
47	.07053	-86.08
48	.07058	-86.29
49	.07055	-86.49
50	.07046	-86.69
51	.07031	-86.88
52	.07009	-87.07
53	.06981	-87.26
54	.06947	-87.45
55	.06906	-87.64
56	.06859	-87.83
57	.06806	-88.02
58	.06746	-88.20



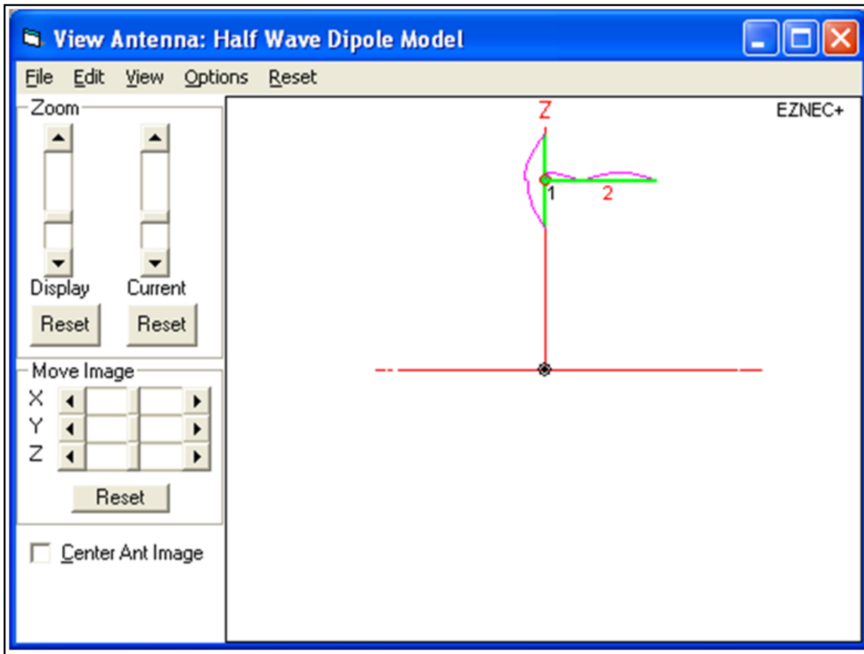
Since there are no significant currents flowing in the feed line there is no change in the gain of the antenna.



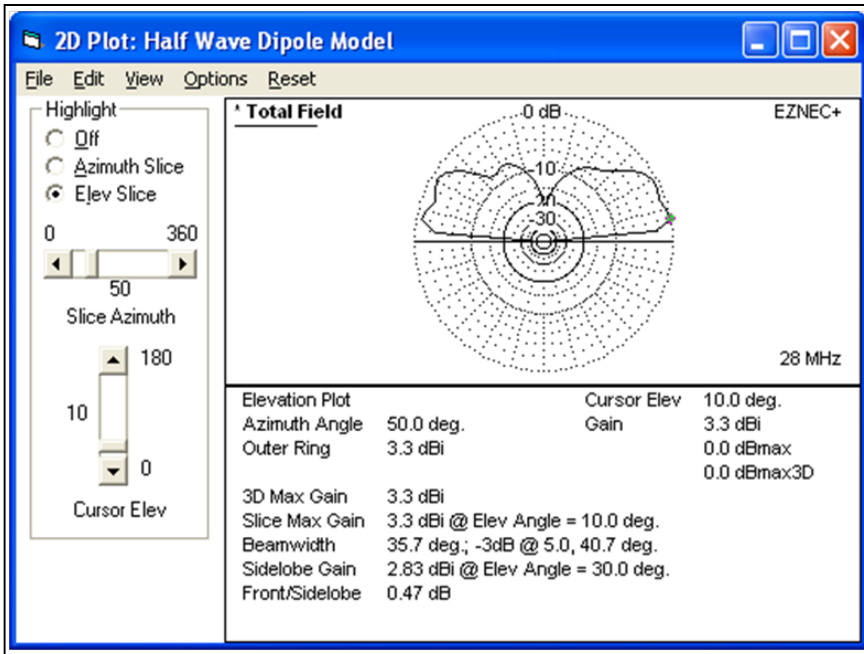
While the SWR of the antenna has not changed much at the operating frequency, close examination of the SWR plot shows that the feed line DOES have an impact off frequency. This hints that the length of the feed line might make a difference.

A little experimentation leads to the discovery that length of the feed line is critical.

The next experiment is to change the length of the feed line away from the 1 wavelength chosen. As it turns out, making the feed line .75 wavelengths will show a larger effect:

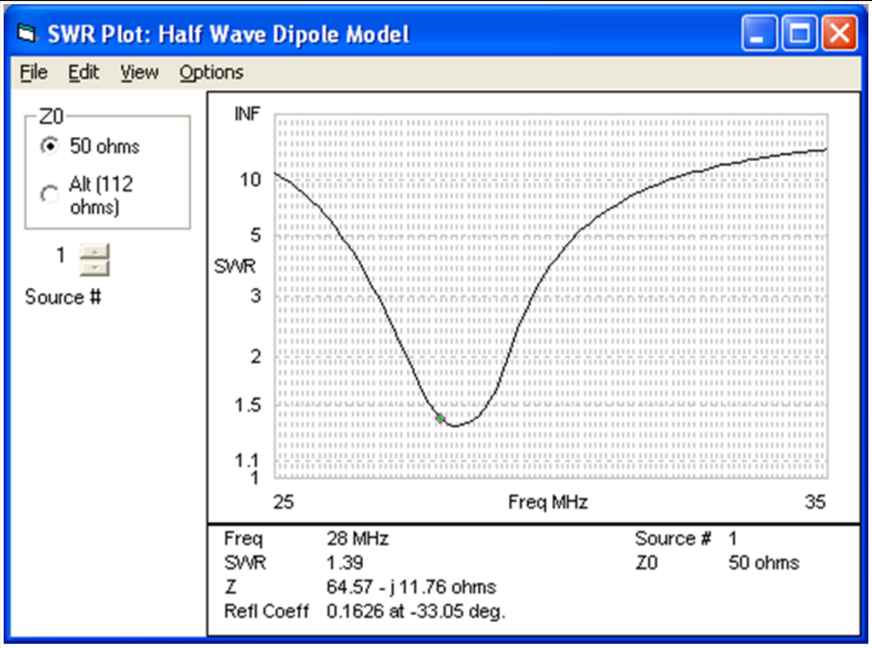


¾ wavelength feed line. Now there are significant feed line currents flowing in wire 2. This leads one to expect a change in antenna performance.



Note that the gain has actually increased from about 3.02 to 3.3. Further, notice that the gain pattern has become more flat. The antenna is beginning to operate somewhat horizontally.

The feed point impedance is shown below. Note that the resonant frequency has moved upward somewhat and that the impedance at resonance has gone down.



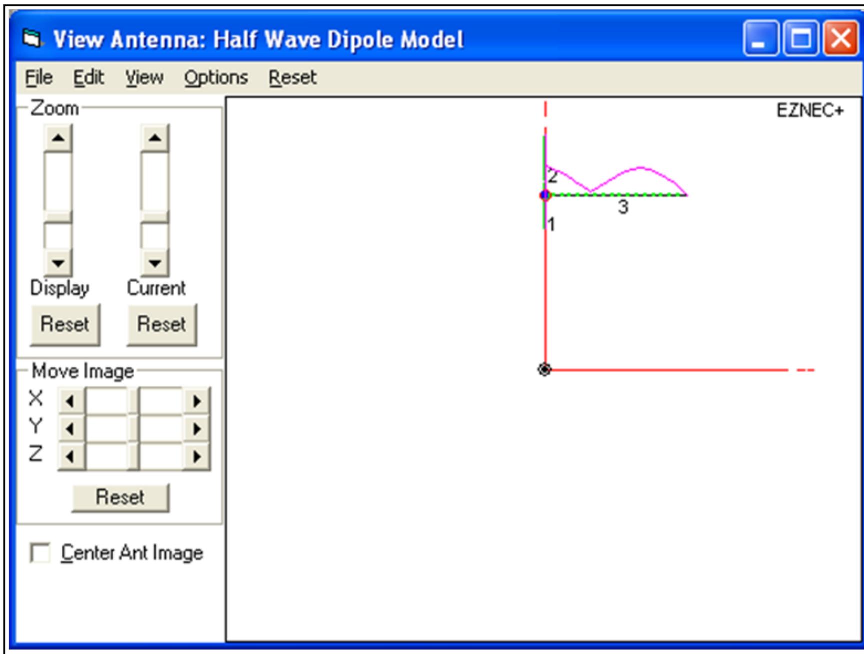
The SWR with the ¾ wave feed line. Note that the resonant frequency has changed somewhat but the shape of the SWR curve is otherwise unchanged.

