108. Dipoles: Variety and Modeling Hazards
Linear, V, and Folded Dipoles in NEC

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A dipole is in basic texts any antenna that exhibits a single current maximum to minimum transition from the center feedpoint to the wire end, and conversely, transitions from minimum to maximum voltage as we move from the center to the outer end of the wire. Basic antenna theory rests to some degree on the performance or the behavior of very short dipoles. In practical antenna circles, the term "dipole" is generally shorthand for a specific subset of these antenna. A practical dipole is a center-fed, resonant or near resonant 1/2-wavelength antenna usually using linear (wire or tubing) construction. When the antenna grows too long, we no longer have the current and voltage transitions that define the dipole, and so the antenna becomes a doublet--a center-fed wire with otherwise relatively undefined characteristics.

In these notes for relative newcomers to antenna modeling, I shall use the practical-dipole definition. Practical dipoles include the idea of resonance, that is, a center feedpoint impedance that is entirely resistive (or nearly so), with no (or very little) remnant reactance. These antennas are very practical for many applications. At this point, we begin to encounter physical variations on the usual linear dipole construction. The key parameter shifts from the pattern of current an voltage along the wire to resonance, and we use resonance to determine that an antenna is an electrical half-wavelength long and hence a dipole. Under this revised view of a practical dipole, we encounter many configurations, all of which count as dipoles if we use resonance and an electrical half-wavelength as the key determining factors. **Fig. 1** shows a number of these configurations, but by no means all of them.

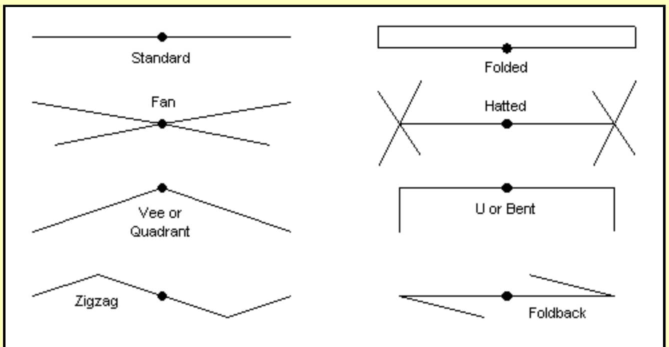


Fig. 1

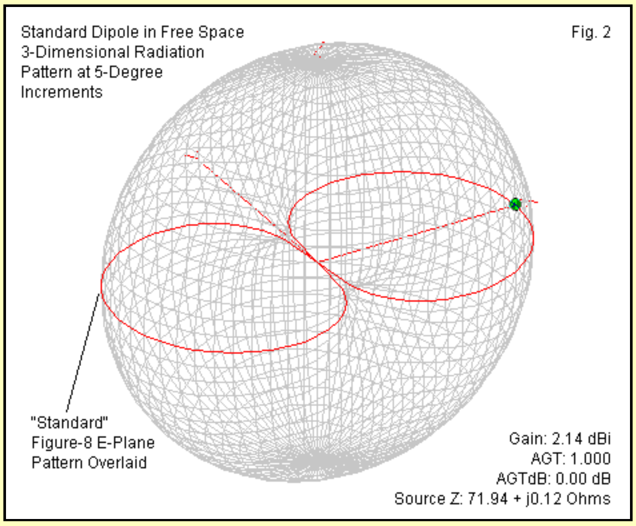
The standard linear dipole and its impedance-transforming partner, the folded dipole, are most familiar to virtually all antenna users. The fan dipole is actually 2 dipoles for separate frequencies with a common feedpoint. The V dipole occurs most commonly as an inverted V, although we may set the V angle at any value. At 90 degrees, with the legs parallel to the ground, we obtain a quadrant antenna. We may also form Ls and inverted-Ls with corner feedpoints as variations on the Vee. The zigzag dipole is simply any set of relative small departures from a truly linear arrangement, usually done to fit a dipole within a restricted space. The hatted dipole uses symmetrical structures at each end of the main element to obtain resonance with a shorter overall length than a full-length dipole requires. The bent or inverted-U form achieves element shortening with single extensions. However, these extensions radiate with vertical polarization, whereas the hat structures usually have self-canceling fields. The final example of a shortened dipole uses fold-back structures. The sketch shows only one of many possible forms, sometimes called the lazy N.

