Constructing and Using Chokes

The first installment of this series introduced basic antenna modeling and demonstrated the generation and control of feed line currents. The control of the feed line currents was accomplished using ideal (perfect) chokes. This section discussion several forms of feed line chokes and examines how they can be used to control feed line currents. Of special interest in this section is the use of chokes in constructing BAZOOKA, COAXIAL, and RESONANT FEED LINE antennas. As will be shown, great care must be taken in constructing these types of antennas because the quality of the chokes can greatly affect their performance.

> Note: one of the most common applications of a choke is in implementing a BALUN; 'BALUN' being short for "Balanced to Unbalanced". The BALUN is used to connect a balanced device (for example a center fed dipole antenna) to an unbalanced device (for example, coax feed line). However, there are many times when the same device is used to connect "unbalanced to unbalanced" and thus should not really be called a BALUN. This paper used the term CHOKE in order to refer to the primary purpose of the device, the suppression of common mode currents.
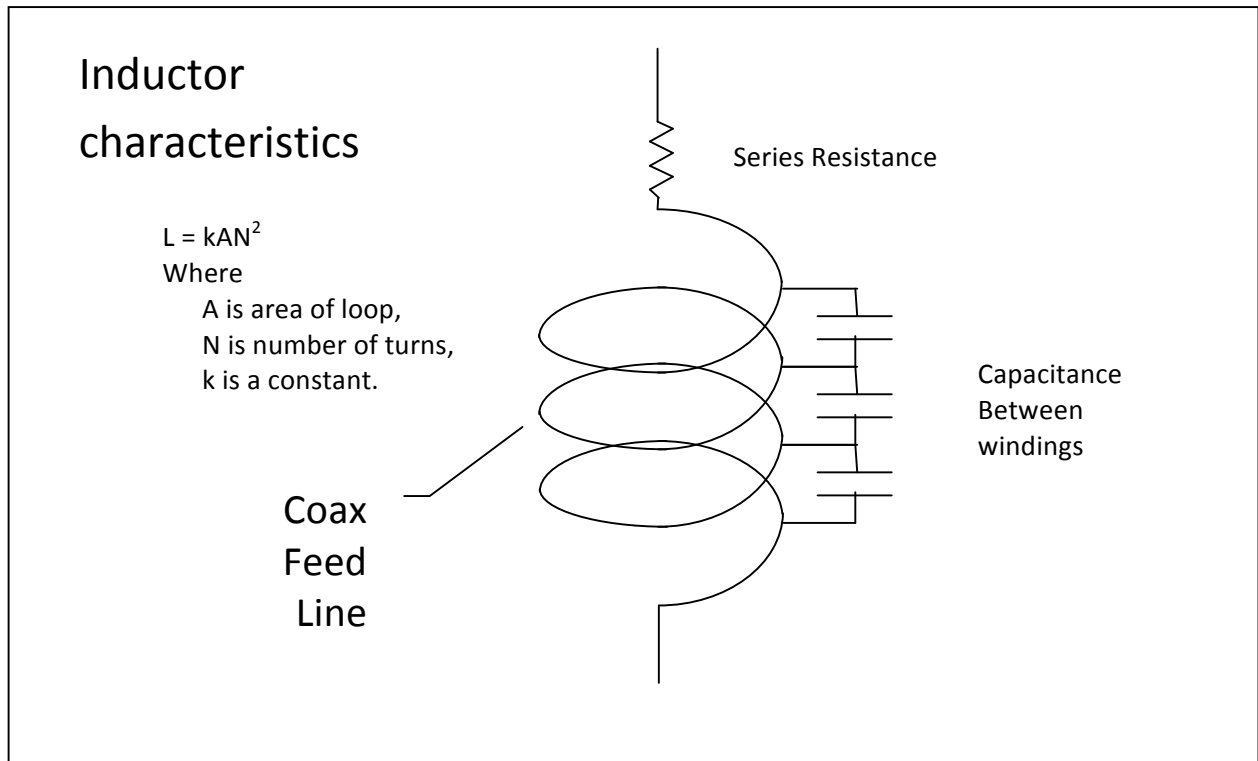
The Properties of Coax "Coil" Chokes

Probably the simplest choke used in radio is the simple coil of wire. When used in feed lines, the choke is constructed using coaxial cable. Remember that coax actually has three conductors. Stated simply: the inner conductor and the inside surface of the shield carry equivalent and opposite currents and the outside of the shield carries any 'common mode' or 'feed line' current.

Under normal conditions, currents flowing on the inner conductor and the inside of the shield cancel each other. As a result, these currents are not affected by the environment outside the coax shield. This is the main appeal of coax and why it is so easy to deploy. It can be run under ground, next to steel or concrete, through water, nearly anywhere without affecting the internal currents. The currents flowing on the outside of the shield, however, are much more susceptible to the environment.

Thus, when a piece of coax is formed into a coil the outer conductor becomes an inductor. The result is that feed line currents are affected by a coil of coax but the signal currents are not.

Unfortunately, inductors are notoriously 'non-ideal' for two reasons. Consider the physical construction of a simple coil:

Inductor characteristics

Series Resistance

$L = kAN^2$
Where
    A is area of loop,
    N is number of turns,
    k is a constant.

Capacitance Between windings

Coax Feed Line

The imperfections of inductors derive from their very construction. Inductors must be made from real conductors which have real resistance. In addition, because the coax is coiled there will be some capacitance between neighboring windings. Generally, chokes should be constructed using nice, neat winding techniques rather than a bunched together. This is largely because the results are more predictable and reproducible.

As with anything containing inductors and capacitors, the inductor generally has at least one resonant frequency. The exact resonant frequency is difficult to determine analytically. Fortunately, extensive tables are available from several sources (e.g. the ARRL Antenna Handbook). However, general principles can be deduced from inspection.

Some chokes are designed to operate as simple inductors. In these cases it is important that the resonant frequency be well above the operating frequency. To ensure this is the case, the windings of the inductor are usually kept well apart; often several conductor diameters. For example, a loading coil may be constructed using a conductor $1/10^{th}$ inch in diameter with a 1 inch winding to winding spacing. To a first approximation, the impedance of such a coil is simply the inductance times the frequency of interest times 2 Pi: $Z = 2\pi FL$.

Other chokes are designed to operate near or at resonance. These chokes take advantage of the winding/winding capacitance to create a higher impedance at a chosen frequency. The inductor is then generally modeled as a parallel L and C. Again, the exact values are difficult to compute but have the general form: $Z = 1/(Z_L - Z_C)$. Thus, when the impedances of the inductance and capacitance are equal, the impedance of the choke is, ideally, infinite.

Here is a spice simulation of a simple inductor and a simple LC network using LTSpice from Linear Technology:
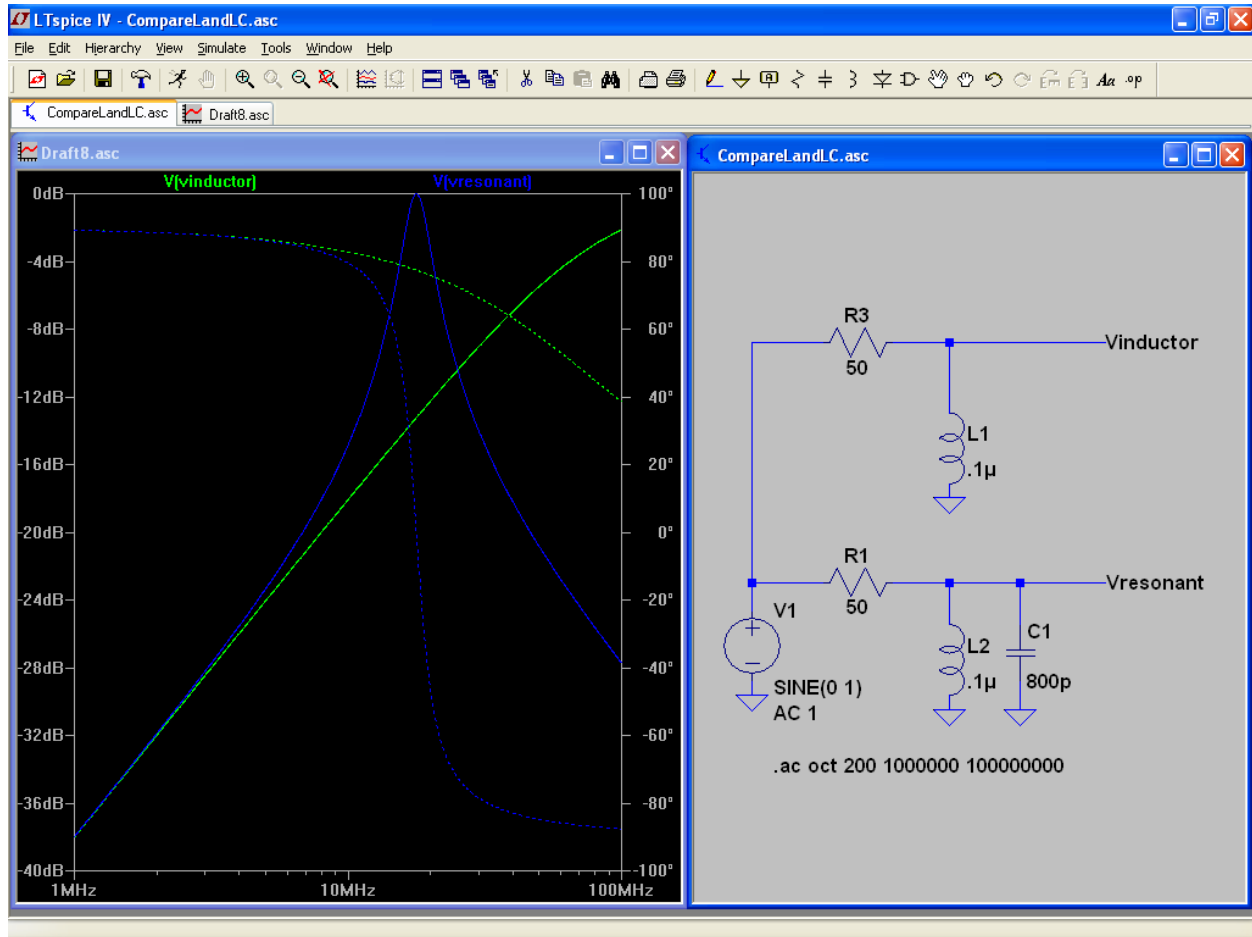

Notice that the impedances of the simple inductor and the LC circuit are equivalent at low frequencies. This is evident on the left side of the graph where the Vinductor and Vresonant lines are coincident. As the frequency increases the resonant LC circuit starts to have substantially higher impedance and out performs the simple inductor reaching a peak at the resonant frequency. Once the frequency increases substantially past resonance the LC circuit impedance starts to fall and ultimately falls below that of the simple inductor.

This graph is quite informative. It shows, for example, that for low frequencies the winding/winding capacitance is relatively unimportant. It also shows that, if the operating frequency is known, using a resonant choke can provide much higher impedances for a given L compared to the simple L. Conversely, if the operating frequency is unknown OR if broadband operation is necessary, an unturned choke is desirable.

To confirm this simulation a 28 MHz, coiled coax choke was constructed and measured. This coil consisted of 8 turns of RF58U coax cable with a 2 inch diameter. Using an AIM4170B antenna analyzer the following graph was created. (The analyzer has not been calibrated for these high impedances but

does provide a useful figure of merit for comparison purposes.)   Unfortunately, the graph below does not show the peak of the impedance. However, it does indicate that the resonant frequency was 27.8 MHz and that at that frequency the impedance was over 7500 ohms.
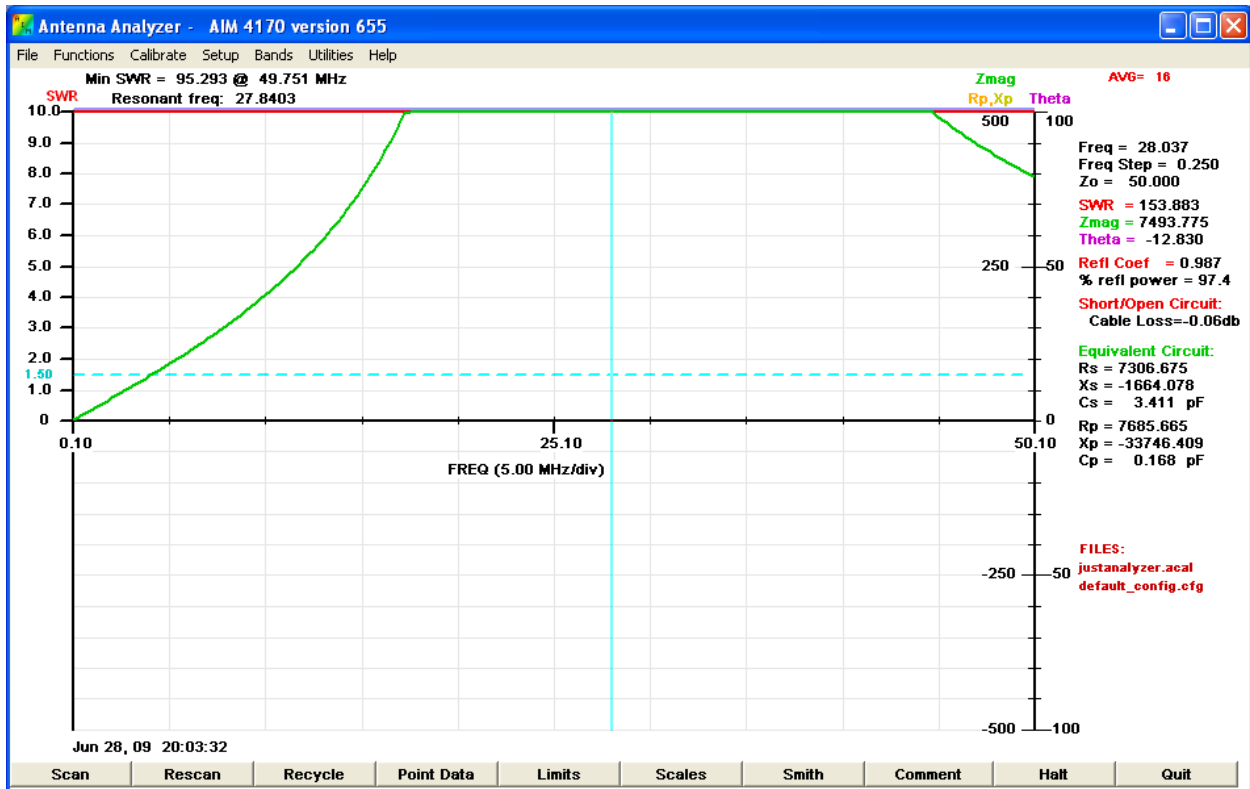
Casual examination of the above graph shows that these coils can be effective over very wide frequency ranges. Above, an impedance of 500 ohms is provided from about 17 MHz up to about 45 MHz; almost a factor of 3.