Up to this point, the feed line has had a relatively minor impact on antenna performance. As it turns out, feeding the dipole with a feed line which is perpendicular to the dipole and at the center is the *best* case.

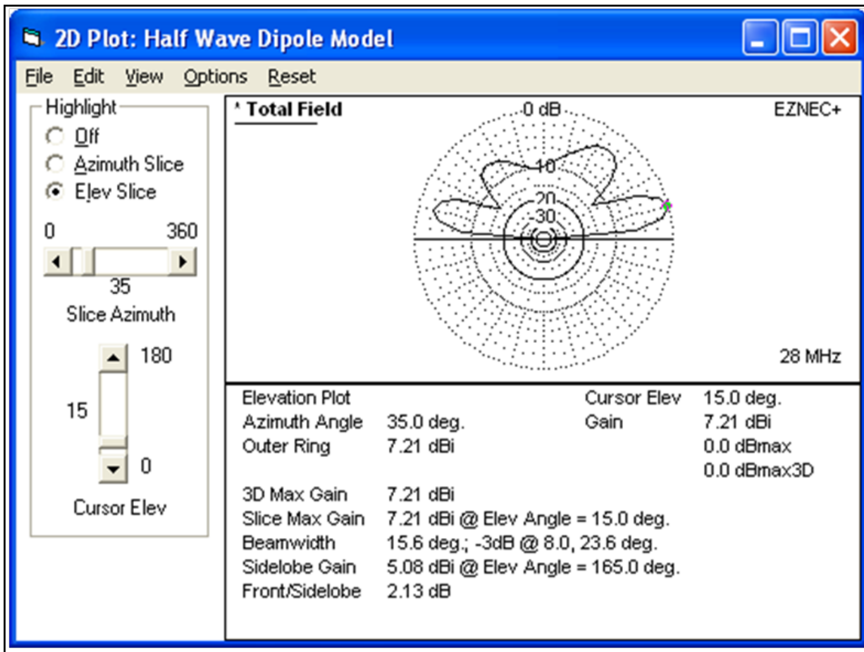
90 Degrees from Off Center Feed

Center fed dipoles are often used at their fundamental resonant frequency AND at their higher, odd harmonics. Thus, it is possible to use an antenna at 7 MHz and 21 MHz. A less common alternative to the center fed dipole is a 33% fed dipole or the "Off Center Fed" (OCF) dipole. This off center feed allows the antenna to be used at its fundamental and EVEN harmonics. For example: 7 MHz, 14 MHz and 28 MHz.

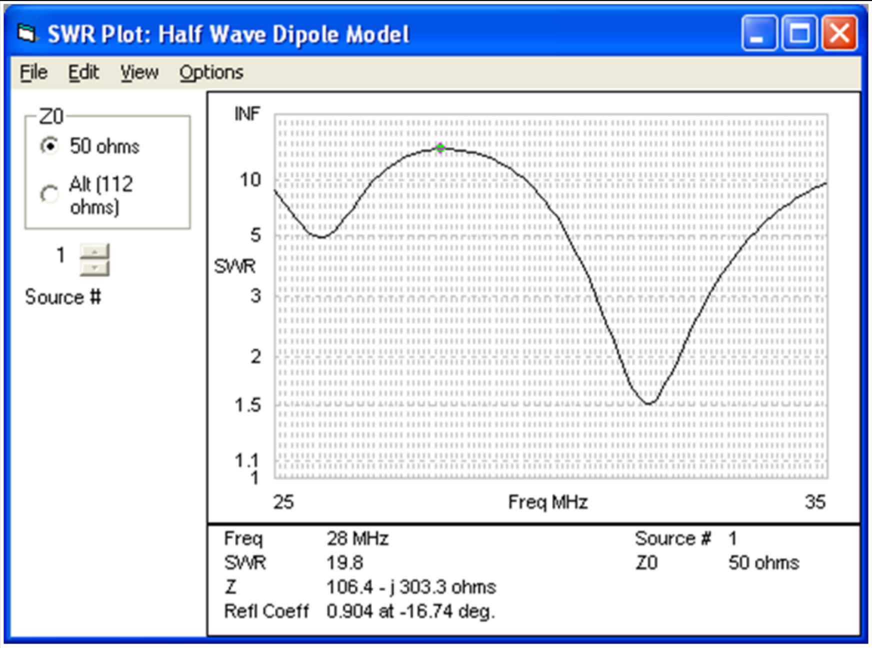
Unfortunately, moving the feed line away from the center of the dipole has a detrimental effect on feed line currents. Look at the currents induced in the feed line when connected off center:



33% off center fed dipole using ¾ wave feed line. The feed line currents are now significant and major changes in antenna performance are expected.



Indeed. The gain pattern is now no longer symmetric and has increased to over 7 dBi. Actually, this antenna now operates more like a horizontal antenna.

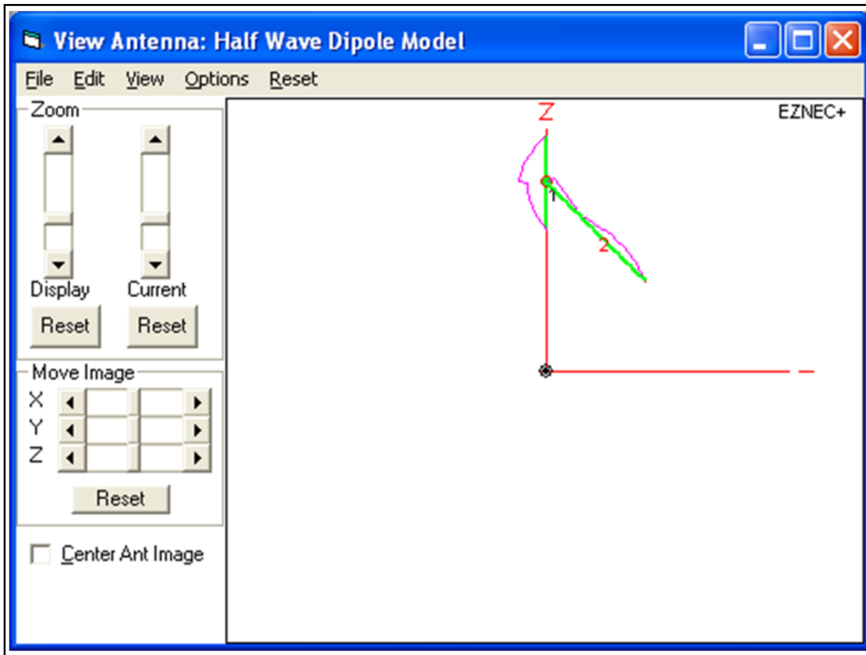


The smoking gun… This antenna is now not working at all as expected. It is not even resonant at the design frequency. Clearly, an off center fed dipole fed with coax will need a little work before it can be deployed.

