17.
Special Radiation Pattern Data

***Objectives**: Our return to the RP command will focus on three types of outputs. One is the full free-space sphere or the hemisphere over ground, useful for surface and gain-averaging plots. Second is the RP1 command for ground waves. The last is a sample of data that we can develop in post-core-run calculations to yield special pattern information.*

In Part B, Chapter 9, we gave extended treatment to the RP0 command. However, we did not exhaust all of the potential of that command. There are a number of items worth reviewing, along with some other matters that we may draw together into a more cohesive picture. For example, the 3-dimensional surface plot, the calculation of radiation efficiency, and the average gain test all share some common features when invoking the RP0 command. So we shall begin our work by reviewing and extending what we have already done.

We specifically omitted the RP1 version of the command. (NEC-2 has a large number of RP options, since the second ground medium is tied to the RP request. However, NEC-4 reduces all options to the RP0 far-field request and the RP1 ground wave request.) We shall not only see how to enter that command and to read its output, but as well, we shall learn something of its special features.

Not everything that we can learn from an antenna model appears in the NEC output report. Further post-run processing of data is possible to formulate data in other and possibly more useful ways. As a sample of what we can do, we shall examine the calculation of circular polarization power-gain components that are useful for dissecting the patterns of axial-mode helices and other antenna producing circular or elliptical polarization.

Special Far-Field Output Data

Reviewing the far-field command begins with the structure of the command itself.

```
Cmd  I1   I2   I3   I4   F1      F2   F3   F4   F5   F6
     I1   NTH  NPH  XNDA THETS   PHIS DTH  DPH  RFLD GNOR
RP   0    1    361  1000 90      0    1.00 1.00 (NU) (NU)
```

When used as a request for a normal phi or theta pattern, the command calls for a series of specifications: a pair of initial bearings (THETS and PHIS in degrees), a pair of increments between successive bearings (DTH and PTH in degrees), and the number of steps in each coordinate sequence (NTH and NPH). Although the initial angle and the increment between angles may use decimal entries, the number of steps must be an integer. The far-field distance in meters (RFLD) is optional and useful only when we need a calculated value for the electrical field at a specific location. GNOR, the gain normalization level other than the maximum value in the pattern, is a special purpose call.

Open model *17-1.nec*, and examine the 2 RP0 requests for this vertical dipole in free space.

```
CM Vertical dipole
CM free space
CE
GW 1 11 0 0 .2625 0 0 .7375 .001
GE
FR 0 1 0 0 299.7925 1
EX 0 1 6 00 1 0
RP 0 361 1 1000 -90 90 1.00000 1.00000
RP 0 1 361 1000 90 0 1.00000 1.00000
EN
```

The first request is for a 360° theta pattern, using a single phi-angle specification (90°). The second request is for a 360° phi pattern using a single theta-angle specification (90°). Note that for each full circle, we specify the result of dividing the circle (360°) by the selected increment plus one more step. The goal is a pair of 2-dimensional plots, each of which covers a selected circle of the pattern sphere presumed to surround the antenna. **Fig. 17-1** shows the antenna in all of its simplicity, along with the resulting patterns.

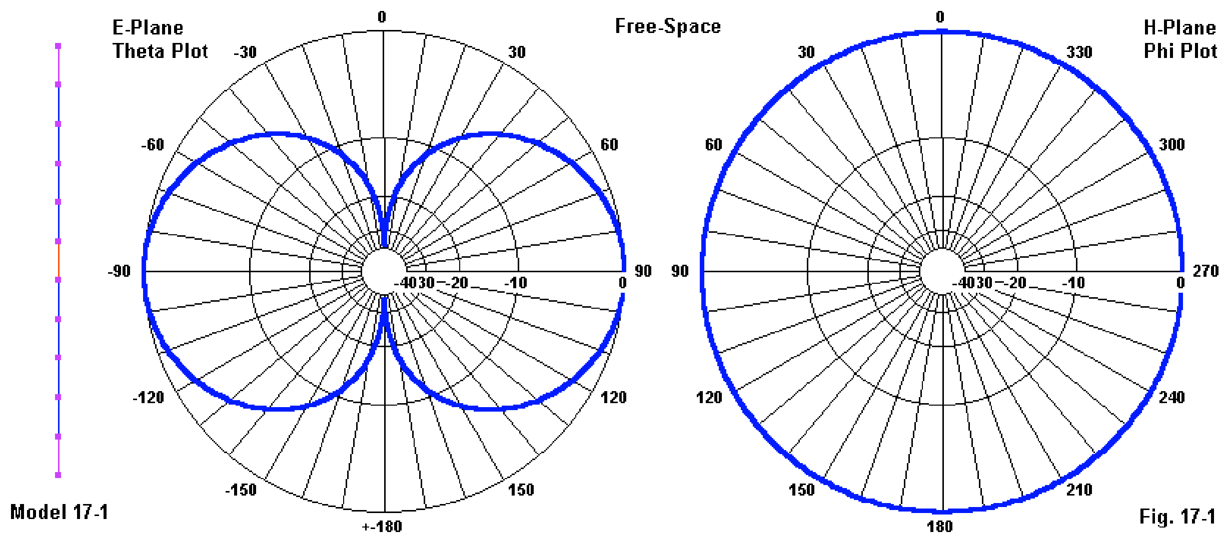


Fig. 17-1

Since the dipole is vertical relative to a presumed ground, the theta plot presents the E-plane pattern, while the phi plot gives us the H-plane pattern. We may produce as many of these patterns as we wish. In practical terms of software limitations, it is usually wise to use successive commands for each 2-dimensional plot that we wish. For an array with a complex radiation pattern, we may take numerous "cuts" using as many theta or phi patterns as may satisfy the need. If we need frequency sweeps, we must re-introduce the multi-frequency FR command prior to each RP command.

Over ground, we make small but critical amendments to the phi and theta pattern requests to arrive at our patterns. First, no theta pattern can extend below ground, forcing us to a half-circle plot. Second, there will be no phi pattern at the horizon (theta = 90°). Instead, we normally take an interest in some angle above the horizon, perhaps the take-off angle or a specified angle of propagation in the HF range. Open model *17-1a.nec*, the same antenna using an SN average ground.

```
GN 2 0 0 0 13.0000 0.0050

RP 0 181 1 1000 -90 90 1.00000 1.00000
RP 0 1 361 1000 76 0 1.00000 1.00000
```

The GN command shows the ground specifications. The first RP entry requests a theta pattern with 181 1° steps, enough to go from one horizon to the other. The second RP command asks for a phi pattern for the full circle, but at a theta angle of 76° (that is, 14° above the horizon). **Fig. 17-2** shows the results of our entries. Again, we may make as many requests as we wish to make, so long as we observe the frequency-sweep loop limitations.