The tables on coax coil inductors provided by the ARRL Antenna Handbook are quite informative. Of particular interest is the impedance which can be achieved.   Impedances on the order of 10k to 15k are fairly routine for HF frequencies. Interestingly, the Antenna Handbook also reports the impedances of 'bunched' coils (coils not neatly wound). In all cases the bunched coil impedance is significantly lower; often by an order of magnitude as frequencies increase!
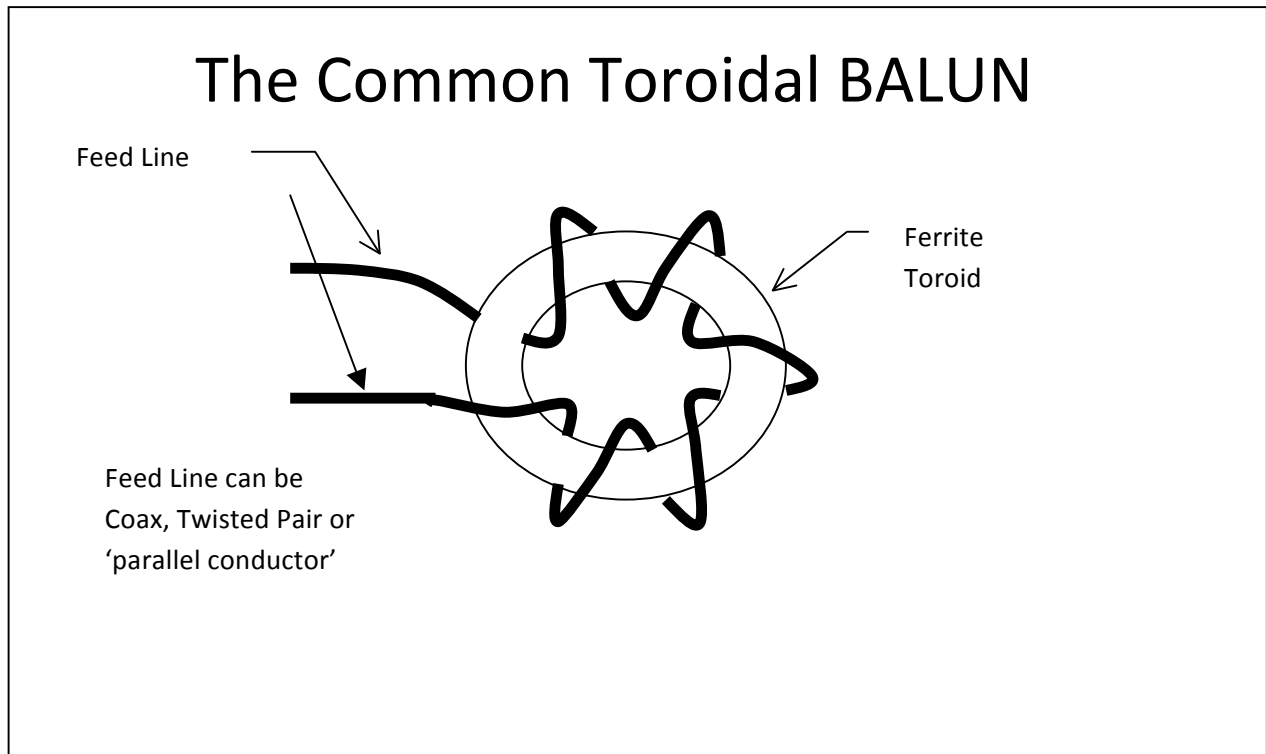
One last observation concerning coiled coax chokes: the coax coiled choke is extremely robust. The only power limitation comes from the coax cable used and the common mode current being suppressed can be very high.

The Common Toroidal BALUN
For wideband applications it is often necessary to construct inductors with very large values without the use of resonance. The coax coils described above can become awkward for a variety of reasons such as weight or size. One way the inductance can be substantially increased while reducing size and weight is to wind the wire around a magnetic material such as iron or ferrite. These devices are almost always

called 'BALUN's or 'UNUN's. Entire books are written about the design and construction of these devices so only the quickest overview is given here. (Sevik)

The simplest form of this type of choke is to simply wind the coil of wire around a ferrite rod. This form of choke has largely fallen out of favor and the toroidal form is generally used. Here is a rough drawing of the toroidal device:


The Common Toroidal BALUN

Feed Line

Ferrite Toroid

Feed Line can be Coax, Twisted Pair or 'parallel conductor'

This type of choke has many advantages. Its construction is relatively simple and tolerant of variation. It is useful over very wide bandwidth; usually more than a decade. And it is relatively small and lightweight.

While the Toroidal Balun has many advantages it is not without some shortcomings, most of which derive from the Ferrite material. The ferrite material used must be chosen for the desired frequency range. When large common mode currents are being suppressed the core can heat up and even explode. There can be significant capacitance across the device which can reduce its utility at higher frequencies. Finally, the Toroidal Balun usually has a resonant frequency.

The W2DU Balun
Another way to use ferrite material to construct a choke was developed by Walter Maxwell. This choke is ingenious in its simplicity. Essentially, this balun is a 'one turn', ferrite core choke. The construction is extremely simple: place a large number of ferrite toroid cores over the coax:

W2DU BALUN

Coax Feed Line
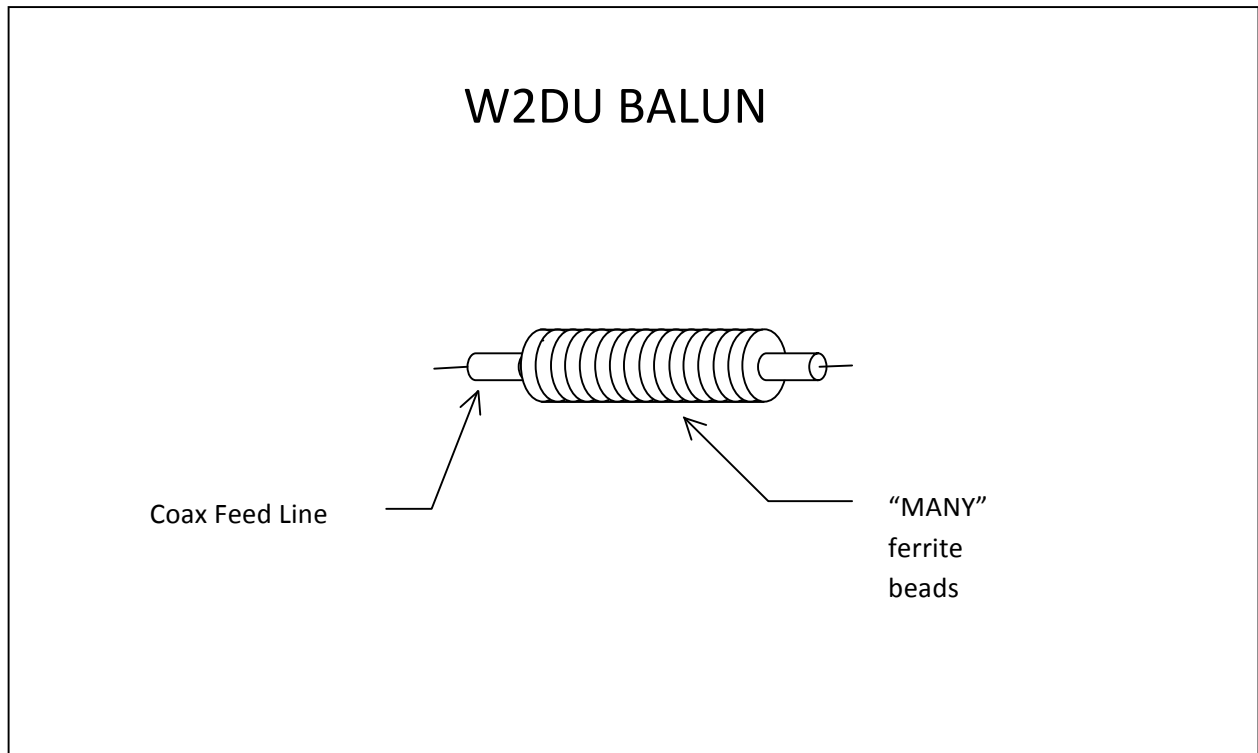
"MANY" ferrite beads

The inductance of the W2DU BALUN is essentially proportional to the number and type of ferrite beads used. The beads need not be all the same and so the W2DU BALUN can be designed to cover extremely wide bandwidths.

As with the toroidal core balun, the W2DU balun can run into problem when large common mode currents are being suppressed. Further, the number of beads required can be quite large at lower frequencies.

Transmission Lines as Inductors and Capacitors

Usually, transmission lines are used to carry a signal from one place to another. A less well known use of transmission lines is to create inductors and capacitors. Consider a short piece of transmission line shorted at one end and driven at the other. Here is a LTSpice simulation over wide frequency range:
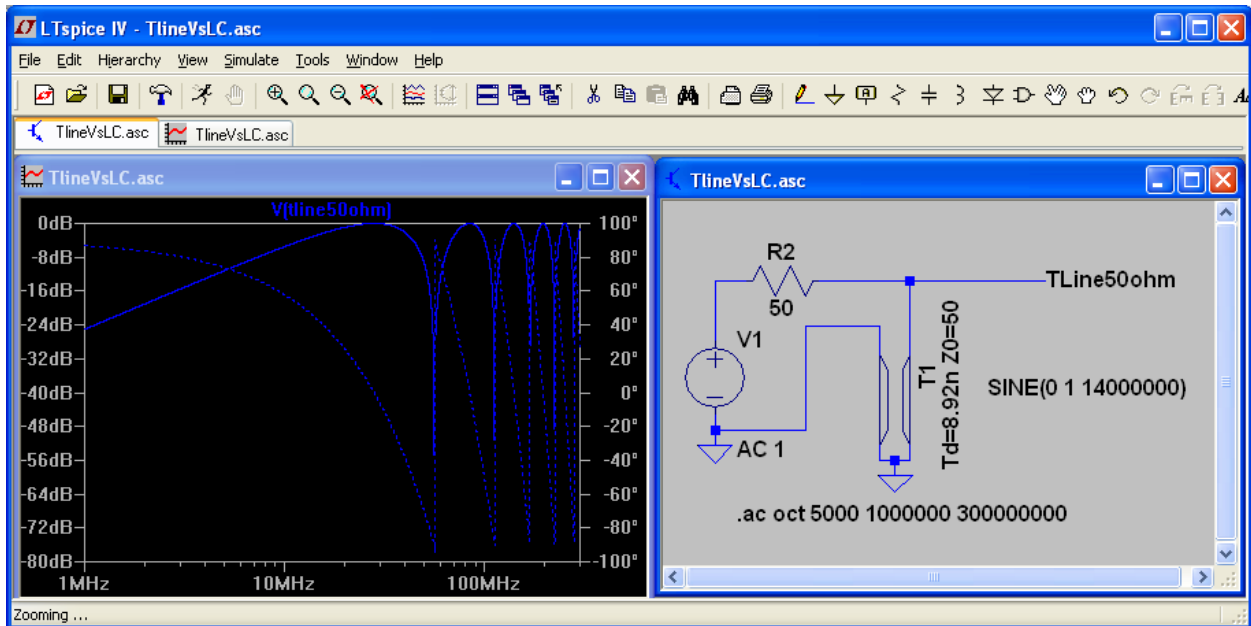
A few observations of the simulation are in order. To start, the transmission line has a propagation of 8.92 ns. which corresponds to a design frequency of 28 MHz. The left side of the graph is a relatively low frequency. Here, the transmission line is acting much like an inductor; increasing frequency results in an increasing impedance.