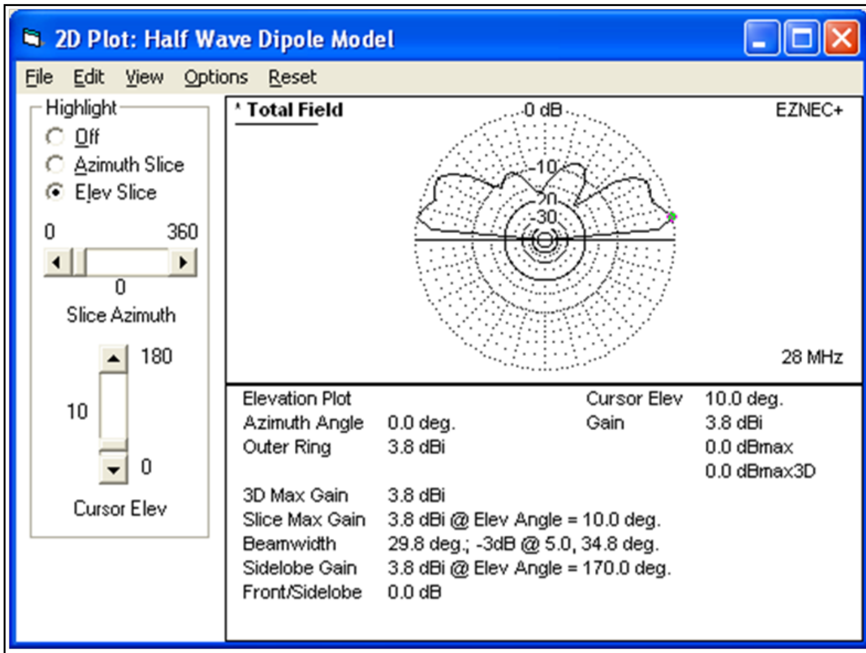
Thus, running the feed line at 90 degrees from the feed point is not sufficient to eliminate feed line currents. A few other cases are now examined.

The Slanted Feed Line

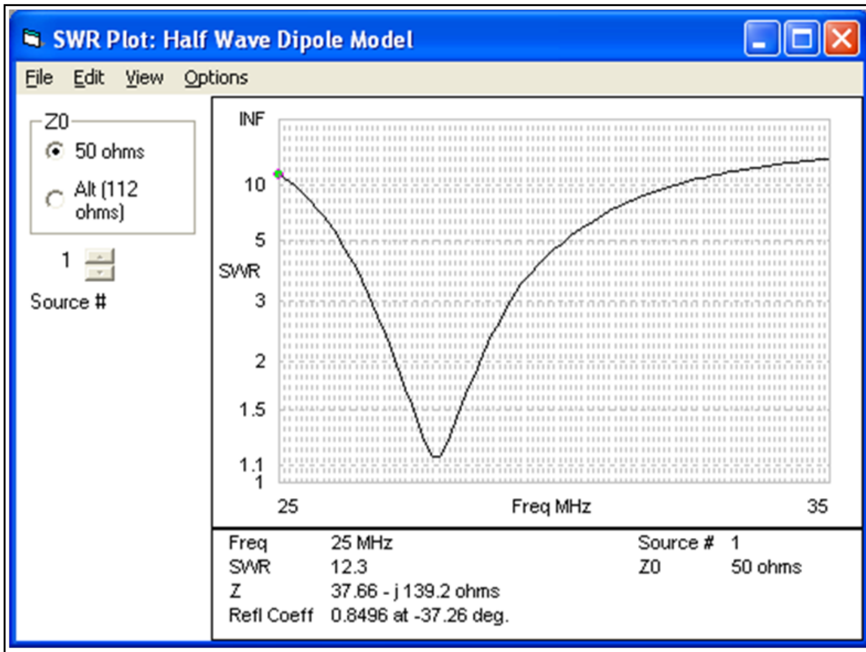
The next experiment is to return the feed point to the center but to connect the feed line at 45 degrees:



Center fed dipole using coax fed 45 degrees down. Again, significant feed line currents are present and antenna performance should be affected.

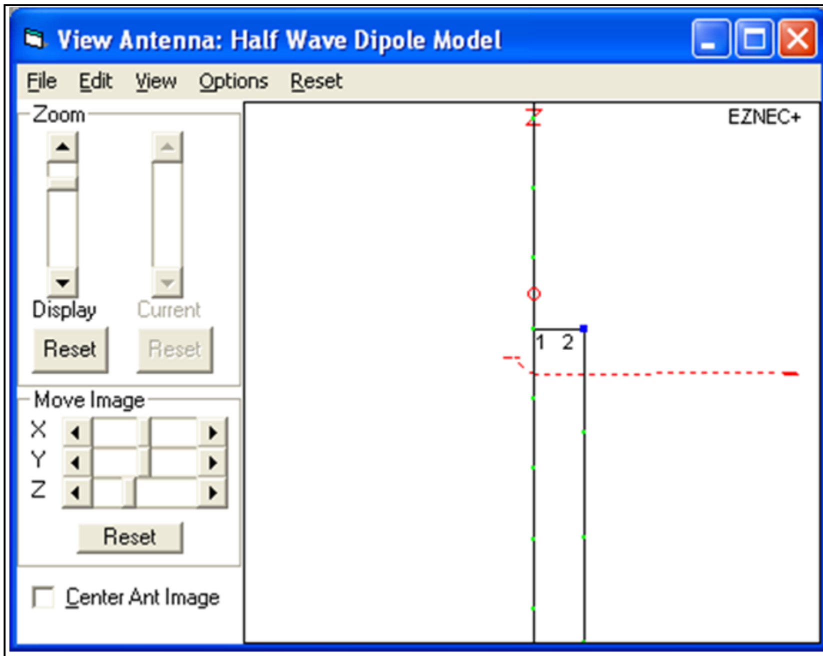


Note that the gain has gone up somewhat and the optimal launch angle is reduced. These are generally accepted as improvements.

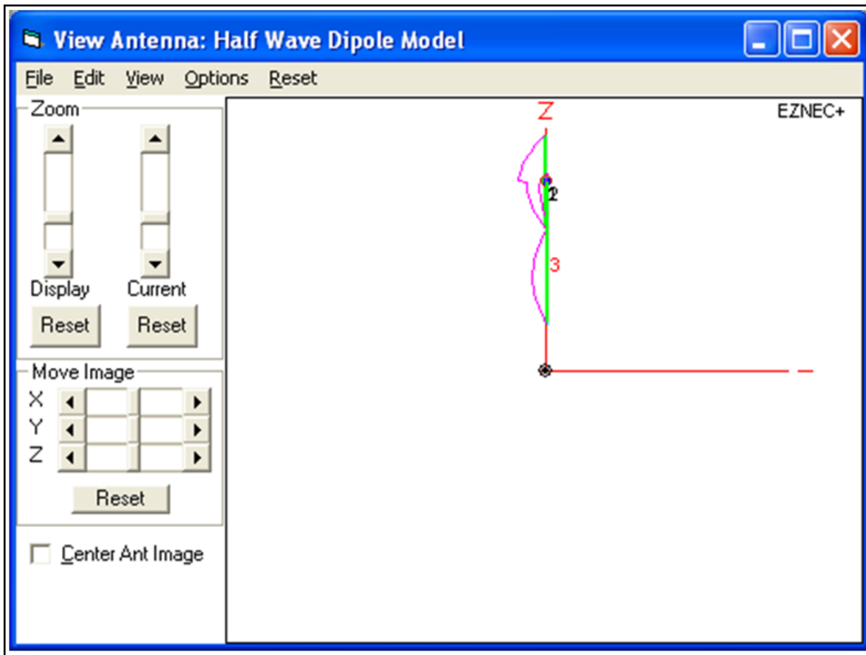


The SWR has gone down and that the bandwidth has been narrowed somewhat. This is because the feed line is contributing to the resonance.