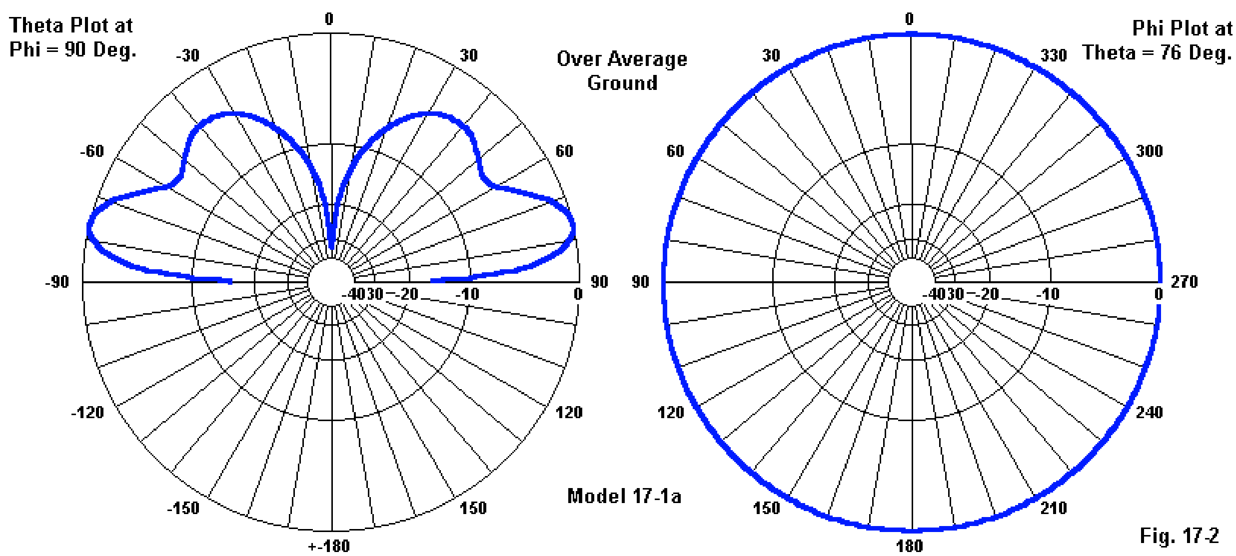


Fig. 17-2

There is no rule within NEC that forbids us from requesting multiple theta angles and multiple phi angles within the same RP request. Open model *17-2.nec* for a sample.

```
RP 0 91 361 1000 0 0 1.00000 1.00000
```

Model 17-2 is the same vertical dipole over the same ground as in model 17-1a. However, the RP0 command now requests a full hemisphere of pattern samples, with 91 theta angles and 361 phi angles. Run the model. First, examine the radiation pattern data section of the NEC output report. Note that NEC runs all of the requested theta angles at the first phi angle, then all of the theta angles at the second phi angle, etc. The result is a mass of information occupying 90% of the report. Selectivity has advantages when ordering the output information.

Next, request a polar plot. At this point you will encounter a practical software limitation. The polar plot facility in GNEC and NEC-Win Pro can handle up to 100 simultaneous plot requests. However, even for 1 frequency, there will be over 450 pattern possibilities. If you perform a frequency sweep, multiply the total by the number of frequencies requested.

Nevertheless, the RP0 request shown does have important uses. For example, it is precisely the form used for a 3-dimensional surface plot, as shown in **Fig. 17-3**.

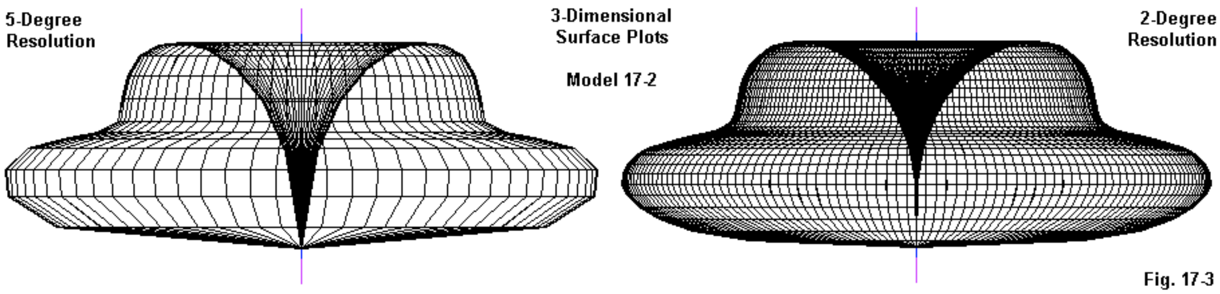


Fig. 17-3

GNEC and NEC-Win Pro delegate the 3-D pattern to a special function. It creates a special temporary file to contain the NEC output data and then deletes the file when you are finished working with the pattern. The graphic also illustrates a special feature of the function: your option to select the increment between steps of the pattern. The 5° option makes virtually every detail of the pattern clearly visible, but at theta angles close to the horizon, the smooth pattern transitions become sharply angular. The 2° option smoothes the angularity, but increases the number of lines so that some plot details may disappear.

The pattern shown is for an antenna above ground, which requires a hemispherical request. For a free-space pattern, we would input the required coordinates for a full sphere.

Above ground RP0:

```
RP 0 91 361 1000 0 0 1.00000 1.00000
```

Free-space RP0

```
RP 0 181 361 1000 0 0 1.00000 1.00000
```

To obtain a radiation efficiency value, we would use the hemispherical RP0 request, as in model *17-2a.nec*. The special feature in this request is the XNDA specification of 1002. Both 1001 and 1002 request gain averaging, but 1002 also suppresses printing of the radiation data.

```
RP 0 91 361 1002 0 0 1.00000 1.00000
```

Run the model to obtain the average power gain: 7.5684E-1. Since radiation efficiency will be half this value times 100, we calculate a radiation efficiency of 37.84%.

The RP0 hemisphere and the RP0 sphere both play roles in obtaining a value for the average gain test. Again, this data emerges from a special function in GNEC and NEC-Win Pro. The command uses the XNDA = 1002 entry. Normally, the version of the model run under the test function also adds a PT command set to -1 in order also to suppress the printing of currents. In large models, data printing suppression can shorten the core run time needed to produce a value.

The average gain test or AGT has some special features. It is a measure of model adequacy based on the fact that an ideal model, when free of resistive losses, will radiate all of the input power. Hence, the average power gain in free space will be 1.0 and the average power gain over a perfect ground will be 2.0. To perform the test, the special function sets all resistive loading to zero, no matter the type of LD entry in which resistance appears. The result is a model whose radiation depends entirely on the structure geometry (with all of the constraints upon segmentation and its relationship to wire radius, as well as other known sensitive condition). Inadequate models may yield average power gains either above or below the ideal value.

Run the AGT test using the perfect ground option and 1° increments to set up the RP0 request that we have been using. The AGT or average power gain value is 1.99358. You may modify the model itself to arrive at your own NEC output report value for the same test by changing the ground type to perfect and by ensuring that XNDA is 1002. The model has no losses other than the initial ground specification.