These notes are not designed to evaluate the relative merits of the various configurations. Instead, we want to examine the modeling challenges that some of them might present. Some of the practical dipoles can easily result in unreliable models if we do not attend to software limitations, especially of NEC. So we shall examine the dipoles using both NEC-2 and NEC-4. One of our tools will be the Average Gain Test (AGT), which assesses the reliability of a model by sampling a lossless model in free space (or over perfect ground, which is not relevant here) over a full sphere of points and comparing the average gain to an isotropic source. Hence, an AGT value of 1.000 is excellent, but values above and below that value indicate potential degrees of unreliability. For source impedances close to resonance, we can derive corrected values by multiplying the AGT value times the reported source resistance. We can also convert the AGT value to a value in decibels. If the derived AGT-dB value is positive, we subtract it from the reported gain to obtain a correct gain value. (This note applies at any vector from the antenna, not just to maximum gain.) If the derived AGT-dB value is negative, we add its absolute value to the reported gain, since it tells us by how much (approximately) the gain report is low. We must always remember that the AGT is a necessary but not a sufficient condition of model adequacy. A good AGT score does not guarantee model adequacy.

This first portion of our journey will deal only with modeling some of the dipoles in NEC (both -2 and -4). In the next episode, we shall compare our results with modeling the same antennas in at least two versions of MININEC. Once we have the basic terms and limits of each program under our belts, we can take up the remaining versions of the dipole using both general types of antenna modeling programs.

The Standard Linear Dipole

We may begin with the linear dipole. For our tests, we shall use a frequency of 28 MHz, with a 1" diameter lossless element. The only challenge is not skimping on the segments. Although the minimum segmentation per wavelength is 10, the recommended minimum is 20. Of course, in NEC, we use an odd number of segments to obtain a center source position. However, we need not always strive for the minimum recommended number of segments. The test model uses 41 segments. Our only opposing danger would be to use so many segments that we press the segment-length to wire-diameter (or radius) ratio. 41 segments with a 1" diameter comes nowhere close to such pressure. **Fig. 2** shows the 3-dimensions free-space pattern and overlays the typical E-plane (azimuth) figure-8 pattern with which we are familiar. The listed gain figure sometimes surprises newer modelers who hear that a lossless dipole in free space has a gain of 2.15 dBi. That value applies to dipoles using vanishingly thin elements, which would be significantly longer than our 1" element. Shortening a linear dipole, even if only enough to restore resonance due to using a fat element, results in a gradual gain reduction.



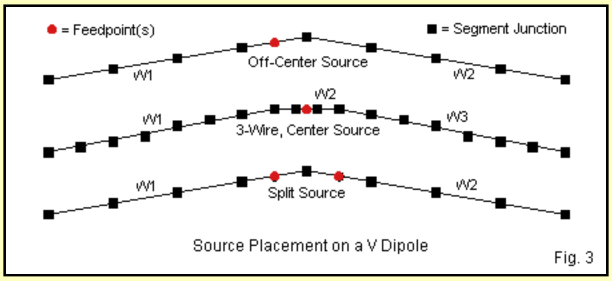
The impedance figure is from NEC-4. NEC-2 yields 71.95 + j 0.17 Ohms. Both values are from the EZNEC cores through version 4.0.20. Different implementations of NEC-2 and NEC-4 may use different Fortran compilers and result in values that differ even from these. In fact, different CPUs in various computer types can also result in variations, although all will be harmlessly small. Both NEC-2 and NEC-4 agree on the AGT score: 1.000, which requires no corrective on the gain or source resistance report.

The total antenna length for our sample model is 199.4", although it will be more convenient for us to speak in half-lengths: +/-99.7". For many of our "deviant" dipoles, the half-length will be a useful catalog number. Although the antenna is an electrical half-wavelength, as indicated by the resonant source impedance, the physical wire is only 0.473-wavelength.