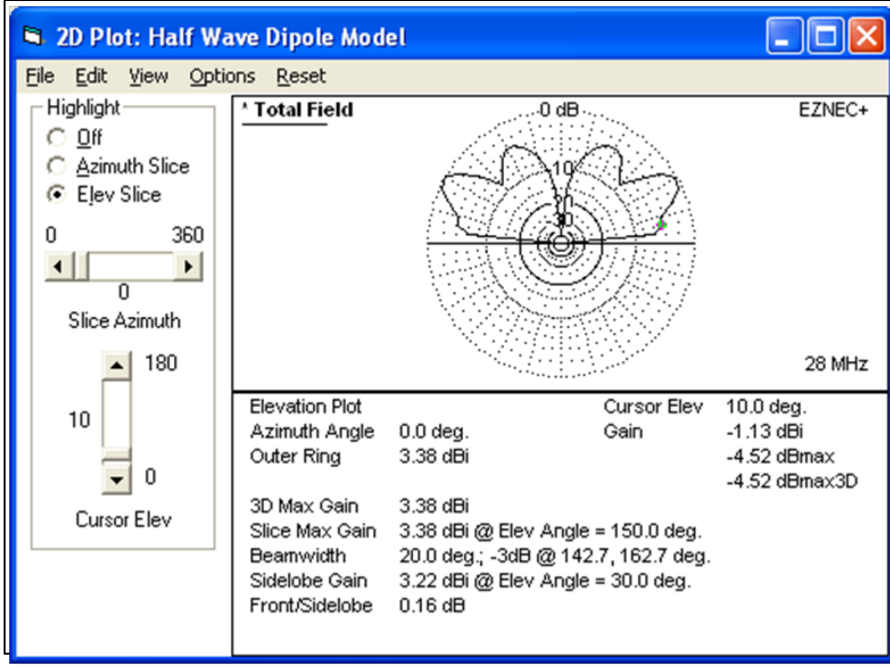
The increasing gain seems to be a good trend so the next logical step is taken, the feed line is run vertically. Here the model gets a little more complicated because a small piece of wire needs to be introduced so that the feed line is parallel to but not touching the vertical dipole. The modeling software starts to have trouble when elements are too close together. For the purposes of this paper the spacing is 3 inches. The close up view of the feed point is shown here:



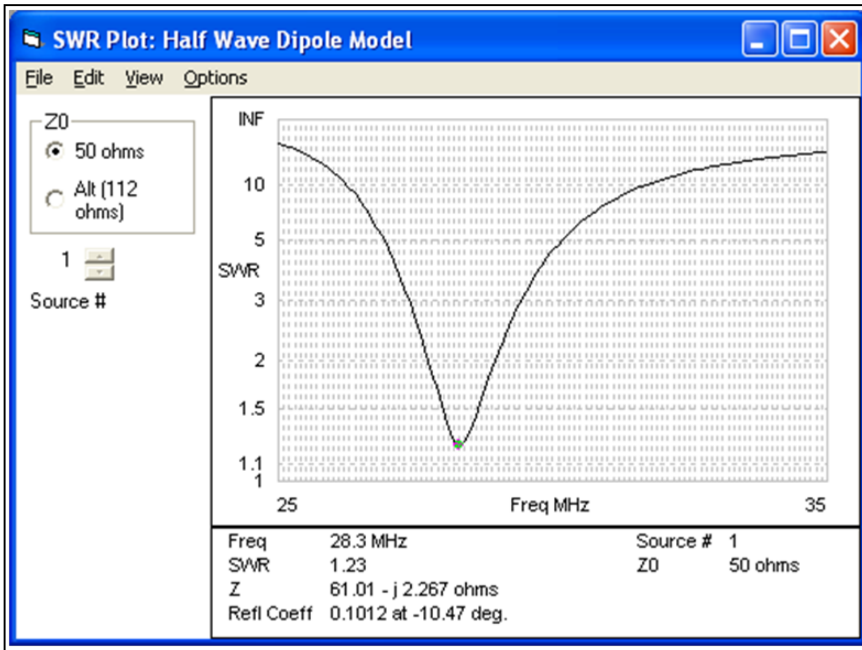
Feed point detail. Center driven vertical with ¾ wave vertical feed line. Spacing from vertical feed line to dipole is 3 inches.



½ wave vertical dipole center fed with ¾ wave feed line. Note that feed line currents are substantial. The impact on antenna performance is expected to be significant.



Antenna gain has changed dramatically. Specifically, the gain at 10 degrees has been reduced from 2.72 db in the first simulation to minus 1.13 db here.



Finally the impedance… Note that the resonant frequency has changed somewhat. In an actual deployment the frequency could be adjusted by changing the length of the feed line or the dipole or both. Also, the width of the SWR valley is more narrow because the feed line is contributing to resonance.

As is shown above, the presence of the feed line can have a significant impact on the impedance and gain of the antenna. This is because the feed line can carry significant currents and these currents contribute to the radiation pattern. As a result, it is often best to think of the feed line as part of the antenna rather than as some secondary issue. Indeed, there are antennas were the vast majority of radiation comes from the 'feed line' currents!

More important than the antenna performance is safety. Significant fee line currents represent a safety hazard to the operator. For resonant dipole antennas, where there is little current there is often very high voltages, particularly at the ends of antennas or feed lines. Even a QRP rig can generate a hundred or more volts at the ends of antennas and resonant feed lines.

Controlling Feed Line Currents

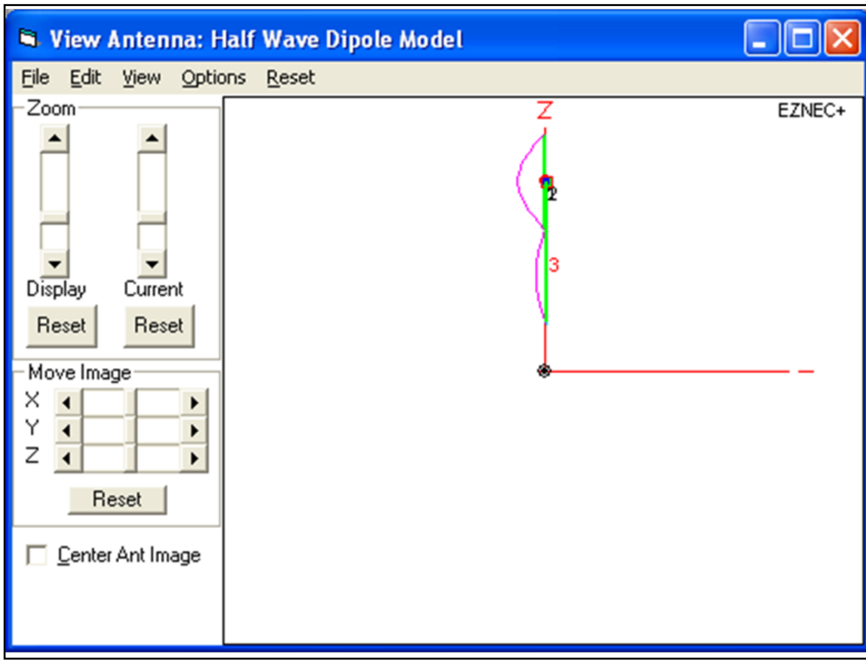
This paper now turns to exploring how to control and eventually exploit these feed line currents. Before doing so, however, there are a couple questions left to be answered: what causes these feed line currents and how can they be controlled?

It turns out there are two basic ways feed line currents can be created. They may be produced 'conductively' when the feed line is connected directly to the dipole and they may be induced through the coupling of the antenna to the feed line through induction or capacitance. It may be reasonably asked, "How can the feed line NOT be connected to the dipole 'conductively'? This idea is now explored.

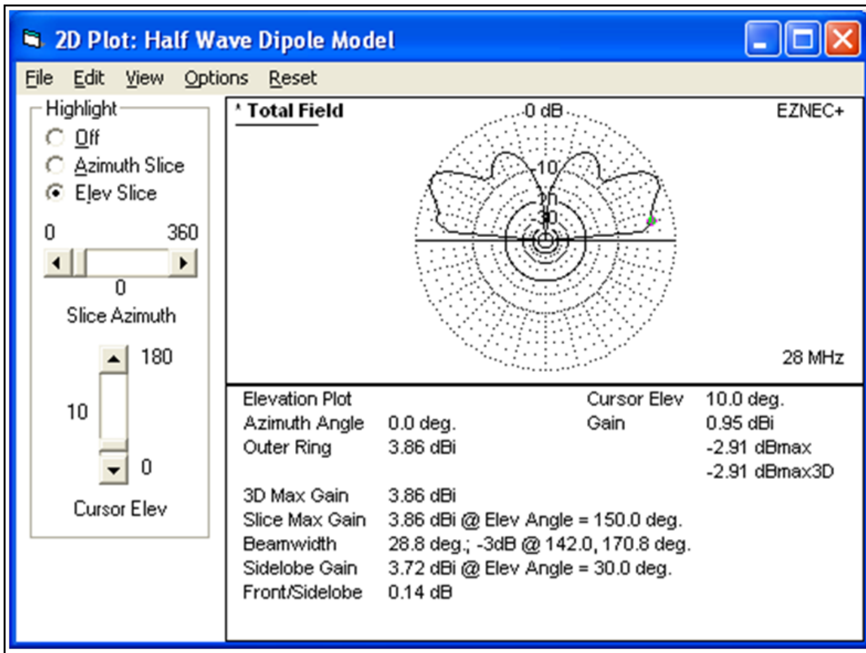
All currents can be essentially blocked by requiring that they flow through high impedance. For RF frequencies, high impedances can be achieved using inductors and resistors. Generally speaking, resistors are avoided because they result in losses. Thus, inductors are almost universally used to control feed line currents. In this application, inductors are often called 'chokes' because the 'choke off' currents.

