80-Meter Dipoles and Inverted-Vs
A Graphical Scrapbook

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Back in the early 1990s, I did an article for *Communications Quarterly* on "The Effects of Antenna Height on Other Antenna Properties" (Fall, 1992, pp. 57-79). Back then, MININEC was the only generally available antenna-modeling program for PCs, and the pace of the work was very slow. However, the article called attention to some cyclical features of dipole performance at lower heights (less than 2 λ) that apparently still elude many amateurs, especially users of the lower HF region, with special attention to the 80-75-meter band. So, with a faster PC and NEC-4 (specifically, EZNEC Pro/4, Version 5), I returned to the old work, but with a few new questions in mind.

One product of the renewed examination of dipoles (and their kindred inverted-Vs) is this set of notes that I view as a graphical scrapbook. The kind of data that emerges lends itself to graphical presentation, and so the following pages are full of graphs accompanied by a number of tables for specific numerical reference. It is a scrapbook and not a compendium. A full systematic treatment of the subject would demand a continuously expanding treatment with each new addition needing data and graphs for each of the many branches on a growing tree of investigation. At best, once we move past the most fundamental points, the exploration must proceed by samples and the assurance that for deviant cases, you can perform the same steps with your own version of NEC (-2 or –4).

The safari will travel down the following trails. First, we shall look at the general question of the effects of 80-75-meter antenna height on dipole behavior with two goals in mind. One aim is to see the general patterns of variation in antenna gain, take-off (TO) angle, and feedpoint impedance as we gradually increase the height in 1/16 λ increments. We shall work with the arithmetic band center (3.75 MHz) as our test frequency and always use AWG #12 (0.0808" diameter) copper wire for our antennas. That will ensure the fairness of all comparisons in these notes. The second goal will be to see how the resonant length and feedpoint impedance change with height changes.

Next, we shall try to find out what difference major changes in soil or ground quality make to the variations that we find. Most of our work will be over average ground (conductivity 0.005 S/m; permittivity 13), but we shall pause also to examine very good soil (conductivity 0.0303 S/m, permittivity 20) and very poor soil (conductivity 0.001 S/m, permittivity 5). Soil quality is one of those variables that we can sample, but cannot pursue for every possibility long the way.

The second trail will include comparisons among the basic dipole and two kinds of inverted-V antennas. Again, we must restrict our choices. Therefore, we shall examine the 30° V (with an included angle of 120°) and the 45° V (with a 90° included angle). Our collection of graphs will grow as we include specific data on each V along with comparative data among all of the antennas that we create. Our comparisons will include a few snapshots of pattern development and SWR properties to help us understand some of the significance of the differences that we uncover.

At this point, the paths through the jungle of possibilities reach an important junction. There are numerous routes to follow as we consider matching a dipole to our equipment. There are many possible ways to provide a match between station equipment and a relatively narrowband antenna like a wire dipole that tries to cover the 80-75-meter band, a 13% bandwidth. We might simulate much fatter wire, modify the dipole itself to increase its bandwidth, or even develop one or more series matching systems using the feedline. However, we shall bypass all of these options and simple connect a single feedline that is 150' long between the feedpoint of our dipole and Vs and a presumed antenna tuner (or ATU). Excluding an analysis of the tuner itself (which can be extremely varied according to network design and construction variables), we shall want to know what sort of performance we can expect from the antenna with its feedline. To assist in this task, we shall freeze the antenna height at ½ λ (131.14' at 3.75 MHz) over average ground and focus on several different feedline choices. (Note that 150' is long enough to reach the antenna if the operating position is almost under the antenna itself.)

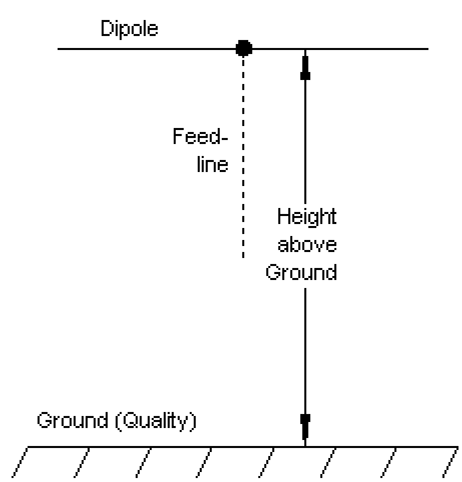
This work will uncover another small pathway down which we shall go. As we explore the antenna gain performance (and the loss relative to a zero-line antenna), we shall change the antenna lengths to resonate at a new frequency that will give us better coverage of the full band on the assumption that we wish to work the full band with relatively equal performance at both ends of the band. Finally, we shall show why the exercise is only a sample of work you can do.

