Chapter 2
The Language of Modeling

Computerized antenna modeling has an extensive set of terms that we must master if we are to be able to model effectively. Some of the language is unique to NEC modeling. However, much of the information derives from geometry--with emphasis on Cartesian concepts--and from various aspects of antenna theory and practice. Let's master all of these terms by doing practical things with them.

In Lesson 3, we shall look at the language that applies to the wire structure we create to make the basic antenna model. Not only shall we encounter the terms "element," "wire" and "segment" once more, but we shall also orient ourselves to the language surrounding the use of X, Y and Z coordinates to specify wire ends.

Lesson 4 will lead us into the fundamental terms of the antenna's environment. We shall look at the available modes of excitation; that is, at both voltage and current sources. The idea of material loading (or losses) will be expanded to cover all of the available types of loads in our programs. By the end of this chapter, we shall be well grounded in ground specifications. We shall also encounter not only the frequency specification, but also the idea of frequency sweeping. We shall also look at transmission lines for the first time.

Lesson 5 will be devoted to data and pattern requests sent to the computing core. We shall meet with multiple pattern coordinate sets that we must keep straight. As well, we shall sample some of the tabular data beyond just the antenna source impedance and SWR. Here, we shall find some unique features in each of our subject versions of *NEC-2*.

In all of this work, we shall learn by doing. So expect to be probing into many more models in each lesson.

Lesson 3
The Antenna Wire Structure
OBJECTIVES

The antenna wire structure or geometry contains two sets of terms that we shall master in this Lesson. First is the inter-relationship among the antenna elements, the model wires and the model segments. Second is the Cartesian system of coordinates, within which we create the wire structure by specifying the end positions of each straight wire making up the model. Since the Cartesian coordinate system may be new to some modelers, we shall devote a number of practical exercises to becoming comfortable with both the system and its terminolgy.

ELEMENTS, WIRES AND SEGMENTS

In our very first Lesson, we briefly encountered the basic terminology describing an antenna, both as a physical object and as a mathematical model. Let's review and expand on this so that we are clear on how a NEC model does its work.

NEC uses only straight wires--each one defined by the Cartesian coordinates for its end points--to simulate antenna elements. A circular element can be simulated by a polygon.

The number of sides would be determined by the degree of exactness we want to achieve in modeling the circle. A hexagon satisfies many general tasks, although an octagon may be more accurate still. For some highly precise applications, some modelers have used dozens of sides for their polygon models of circles.

Most actual amateur radio antennas (but certainly not all) are composed of elements with straight sections. Therefore, the straight-wire requirement is not a restriction, but an accurate representation of the antenna element.

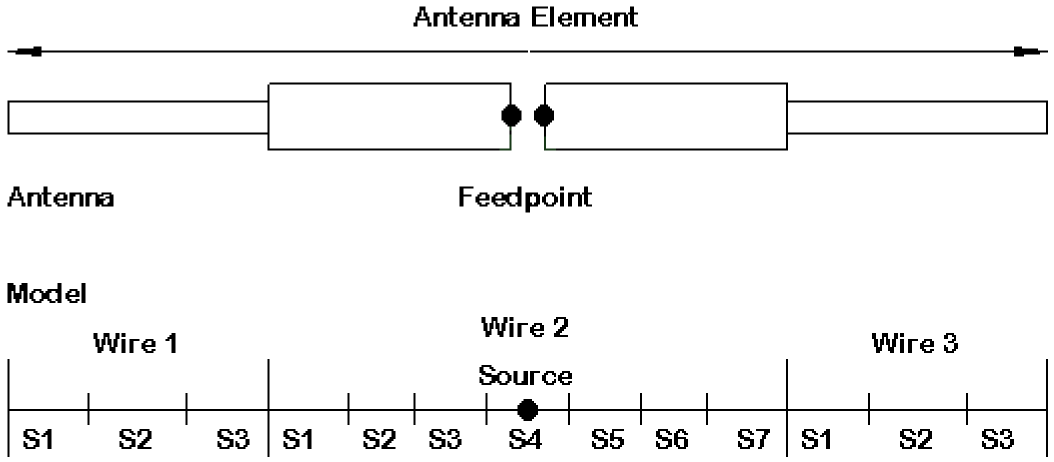


Fig 3-1--A typical linear antenna element, made of telescoping aluminum tubing.

Fig 3-1 shows a typical linear antenna element made of two different diameters of conductor "wires." It is physically split in the center using an insulator of some sort so that we may connect a feed line or energy source. For virtually all antennas, the energy source, whether a transmitter or a feed line, is viewed as being in series with the antenna element.

The lower portion of Fig 3-1 shows the representations of the wires that go into this model. Each different diameter of conductor must be specified as a different wire. Hence, our model will have three wires. At this point, you may well ask the question: "Why do you use only *three* wires? I see four pieces of tubing used in the actual antenna."

The middle wire, Wire 2, contains the energy source (or excitation) for the modeled element. In effect, the NEC computational core requires an "infinitely thin gap," as though the insulator in the middle is vanishingly small. We do not split the wire, but instead place the source on the segment that most closely approximates the physical position of the element feed point. The program places this source in series with the wire itself.

The physical gap that we make in the antenna to connect the feedline is handled by NEC mathematically within the wire source segment. Hence, you will need to adjust your picture of an antenna feedpoint when modeling to think of the source wire as continuous (with some special exceptions that we shall meet in future lessons).

The end-point coordinates for End 2 at the right-hand end of Wire 1 are the same as the coordinates for the End 1 point (left-hand end) of Wire 2. Likewise, the End 2 coordinates for Wire 2 are the same as the End 1 coordinates for Wire 3. *NEC-2* treats matching end-point coordinates as forming a junction to create a continuous structure, just as it treats junctions between segments as forming a continuous structure.

Each wire is subdivided into segments. Since we specify for each wire the number of segments used to subdivide it, each segment within a wire will automatically have the same length. Here are some rules-of-thumb regarding segmentation for beginning modelers. They are generally safe guidelines for most models developed by hams, although they do not press the limits of the *NEC-2* program.

1. Use at least 10 segments per half wavelength of wire at the highest operating frequency. (Ten segments per full wavelength is sometimes used to specify the longest allowable segment length -- 0.1λ -- but doubling the segment count yields more accurate results for a larger variety of geometric wire assemblies.)