Besides power data, we may derive from RP0 commands information on the electrical field. The required modification that we must make to our continuing vertical dipole model is to add an RFLD entry to specify a distance from the coordinate system origin, the presumed approximate location of the antenna. Open model *17-3.nec* and examine the RP0 request.

```
RP 0 181 1 1000 -90 90 1.00000 1.00000 100
```

The last entry calls for a distance of 100 meters from the origin. The distance must be well into the far field for accuracy, which is not a concern at the test wavelength of 1 m. Regardless of the units used in setting up the geometry, the RFLD entry must be in meters.

Run the model, but do not bother with the radiation pattern electric field information at this time. Most such information is useful only when we set the excitation to a certain level, for example, 1000 w. Hence, for this run, the data of interest is the input power: 7.25764E-3 w. If we take the square root of the ratio of the 1000-w desired power to the current power for a 1-volt source, we can arrive at the required excitation voltage: about 371.2 volts peak. Open model *17-3a.nec* and look at the EX0 command. We now wish to know the electric field strength at a distance of 100 meters for a source power of 1000 watts.

```
EX 0 1 6 00 371.19617 0
```

Run the model and examine the electric field information. Because the antenna element is vertical relative to the ground, The Ephi values are all too small to show a value greater than 0. However, the Etheta voltage values vary as the theta angle changes. The highest value occurs at the take-off angle (theta = 76°): 3.0357E0 peak volts/meter. You may wish to modify the model, using a variety of distances for RFLD and a variety of excitation power levels. However, save the original model 17-3a, because we have one more task for it.

You may plot electric fields within GNEC and NEC-Win Pro as rectangular graphs. The model requested a full 180° theta pattern, so such a graph would give you a view of the electric field strength at every theta angle, where -90° represents one horizon and +90° represents the other. Examine **Fig. 17-4** and project the curves onto the theta pattern in **Fig. 17-2** or in **Fig. 17-3**. As a passing matter, although perhaps not insignificant, note the relatively high values of electric field strength at the take-off angle as far away from the antenna as 100 meters with a commonly used power level: 1000 watts.

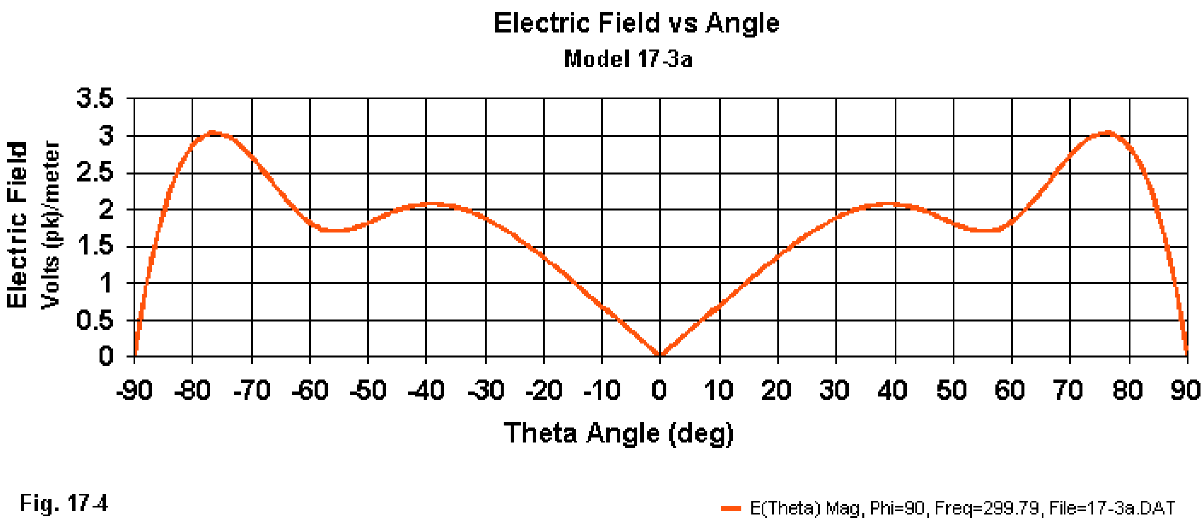


Fig. 17-4

Our review of the RP0 command allowed us to draw together several ordinary and special uses of the command when we set it up for a full sphere (in free space) or hemisphere (over ground). Our quick review of the RFLD entry has not been superfluous, since that feature will be integral to our next set of exercises involving the RP1 or ground wave option. So too will be setting a standard power level for comparative data.

The RP1 Command Option

When used for ground wave analysis, the RP command changes the meaning of some of its entries.

Cmd	I1	I2	I3	I4	F1	F2	F3	F4	F5	F6
	I1	NTH	NPH	XNDA	THETS	PHIS	DTH	DPH	RFLD	GNOR
RP	0	1	361	1000	90	0	1.00	1.00	(NU)	(NU)
					z				ρ	
RP	1	1	37	0000	0	0	1.00	10.00	100	(NU)

The example compares a rather ordinary far-field request with a ground wave entry. The phi entries maintain their meanings. NPH is the number of phi steps; PHIS is the starting phi angle, and DPH is the increment between phi angles. However, the theta entries change their orientation. Instead of registering theta degrees, they measure distances in the X-Y plane, beginning at Z = 0. Hence, they create a cylinder whose radius is defined by the RFLD entry, always in meters from the coordinate system origin and designated ρ. Then, THETS records the starting height above zero (designated z) and may include zero, as it does in this example. NTH is the number of sampling points, beginning with THETS and proceeding straight upward. Since there is only 1 sampling point, DTH--the increment between samples in meters--can be any arbitrary number. The result is a request for ground-wave analysis at a point 100 meters from the coordinate origin at ground level. For ground waves, the first digit of XNDA makes no difference.

Since the distance in the X-Y plane (ρ) and the height above ground (z) work with cylindrical coordinates, the distance that you enter does not record the distance to the observation point unless that point is at ground level. The actual distance to the observation point (d) is the square root of $\rho^2 + z^2$.

To see how the RP1 request integrates into an entire model, open model *17-4.nec*.

```
GW 1 11 0 0 0 0 0 4.85 .001
GE 1
GN 1
FR 0 1 0 0 15 1
EX 0 1 1 00 269.19 0
RP 0 181 1 1000 -90 90 1.00000 1.00000 100
RP 1 1 37 0000 0 0 1.00000 10.00000 100
EN
```

The model is for a 1/4λ monopole that touches a perfect ground at the coordinate center. The model has two RP commands: a far-field theta pattern and an RP1 ground-wave request that uses the 100 meter distance and ground level as the single read-out height for 37 equally spaced readings in the phi plane. The test frequency is 15 MHz, where its wavelength is about 20 meters.