The V Dipole

V dipoles occur using almost any included angle between the wires. Let's restrict ourselves to a single angle of 90 degrees between wires. That is equivalent to bending each leg 45 degrees from the linear configuration. In terms of modeling, the action will necessarily result in a model with at least 2 wires. MININEC models will place the source on the junction of the two wires at the apex. However, uncorrected MININEC 3.13 will provide two kinds of errors if we are not careful. First, there is a frequency offset that increases with rising frequency. Second, MININEC creates errors in current calculations at sharp angular wire junctions. We can largely overcome the second error condition by using a very large number of segments, since the amount of error varies with the segment lengths. However, many later implementations of MININEC 3.13 provide corrections for both error sources within the code and yield very reliable results. However, unless you possess more than one version of MININEC 3.13, you may not be able to assess the level of correction available within the program you use. I have provided some performance comparisons over a number of MININEC potential trouble spots in a past column.

NEC users face a slightly different challenge. Since the apex of the V will be a junction of 2 wires and since NEC sources lie within segments, we must figure out where to place the source. **Fig. 3** shows 3 of our options. The black squares are segment junctions, while the red dots are potential source locations. For all of our tests here, we shall stay at 28 MHz and retain the 1" diameter lossless element.



The top version of the V model uses a simple procedure of placing the source on one of the segments adjacent to the apex of the V. The justification lies in the fact that at high current regions of most antennas, the current changes very slowly as we move away from the precise antenna center. Hence, the potential error is very small, especially since these models use the same total number of segments as the linear dipole (actually 42). The bottom model uses a split or dual source, with a source placed on each side of the apex. EZNEC will internally total the sum of the two source impedance values, but manual addition is simple enough. Otherwise, the model is identical to the top offset-source model.

The middle model uses a different technique. It creates a level wire at the center. The wire uses 3 segments so that the segments adjacent to the center source segment are of equal length with the source segment. That model design maneuver tends to yield maximum accuracy in the current calculations. Each wire extends +/- 7.5" from the center point. The sloping legs each have 19 segments, for a total of 41 segments in the model, and the leg segment lengths are close to the length of the segments in the source wire.

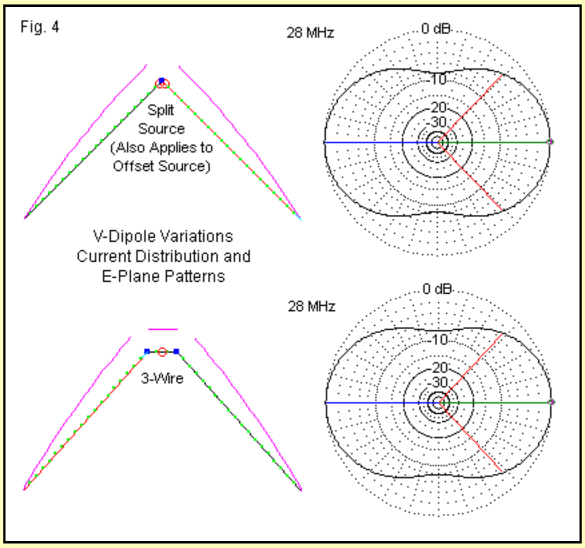


Fig. 4 shows two relevant facts about the models. The wire layouts have superimposed current magnitude curves that verify the current distribution as appropriate to a dipole as defined earlier. The E-plane patterns broadside to the plane of the V structures are virtually identical. To a casual viewer, the models might seem indistinguishable. However, the following table shows that there are indeed a few important distinctions among them.

Comparison of V-Dipole Models in NEC-2 and NEC-4
All models use 1" diameter lossless elements in free space.