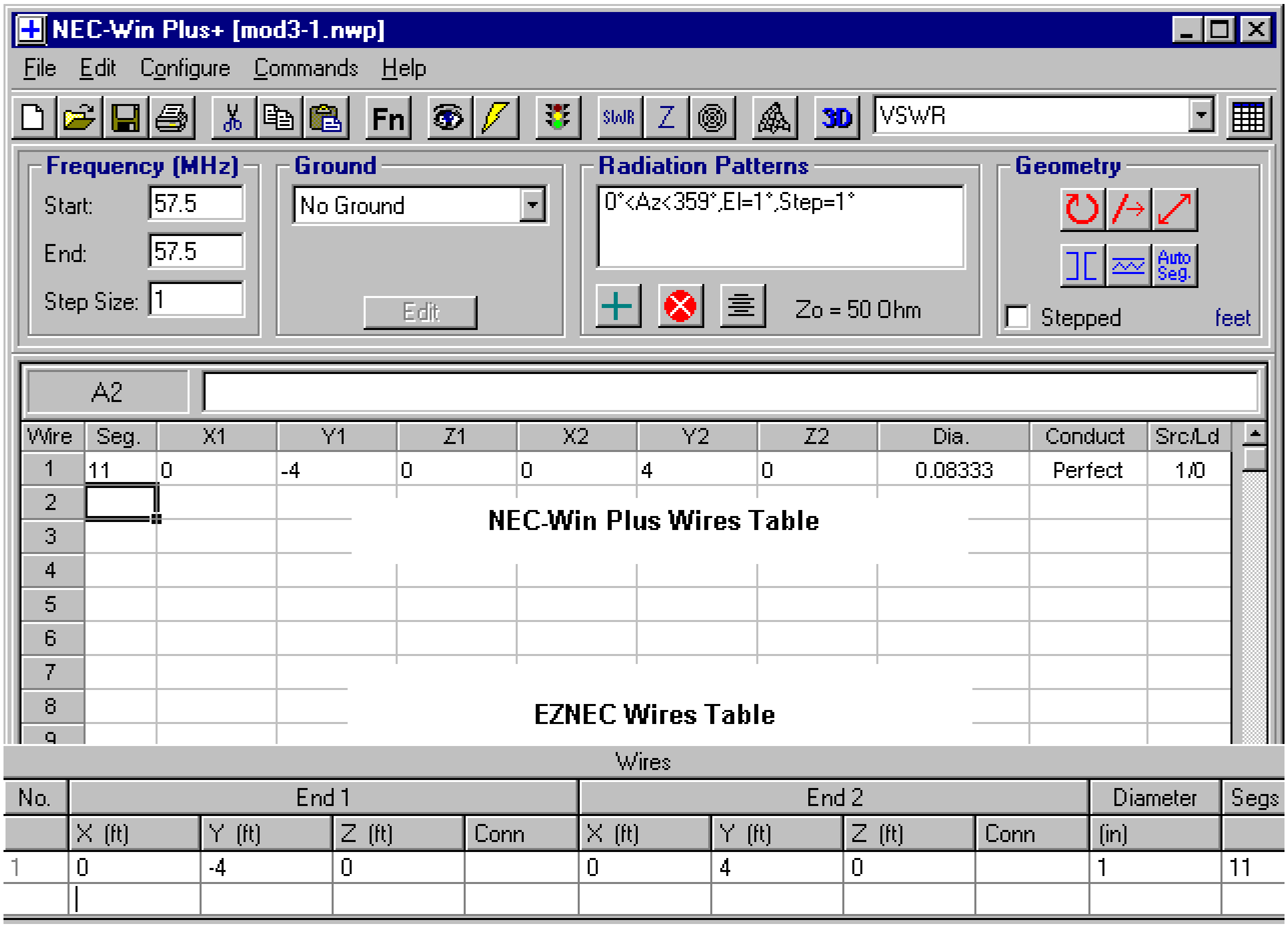
2. Use a segment-length-to-diameter ratio of at least 4:1. (Although the absolute limit is sometimes given as a segment-length-to-radius ratio of 1:1, the much larger recommended ratio tends to prevent problems in complex geometries with angular junctions of wires.)

3. If an element is composed of more than one wire, the length of segments on each wire in the assembly should be as equal as possible.

4. To the degree possible, for parallel wires, let the segment junctions align as closely as possible. (This rule is absolutely essential when wires are closely spaced, as in a folded dipole, and thus makes good sense as a general practice in all modeling.)

Throughout these lessons, we shall use the term "element" to refer to the physical antenna part. The terms "wire" and "segment" will refer to parts of the antenna model. (There are a few cases in which we must use a few extra words for clarity. For example, the common 80-meter wire dipole will become an 80-meter wire dipole element when referring to the antenna in the back yard.)

NEC-2 internally works in meters. We may specify the wire geometry in any units of measure so long as we provide a scaling factor so that the core can calculate in meters. This job is done automatically by commercial implementations of *NEC-2*. However, there may be differences in the way programs carry out this task.



Frequency (MHz)
Start: 57.5
End: 57.5
Step Size: 1

Ground: No Ground

Radiation Patterns: 0°<Az<359°,El=1°,Step=1°

Zo = 50 Ohm

Geometry: ☐ Stepped feet

Wire	Seg.	X1	Y1	Z1	X2	Y2	Z2	Dia.	Conduct	Src/Ld
1	11	0	-4	0	0	4	0	0.08333	Perfect	1/0
2										
3										
4										
5										
6										
7										
8										
9										

Wires

No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	0	-4	0		0	4	0		1	11

Fig 3-2--Examples of wire tables from *NEC-Win Plus* and *EZNEC 3.0* for a 57.5-MHz dipole.

Fig 3-2 overlays the wire tables of *NEC-Win Plus* and *EZNEC* for the same model-a dipole for 57.5 MHz that we shall use later in this lesson. In both cases, the unit of measure is feet, and the wire end-points show the same values: -4 and +4. However, each program handles the wire diameter differently. *EZNEC* specifies the wire diameter in inches when using any English unit of length. When using metric lengths of any size, the diameter is entered in millimeters. In contrast, *NEC-Win Plus* requires that the diameter be specified in the same unit of measure as the length. Hence, the 1" diameter of the wire becomes 0.08333'. The Appendix contains a handy chart of English-Metric conversion factors. An alternative method for specifying the size of a wire in both *EZNEC* and *NEC-Win Plus* is to specify an AWG gauge. The diameter, however specified, will be internally converted by either program into a radius.

CARTESIAN COORDINATES

The wire tables in Fig 3-2 show us some basic ways to create wires for an antenna model. We define the end points of each wire on a Cartesian coordinate system, using values of X, Y and Z--plus a pre-selected unit of measure. The wire runs in a straight line between these end points and is subdivided into the number of segments that we specify for each wire.

Rene Descartes, the 17th century French mathematician and philosopher, would likely be chagrined by the confusion about the coordinate system that bears his name. He developed the system to simplify the specification of positions and the calculation of relative distances between them. Let's spend a little time becoming more familiar with the system. Then we can practice using the coordinate system in a series of exercises.