Moving to the right, the impedance reaches a maximum at 28 MHz. At this point, the transmission line is 'resonant' and appears as an open circuit. Just to the right of resonance the impedance begins to go back down. Here the transmission line is acting like a capacitor; increasing frequency results in decreasing impedance. At twice the design frequency the transmission line now appears as a short circuit. Proceeding past this minimum, increasing the frequency again increases impedance and again reaches an open circuit condition at 3 times the design frequency. This pattern repeats.

If the transmission line were not shorted at the end but instead left open, the impedance would start out at the 'open circuit' point and proceed with the same pattern as above:
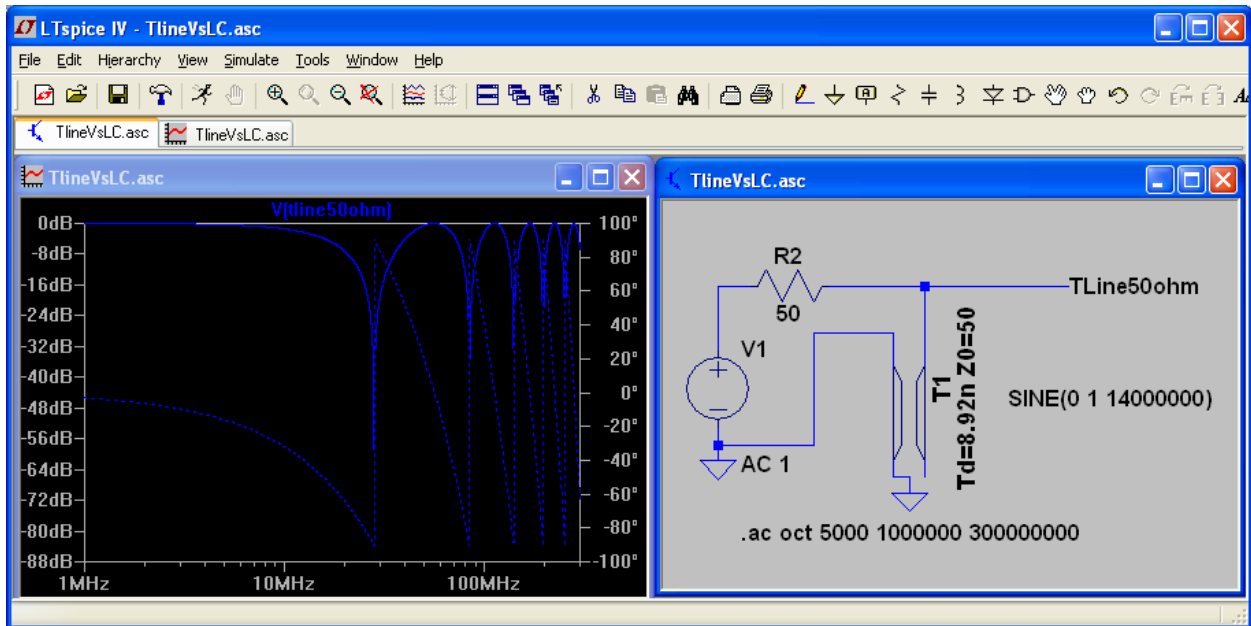
Thus, a simple piece of transmission line such as coax can be used to implement an inductor, a capacitor and even an LC circuit. This flexibility, when integrated with feed lines, can be exploited to implement tuned chokes.
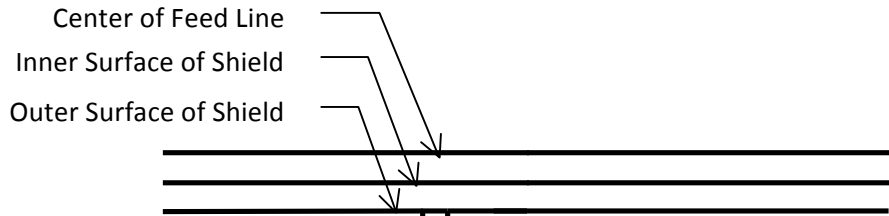
Transmission Line Chokes

The discussion now turns to various ways one can use transmission lines to implement common mode chokes. The first such choke starts with a simple piece of coax. Remember that for RF frequencies coax has three conducting surfaces. In the drawing below, the three conductors are drawn separately.

The first step in the evolution is to add a parallel conductor transmission line to the outer surface of the shield of the feed line:

Simple Transmission Line Choke

The Three Conductors of Coax

Center of Feed Line

Inner Surface of Shield

Outer Surface of Shield

A transmission line "Tuned Choke" is added.

Impedance looking to transmission line will be HIGH when transmission line shield is correct length.

The next step is to turn the transmission line choke 90 degrees. The two surfaces of the added transmission line are shown here as collapsed:
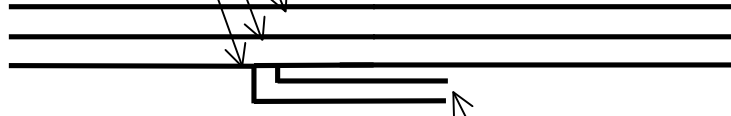
Evolution of the Sleeve Choke

Three Conductors of Coax

Center of Feed Line

Inner Surface of Shield

Outer Surface of Shield

Tuned choke is rotated 90 degrees.

Impedance looking to transmission line will be HIGH when transmission line shield is correct length.

The last step is to join the outer surface of the coax shield and the close part of the transmission line choke:

Evolution of the Sleeve Choke

Three Conductors of Coax

Center
Inner Shield Surface
Outer Shield Surface

Outer Surface of Feed Line and 'close' half of transmission line choke are merged

Impedance looking to transmission line will be HIGH when second shield is correct length.
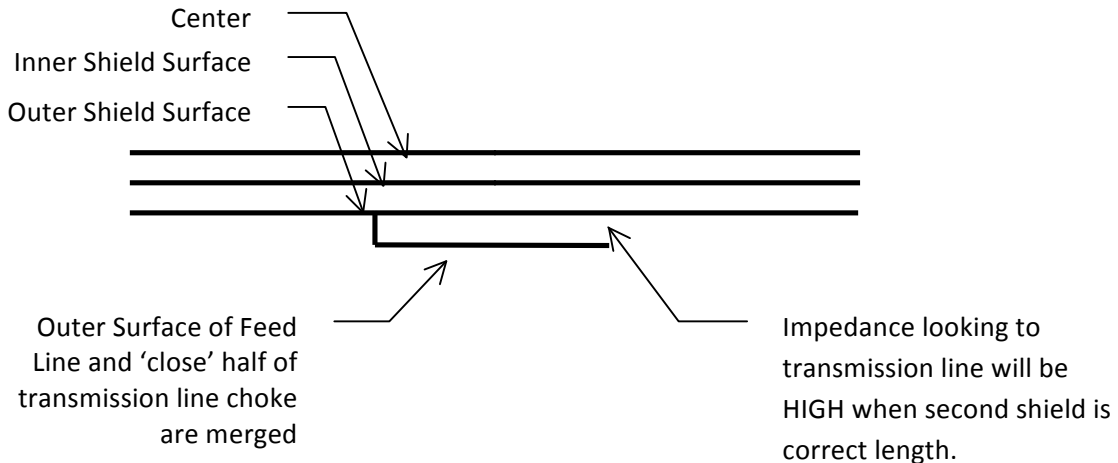
Intuitively, the operation of this circuit is straight forward. Consider what would happen if a current were to flow from the left to the right of the coax shield. Current would start at the left and proceed to the added shield. At this point the current turns downward and then to the right along the outer surface of the added shield. Upon reaching the end of the added shield the current would have to enter the transmission line formed by the two shields. The input impedance to this transmission line is high impedance and so the current must stop. The second shield has effectively formed a common mode choke!

Using the Sleeve Choke

The sleeve choke is very common at VHF frequencies. It is less often found at HF frequencies. There are a variety of ways to construct the sleeve balun.   There are a few pitfalls, however, which should be avoided.