The observation point is about 5λ from the antenna. For highest accuracy, ground wave requests should be more than 1λ away from the source. Ground wave analysis uses far-field approximations plus a surface wave calculation. In other words, the ground wave calculation includes both surface wave and space wave components. As the frequency and the distance increase, the surface wave component diminishes to a level where the only significant component may be the direct (or point-to-point) sky wave. As we shall see, there is also a considerable difference in the ground wave between vertically and horizontally polarized antennas.

Model 17-4 is actually a second-run model. The first run established the source impedance (36.228 + j0.372 Ω) and the associated input power with a 1-v source. However, virtually all ground wave analyses will need a set power level. 1000 w is the value used throughout these exercises. In the version of the model shown, an EX0 voltage of 269.19 v achieves that power.

```
                    - - - RADIATED FIELDS NEAR GROUND - - -

  - - - LOCATION - - -      - - E(THETA) - -      - - E(PHI) - -      - - E(RADIAL) - -
RHO     PHI        Z          MAG       PHASE       MAG       PHASE       MAG       PHASE
METERS  DEGREES   METERS   VOLTS/M   DEGREES    VOLTS/M   DEGREES     VOLTS/M  DEGREES
100.00    0.00    0.00    4.4291E+00   86.57   0.0000E+00    0.00    0.0000E+00   0.00
```

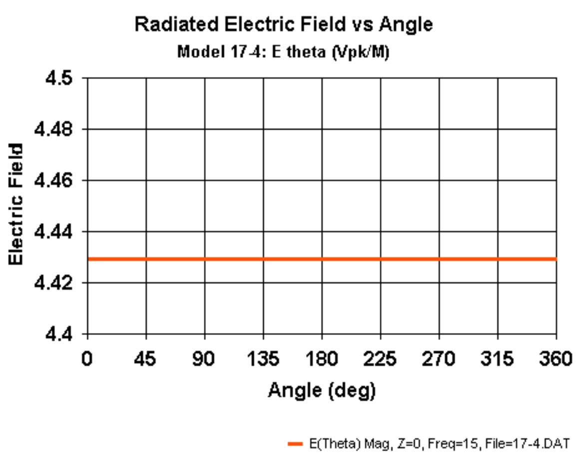
The output report has the form of the 1-line sample shown above. Since the monopole has a symmetrical pattern, all of the remaining 36 lines have the same data, since each observation point is at the same distance from the origin and the same height. Since the monopole is vertical and above a perfect ground, the only entry with a value above zero is Etheta, essentially the vertically polarized electrical ground-wave field strength in peak volts/meter.

For the contrast, let's create a 15-MHz horizontal dipole at 1λ above the same perfect ground. We shall sample the ground wave at ground level at a distance of 100 meters, using 73 points in a half phi circle (since the dipole pattern is the same in the other half circle). Open model *17-5.nec*.

```
GW 1 21 0 -4.88 19.986 0 4.88 19.986 .001
GE 1
GN 1
FR 0 1 0 0 15 1
EX 0 1 11 00 378.837 0
RP 0 181 1 1000 -90 0 1.00000 1.00000 100
RP 1 1 73 0000 0 0 1.00000 2.50000 100
```

The model has one other difference. The dipole requires a source voltage of 378.837 peak volts to achieve a 1000-w input with an impedance of 71.758 + j0.174 Ω.

The output report differs in several important respects from the one for model 17-4. First, the significant readings occur in the Ephi column, since the antenna is horizontally polarized. However, the Etheta readings are not so low as to be unreportable. They are just too low to be significant to the overall field strength 100 meters away at ground level. Second, the Ephi readings change at every new phi angle, in tune with the overall pattern of the dipole, with its bi-directional broadside lobes. Finally, even the strongest field-strength value is many orders of magnitude less than the vertical monopole field strength at the same distance from the antenna.



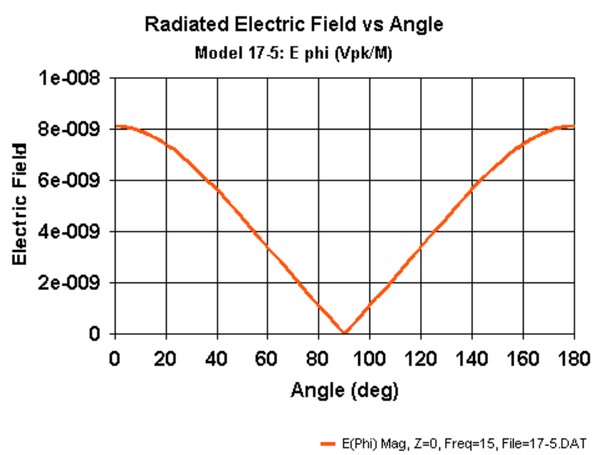


Fig. 17-5 compares rectangular plots of the two test cases. On the left, the full phi-circle plot shows the constant field-strength at about 4.43 peak volts/meter. On the right, the 180° plot tracks the pattern from one lobe peak to the other lobe peak, with virtually zero field strength off the antenna ends. The peak value is about 8.1E-9 peak volts/meter.

If we introduce a real or lossy SN ground to the ground-wave analysis, we must take into account more than just the horizontal and vertical components of the ground wave. As shown at the left of **Fig. 17-6**, we have a radial value to consider, taken along a line from the system origin to the observation point. You may use ρ and z to calculate not only the length of the radial line, but also the angle above the horizon. (Of course, you may also convert that elevation angle into a theta angle by subtracting the elevation angle from 90°.) All three field-strength components have phase angles that may differ from each other. Hence, arriving at a peak value is not a simple calculation. If ρ and z define the cylinder-based observation point, then we may have field strength values along 3 axes that define that point.

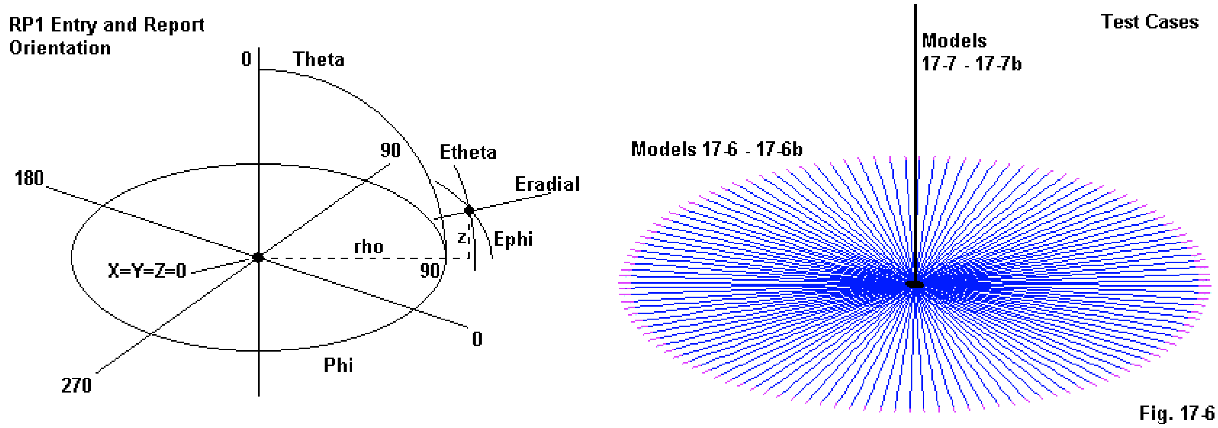


Fig. 17-6

To make a significant example, however otherwise limited, let's move the test frequency to 1 MHz, about the center of the U.S. AM broadcast band. The typical radial field for antennas in this region consists of 120 radials, each about 1/4λ long, although site and engineering considerations may call for other lengths in some cases. Then we have the antenna itself, a 1/4λ monopole with an actual height of 74 m above ground. For simplicity, we shall use 2-mm diameter wire throughout the exercise, however unrealistic that may seem. See the right side of **Fig. 17-6**.