Let's begin using only two dimensions. Consider a flat surface. We shall observe this surface from a position above it. We shall designate a center point or *origin* for the surface. In one direction-by convention from left to right-we shall draw a line, marking the left end -X and the right end +X. We call this line the *X axis*. Next, we draw a line-by convention vertically on a piece of paper-and label the bottom end -Y and the upper end +Y. This line is the *Y axis*. Finally, we divide each line into equal-length units and label them. By drawing dashed lines through each marker, we obtain a grid, like the one shown in **Fig 3-3**.

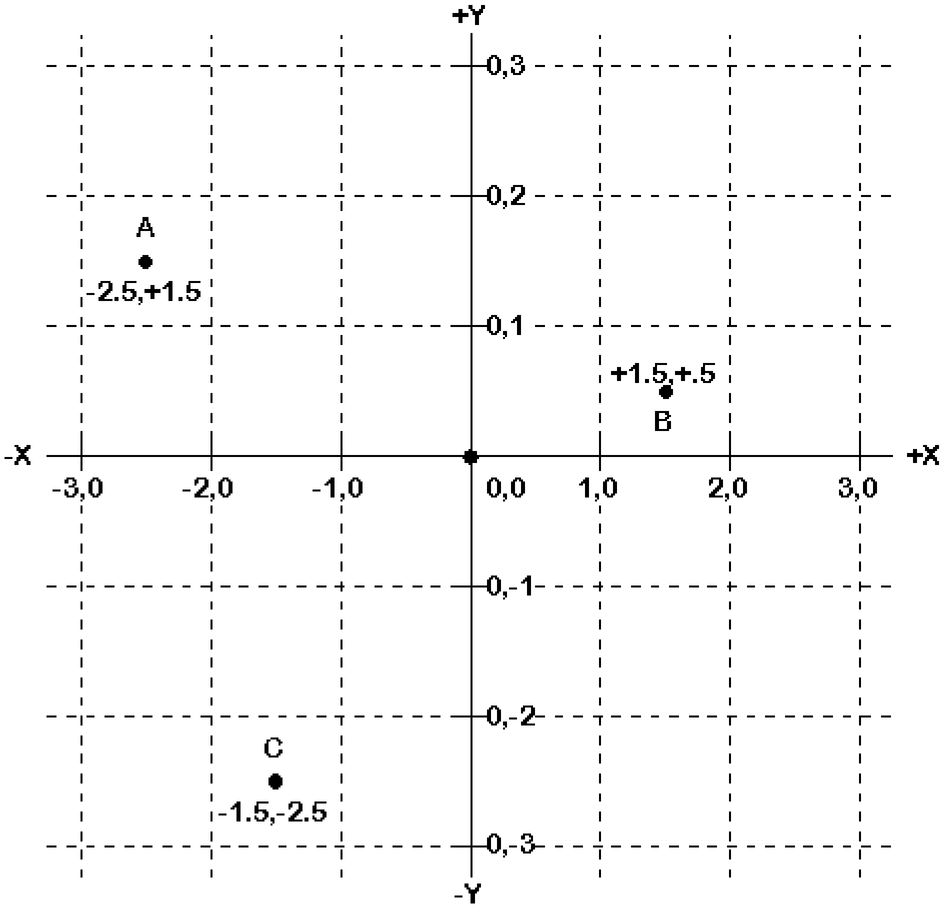


Fig 3-3--Two-dimensional Cartesian coordinates.

Note that each position consists of two numbers. By convention, we list them in the order (X, Y). Any point on the surface can now be easily identified with respect to the origin by listing its coordinates relative to the X and Y axes. Points A, B and C are samples. Note that each point forms a right triangle with the origin and the axes of the coordinate system. Hence, we can now apply a very simple equation to determine the distance of a point from the origin:

$$D = \sqrt{X^2 + Y^2} \qquad \text{Eq 1}$$

where D is the distance from the origin, and X and Y are the distances of the point along each axis. With a little more trigonometry, we might also calculate the distances between the three points, but this sample will suffice to illustrate the utility of Cartesian coordinates.

In most cases, we shall lay out our antenna elements parallel to the axes, thereby simplifying our task. Before the end of this lesson, we shall see some ways to move an initial layout around the system. In a later lesson, we shall even find a way to rotate an antenna in 1° or smaller increments.

The two-dimensional Cartesian coordinate system satisfies most of our needs for setting up *planar* or flat antennas, ranging from dipoles to long Yagis, or to longer rhombics. However, for many purposes, we need a three-dimensional version of the coordinate system. Now we need to think about both free space and a flat earth.

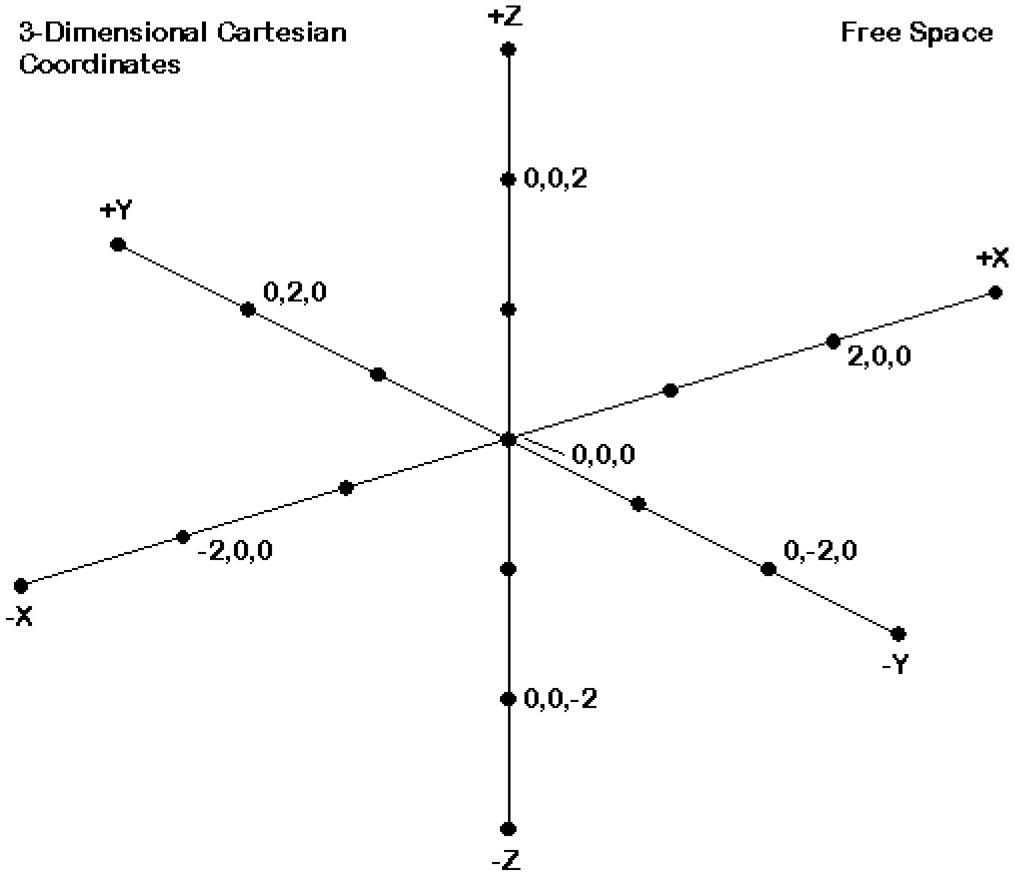


Fig 3-4--A three-dimensional Cartesian coordinate system.