By themselves, inductors are 'low pass' devices; they pass currents at low frequencies but not at high frequencies. Used in conjunction with capacitors, the inductors can be 'tuned' and therefore made into 'band pass' or 'band block' devices. The impedances of 'tuned' or 'resonant' chokes can be made extremely high. The second paper in this series discussed the construction of chokes and tuned chokes.

So, by using inductors and capacitors the RF currents in the feed line can be manipulated. The most common choke used is probably the common balun; "balun" being short for "balanced to unbalanced". For the purposes of this discussion, the balun is really just a choke which stops RF currents flowing from the feed point onto the feed line. The results of putting this balun (here-after, choke) at the feed point of the most recent model are shown below. Here the choke is considered 'perfect' (infinitely high impedance). Note that the feed line current is affected but that there remains significant current flowing on the feed line even when using this perfect choke.



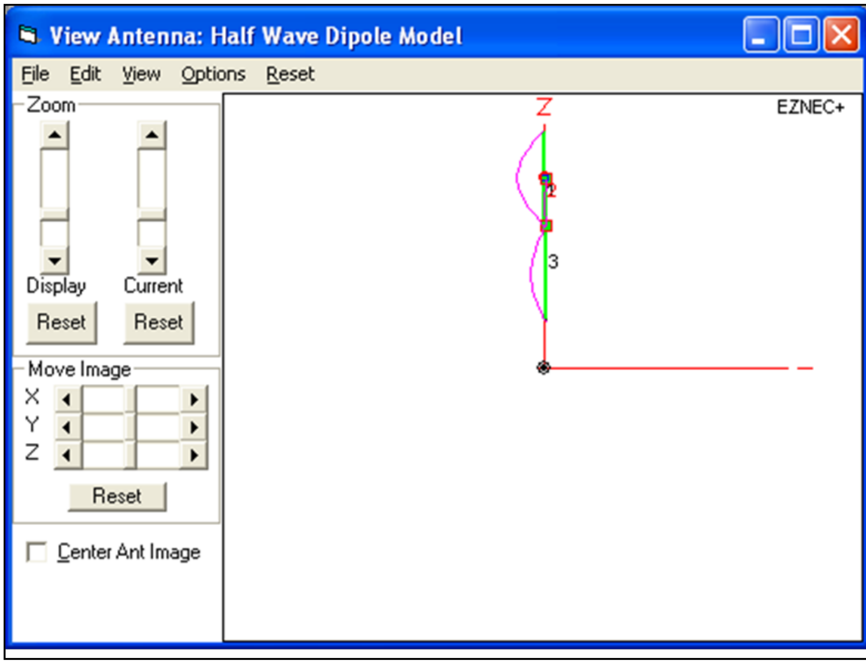
A perfect choke ‘balun’ is placed at the feed point. Note that the current in the upper part of the feed line is gone but there is still significant feed line current in the lower part of the feed line.



The balun has changed the gain somewhat. The 10 degree gain is up from -1.13 dBi to .95 dBi.

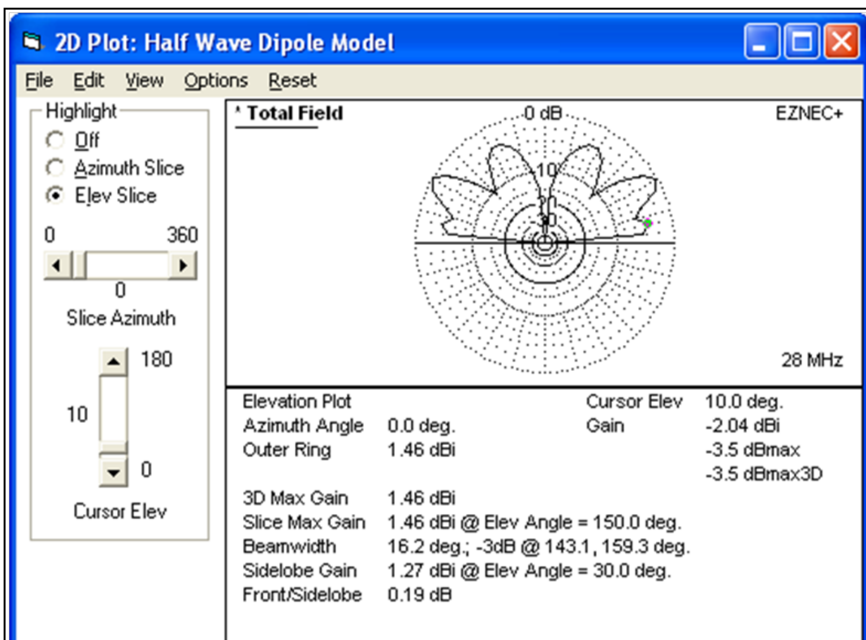
Still, there is significant current flowing in the feed line. This not only affects the performance of the antenna but also can affect safety.

So how can these feed line currents be reduced even more? Since the feed point choke eliminated any ‘conduction’ mechanism, the feed line must be somehow ‘coupled’ to the dipole. Perhaps the coupling occurs because the feed line runs close to the lower half of the dipole? In order to check this one can introduce a second, perfect choke in the feed line at the bottom of the antenna. In the following picture, note the small, red square at the bottom of the dipole. This shows the placement of this second choke.



Two perfect chokes are used. One at the feed point. The second is on the feed line level to the bottom of the dipole. If currents are being induced because the feed line is 'close' to the dipole, this second choke should have eliminated them. Thus, it is not just the close spacing of the feed line that is causing the feed line currents.

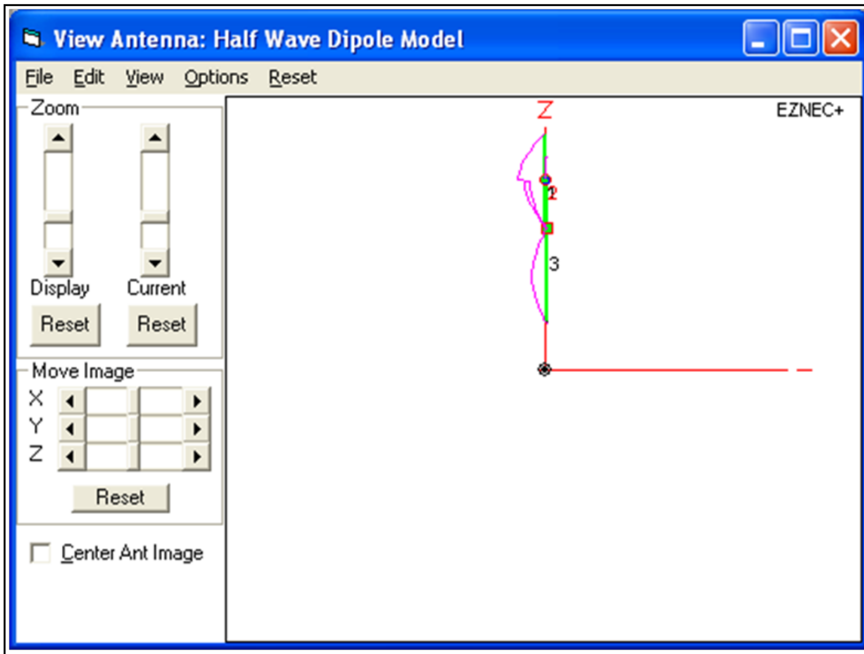
In this experiment a choke was placed at a 'current minimum' and had no significant effect. This observation can be generalized somewhat: chokes placed at current minima are often ineffective. This behavior is discussed in subsequent writings.