If we work with NEC-2, then our radial system must be placed above ground level. A height of 0.02998 m above ground is 1e-4λ and allows a 3-radius clearance distance for the radial wires. The radials will use 25 segments per wire. We shall also specify three different ground qualities. Very good soil will have a conductivity of 0.0303 S/m with a permittivity of 20. Average soil will use 0.005 S/m and 13 as its values. Finally, very poor soil will enter values of 0.001 and 5 for the ground constants.

Even without the antenna, it appears that we have 3 very large models each with 3000 segments. However, we shall use a short-cut to the required run time by first setting the radials into a model that writes an .NGF file, as we did in Chapter 6. We shall also make use of the rotational symmetry command to create the radials wires, per the work we did in Chapter 5. We might create a single model for all three soil conditions, changing the GN entry with each run. However, for this exercise, examine models *17-6.nec*, *17.6a.nec*, and *17-6b.nec*. The first of the three has the following form.

```
GW 1 25 0 0 .02998 0 74.95 .02998 .001
GR 1 120
GE
GN 2 0 0 0 20 .0303
FR 0 1 0 0 1 1
WG radials-vg
EN
```

The only differences among the 3 models are the GN entries and the file names in the WG command. The use of the combination of GR and WG commands results in two significant savings. First, the run time for the radial file is 10 seconds or less, even on a slow PC. Second, the storage space required for the partial results is only about 1.7 MB, compared to perhaps 140 MB for a radial system created using the GM command or a very large number of GW entries.

Once the NGF files exist, you may use them for any number of antennas atop the radial field.

The second part of the work consists of creating one or more models for the monopole. Once more, we might use a single model and change the file name in the GF command before each new run. However, for reference, we shall use 3 models: *17-7.nec*, *17-7a.nec*, and *17-7b.nec*.

```
GF 0 radials-vg
GW 201 21 0 0 .02998 0 0 74 .001
GE 1
EX 0 201 1 00 277.1 0
RP 0 181 1 1000 -90 90 1.00000 1.00000
RP 1 1 1 0000 2 0 1.00000 1.00000 1000
EN
```

The GF command is the first geometry entry, followed by any additional structures. In this case, we have only the 74-m monopole wire. The tag number is arbitrary, selected to be larger than the largest tag number within the radial field. The RP commands include both a far-field theta request to check the antenna gain and take-off angle and a ground-wave request with ρ = 1000 m and z = 2 m. As with the preceding models in this exercise set, we shall make 2 model runs in order to reset the excitation voltage to a level that gives us 1000 w input power. Each model will display a slightly different source impedance and thus require a unique excitation voltage to maintain equal power input levels. Note that the model does not specify the frequency or the ground conditions, since those commands appear in the model that wrote the NGF file.

Depending upon PC speed, the models require between 1 and 3 minutes of run time. The required run-time is far lower than for models that include all 3021 segments in the same model using no symmetry. Hence, even a double run to set the power level is not a significant delay. The following table summarizes the results of the runs on the sequence of models, where VG means very good soil, Ave means average soil, and VP means very poor soil.

Ground Quality	Gain dBi	TO Angle degrees	Impedance R +/- jX Ω	Etheta peak V/m	Ephi peak V/m	Eradial peak V/m
VG	3.56	74	35.9 + j9.5	4.35E-1	2.76E-14	1.85E-2
Ave	1.76	69	37.9 + j6.3	3.83E-1	9.48E-14	3.96E-2
VP	-0.35	64	35.6 + j2.5	2.82E-1	6.32E-13	6.33E-2

The more familiar gain and take-off angle data follow normal expectations. However, for some soil qualities, the source impedance is lower than the value for a monopole with a perfect ground. We would ordinarily expect at least a slightly higher value, but the elevated radial system cannot incorporate losses from wires in contact with the ground. The less familiar data on the field strength shows the dominance of the Etheta values, with a decrease in strength at the 1000-meter distance that coincides with the worsening soil quality. Note that there is also a radial field strength value well below the level of Etheta, but very much stronger than Ephi.

Although NEC-2's slightly elevated radials are often used to simulate buried radial system, those using NEC-2 can only wonder to what degree they are a satisfactory simulation. Those with NEC-4, of course, can create buried radial systems. Let's run through that exercise, noting mostly how it must differ from the NEC-2 models. The soil conditions will remain the same, resulting in 3 radial models that will write new NGF files. Open models *17-8-nec4.nec*, *18-8a-nec4.nec*, and *18-*

8b-nec4.nec.

```
GW 1 25 0 0 -1 0 74.95 -1 .001
GR 1 120
GE
GN 2 0 0 0 20 .0303
FR 0 1 0 0 1 1
WG bradials-vg
EN
```

The radial system is 1 meter below ground level. Although that depth is lower than most radial systems, it will not make a significant difference to the outcomes at 1 MHz. As well, the radials retain their 25 segments, even though the vertical sections of the array will use a segment length of 1 m. You may wish to develop modified models in this sequence to check whether we obtain any significant changes from using a shallower depth for the radials and whether we need additional segments in the radials. To reduce the total segment count without harming accuracy, you may employ the GC wire-continuation command (chapter 3) to length-taper both the radial and the aboveground monopole wires.

The upper portion of the system appears in model *17-9-nec-4*, *17-9a-nec-4*, and *17-9b-nec-4*.

```
GF 0 bradials-vg
GW 201 1 0 0 -1 0 0 0 .001
GW 202 73 0 0 0 0 0 73 .001
GE -1 0 0
EX 0 202 1 00 287.139 0
RP 0 181 1 1000 -90 90 1.00000 1.00000
RP 1 1 1 0000 2 0 1.00000 1.00000 1000
EN
```

The vertical portion of the antenna consists of two wires. The first connects the hub of the buried radials to the ground level. The second extends the vertical above ground to a height of 73 m. The total vertical length above the radials is 74 m. The excitation is on the lowest segment of GW202. If we run these models, we obtain the following reported values.