Fig 3-4 provides a representation of a three-dimensional Cartesian coordinate system in free space. Free space is in many ways like outer space: There is no reflective plane beneath the antenna to alter the trajectory of the radiated signal. Therefore, a simple wire antenna in free space may radiate downward as effectively as it radiates upward.

We may place an object (or specify a point) anywhere in the three dimensions by specifying coordinates for the X and Y axes, and for the new Z axis. By convention, Z represents the vertical axis, running from -Z at the lower limit to +Z at the upper limit. The full specification of the position of any point will now require three numbers, listed in the order (X, Y, Z).

Eventually, we shall encounter vertical monopoles and dipoles. These antennas will have end points that lie along the Z-axis. We shall also encounter quad loops, consisting of flat squares of wires having end points along the Z-axis and either the X- or the Y-axes. Finally, we shall encounter arrays that require end points in all three axes, with values that change with every wire in the model.

In Lessons 5-8, we shall work extensively with setting up complex wire assemblies that mathematically replicate the antenna we want to analyze and that stay within the *NEC-2* guidelines. For the moment, we simply want to become comfortable in thinking about the X, Y and Z of Cartesian coordinates.

NEC-2 does not permit wires to be on or beneath the surface of the ground. Therefore, the Cartesian coordinate system become slightly less complex whenever we specify a model over a ground. *NEC-2* presumes a flat earth, which is quite satisfactory for establishing the operating properties of an antenna. Therefore, whenever we place an antenna over ground, we can simplify the three-dimensional Cartesian coordinate system by removing the -Z portion of the Z-axis. **Fig 3-5** shows the result.

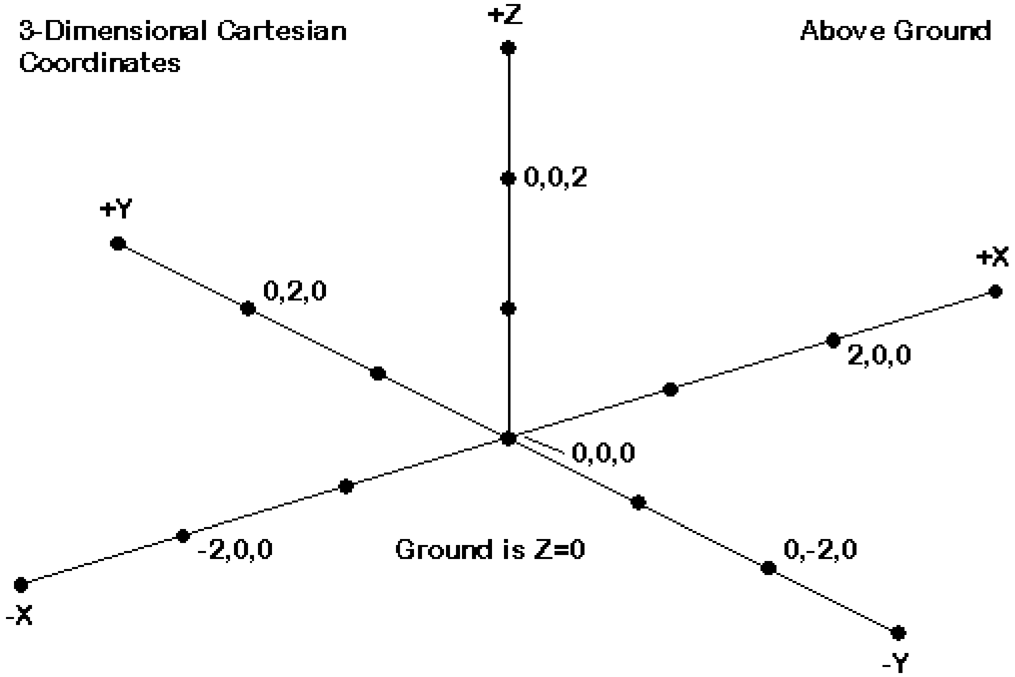


Fig 3-5--A three-dimensional Cartesian coordinate system.

The three-dimensional system is not much more difficult to use than the two-dimensional version. The distance of any point we might specify from the origin can be determined from a simple equation:

$$D = \sqrt{X^2 + Y^2 + Z^2} \qquad \text{Eq 2}$$

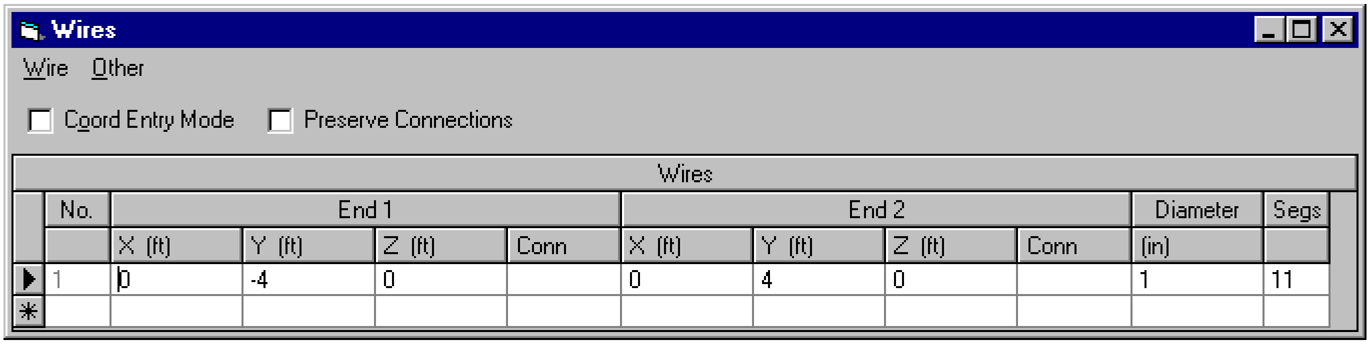
where D is once more the distance of the point from the origin and X, Y and Z are the coordinate specifications for the point. This sample just begins a whole process of determining distances within a Cartesian coordinate system. However, rather than fill these pages with equations, we can use some simple steps to place an element anywhere we wish on the system.