Source Method	Core	Wire Length Inches	Gain dBi	Source Impedance R +/- j X Ohms	AGT	AGT-dB	Corrected Gain dBi
Offset	NEC-2	+/-103.3	1.52	44.75 + j0.02	0.949	-0.23	1.75
	NEC-4	+/-103.3	1.50	45.00 - j0.22	0.943	-0.25	1.75
Split	NEC-2	+/-103.3	1.52	44.75 + j0.22	0.949	-0.23	1.75
	NEC-4	+/-103.3	1.50	45.01 + j0.02	0.943	-0.25	1.75
3-Wire	NEC-2	+/-102.3	1.72	41.31 + j0.25	1.004	0.02	1.70
	NEC-4	+/-102.3	1.73	41.26 + j0.00	1.005	0.02	1.71

Note: Wire Length is the total half-element length from the apex to the tip in offset and split-source versions and from the source point to the wire

Between the offset-source and the split-source models we find only tiny differences. For each core, the difference falls mostly in a 0.2 consistent differential in the source reactance. We might assign the gain difference between NEC-2 and NEC-4 versions to differences in the core. This assignment would be correct, but not merely due to random compiler or CPU operations. If we move to the AGT and AGT-dB columns, we find values that are far less than perfect. The differences in the AGT values relative to the 2 cores are small but significant. If the initial gain report seemed low, it was. A corrected gain report brings the value more within expectations for a full-size antenna, even if we allow for some broadside gain loss to compensate for the shallower side nulls in the E-plane patterns.

The less than perfect AGT values result from the use of relatively fat elements. Each segment is about 5" long, and the wire diameter is 1". At the apex of the V, the wire segments that join inter-penetrate a considerable, but not fatal distance relative to any use to which one might apply the model. If we had used thin wires, the small wire diameter would have resulted in much less penetration toward the junction segment centers, and the AGT values would have been closer to ideal values. Obviously, I have constructed the sample model to reveal the effect, rather than hiding it by the use of thin wires.

The 3-wire version of the model achieves a set of AGT values much closer to ideal Whether the very small difference in correct gain values is a function of the core or of the slightly different structure is indeterminate from the available data, but we do note that the total amount of element from the source point to the element tip differs by an inch from the 2-wire models. As well, we may note that the 3-wire models result in lower source resistance values. However, you may wish to compare the values after multiply each reported resistance by the basic AGT value.

Even if we discount this sequence of models as unlikely candidates for implementation, they do reveal the importance of making constant reference to the AGT values of a model. Had we used the raw reports from the 2-wire models as a comparator to the linear dipole, we would have drawn very wrong conclusions about the degree of gain deficit. As well, we should not be too hasty in discounting the models, since the design, turned 90 degrees so that all elements parallel the ground surface, forms a common structure of some antennas with forward-sweep elements.

Folded Dipoles

Folded dipoles are actually hybrid constructions. They are indeed dipoles, but the folded structure adds an extra set of currents. These transmission-line currents are a function of the folded dipole's impedance transformation relative to a linear dipole. The upper left portion of **Fig. 5** shows the result of combining the 2 sets of currents. The transmission line currents are relatively constant in magnitude. Hence, the radiation currents overlay them. The resulting curve rises above and falls below the average current magnitude, but does not go to zero at the ends of the wires, as we would find for a linear dipole.