Ground Quality	Gain dBi	TO Angle degrees	Impedance R +/- jX Ω	Etheta peak V/m	Ephi peak V/m	Eradial peak V/m
VG	3.19	74	39.1 + j9.1	4.18E-1	5.24E-18	1.78E-2
Ave	1.86	69	38.2 + j9.2	3.90E-1	3.72E-17	4.01E-2
VP	-0.20	64	36.5 + j7.0	2.85E-1	3.51E-16	6.37E-2

The gain range is somewhat smaller with the buried radial model, but not remarkably so, as shown in the comparative patterns in **Fig. 17-7**. All of the source impedance values are higher than for a perfect-ground monopole. In terms of field strength, the most notable effect of using buried radials is the reduction in the Ephi values, although they began and remain nearly insignificant.

These models, of course, are not suitable for deciding any issues. Their purpose is to show how both RP0 and RP1 requests integrate within a single model that also employs a number of other modeling techniques.

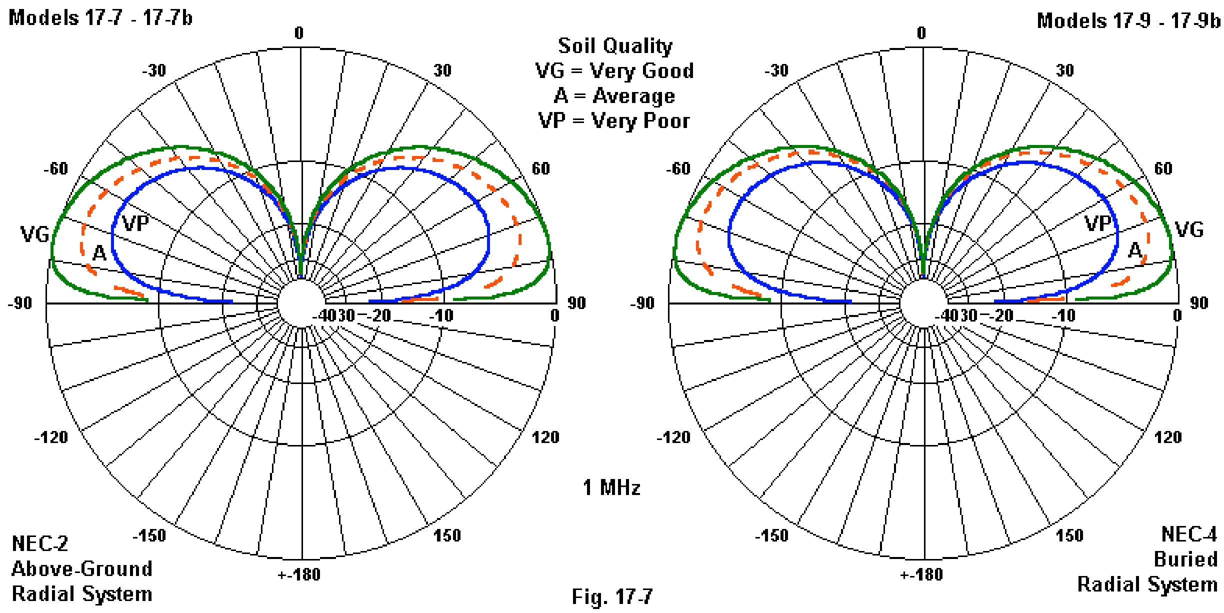


Fig. 17-7

Supplementary Far-Field Data Calculations

In its RP0 or far-field output report, NEC provides a good bit of information. To illustrate, I have extracted a single line from a 180-degree theta (elevation) report for an axial-mode helical antenna.

```
                   - - - RADIATION PATTERNS - - -

 - - ANGLES - -            - POWER GAINS -          - - - POLARIZATION - -
THETA     PHI        VERT.   HOR.    TOTAL       AXIAL      TILT   SENSE
DEGREES  DEGREES      DB      DB      DB          RATIO      DEG.
  0.00    90.00     10.39    3.84   11.261      0.46544    -3.89   RIGHT

        - - - E(THETA) - - -      - - - E(PHI) - - -
        MAGNITUDE     PHASE       MAGNITUDE     PHASE
         VOLTS       DEGREES        VOLTS      DEGREES
        1.00721E+00   -99.56     4.73544E-01   163.94
```

The report line begins with the theta and phi angles for the pattern position. The next three entries are the ones most printed along with polar plots: the power gains in dBi for the total field, the horizontal component, and the vertical component. The component powers add up to the total field power level, however, not by direct addition of dB. Rather, we must first convert the values in decibels into dimensionless power gain, using the standard procedure of dividing the value in dB by 10 and taking the antilog (base 10) of the result. The horizontal gain is 10.94, while the vertical gain is 2.42, for a total of 13.36. The dimensionless power gain of the total field is 13.37, although this simple exercise must allow for rounding of the original double-precision calculation numbers.

The central columns are relevant to elliptically polarized antennas. Although very important to numerous applications involving elliptical polarization, we shall pass over them in this exercise. Basic explanations of the terms "axial ratio" and "tilt angle" appear in many basic college antenna texts. Perhaps the most important function of this data within this exercise is to remind us that even axial-mode helices yield elliptically rather than circularly polarized patterns, where a perfectly circularly polarized pattern would have an axial ratio of 1.0. Although ideally, a linearly polarized pattern would have an axial ratio of zero, NEC will classify a pattern as linear when the minor axis is many orders of magnitude smaller than the major axis so that a practical calculation of the value results in a zero value. Apparently, to avoid excessively large numbers, NEC inverts the classic or textbook definition of axial ratio to "minor axis over major axis."

Relative to the central set of three columns, our interest is in the last entry, the sense. It tells us whether a circularly or elliptically polarized antenna has right-hand (clockwise) or left-hand counterclockwise) polarization. (The terms "clockwise" and "counterclockwise" are apt only if we view the antenna from the source end toward the most forward end.) Since virtually no antenna will produce a pure circularly polarized signal that is only one or the other hand, the sense tells us which pattern will dominate--the left-hand or the right-hand pattern.

Open model *17-10.nec*, using either the NEC-2 or NEC-4 version. Since the calculations to follow are based on the NEC-4 version, we may begin with it.

```
CM General Helix over Perfect Ground
CE
GH 1 100 5 .6959 .191 .191 .0005 .0005 0
GE 1 -1 0
GN 1
EX 0 1 1 0 1 0
FR 0 1 0 0 299.7925 1
RP 0 181 1 1000 -90 90 1.00000 1.00000
EN
```

The third numeric entry on the GH line is positive (and records the number of turns in this NEC-4 version). Hence, the helix formed is a right-hand helix with a dominant right-hand polarization.

The NEC-2 version of the same model uses the following GH entry to achieve the same right-hand polarization.

```
GH 1 100 .13918 .6959 .191 .191 .191 .191 .0005
```

Review Chapter 4 if the differences in entry format are not clear. The key difference is that NEC-4 uses the number of turns as an entry, while NEC-2 uses the spacing between turns.