CARTESIAN COORDINATE SYSTEM APPLICATIONS

Return to Fig 3-2, which shows both the *NEC-Win Plus* and *EZNEC* wire tables for an antenna that we can use to become comfortable pushing antenna geometries around the Cartesian coordinate system. The antenna element is a 1 inch diameter 8 feet long center-fed dipole. The dimensions were chosen to yield simple dimension numbers, along with some familiar numbers in some variations that we shall run.

For this exercise, we may use a perfect or lossless conductor. We shall also place the antenna in free space. The antenna happens to be resonant at 57.5 MHz in free space. For this exercise, let's be more precise than normal. The antenna will be considered resonant if the reactance is less than $\pm j\,1\ \Omega$. In this case, the resonant impedance happens to be $71.55 - j\,0.45\ \Omega$. This is a number to remember for the remainder of the exercises.

You may conduct the exercises in one of two ways. After you open the file for Model **MOD3-1**, you may open subsequent files **MOD3-2** through **MOD 3-6**, as we call for them. Alternatively, you may wish to practice modifying the wires table of the file you already have open to match the values for each of the new models. Once perfected, you may then save the new model you have created. A good way to save it will be as MOD3-XA. The X stands for the exercise file that you are replicating with your own work. The A portion will prevent the file that you save from overwriting the exercise file that already has that number. In this way, you may compare your work with the files provided for this lesson.



☐ Coord Entry Mode ☐ Preserve Connections

Wires

No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	0	-4	0		0	4	0		1	11

Fig 3-6--EZNEC 3.0 wire table for model dipole MOD3-1.

Open file MOD3-1. Check the wire table shown in **Fig 3-6**. You may compare these values with those in the *NEC-Win Plus* wire table by using Fig 3-2 as a guide. In this model, we have extended the wire from -4 to +4 in the ± Y direction, meaning that the wire is parallel to (and, in this case, right on) the Y-axis. When horizontal elements are aligned in this way, the major lobes of the pattern will reach maximum gain at or very near 0 and 180 degrees on the azimuth pattern that has been requested. If you run the model and obtain an azimuth pattern, it will look like **Fig 3-7**. The only difference between the *NEC-Win Plus* pattern and the corresponding *EZNEC* azimuth pattern is that the basic layouts are 90° apart. *EZNEC* places 0° to the far right, while *NEC-Win Plus* places 0° straight up.

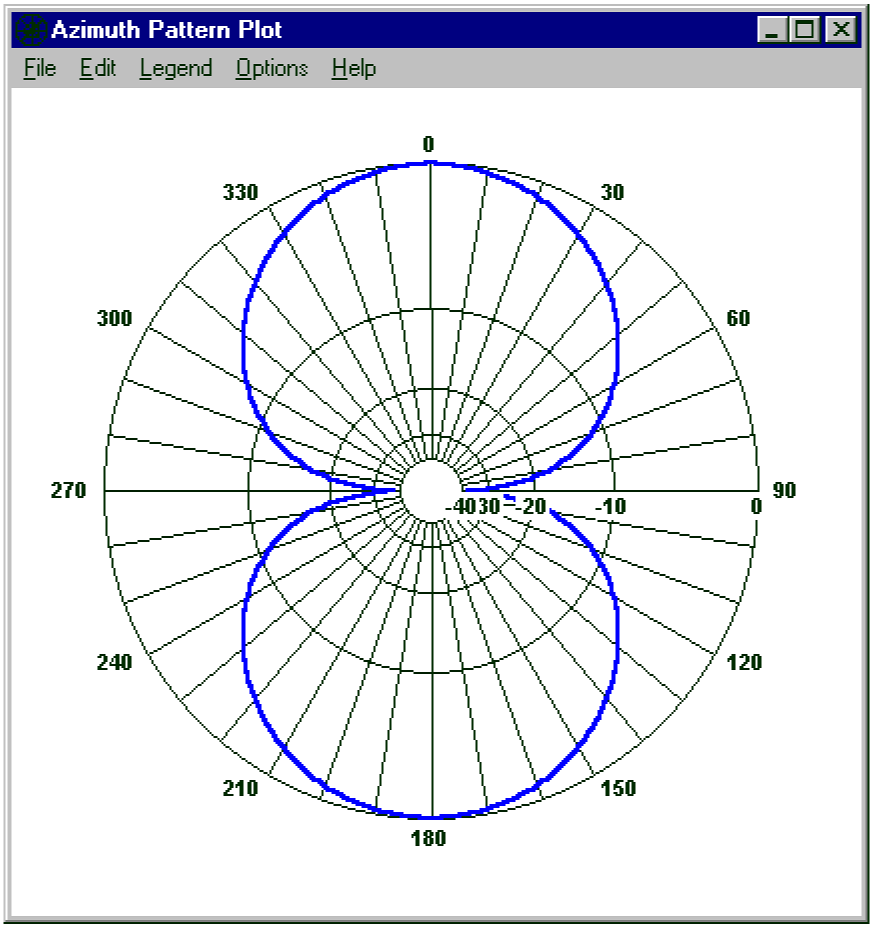
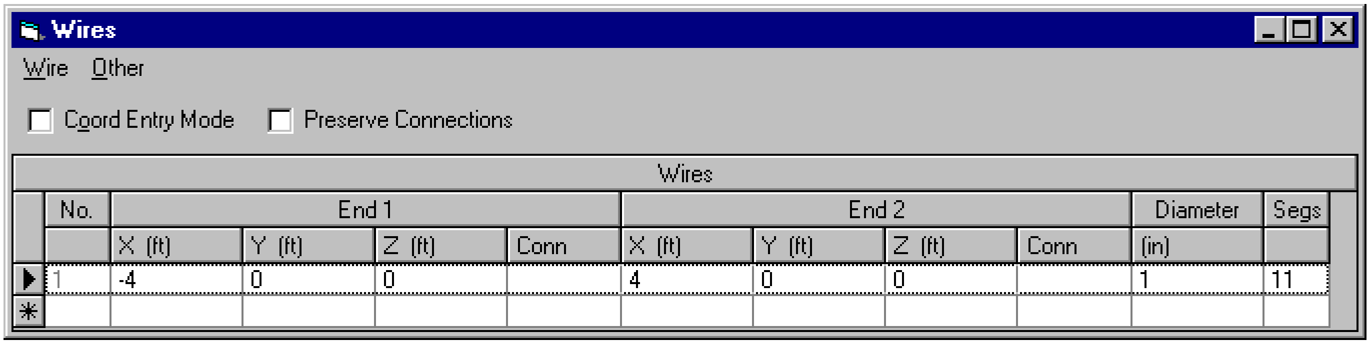


Fig 3-7--Azimuth pattern generated by *NEC-Win Plus* for model MOD3-1, with dipole wire lying on the Y-Axis.