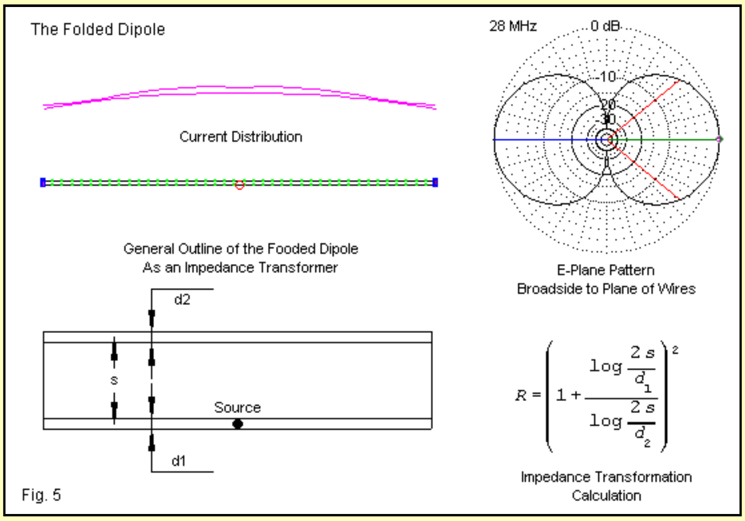


Fig. 5

Once we separate the two currents, the radiation currents are virtually identical to those that we find in a linear dipole. Hence, the radiation pattern on the upper right is indistinguishable from the patterns of standard dipole. The resonant folded dipole will be shorter than a line dipole, since the effective diameter of the two parallel wires, each the same diameter as the single wire in a linear dipole, is considerable greater. The 28-MHz model of a folded dipole with 1" diameter elements is 4.5" shorter at resonance than the linear dipole that we reviewed earlier. The modeled folded dipole uses a wires separation of 2" center-to-center, with 41 segments in each long element section.

With both elements having an equal diameter, the resonant impedance is between 281 and 282 Ohms, or about 4 times the impedance of a single element dipole (70 Ohms). However, the exact ratio of impedance transformation is only 4:1 if both elements have the same diameter. The lower half of **Fig. 5** shows the key elements in calculating the transformation ratio, R. The equation involves the spacing (s) between elements and the relative diameters of the two element sections, where d1 is the section with the feedpoint and d2 is the section parallel to the driven section. Note that s, d1, and d2 must use the same units of measure for the equation to produce usable results. If both elements have the same diameter, then the ratio of logs reduces to 1, and the ratio turns out to be 4. If the driven section is smaller, then the ratio is greater than 4:1. If the undriven section is smaller, then the ratio is less than 4:1 but always greater than 1:1.

We may reduce the undriven section to any diameter. Let's use 0.1". The equation yields 1.89:1 as the transformation ratio. If we assume a linear dipole impedance of 70 Ohms, then the folded dipole with a larger driven section and a smaller undriven section should show an impedance close to 132.5 Ohms. Slight variations will occur because the equation does not take the end connecting wires into account. We shall use the same segmentation level (41 segments per section) that we used on the folded dipole with equal-diameter sections. Since the transformation involves only the transmission-line currents, the gain and pattern of the folded dipole with unequal-diameter elements should be the same (within close tolerances) as the corresponding results from the equal-diameter folded dipole. The following table summarizes the results for both kinds of folded dipole using both NEC-2 and NEC-4.

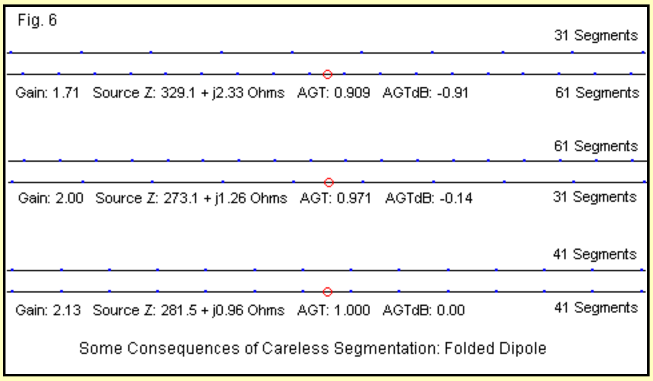
Comparison of Folded-Dipole Models in NEC-2 and NEC-4: Equal and Unequal Diameter Elements
All models use 1" diameter lossless driven elements in free space. Second elements are 1" or 0.1" diameter lossless wires.

Diameters Driven/Other	Core	Wire Length Inches	Gain dBi	Source Impedance R +/- j X Ohms	AGT	AGT-dB	Corrected Gain dBi
1"/1"	NEC-2	+/-97.45	2.13	281.6 - j0.54	1.000	0.00	2.13
	NEC-4	+/-97.45	2.13	281.5 - j0.96	1.000	0.00	2.13
1"/0.1"	NEC-2	+/-99.2	4.34	230.2 - j10.59	1.662	2.21	2.13
	NEC-4	+/-99.2	2.96	164.5 + j0.60	1.209	0.82	2.14
	Calculated Impedance			132.5			

Note: Wire Length is the total half-element length from the center to the tip.