Fig. 17-8 shows the outline of the helix, along with circularly polarized patterns taken from the NSI Multi-Plot function. These patterns use a linear reference scale, but are normalized to the maximum value for each pattern. Hence, their peak values are very different.

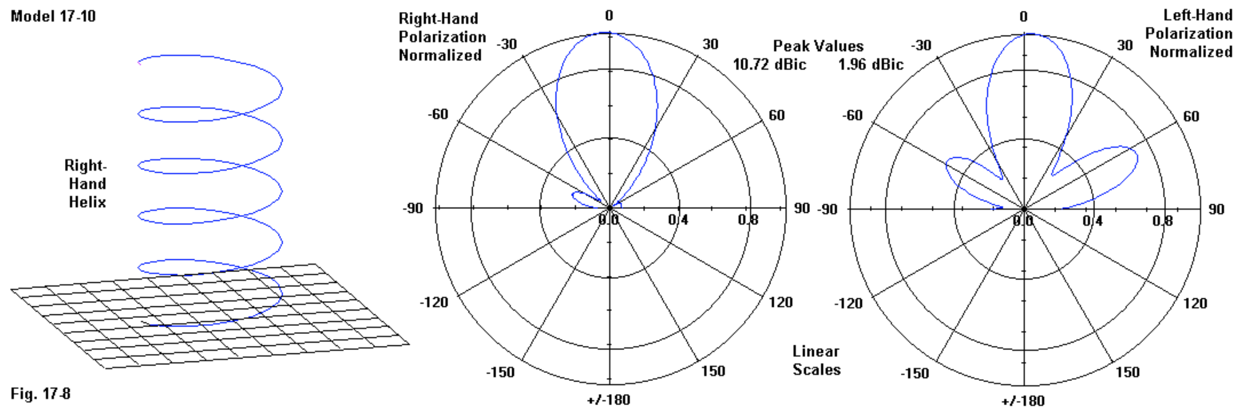


Fig. 17-8

The sample output report line with which we started is for the zenith angle overhead and the helix is pointed straight up. Hence, we might believe that the total field value is the maximum gain. However, because the pattern for the axial-mode helical antenna is a combination of left-hand and right-hand components, the actual maximum total field gain heading is a degree off the zenith or 0°-theta angle heading. The source of the asymmetry is intersection of the helix wire with the ground plane.

We can calculate the pattern values for both the left-hand and right-hand patterns using the previously ignored Etheta and Ephi data. Some implementations of NEC, such as GNEC, NEC-Win Pro, and NEC-Win Plus, already perform these calculations. However, it is useful to understand the calculation of these values, which is a post-core-run process. In order to see how the calculation proceeds, let's repeat the relevant parts of our sample line.

```
  - - ANGLES - -   - POWER GAIN -   POLARIZATION
  THETA     PHI       TOTAL          SENSE
 DEGREES  DEGREES      DB
    0.00    90.00    11.261          RIGHT
                            - - - E(THETA) - - -      - - - E(PHI) - - -
                            MAGNITUDE     PHASE       MAGNITUDE     PHASE
                            VOLTS         DEGREES     VOLTS         DEGREES
                            1.00721E+00   -99.56      4.73544E-01   163.94
```

The procedure begins by taking the real and imaginary components of each value of E (theta and phi). They appear in terms of magnitude and phase angle in the sample line. The steps use spreadsheet notation, since that is the most likely medium for using the equations. However, you may easily translate them into standard algebraic notation.

vetr = EthetaMag * cos(Ethetaphase); theta real
veti = EthetaMag * sin(Ethetaphase); theta imaginary
vepr = EphiMag * cos(Ephiphase); phi real
vepi = EphiMag * sin(Ephiphase); phi imaginary

These initial values are simply intermediate steps. We next must re-combine the collection into units that reflect the polarization of the antenna.

velr = 0.5*(vetr + vepi); left real circular component
veli = 0.5*(veti - vepr); left imaginary circular component
verr = 0.5*(vetr - vepi); right real circular component
veri = 0.5*(veti + vepr); right imaginary circular component

Now we can combine the circular components into values of magnitude by standard "square root of squares" techniques.

elm = sqrt(velr*velr + veli*veli); left magnitude
erm = sqrt(verr*verr + veri*veri); right magnitude

We now have the magnitudes of the left-hand and the right-hand electrical fields in volts (peak)/meter. The move from these voltage magnitudes to pattern data in dBic (dBi circular) requires a few more steps. The following are the calculations required for the conversion.

a. Convert the Total Field Gain into a dimensionless gain measure.

PwrGn = antilog (base 10) (TtlFldGn/10)

b. Square the ratio of the right voltage magnitude (erm) to the left voltage magnitude (elm). This squared ratio is the ratio of the dimensionless power gains for right and left patterns.

RatSq = (erm/elm)^2

The next steps are predicated on the assumption that the sum of the two dimensionless circular power gains is the dimensionless total field power gain.

c. Right Gain and Left Gain are 2 unknowns that are subject to simultaneous equations. Selecting Right Gain first, we obtain the following 2 steps.

GnRt = RatSq * PwrGn/(1 + RatSq)

GnRtdBi = 10 * log(GnRt)

d. Left Gain is simply the power gain minus the right gain (all dimensionless).

GnLf = PwrGn - GnRt

GnLfdBi = 10 * log(GnLf)

For our single sample line of RP 0 reporting, we obtain the following values.

```
Theta     ERM     ELM     Sense   RatSq   PwrGn
0         .7393   .2697   right   7.516   13.369
                              GnRt     GnRtdBic   GnLf     GnLfdBic
                              11.799   10.718     1.570    1.959
```

A spreadsheet or other program can be set-up to handle as many entries as we might need to encompass a full pattern for the range of angle that we choose. Examine the NEC output report for model 17-10 at 10° increments. Notice that the pattern changes its sense along the selected sampling path. At the horizons, the Etheta values dominate to a degree that allows NEC to classify the pattern as linear. The left-hand and right-hand reversals may be less apparent until we perform the circular pattern calculations on them.

	Values Calculated by the Listed Equations				
Theta	ERM	ELM	Sense	GnRtdBic	GnLfdBic
-90	0.0518	0.0518	linear	-12.367	-12.367
-80	0.1278	0.1105	right	-4.529	-11.916
-70	0.1675	0.1105	right	-2.178	-5.786
-60	0.1226	0.1399	left	-4.891	-3.743
-50	0.0578	0.1226	left	-11.414	-4.891
-40	0.2399	0.0676	right	0.943	-10.056
-30	0.4460	0.0847	right	6.329	-8.100
-20	0.6136	0.1701	right	9.100	-2.045
-10	0.7153	0.2378	right	10.432	0.866
0	0.7393	0.2697	right	10.718	1.959
10	0.6841	0.2611	right	10.044	1.679
20	0.5585	0.2116	right	8.283	-0.148
30	0.3860	0.1287	right	5.072	-4.469
40	0.2057	0.0682	right	-0.393	-9.977
50	0.0635	0.1329	left	-10.605	-4.190
60	0.0274	0.1885	left	-17.890	-1.150
70	0.0506	0.1805	left	-12.578	-1.529
80	0.0486	0.1196	left	-12.924	-5.105
90	0.0574	0.0574	linear	-11.486	-11.486

For the entries sensed as left, the higher gain in the left-hand gain column becomes much more apparent. Of course, the table--or any enlargement of it--becomes suitable for creating a polar or rectangular plot of the two circular components of the overall helix pattern.