Be certain to look at the source impedance for the antenna. In *EZNEC*, click on **SrcDat** button in the left column of the main screen. In *NEC-Win Plus*, there is a list of tables in the upper right corner. Select the SWR table and then press the symbol to the right of the list. In each case, you will see an impedance value of 71.55 - *j* 0.45 Ω. The number you see may be carried out to additional decimal places, but even using two decimal places for the impedance is greater exactitude than we could actually measure. For this exercise, the numbers simply verify that we have a 1" diameter dipole at 57.5 MHz that is exactly 8' long.



☐ Coord Entry Mode ☐ Preserve Connections

Wires											
	No.	End 1				End 2				Diameter	Segs
		X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
▶	1	-4	0	0		4	0	0		1	11
*											

Fig 3-8--*EZNEC 3.0* wire table for model MOD3-2, where dipole is lying on the X-axis.

Now, either open model **MOD3-2** or modify the wire table of your present model to match the wire table in **Fig 3-8**. The changes are simple but significant. We have now stretched the dipole in the ± Y direction so that the antenna is now parallel to (and right on) the X-axis. Since we have not changed the length of the wire-it is still exactly 8' long--we should not have changed the performance of the antenna in any way. We should still obtain a source impedance of 71.55 - *j* 0.45 W when we run the model. The only difference will be the orientation of the azimuth pattern, which (in either program) will be displaced 90° from the pattern in Fig 3-7. **Fig 3-9** tells the story.

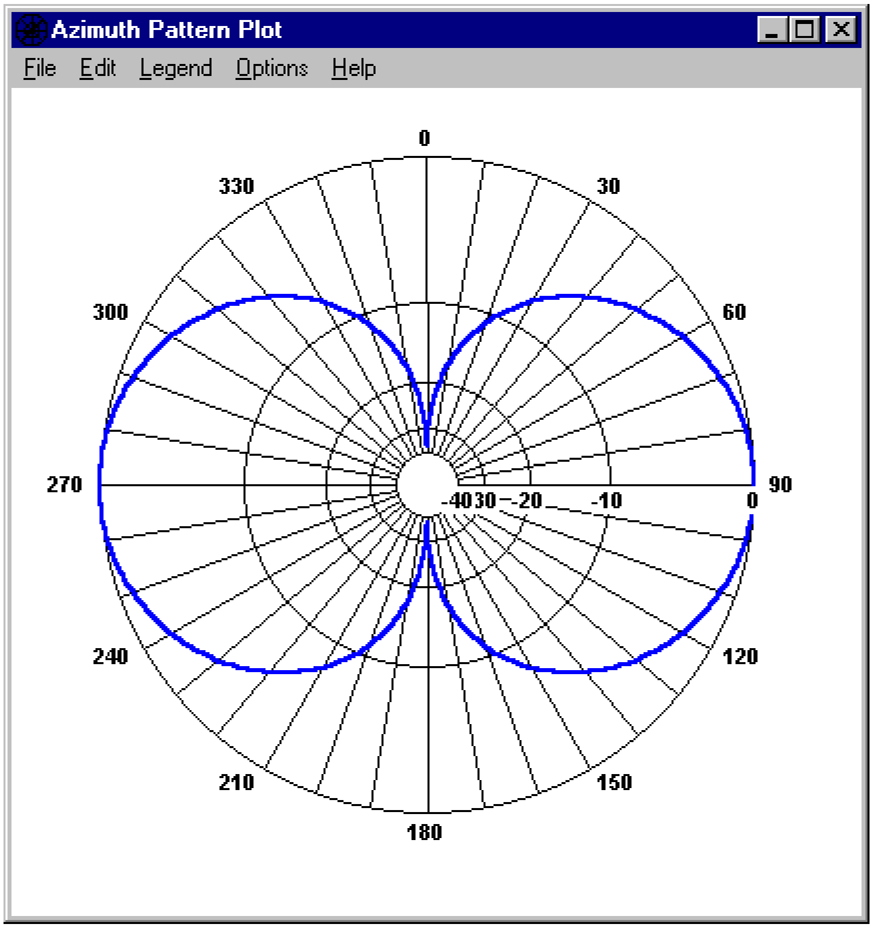
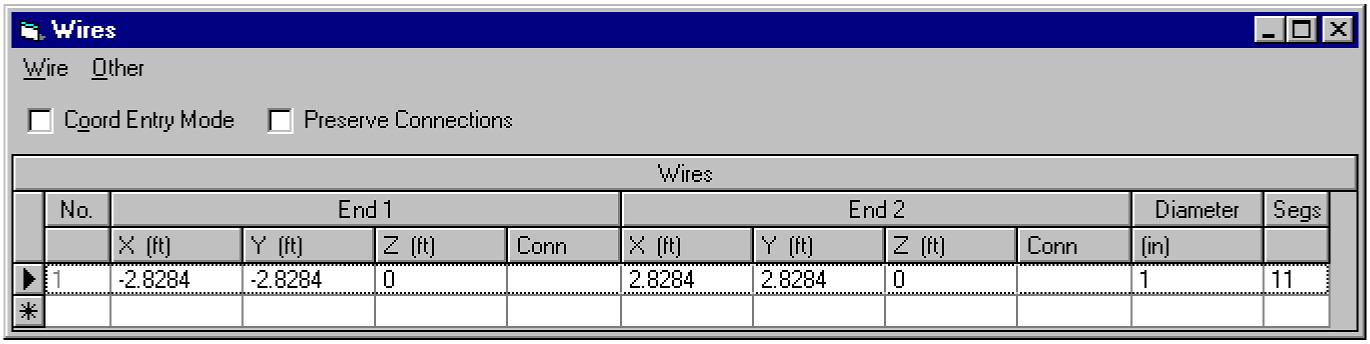


Fig 3-9--*NEC-Win Plus* free-space azimuthal pattern for dipole lying on X-axis.

Suppose that we wish to place the antenna at some other angle in the coordinate system. We still want the antenna to be resonant at 57.5 MHz, which means keeping its length exactly 8' long. How would we figure the coordinates? Let's make our first move fairly simple and only change the orientation relative to the X and the Y axes, leaving Z at zero. We want the antenna model to run through the origin (0,0) at a 45° angle to both the X and Y axes. Now it is time to open model **MOD3-3** or to modify our present model to meet the goal we have in mind.



☐ Coord Entry Mode ☐ Preserve Connections

Wires										
No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	-2.8284	-2.8284	0		2.8284	2.8284	0		1	11

Fig 3-10--EZNEC 3.0 wire table for dipole moved to make a 45° to both X and Y axes.