The equal-diameter version of the folded dipole shows good results from both NEC-2 and NEC-4, since both cores produce an AGT of 1.000. The gain values are identical, and the reported impedance values are almost identical. However, the reported values for the folded dipole with unequal diameter sections fall way off the mark. NEC-2 is considerably worse than NEC-4 with respect to anticipated values of gain and impedance. In fact, both NEC-2 and NEC-4 become error prone with angular junctions of wires having dissimilar diameters. NEC-4 improves upon the performance of NEC-2 in this regard, but falls seriously into error as the change of diameter increases. In this model, the ratio is 10:1, so that even NEC-4 yields an unacceptable AGT value. Note that the AGT-dB values bring the gain report close to the anticipated value. However, at a certain level, the AGT value itself becomes useless in correcting the reported source resistance. MININEC does not share the NEC limitation relating to changes in element diameter at wire junctions. Hence, it is generally able to handle models like the folded dipole with unequal-diameter element sections with no problems. If the version of MININEC 3.13 has had other limitations corrected, then it should yield quite accurate results for our test case.

Both models that we have just examined used 41 segments on each long wire. The results are a set of well-aligned segment junctions in the closely spaced parallel wires. Although providing each wire with the same number of segments seems quite natural, we sometimes encounter cases of somewhat careless segmentation. **Fig. 6** shows the center portions of equal-diameter folded dipoles that differ only in the assignment of segments per wire. (All end connection wires use 1 segment.) In one case, we have 61 segments on the driven wire and 31 on the other wire. The second case reverses the assignment. At the bottom, the figure shows the segmentation of the preferred model.



Some Consequences of Careless Segmentation: Folded Dipole

The upper two models clearly do not show a pattern of well-aligned segment junction. The following table shows the results of the misalignment, with all other factors being the same for all three models.

Comparison of Folded-Dipole Models in NEC-2 and NEC-4: Careless vs. Careful Segmentation
All models use 1" diameter lossless elements in free space.

Segments Driven/Other	Core	Wire Length Inches	Gain dBi	Source Impedance R +/- j X Ohms	AGT	AGT-dB	Corrected Gain dBi
61/31	NEC-2	+/-97.45	1.88	342.5 + j2.31	0.946	-0.24	2.12
	NEC-4	+/-97.45	1.71	329.1 - j2.33	0.909	-0.41	2.12
31/61	NEC-2	+/-97.45	1.84	263.6 + j2.23	0.937	-0.28	2.13
	NEC-4	+/-97.45	2.00	273.1 + j1.26	0.971	-0.13	2.12
41/41	NEC-2	+/-97.45	2.13	281.6 - j0.54	1.000	0.00	2.13
	NEC-4	+/-97.45	2.13	281.5 - j0.96	1.000	0.00	2.13

Note: Wire Length is the total half-element length from the center to the tip.

Fig. 6 provides the NEC-4 reported data for each model. The degree to which the unevenly segmented models depart from correct values depends on both the core used (NEC-2 or NEC-4) and the ratio of segments in the 2 wires, where the ratio shows the misalignment. Admittedly, the sample models provide cases of extreme misalignment. However, even small misalignments can draw the results away from the ideal AGT values attained by the model with well aligned segments. Alignment becomes ever more critical as we close the spacing between wires. Once more, it pays dividends to check the AGT values for any model. Checking those values becomes even more important when we need or wish to compare the reports of one model with another, whether we are using similar or dissimilar geometries.

Conclusion to Part 1

We have not gone very far in our exploration of resonant half-wavelength dipoles, and already we have seen some modeling snares. Some of those traps are modeling practices that we can easily avoid. Others involve limits to the NEC cores that we cannot avoid except by deferring the model construction. Folded dipoles with unequal elements form one of those NEC limitations and require the use of antenna modeling software that lacks the particular limitation involved. MININEC is one of those usable cores.

In addition to running into potential pitfalls, we have also run out of room in this column. Therefore, we shall have resume our journey in the next episode. We shall discover whether or not MININEC can handle those odd folded dipoles--and more.

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