The first pitfall is in determining the length of the sleeve itself. There are some web sites which indicate that the length of the sleeve is somehow affected by the 'velocity factor' of the coax being used. This seems unlikely. The velocity factor of the coax is determined by the dielectric material between the center conductor and the braid of the coax. Since the sleeve choke is constructed using the outer braid of the coax and the added sleeve, the jacket of the coax is the insulating material, not the coax dielectric.   In order to verify this, an experiment was run. In the first experiment a piece of RG58U coax was tuned to 28 MHz resonance. The velocity factor of this coax was determined to be close to .67 and the resulting piece of RG58U was 67 inches long. An AIM4170B antenna analyzer was used to verify operation and the following plot was obtained:
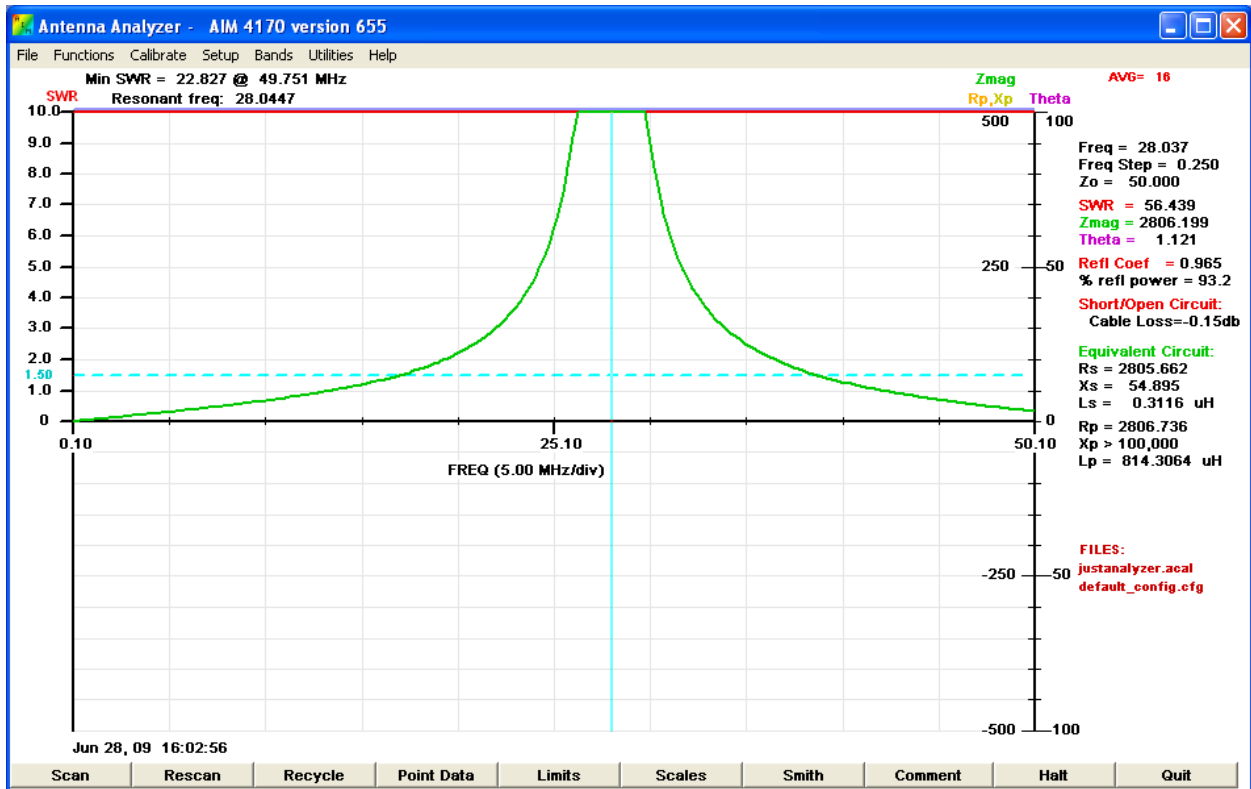
The above plot shows that the RG58U was resonant at 28.04 MHz and that the impedance was about 2800 ohms at this frequency. Importantly, the impedance was not INFINITE which means that the RG58U coax was lossy.
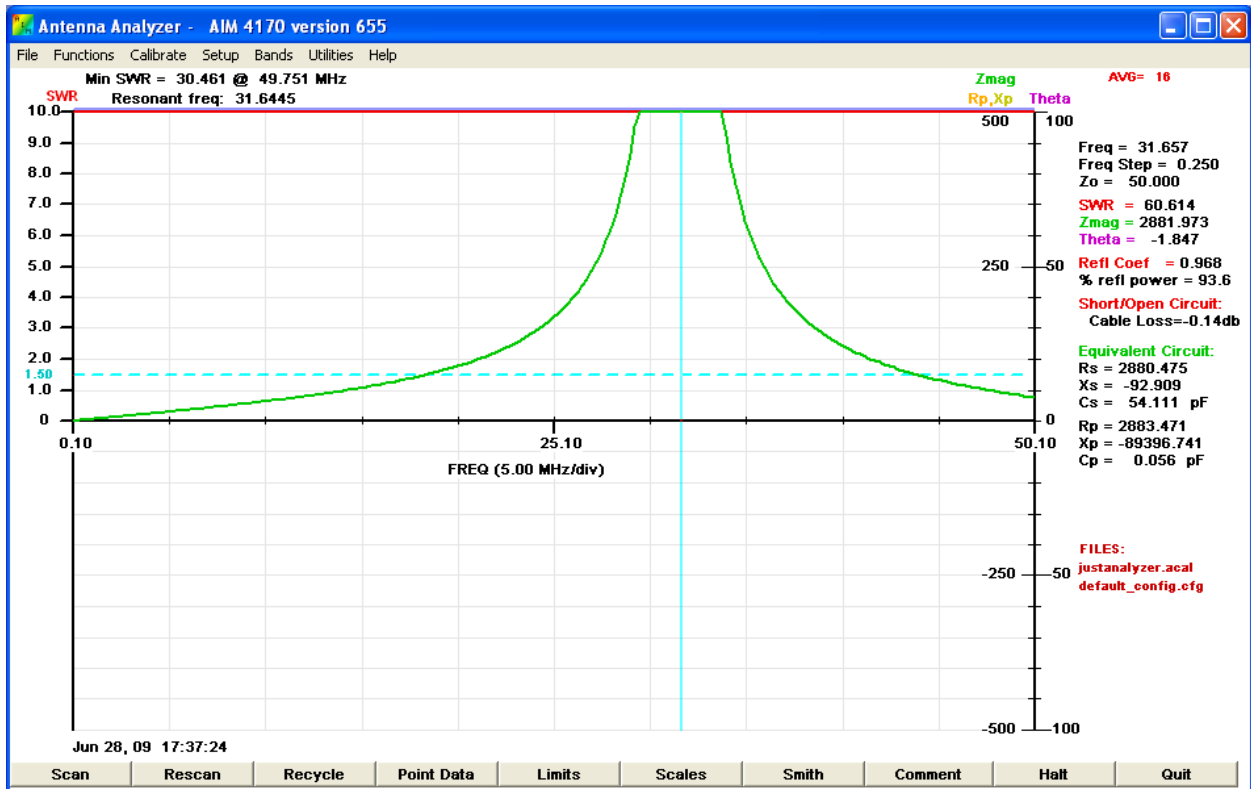
A sleeve choke was then added to this 67 inch piece of coax using a ¼ inch piece of copper tubing. The coax was a very tight fit inside this tubing. The same antenna analyzer was then used to check the impedance of the sleeve balun. The plot is shown below:
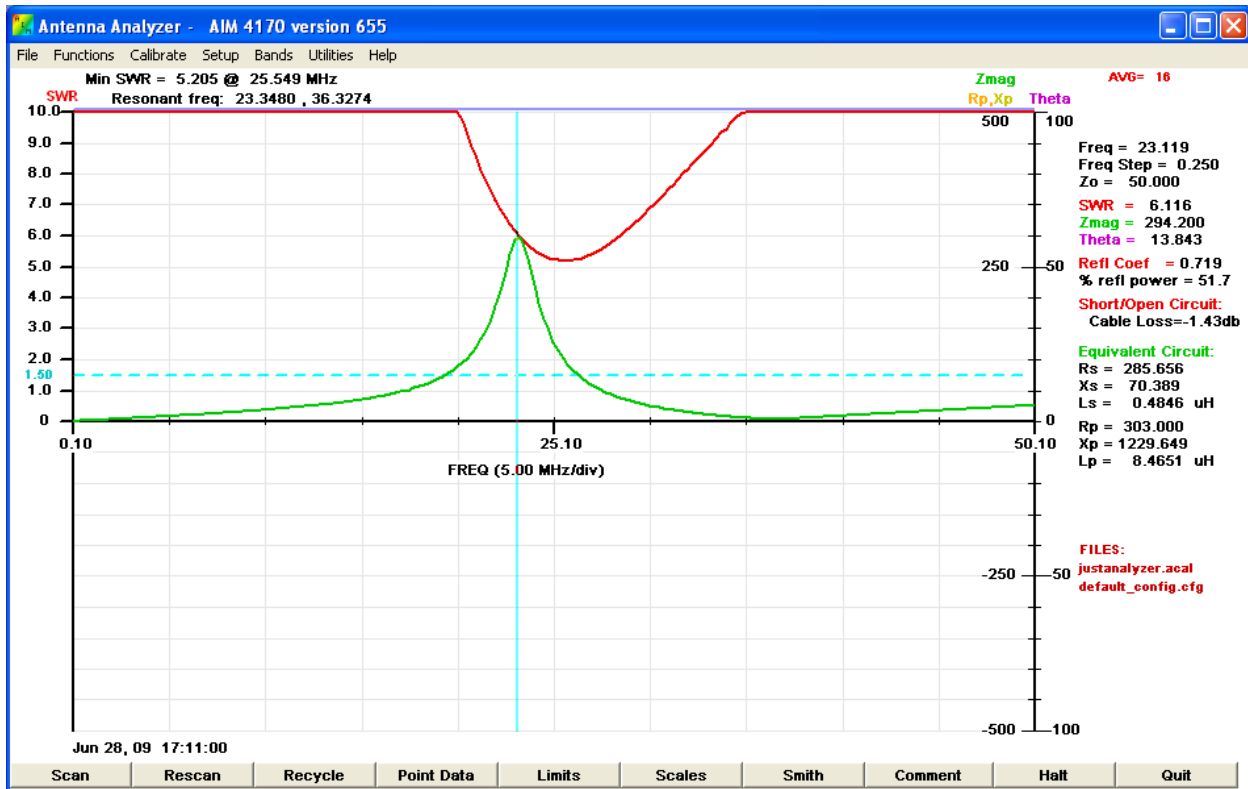
Note the resonant frequency is now 23.3 MHz. If the length of the sleeve was dictated by the velocity factor of the coax then the frequency would be unchanged. Since the frequency did change the only conclusion is that the coax jacket, rather than the internal dielectric, must determine the sleeve velocity factor.

The second pitfall when implementing the sleeve choke is in ignoring the material between the coax shield and the sleeve material itself. The importance of this material is demonstrated by examining the peak impedance in the above plot. The peak impedance shown above is only about 300 ohms! The transmission line formed by the coax shield and the copper tubing sleeve is VERY lossy. This would be a very poor choke.

A second experiment was then performed. In this case the 67 inches of RG58U was run down the center of a piece of 1/2 inch copper tubing. In this case the sleeve transmission line dielectric is now largely air rather than the jacket of the coax. A transmission line using air as the dielectric should have a velocity factor above the RG58U and so the resonant frequency should be higher than 28 MHz.

Antenna Analyzer - AIM 4170 version 655

File   Functions   Calibrate   Setup   Bands   Utilities   Help

Min SWR = 30.461 @ 49.751 MHz
Resonant freq: 31.6445

SWR   Zmag   Rp,Xp   Theta   AVG= 16

Freq = 31.657
Freq Step = 0.250
Zo = 50.000

SWR = 60.614
Zmag = 2881.973
Theta = -1.847

Refl Coef = 0.968
% refl power = 93.6

Short/Open Circuit:
Cable Loss=-0.14db

Equivalent Circuit:
Rs = 2880.475
Xs = -92.909
Cs = 54.111 pF

Rp = 2883.471
Xp = -89396.741
Cp = 0.056 pF

FILES:
justanalyzer.acal
default_config.cfg

FREQ (5.00 MHz/div)

0.10   25.10   50.10

Jun 28, 09 17:37:24

Scan   Rescan   Recycle   Point Data   Limits   Scales   Smith   Comment   Halt   Quit

The resonant frequency is now higher, up to 31 MHz. because the insulating material is now air. More importantly, the impedance has gone back up to 2880 ohms; higher than the RG58U itself. Thus, the losses and length of the sleeve choke are controlled by the insulating material between the coax shield and the sleeve conductor.

As a quick aside, notice that the above waveform is very narrow when compared to the earlier coiled coax choke. The coiled coax was over 500 ohms from 17 to 45 MHz. Above, the transmission line choke is over 500 ohms only from roughly 29 to 33 MHz. Thus, the transmission line choke would be useful only for a single band while the coiled coax choke could be useful for several HF bands if properly designed.

The COAXIAL or BAZOOKA Antenna

The literature describes two antennas which incorporate the sleeve choke into their basic design. Their basic form is shown below.
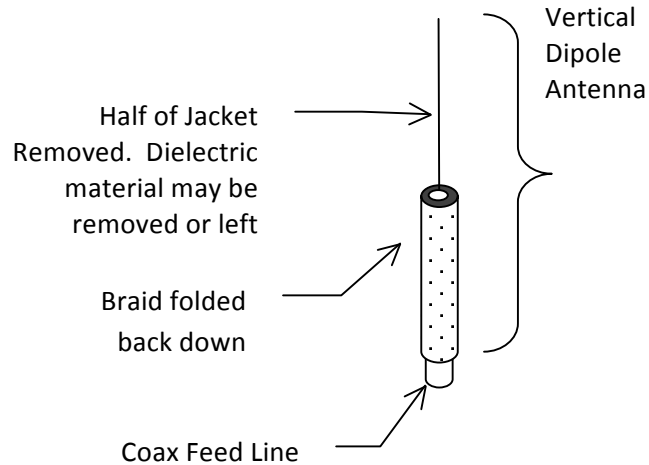
General Form of the COAXIAL or BAZOOKA Antenna

Sleeve connected
to coax shield

Vertical
Dipole
Antenna

Sleeve Choke

Coax Feed Line
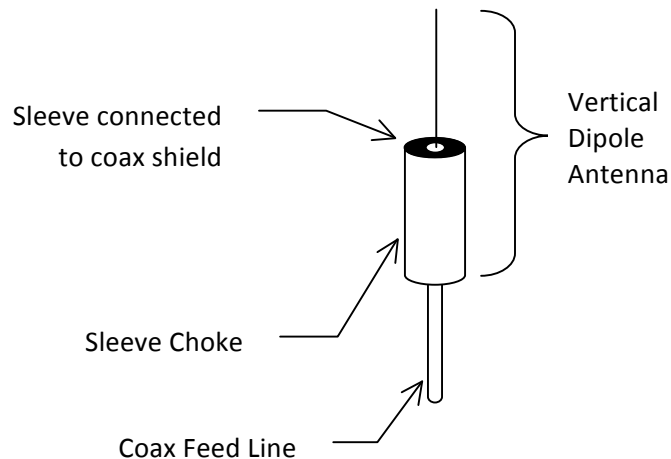
The primary difference between the typical COAXIAL and the typical BAZOOKA is the implementation of the sleeve choke. The sleeve of the COAXIAL antenna is usually constructed using a piece of copper or aluminum tubing and the coax is usually RG8 coax. The tubing is usually much larger than the RG8 and, when constructed this way, the dielectric inside the sleeve choke is typically air and the sleeve length is very close to ½ the length of the dipole. This is a very good antenna which does a good job of suppressing conducted feed line currents because of the integrated choke.

In the typical BAZOOKA antenna the sleeve is constructed using the braid of the coax cable. Construction starts with a piece of RG8 (or other) coax which is about 1 and ½ times as long as the dipole antenna will need to be. Then the outer jacket is removed from ½ of the coax and folded back over the remaining jacket. A rough sketch is:

The Typical Vertical BAZOOKA Antenna

Vertical Dipole Antenna

Half of Jacket Removed. Dielectric material may be removed or left

Braid folded back down

Coax Feed Line

Since the dielectric of the coax jacket is not known precisely the sleeve length must be adjusted experimentally. This can be done using a dip meter or an antenna analyzer. The sleeve is adjusted by connecting the analyzer to the two braids at the bottom of the above picture. The sleeve and coax braid are then shortened until a high impedance is found at the desired frequency. Remember that the impedance will probably not be very high (a few hundred ohms) because the jacket is a very lossy dielectric.

Once the sleeve length has been tuned to the desired frequency the feed line and a VSWR meter are connected to the antenna. The length of the top half of the antenna is then adjusted to achieve the desired resonant frequency by minimizing the VSWR. Tuning the COAXIAL or Bazooka antenna any may prove difficult…

Measuring the VSWR of COAXIAL Antennas

It may be difficult to tune the COAXIAL and BAZOOKA antennas because the test equipment is often in close proximity to end of the dipole antenna. In general, the ends of dipoles are very sensitive to their immediate surroundings. Just standing near a dipole can substantially change its resonant frequency.

There are two choices in connecting the test equipment to the antenna: the equipment can be connected directly or it can be connected using a feed line. If the equipment is connected directly then the end of the dipole may couple directly to the test equipment itself. This will almost certainly affect the resonant frequency of the antenna and thereby confuse the process.

If the antenna is connected to the test equipment using a feed line the antenna can couple to the feed line itself as described in the paper on Feed Line Currents. The recommendation is to place a coiled

choke ¼ wavelength down the feed line to eliminate any induced feed line currents. In this way, the test equipment can be physically removed from the antenna and the antenna can be reproducibly tuned. A detail discussion of the issues involved follows shortly.

The Resonant Feed Line Dipole Antenna.