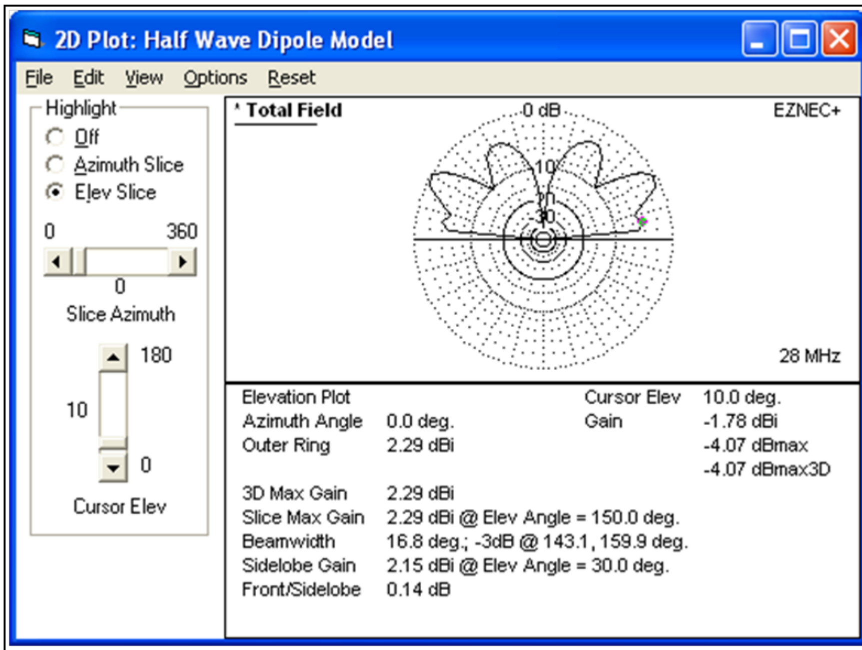
Indeed, introducing this second choke has changed the gain pattern. A great deal of RF energy is being launched upward.

In nearly every way, the introduction of the second choke has reduced performance. The maximum and low angle gain have gone down by over 2 dB! A great deal of RF energy has now directed upward. Again, if the goal is to launch RF energy upward this is good but generally this is not the goal.

As a quick check, suppose one takes away the feed point choke but leaves the second choke. What happens? Currents look different…



Back to one choke but this time not at the feed point. Rather, it is on the feed line at the bottom of the dipole.

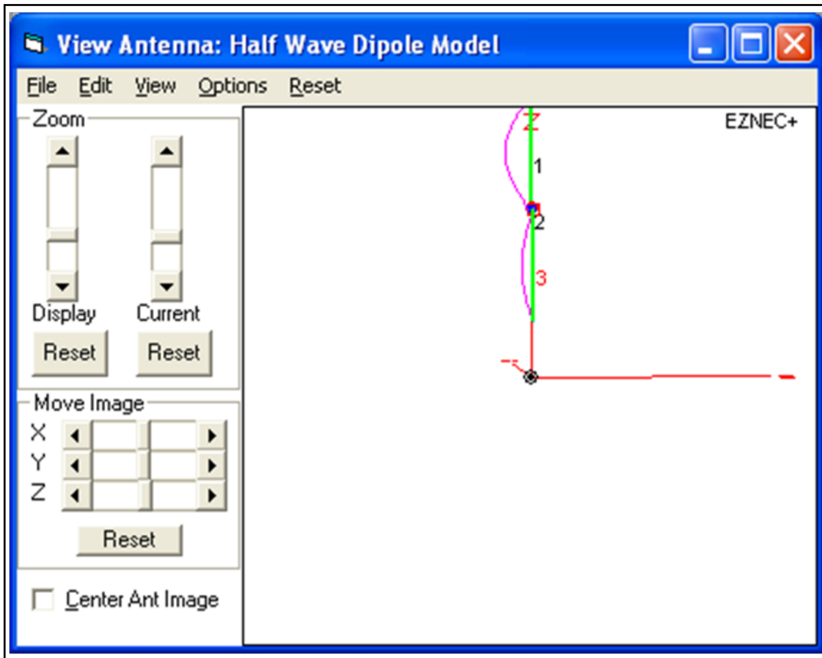


The gains look much the same but are generally improved except for the high launch angle:

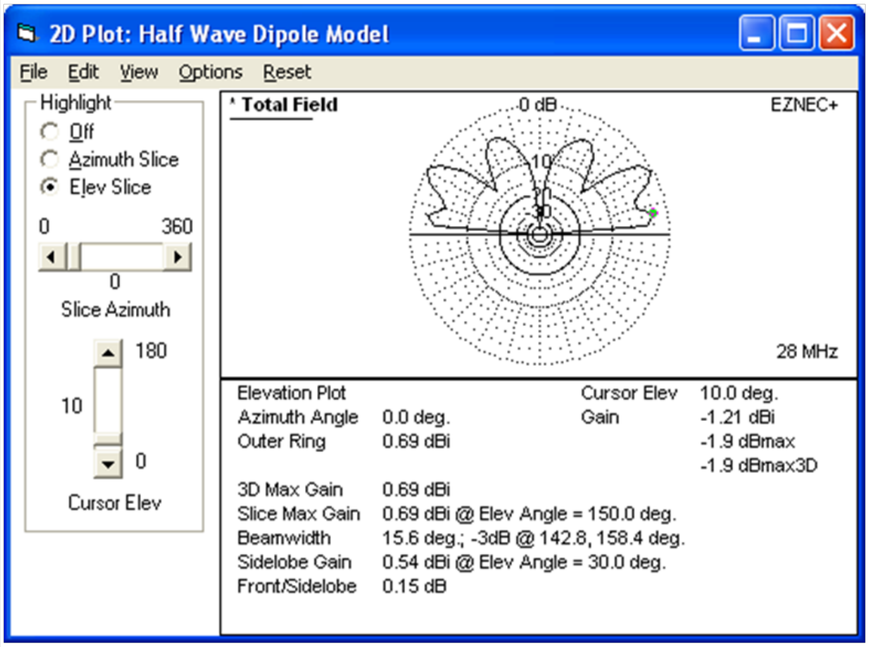
Thus, if one is going to have a single choke would be generally be 'better' to place it at the level of the bottom of the dipole rather than at the feed point. (Generally, it is considered 'better' to have a lower launch angle. This is because there are easier ways to launch RF energy vertically.)

It should be pointed out that this antenna configuration (center fed, half wave dipole) with a feed line dropping from the bottom of the antenna is VERY common. The classic 'bazooka' antenna works this way as does the 'Coaxial' antenna. Several commercial antennas have exactly this configuration.

These last two experiments teach a huge lesson best explored through another experiment. Remember that the dipole may be fed at any point with only a change in impedance. Suppose the feed point were moved to the bottom of the dipole. Then there would be no feed line running in close proximity to the dipole. This configuration is typical of 'end-fed' antennas which use a matching transformer to convert a 50 ohm feed line into a 2000 ohm drive impedance. However, there is still significant feed line current as shown below:

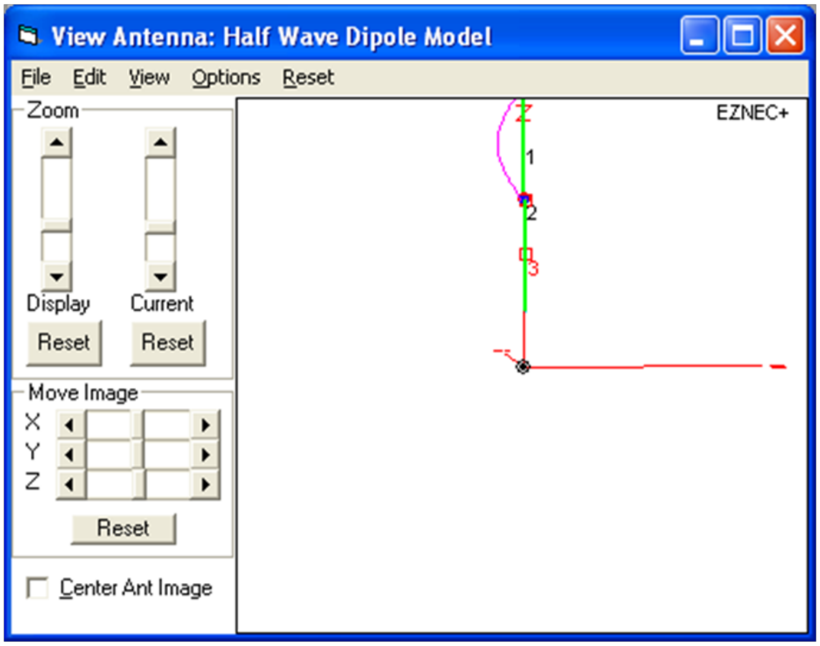


Feed line connected to bottom of dipole. Perfect choke used to isolate the feed line from the dipole. Significant currents continue to flow. No current is 'conducted', it is all induced.