Fig 3-10 shows the resulting wire table. How did we arrive at the values for X and Y? Refer to Eq 1 in our discussion of the two-dimensional coordinate system. Since the square of the length from the origin to the wire end is the sum of the squares of the two coordinates, then

$$X = \sqrt{D^2 - Y^2} \qquad \text{Eq 3}$$

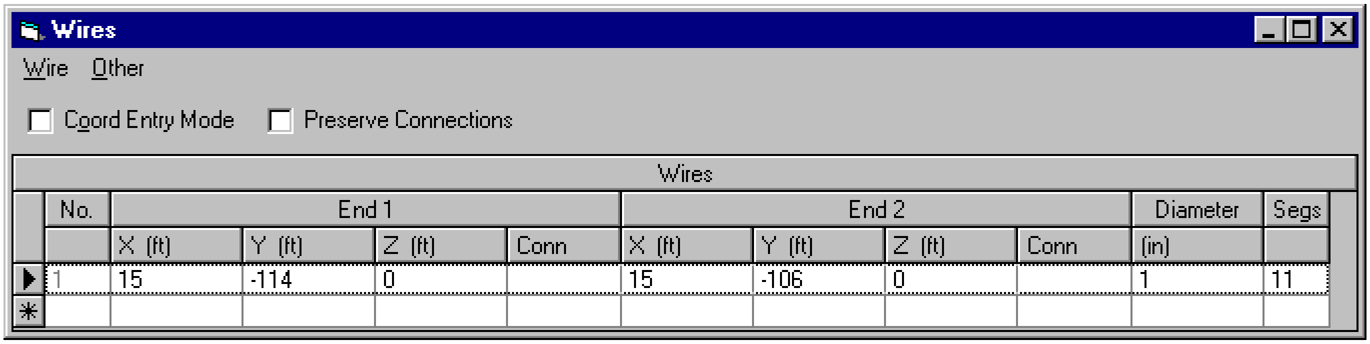
where D is the length of the wire from the origin to the end and X and Y are the end-coordinate values. This equation is handy where we know one coordinate value and need the other one. However, in this case, we need both values, but they are equal to each other. Hence,

$$X = Y = \sqrt{\frac{D^2}{2}} \qquad \text{Eq 4}$$

where all of the letters have the same meanings as given earlier. Since the distance from the origin to the wire end is 4.0, the values of X and Y will be 2.8284 (or -2.8284 in the other direction from the origin).

The test for our pocket calculator work lies in entering the values into the model wire table and then finding out if the source impedance checks out. Only if the wire is exactly 8' long in its new orientation (subject to tiny departures for rounding off the calculated numbers) will the impedance be 71.55 - *j* 0.45Ω.

The technique that we have just used is handy for changing the orientation of a model wire. Sometimes, however, we wish to move the wire away from its centered position around the origin of the coordinate system. Suppose, for example, that we wish to center the dipole at X = +15 and Y = -110, with the antenna extending parallel to the X-axis (and hence extended in the ± Y direction from its new center point). The end-points would now be Y = -114 and Y = -106. **Fig 3-11** shows the resulting wire table for model **MOD3-4**.



☐ Coord Entry Mode ☐ Preserve Connections

	Wires									
No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	15	-114	0		15	-106	0		1	11

Fig 3-11--Wire table for dipole centered at X = +15 and Y = -110.

Since the antenna is exactly 8' long, the impedance will not change from the values previously calculated. If you view the antenna structure, you will see the wire centered within the NEC-Vu module of *NEC-Win Plus*. *EZNEC* offers you the choice of seeing the model in its actual position relative to the coordinate system or centered on the origin.