From an architectural and operational perspective, the Resonant Feed Line Dipole Antenna is essentially the same as the COAXIAL and BAZOOKA antennas:
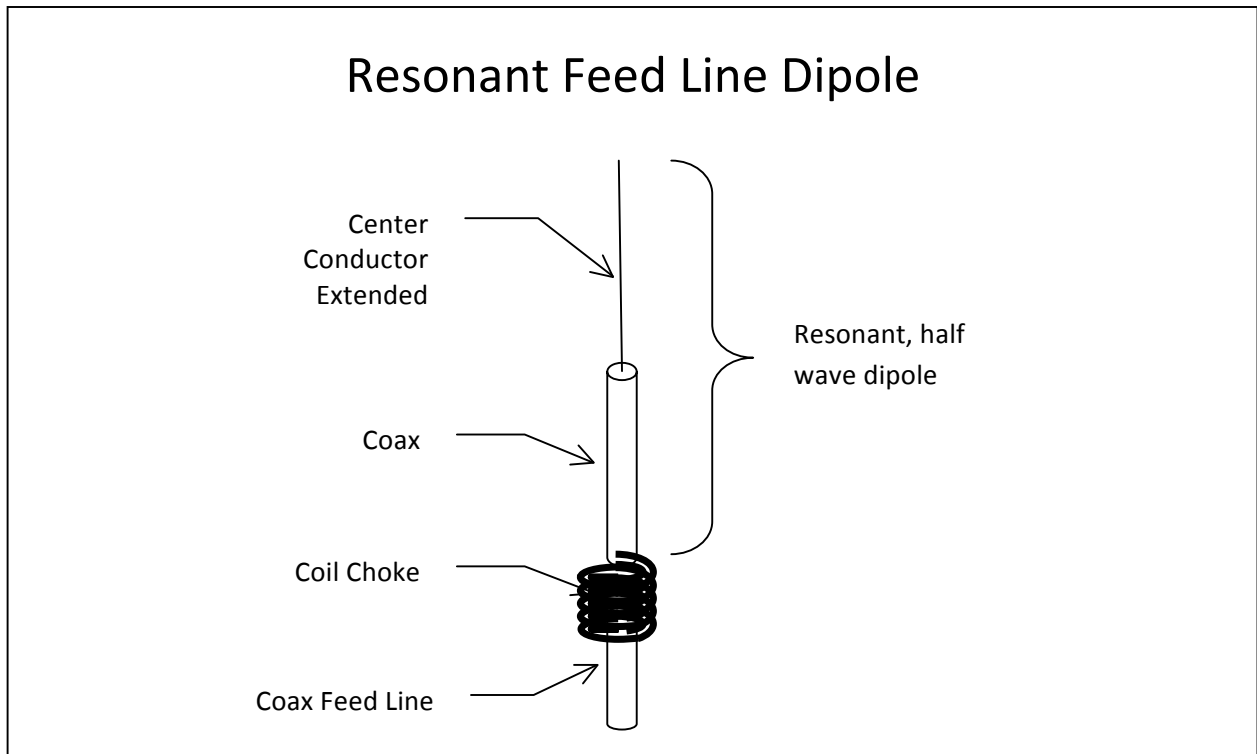

The only significant difference between the COAXIAL antenna and the Resonant Feed Line antenna is the implementation of the choke. For the COAXIAL antenna the choke is implemented as a sleeve choke. For the Resonant Feed Line antenna the choke is implemented using resonant coax coil or a Ferrite choke of some form. The 'trick' is to recognize that the lower half of the dipole is implemented using the outer surface conductor of the coax shield instead of the outer surface of a sleeve. As a result, the Resonant Fed Line antenna is extremely easy to construct.

In the Resonant Feed Line antenna the dipole consists of a single wire connected to the center conductor of the feed line coax and the outer surface of the feed line above the choke. Current flows up the inside of the feed line shield, reaches the end of the braid and turns around and heads back down to the choke where it is stopped. The current flowing on the center conductor of the feed line simply proceeds up to the upper half of the dipole. In essence, operation of the RFL antenna is exactly the same as the bazooka and coaxial antennas.

## The Effects of Imperfections

The three antennas described above have many features in common. The most important for this discussion is their reliance on a common mode choke to establish the resonant length of the dipole and to eliminate common mode currents on the feed line.   Each of these chokes is implemented using a different technique. How do these techniques stack up in actual usage? As with previous examples the operating frequency of these experiments will be 28 MHz.   The basic antenna is:
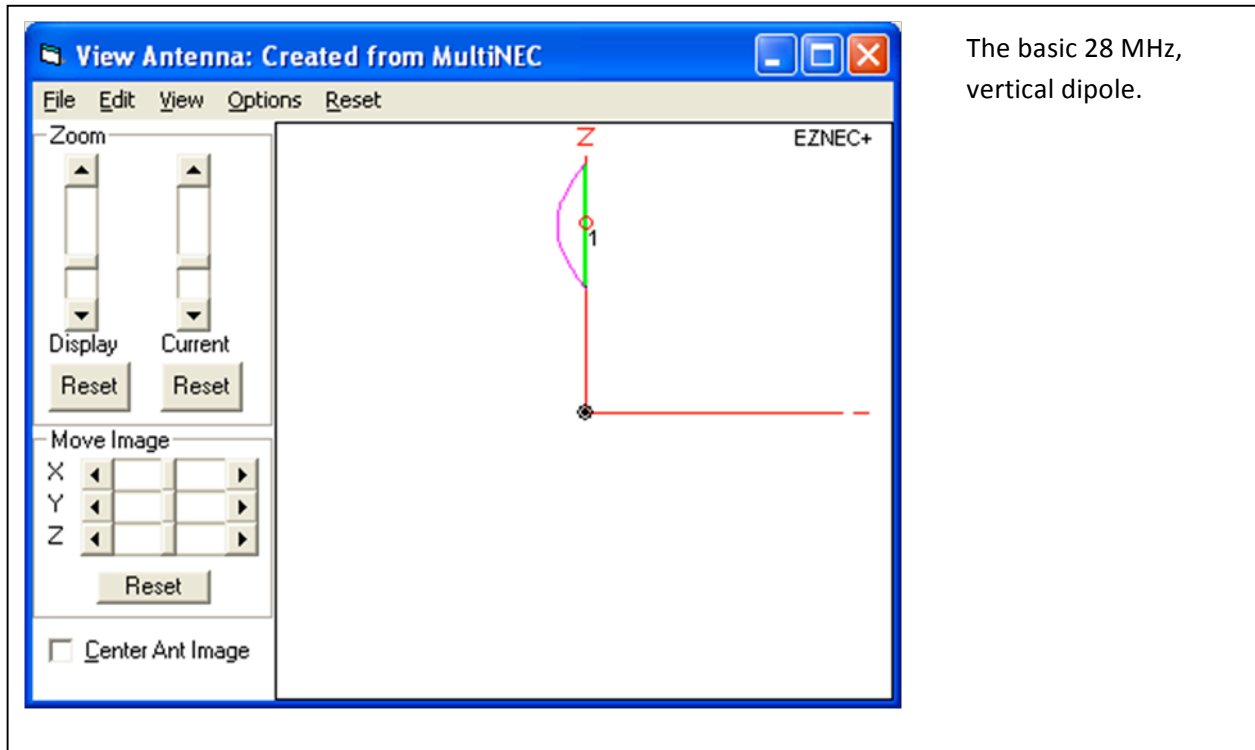
The basic 28 MHz, vertical dipole.
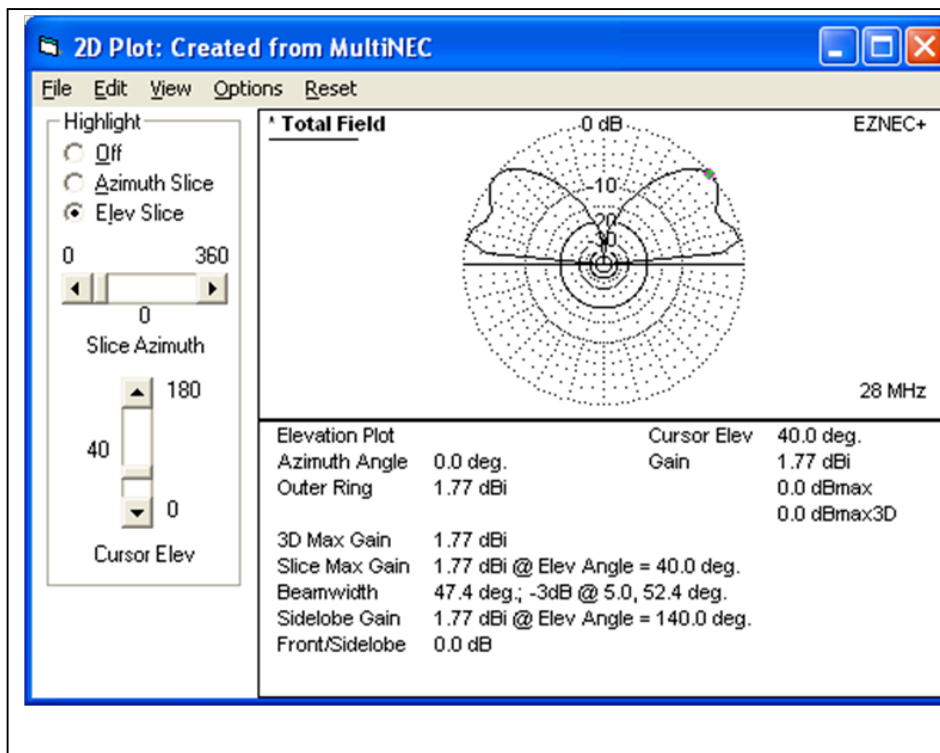
The gain of a 28 MHz vertical, half wave, resonant dipole centered ¾ of a wavelength above ground.
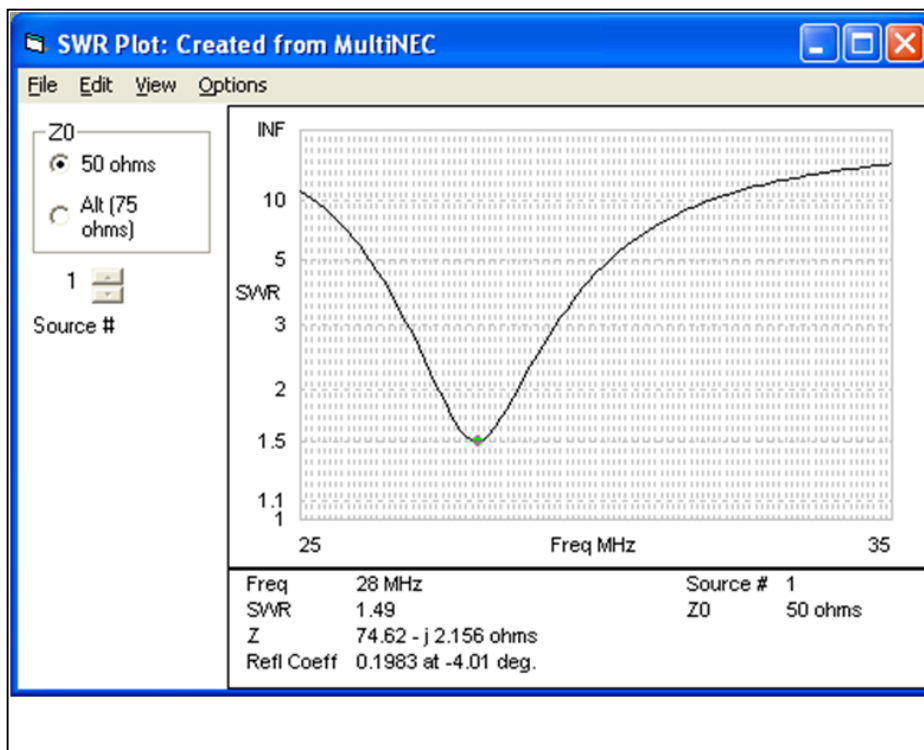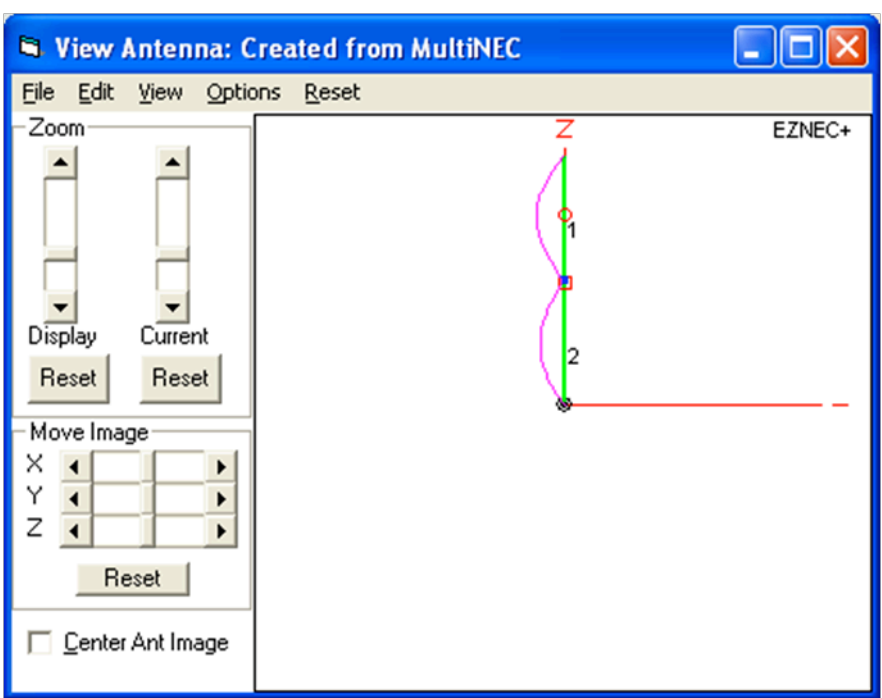
The SWR of the basic vertical dipole. Note impedance is ~75 ohms; pretty much what would be expected of a dipole in free space.