As one final exercise, let's see what happens for a helix that is left-handed, as in model *17-11-nec-4* or *17-11-nec2.nec*.

```
CM General Helix over Perfect Ground
CE
GH 1 100 -5 .6959 .191 .191 .0005 .0005 0
GE 1 -1 0
GN 1
EX 0 1 1 0 1 0
FR 0 1 0 0 299.7925 1
RP 0 181 1 1000 -90 90 1.00000 1.00000
EN
```

The only difference between this model and the one that we have previously used is the minus sign in the third entry of the GH or helix-forming line. The negative value for the number of turns creates a left handed helix, as shown in **Fig. 17-9**.

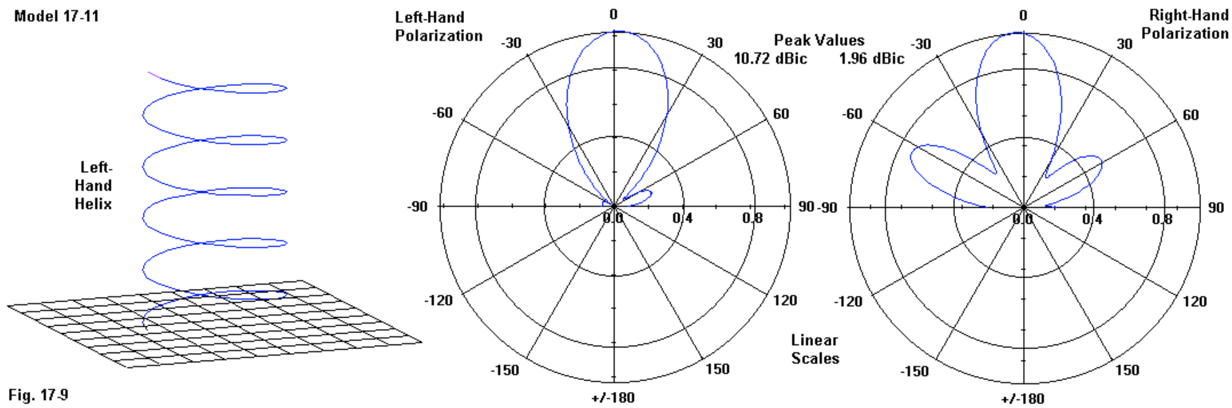


Fig. 17-9

The corresponding NEC-2 GH entry has the following appearance. Note that the required minus sign to create a left-hand helix attaches to the helix length entry.

```
GH 1 100 .13918 -.6959 .191 .191 .191 .191 .0005
```

The sample RP 0 line that corresponds to the one for the previous example appears in the NEC output file.

```
- - ANGLES - -          - POWER GAINS -        - - - POLARIZATION - -
THETA    PHI         VERT.   HOR.    TOTAL       AXIAL      TILT   SENSE
DEGREES  DEGREES       DB      DB      DB         RATIO      DEG.
 0.00    90.00       10.39    3.84   11.261     0.46544    3.89    LEFT
[0.00    90.00       10.39    3.84   11.261     0.46544   -3.89    RIGHT]

        - - - E(THETA) - - -      - - - E(PHI) - - -
        MAGNITUDE      PHASE      MAGNITUDE     PHASE
         VOLTS        DEGREES       VOLTS      DEGREES
        1.00721E+00    80.44     4.73544E-01   163.94
       [1.00721E+00   -99.56     4.73544E-01   163.94]
```

The bracketed entries are from the right-hand helix report. Very little has changed, but the changes make a world of difference. Only the tilt angle and the Etheta phase angle have different numbers. However, those numbers alter the circular polarization calculations.

```
Theta     ERM     ELM     Sense    RatSq    PwrGn
0         .2697   .7393   left     0.133    13.369
                              GnRt      GnRtdBic     GnLf      GnLfdBic
                              1.570     1.959        11.799    10.718

Theta     ERM     ELM     Sense    RatSq    PwrGn
0         .7393   .2697   right    7.516    13.369
                              GnRt      GnRtdBic     GnLf      GnLfdBic
                              11.799    10.718       1.570     1.959
```

The sample output lines are for the left-hand and the right-hand helices in order. The values for the zenith angle show a flip-flop that is not true of the values for the entire pair of left- and right-hand patterns. The pattern on the right sides of **Fig. 17-8** and **Fig. 17-9** show some differences and are not simple mirror images. Axial-mode helix patterns are not perfectly symmetrical. Since the helixes start in the same place but move the wires in opposite directions, one pattern is a mirror of the other's pattern 90° separated.

Although the NSI Multi-Plot feature calculates the gain in dBic for you, it is always useful to understand from where the numbers come. As well, the exercise may provide further evidence that NEC is not only a calculating engine, but also a data resource from which you may derive a large amount of other interesting information.

Summing Up

We began our further look into the RP command with a review of the essentials of requesting 2-dimensional polar plots. We turned quickly to the RP0 requirements for patterns using a complete far-field sphere in free space or full hemisphere over ground. Besides discovering the required command entries, we also explored what 3-dimensional surface plots, radiation efficiency plots, and average gain test plots had in common and how they differed according to the goals of each task.

When we turned to the RP1 ground wave request, we replaced the theta entries with new cylindrical concerts: ρ or the distance from the origin in the X-Y plane and z or the height above ground. The far-field and surface wave calculations yield electric field values for Etheta, Ephi, and Eradial in peak volts/meter. These values acquire useful comparative significance when we also adjust the excitation to a specific power level. In fact, the exercises stressed the integration of many geometry and control commands into the most efficient models for achieving the desired output.

The NEC output report proved to be less a final report than it is a source of data for additional calculation. Using axial-mode helical antennas, we learned how to use the radiation pattern data to calculate the left-hand and the right-hand components (in dBic) of the total field gain as just one possibility for making further use of the NEC output information.

The exercises in this chapter have provided you with a sampling of ways of treating an antenna model as a fully integrated unit. The process starts with the commands by which we create the geometry and proceeds through the control commands by which we request useful outputs. It does not end with a simple output report and its graphical presentation. Instead, full integration of the modeling process involves the interpretation and manipulation of those outputs to arrive at the most useful data set for a selected task.