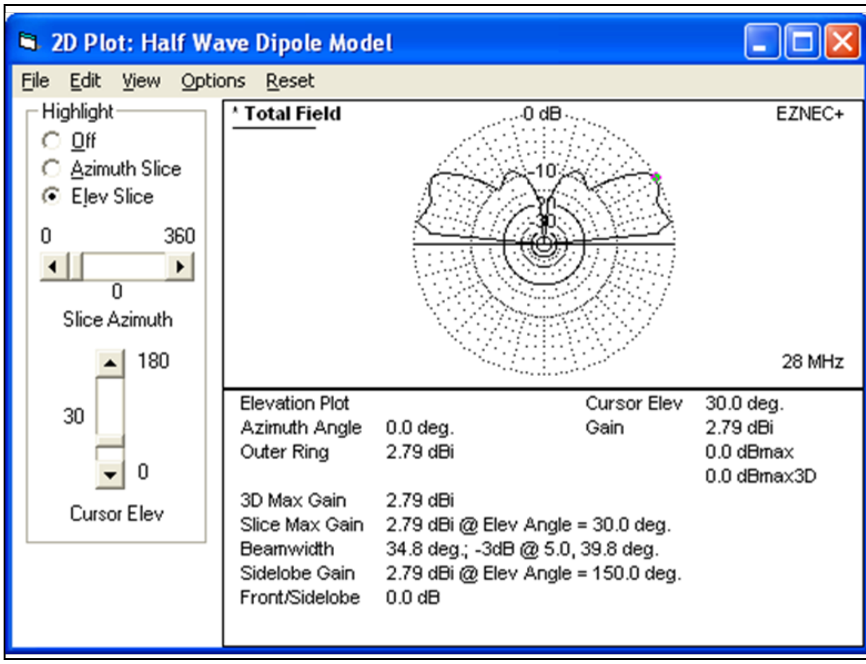


The gain is essentially unchanged.

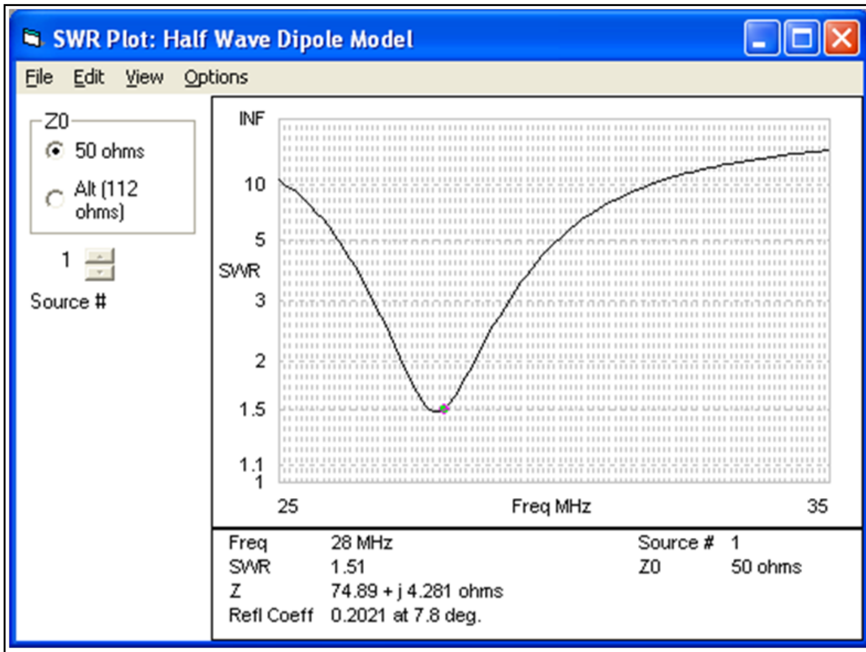
This experiment teaches a huge lesson. Remember that the choke is modeled as perfect. There is no RF conductive path from the dipole to the feed line; the induced currents are ‘coupled’ or ‘induced’, not ‘conducted’. Further, the coupling to the feed line is not necessarily because the lines are closely spaced. Thus, any antenna similar the above situation can have significant feed line currents. Unfortunately, nearly every ‘end fed’ antenna must confront this problem. The good news is that the solution is well known; simply place a second choke at the peak current point in the feed line. Doing so in the previous example results in the following:



A second choke is placed at the high current path on the feed line. Feed line currents are now eliminated.

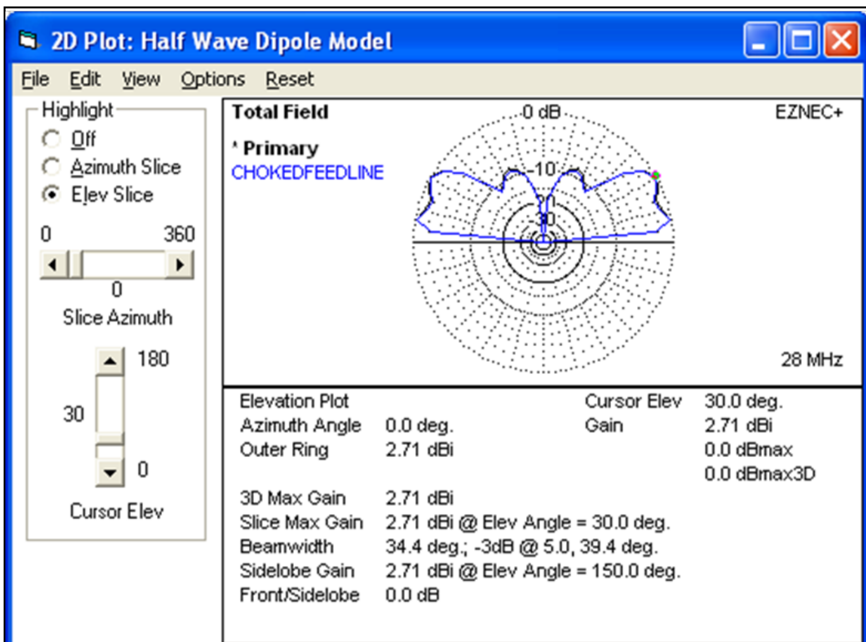


The gain pattern is returned to the original. The feed line now has no effect on the antenna performance.



And the SWR has returned to the original.

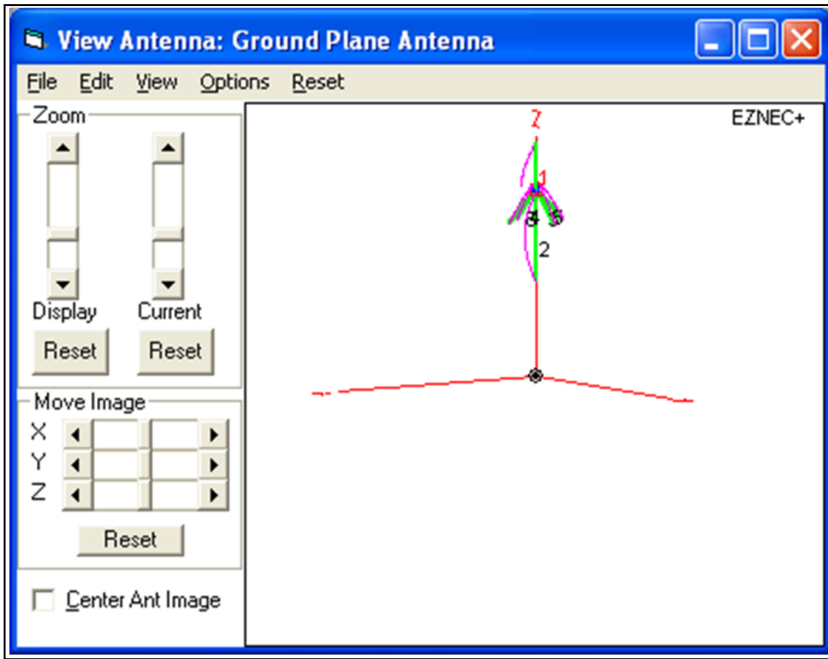
For the purposes of comparison, the gain pattern of the ‘choked feed line’ is compared to the simple dipole with which this paper started. As can be seen, the gain patterns are, unsurprisingly, identical.