Resonant, ungrounded feed lines

With the above, isolated antenna as an 'ideal', the effect of the feed line can now be examined. As expected, the worst case for feed lines is when they are 'resonant' and that case is examined here. In the first part of this section feed lines are resonant but NOT grounded…

The chokes of these antennas are located at the electrical end of a resonant dipole. As a result, they are working at a location in the antenna where the currents are small and the impedances are voltages are high.

A common rule of thumb is that a feed line choke or 'balun' should have an impedance of at least 10 times the feed line impedance. This would mean that the choke should have an impedance of around 500 ohms. Let us examine what happens when a resonant, ungrounded feed line is connected to the bottom of this antenna with a 500 ohm choke:


The dipole now has a resonant feed line connected to the antenna using a 500 ohm choke. The feed line is NOT connected to ground.

Remember that the feed point is still at the 50% point as this is the case for these types of antennas.
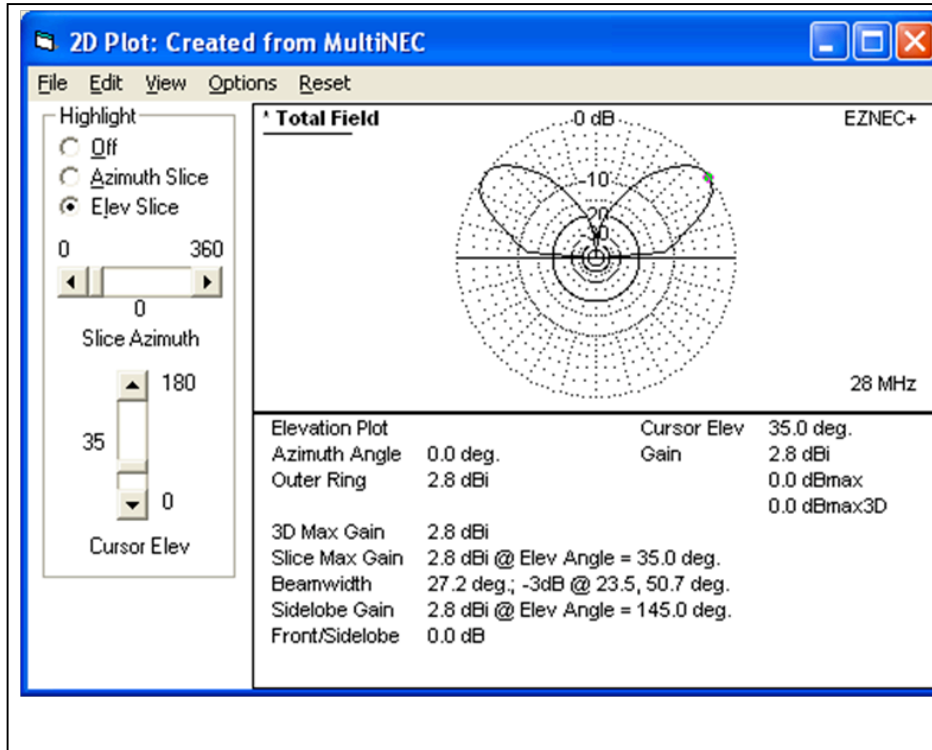
The addition of the feed line and the choke have significantly affected the gain pattern of the antenna. Note that the gain is actually greater (2.8 dBi here) but also higher (up to 35 degrees).

Previous writings have indicated that a feed line choke added at a feed line current maximum would help. That choke is now added:
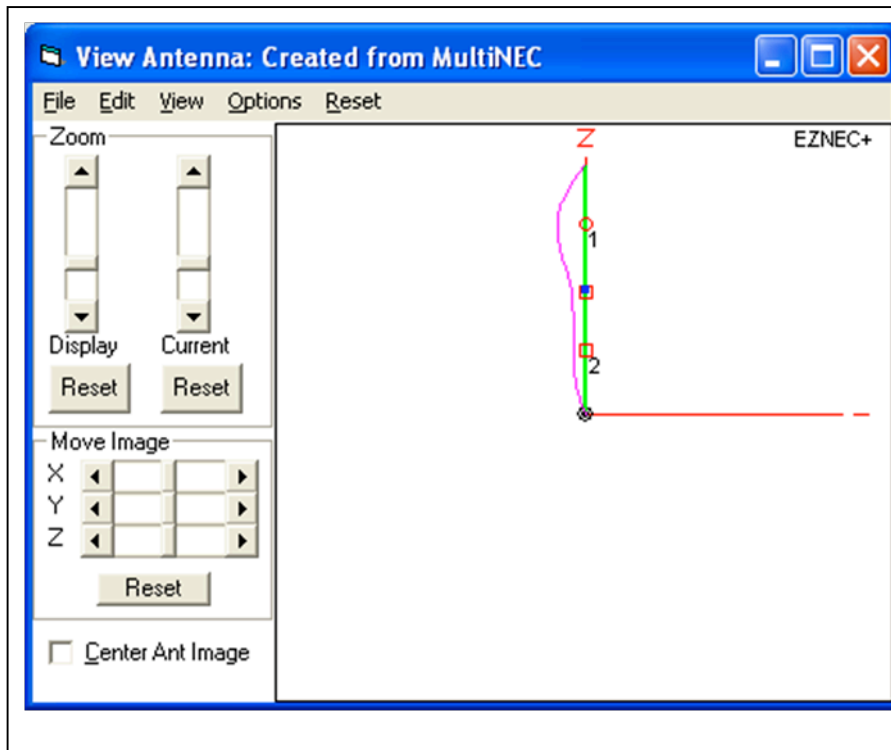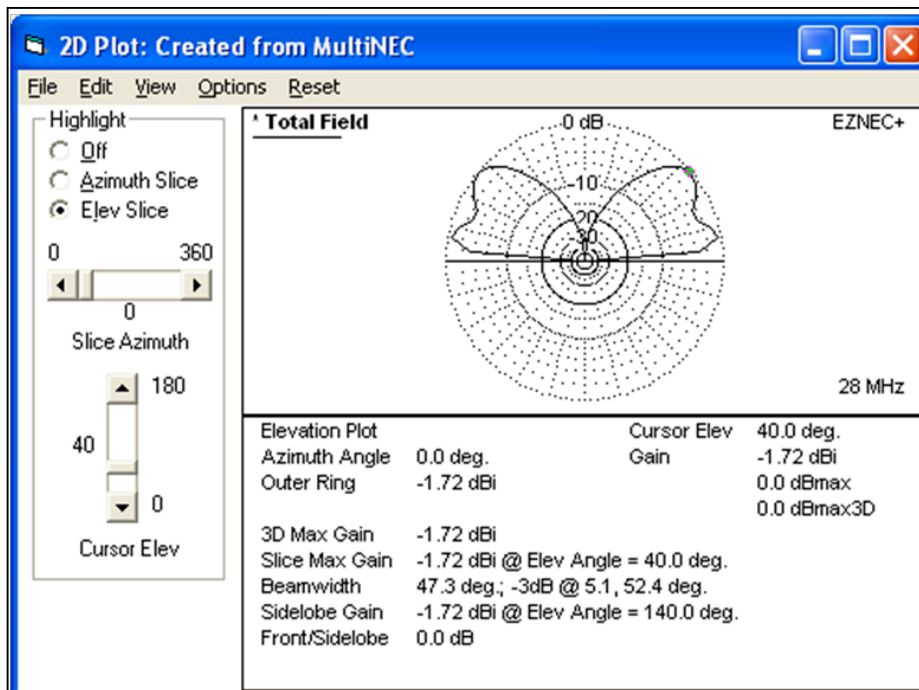

There are now two chokes, both 500 ohms. The currents are much reduced but no nearly gone.
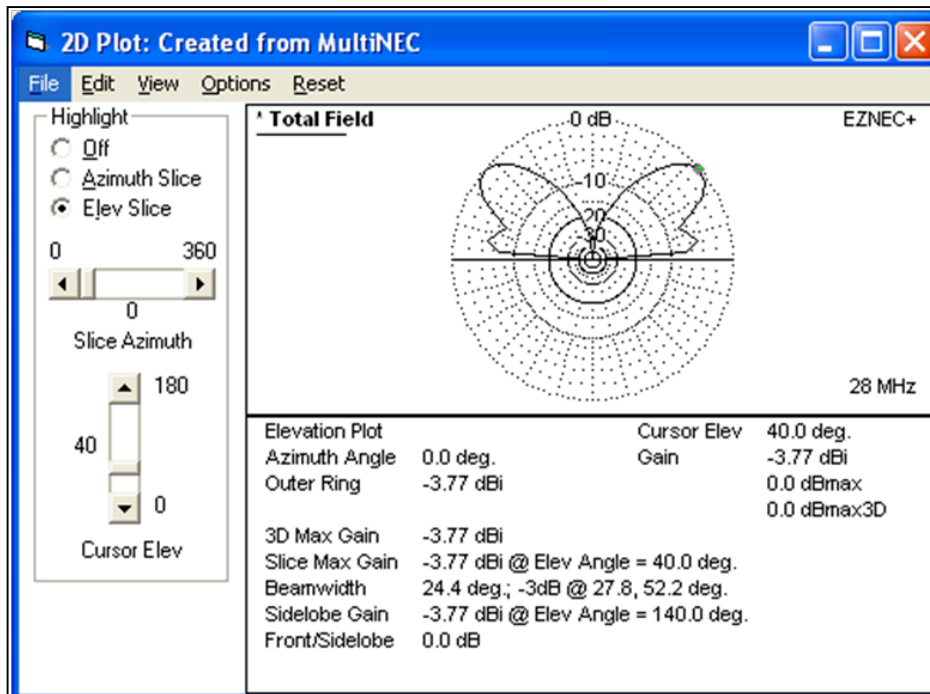
The antenna performance still suffers. Note that the peak gain is down to -3.77 dBi (!)

As has been shown the 'rule of thumb', 500 ohm chokes are inadequate to suppress feed line currents in these antennas. What happens when the choke impedances are increased to the 2800 ohm level:
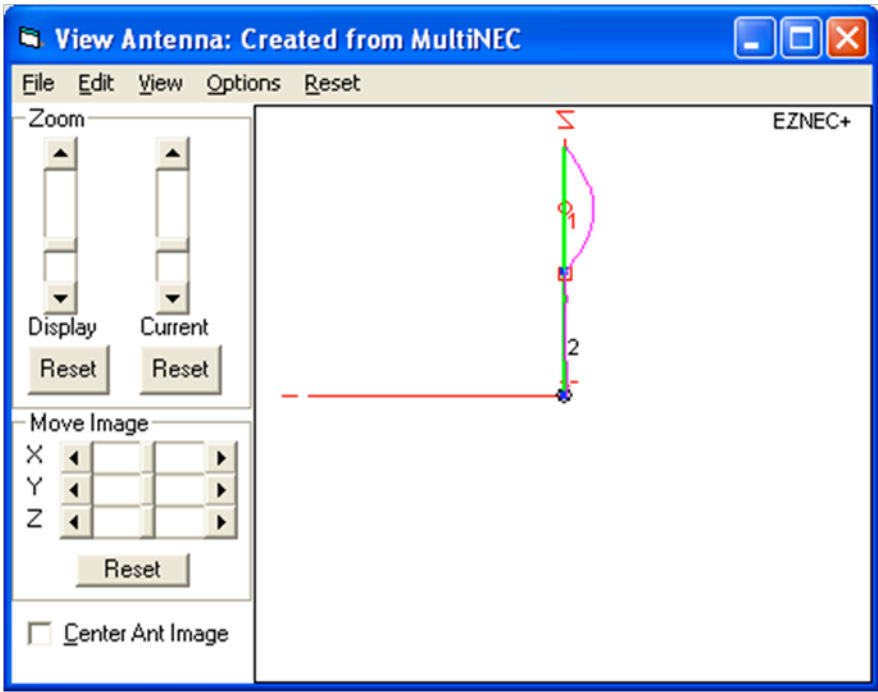