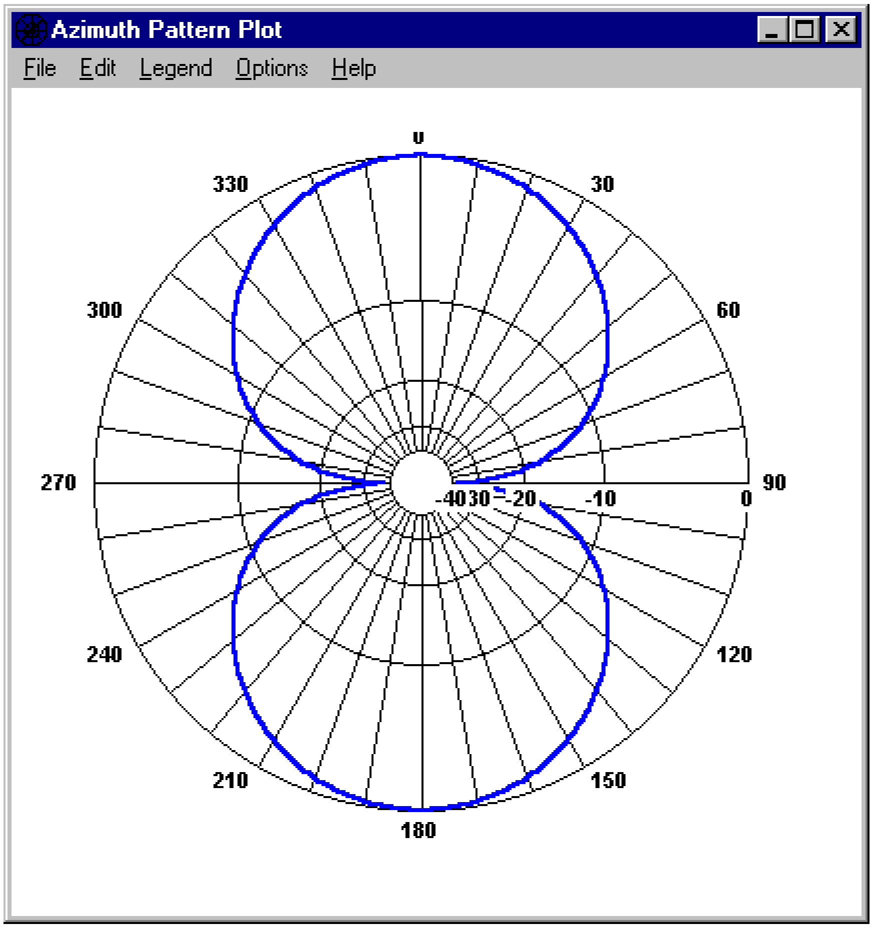


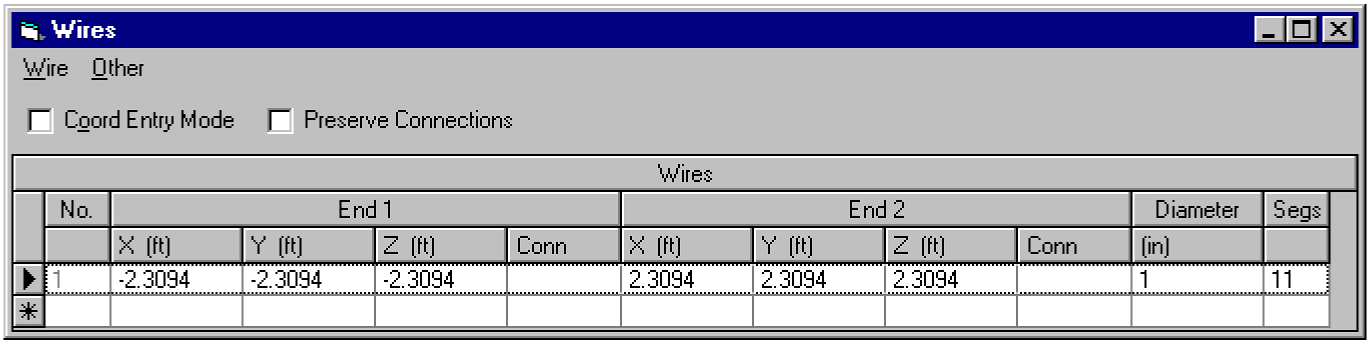
Fig 3-12--*NEC-Win Plus* azimuthal pattern for dipole whose wire table is shown in Fig 3-11.
Moving the origin doesn't change the pattern in free space.

NEC-2 itself does not care where you place the model within the coordinate system in free space. A polar azimuth plot of the antenna pattern, shown in *NEC-Win Plus* format in **Fig 3-12**, will be identical to the pattern we derived when the antenna was centered on the origin (in Fig 3-7). Hence, you have great flexibility in placing your model within the coordinate system. However, the best procedure to follow may be the one we have used here. First, establish the wire end-point coordinates with the wires centered at the origin of the coordinate system. Then displace each and every end-point coordinate value by the same amount for X and the same amount for Y to place the wires at the desired place in the system.

So far, we have been thinking in only two dimensions, modifying values along the X and Y axes to modify the antenna orientation within the coordinate system. Suppose that we wanted to place the antenna in a position that is 45° relative to each of the three axes. If we think back to Eq 2 in our initial discussion of the coordinate system, we can derive the correct values from a modification of that equation:

$$X = Y = Z = \sqrt{\frac{D^2}{3}} \qquad \text{Eq 5}$$

where all of the letters have their familiar meanings. Since the distance from the origin of the antenna to one end is 4, the resulting values for X, Y and Z are either 2.3094 or -2.3094. you may alter MOD 3-1 to use these values in the wire table or open model **MOD3-5** to find the wires table in **Fig 3-13**.



☐ Coord Entry Mode ☐ Preserve Connections

Wires

	No.	End 1				End 2				Diameter	Segs
		X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
▶	1	-2.3094	-2.3094	-2.3094		2.3094	2.3094	2.3094		1	11
*											

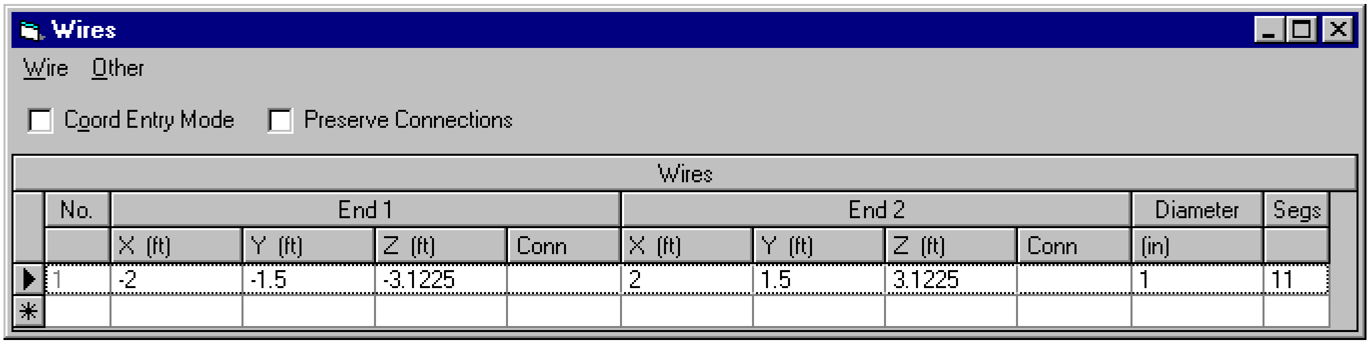
Fig 3-13--*EZNEC 3.0* wire table for MOD3-5 dipole reoriented 45° from X, Y and Z axes.

The proof of this model lies in the source impedance-once more 71.55 - *j* 0.45 Ω. Hence, the antenna must be 8' long in total length. You may explore the antenna views to see how the antenna tilts among the three axes. As well, as a supplemental exercise, you may swap end values for a single axis or for two axes to see how the antenna takes on a different tilt in the coordinate system with each change.

Finally, suppose that you know two of the coordinate pairs and wish to find the third. For example, suppose that you wish to use X = -2 and X = 2 along with Y = -1.5 and Y = 1.5 for the coordinates of the endpoint of the dipole. What values shall we choose for Z, assuming that the antenna passes through the origin? We need only look back to Eq 2 to arrive at a modification that will yield the correct result:

$$Z = \sqrt{D^2 - (X^2 + Y^2)} \qquad \text{Eq 6}$$

where X, Y, Z and D have the usual meanings. Since the sum of the squares of the pre-selected values for X and Y is 6.25 and the square of the distance from the origin to the wire end point is 16, the difference is 9.75. The value of Z is ± 3.1225. If we plug these values into a model, we arrive at model **MOD3-6**. The wire table for this appears in **Fig 3-14**.



No.	End 1				End 2				Diameter	Segs
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)	
1	-2	-1.5	-3.1225		2	1.5	3.1225		1	11

Fig 3-14--Wire table for MOD3-6 dipole, calculated using Eq 6.

If you run this model, you will once again find that you have retained the 8' overall length of the dipole, because the familiar source impedance will once more emerge from the *NEC-2* calculations.

Once you have confirmed that your model is correct and true to the original antenna, whatever its orientation within the coordinate system, you may displace it to any other position by making equal changes in the values of either X or Y or Z or any combination of the three. But perhaps we have pushed our 8' dipole around enough for one day's work.

SUMMARY

In this lesson, we have grown a bit more comfortable with the language and basic parameters of the *NEC-2* system of handling antenna geometry. We have set forth some basic rules-of-thumb to guide in segmenting the wires that model antenna elements. We also explored Cartesian coordinates in both two and three dimensions. Finally, we practiced setting up one antenna in as many different ways as we could think of within the coordinate system so that maneuvering in the system with the end points of wires would become more natural. You may wish to practice some more using any of the models that we have so far offered, including MOD2-1, the 2-element Yagi with complex element structures. However, take time out to work with the review questions for this Lesson.