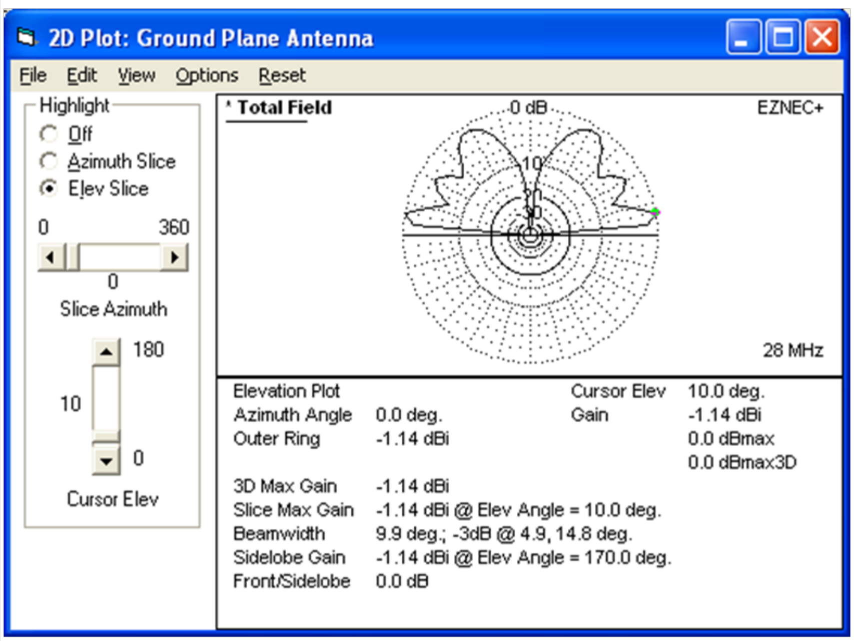
Comparison of original, isolated dipole and final dipole with ‘choked’ feed line. The gain patterns are essentially identical showing that the feed line has no effect.

Even the Supposedly Immune Can Be Affected.

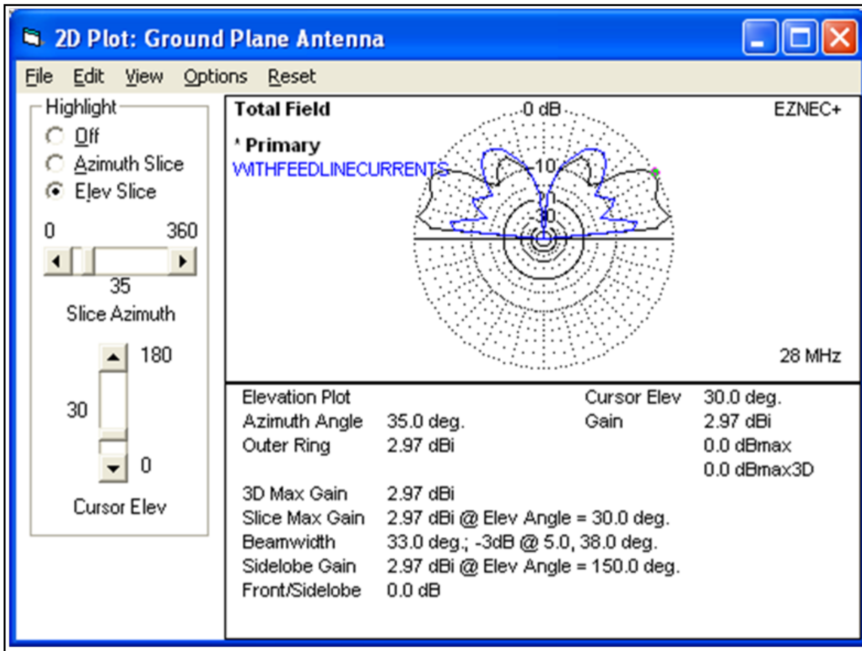
As a quick aside, a short visit to the common elevated ground plane antenna is in order. Even this antenna can have significant feed line currents.



Feed line currents on elevated ground plane antenna. Perfect choke is used at the feed point. Feed line is ½ wave-length long and therefore resonant. This is the worst case.

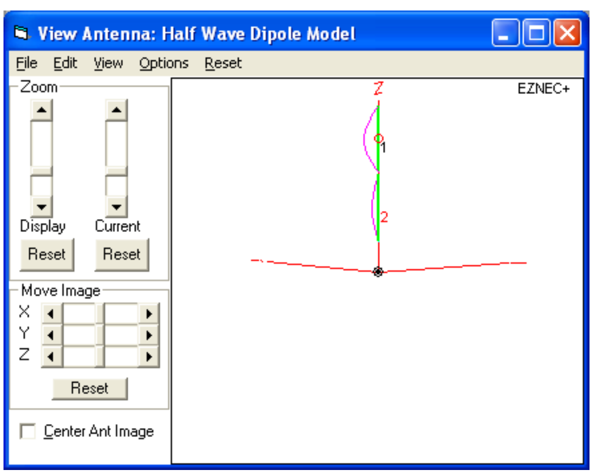


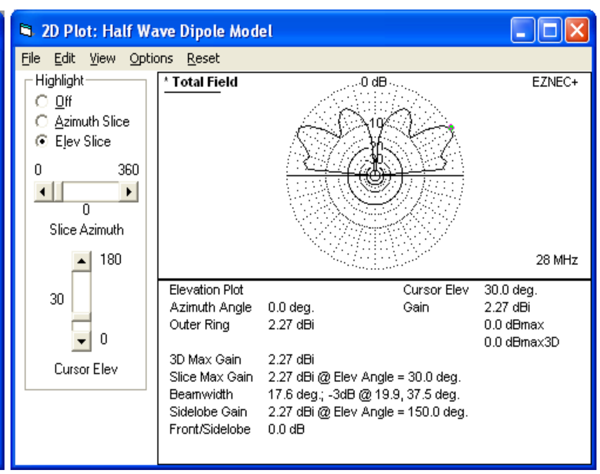
Gain pattern of elevated ground plane antenna with resonant feed line and perfect choke. Max gain, -1.14dBi.



Compare elevated ground with and without feed line currents. With feed line currents

To drive home the point of this section, consider the original half wave dipole center driven. Below that one places a second, half wave vertical dipole. The two dipoles are NOT connected. Notice the currents and the gain pattern. From these two graphs it is easily seen that significant feed line currents can be induced and have a significant impact on antenna performance EVEN when not physically connected. One simply must take induced currents into account when deploying an antenna.





But there is more yet to learn. This last experiment shows that it is not just feed lines which can cause problems. Any resonant conductor can have induced currents: towers, masts, gutters, downspouts,feed lines, other antennas, you name it. If it conducts and if it can resonate at the chosen frequency, it can have a big effect. Specifically, if the feed line is balanced ladder line there can be feed line current problems!

Summary

This paper demonstrated that feed line currents can be produced through two independent mechanisms: conducted and induced. These feed line currents can be suppressed through the proper use of chokes. While most antenna installations using coaxial feed lines use a balun at the feed point, this practice represents only a partial solution because it addresses only the 'conducted' mode.   The use of a second choke at a feed line current maximum can successfully suppress the induced currents. Following chapters will discuss the many implementations of chokes and their application in many of the more popular antennas used today.