The antenna with two, 2800 ohm chokes. The antenna performance still suffers. The original was 1.77 dBi. Even 'good' chokes result in a 3.5 db reduction in antenna gain.
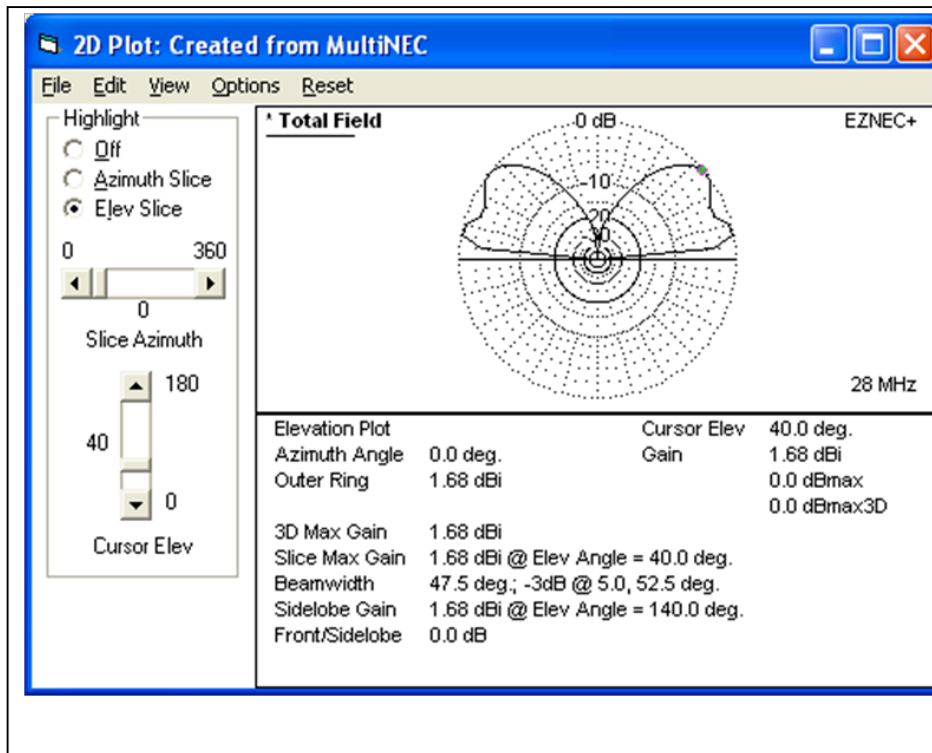
When the choke impedances are increased to 7500 ohms the antenna gain finally reaches about .65 dBi; a reduction of 1.1 dB from the 'ideal'. Thus, with significant attention to detail the COAXIAL or RFL antenna can be made reasonably efficient. Note that TWO chokes were needed, one at the bottom of the radiating dipole element and one, ¼ wavelength down the feed line.

Resonant, Grounded Feed Lines

Up to this point the high value, 7500 ohm chokes appear to be adequate to deal with resonant, isolated feed lines. To complete the examination another case needs to be examined: non-isolated feed lines. To start out, consider the 28 MHz, Coaxial or Bazooka antenna with a ¾ wavelength feed line connected to ground:
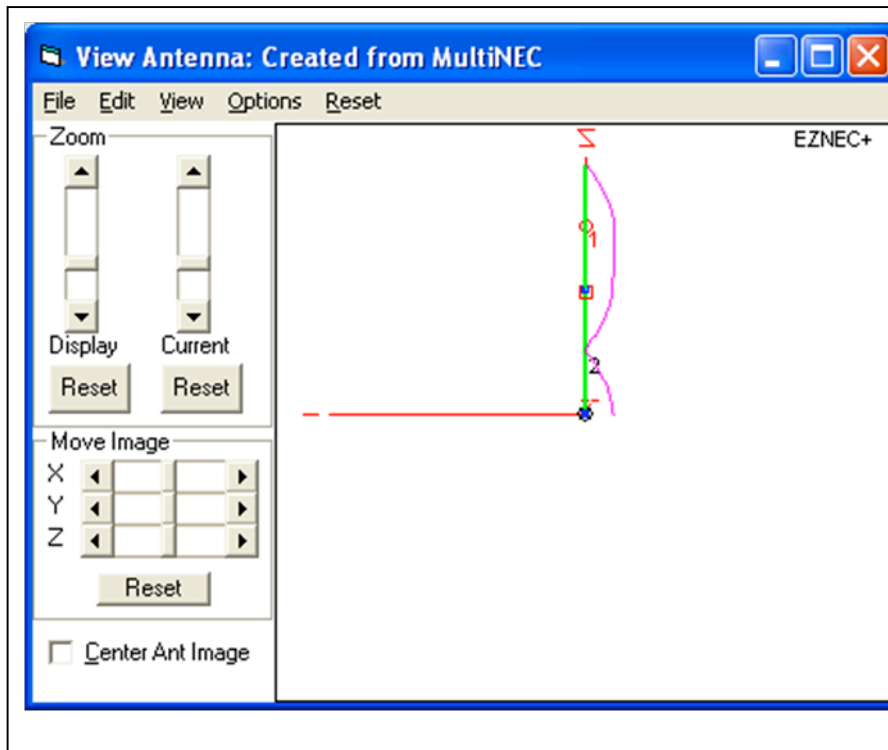

28MHz COAXIAL antenna with a ½ wavelength feed line connected to ground. (Feed Line length measured from bottom of dipole.) Here the choke is modeled as perfect. Feed Line Currents are quite small and have little effect on the antenna performance.

2D Plot: Created from MultiNEC

File Edit View Options Reset

Highlight
- Off
- Azimuth Slice
- Elev Slice

0 — 360

0

Slice Azimuth

180

40

0

Cursor Elev

Total Field · · · 0 dB · · · EZNEC+

28 MHz

Elevation Plot		Cursor Elev	40.0 deg.
Azimuth Angle	0.0 deg.	Gain	1.68 dBi
Outer Ring	1.68 dBi		0.0 dBmax
			0.0 dBmax3D
3D Max Gain	1.68 dBi		
Slice Max Gain	1.68 dBi @ Elev Angle = 40.0 deg.		
Beamwidth	47.5 deg.; -3dB @ 5.0, 52.5 deg.		
Sidelobe Gain	1.68 dBi @ Elev Angle = 140.0 deg.		
Front/Sidelobe	0.0 dB		

The gain of the antenna is pretty much as expected.

In the next experiment, the perfect choke is replaced with a 500 ohm choke as recommended by the previous rule of thumb:

View Antenna: Created from MultiNEC

File Edit View Options Reset

Zoom

Display   Current

Reset   Reset

Move Image
X
Y
Z

Reset

☐ Center Ant Image

EZNEC+

With a choke of a mere 500 ohm the antenna performance is dramatically affected. The current distribution is completely wrong.
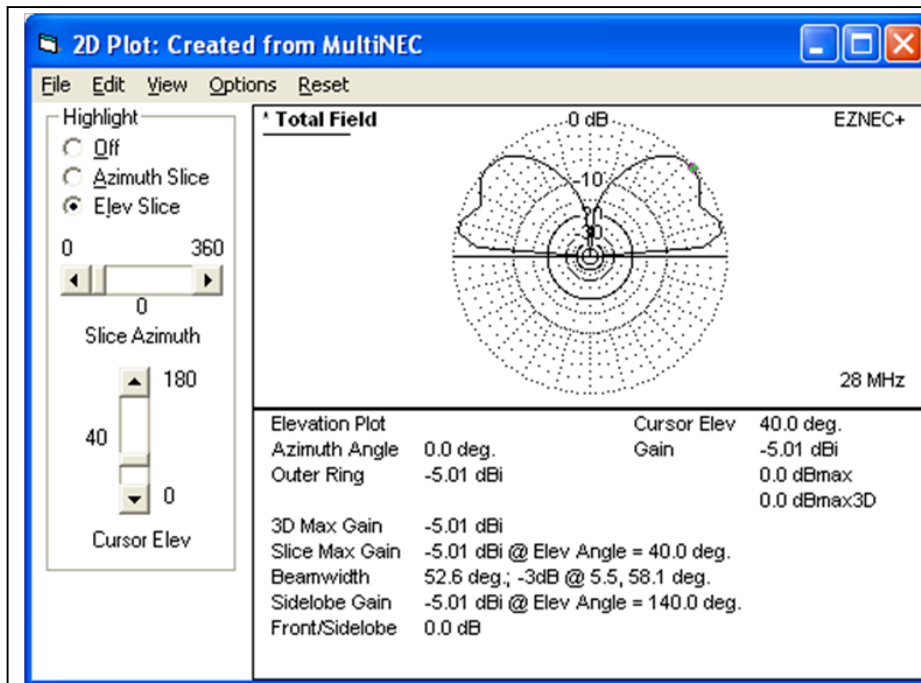
The gain is down to negative 5.01 dBi.

Earlier sections suggested that a second choke can be added to help with feed line currents. However, it has already been shown that low value chokes placed at low current points have little effect. Here is a plot of the currents with TWO 500 ohm chokes installed as previously described:
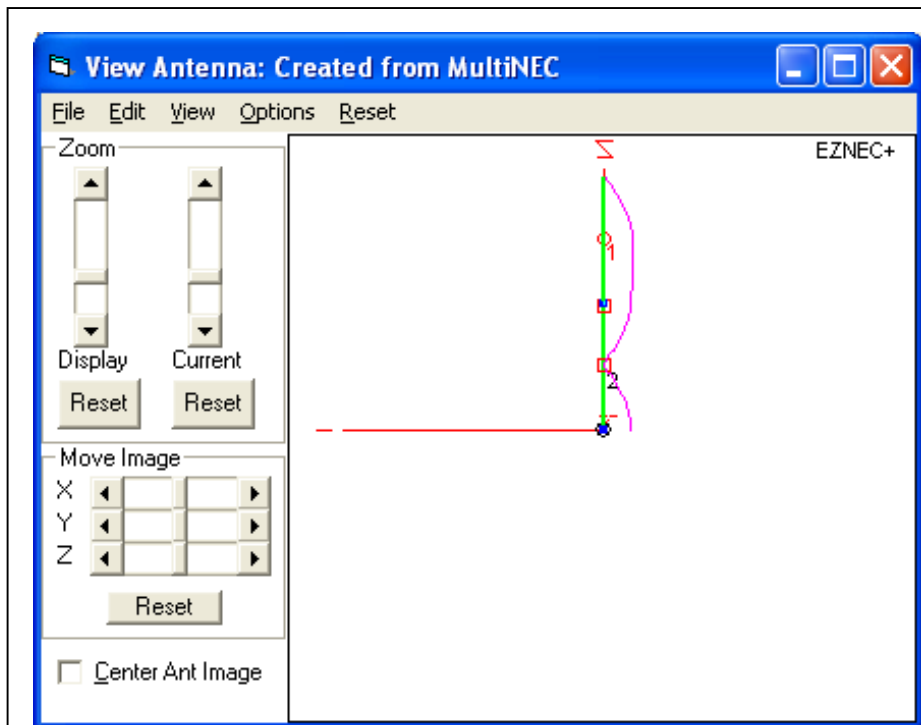

Two, 500 ohm chokes installed as previously described. The feed line currents remain significant and the antenna performance continues to suffer.

As can be seen above and as expected, the second choke provides no real improvement. The next step would be to add a third choke:

Three chokes still isn't good enough.
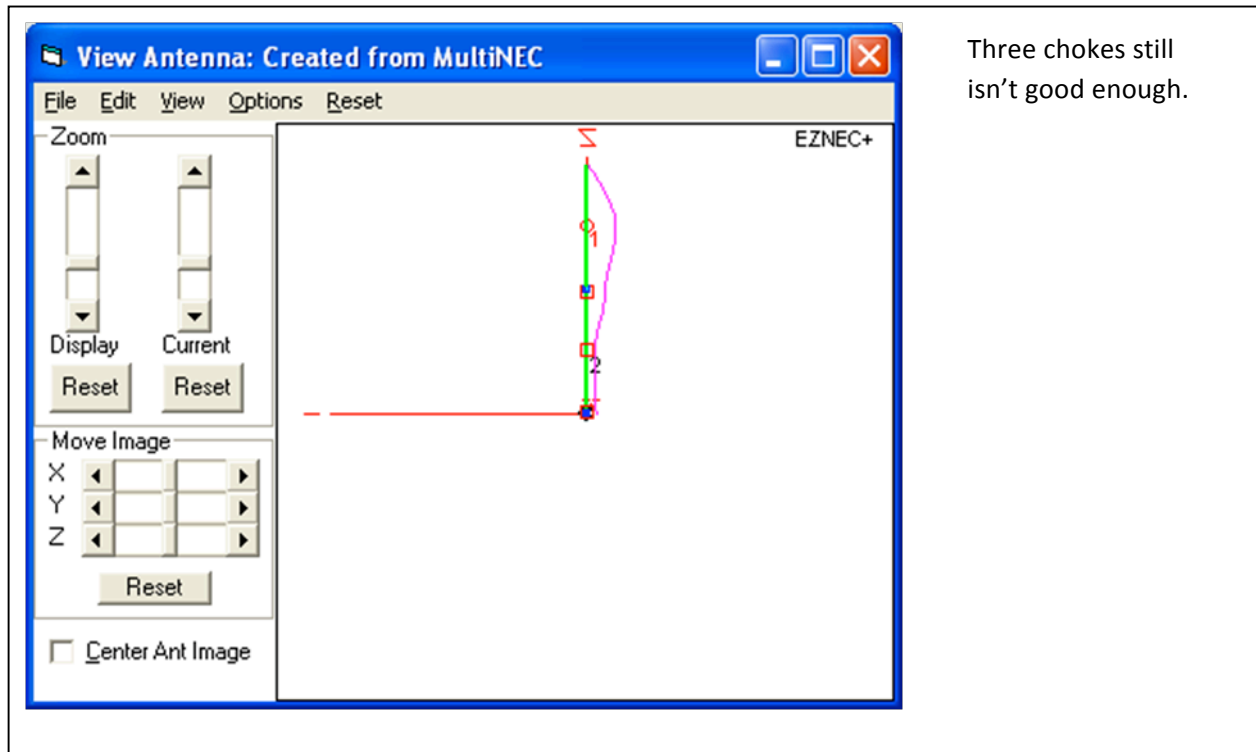
It is clear at this point that 500 ohm chokes will not be sufficient to control the feed line currents of the COAXIAL/BAZOOKA/RFL antennas in all situations. This may well explain why casual construction of this class of antenna often results in poor performance. Since 500 ohm chokes are insufficient, the next question is, what impedance is required. The following what happens as the impedance is increased:
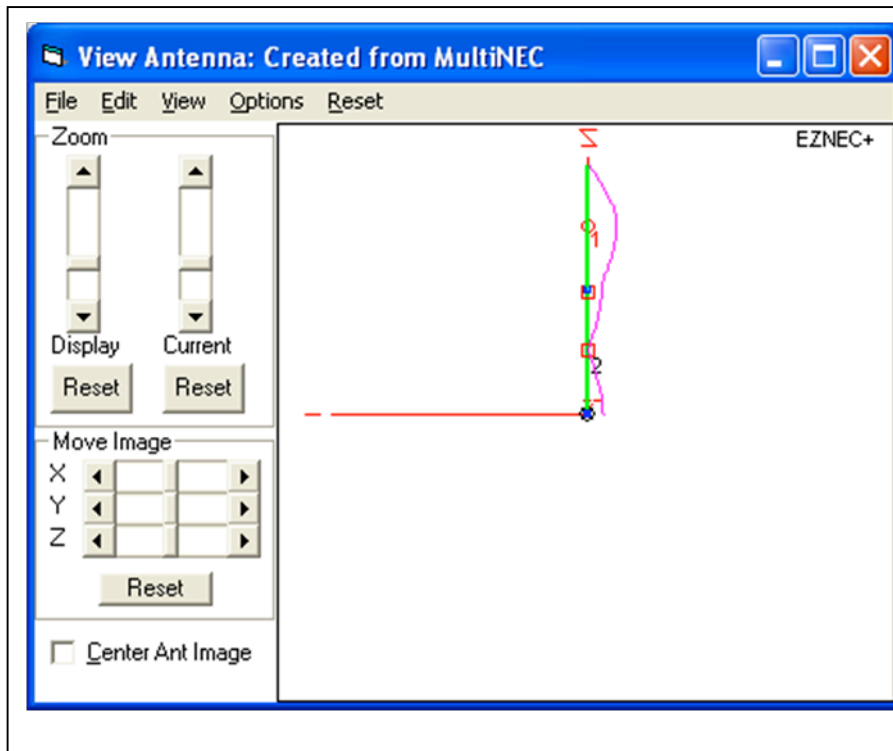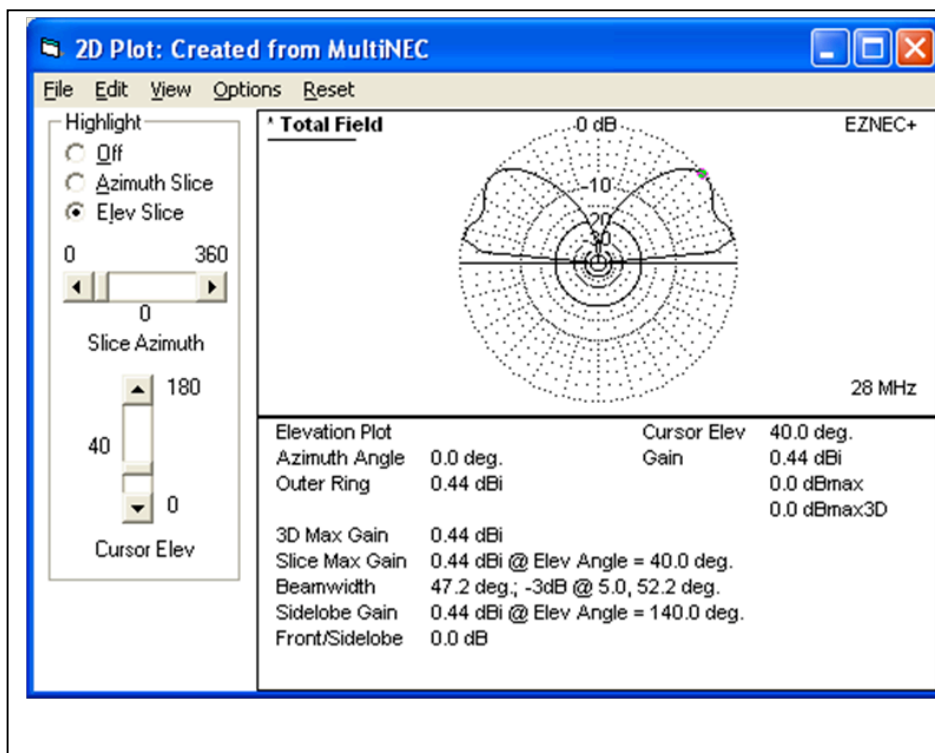
1000 ohm chokes:
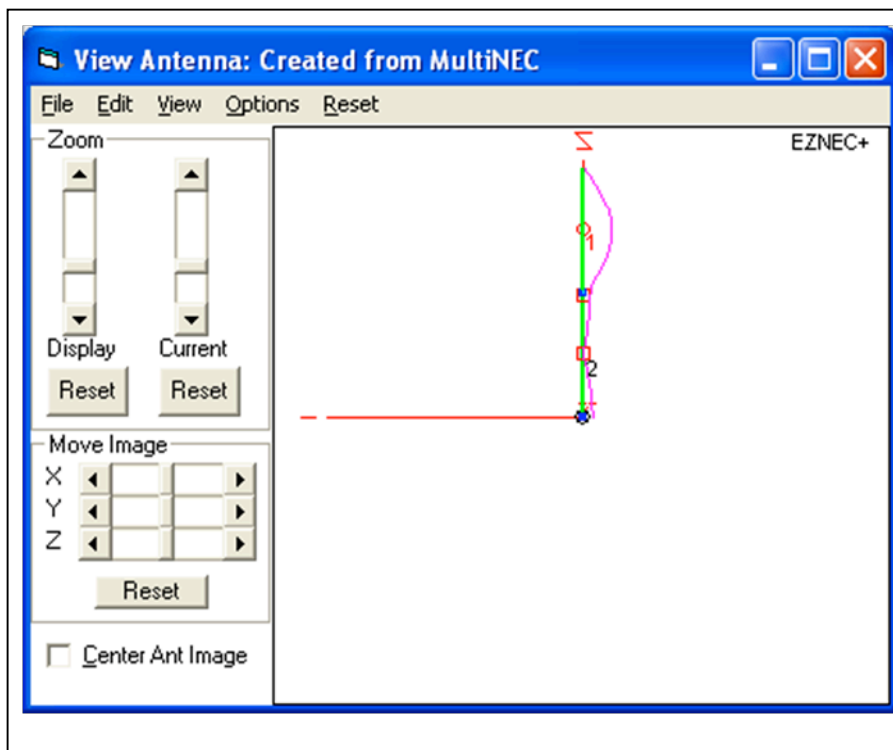
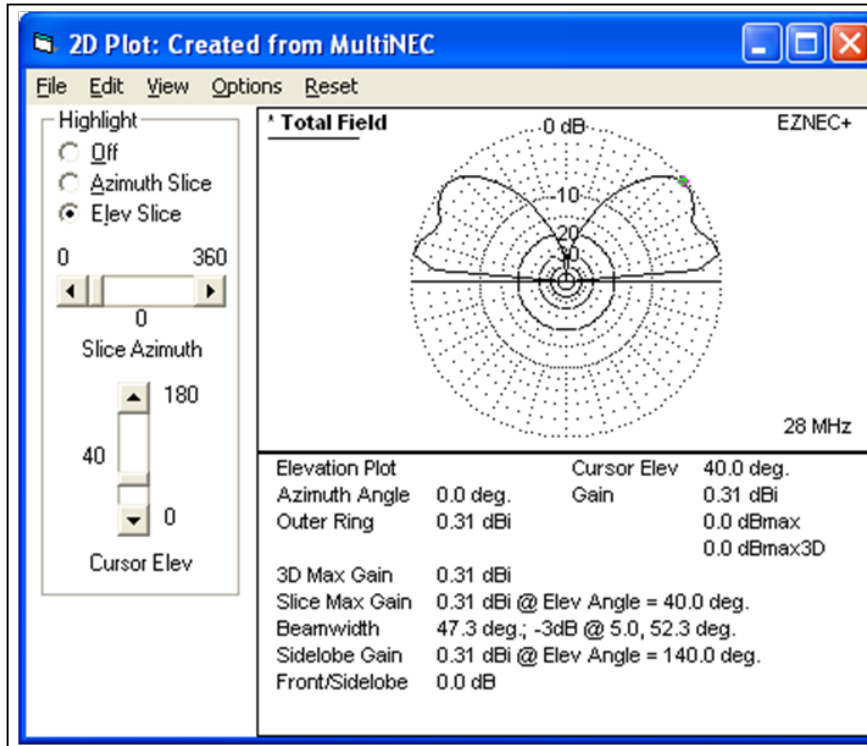2000 ohm chokes. This is starting to look good.
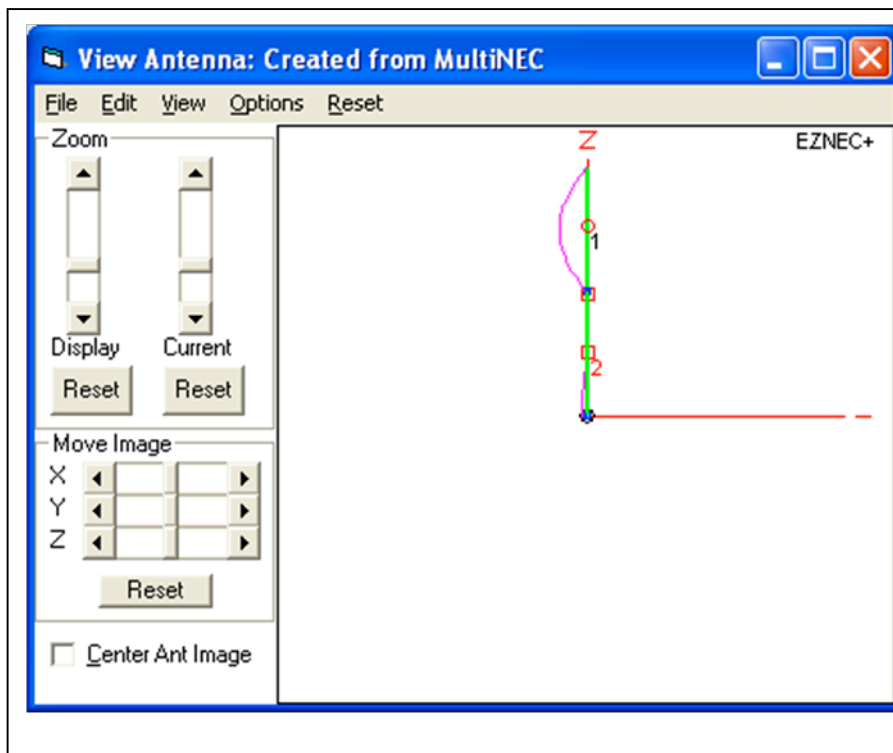
7500 ohm chokes, the currents look pretty good…

The gain is only down 1.3 dB or so.

Finally, it is possible that only one choke need be 'good'. What happens if the choke at the top of the feed line (bottom of the dipole) is 7800 ohms but the choke in the middle is only 500:

Reducing the quality of the middle choke to 500 ohms reduces the antenna gain by only .1 dB or so.

As a result of these experiments it is clear that two chokes are needed with this class of antennas. The top choke, the one which controls the length of the dipole, must be of high quality; on the order of 7000 to 8000 ohms. The second choke which deals with induced feed line currents need only be average; a value of 500 ohms seems adequate. The 7000 ohm choke is impractical with sleeve chokes except when great care is taken in their construction. Coiled coax chokes have no trouble delivering these high impedances.

Summary

In this second article the implementation of several forms of chokes were discussed and several physical implementations were measured and reported. Having examined each of the various chokes architectures this section turned to the implementation of the COAXIAL type antenna. It was shown that with resonant feed lines the quality of the chokes used critically affected antenna performance. This section ended by showing that the choke at the bottom of the radiating element was most critical and needed to have a value largely unrealizable by standard sleeve chokes and that the Resonant Feed Line antenna held more promise of providing a highly efficient antenna.