The last page of the scrapbook will not be the last page of investigation into the 80-75-meter dipole and V collection. The study will end, but the exploration is open ended. We shall have shown a way of investigation, but not results that apply directly to your actual or proposed installation. So the remaining pages are simply blank as you retrace the work, using your own antenna, its height, its soil, your cable choice, its length, and such other factors as may fit your needs. At most, the scrapbook is an appetizer to show you the need for your own specific menu in advance of setting up a basic antenna to do some serious work on one of the widest of all amateur bands.

The Basic Properties of Dipoles at Relatively Low Heights

Let's begin with an AWG #12 copper wire dipole modeled to be resonant at 3.75 MHz in a free-space environment. The dipole length is 127.7', and the resonant impedance is 73.6 – j0.4 Ω. Next, let's place this dipole over ground, beginning with average ground. **Fig. 1** shows the general outline of our effort.

Fig. 1



Dipole Height and Ground Quality
as Performance Variables

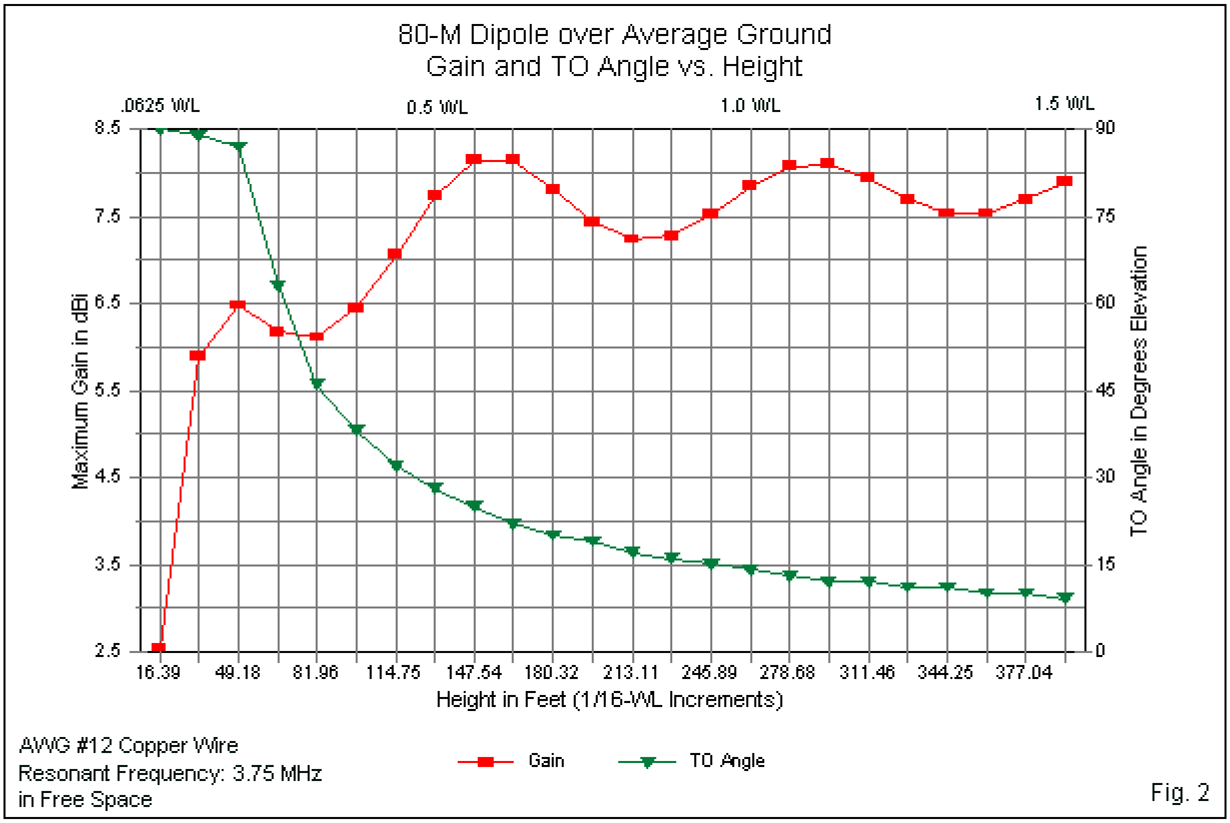
We can change the dipole's height above ground in small increments. Let's use 1/16 (0.0625) λ as our increment. At 3.75 MHz, each step is 16.39'. With the NEC S-N ground system, we can obtain results that are quite accurate down to the smallest increment. Note that at the test frequency, 1/8 λ or 32.79' is about the height used by many suburban 80-75-meter dipole users. We can extend the tests up to a height of 1.5 λ (393.43'), well above the height at which any amateur would be able to place a dipole, but the extra height will allow us to display any cyclic behavior. **Table 1** shows the numerical results of our efforts over three types of soil, but initially, let's focus in on the middle or average ground values.

3.750-MHz AWG #12 copper dipole above different ground qualities													Table 1
		Very Good Ground (c=0.0303 S/m, p=20)				Average Ground (c=0.005 S/m, p=13)				Very Poor Ground (c=0.001 S/m, p=5)			
Ht wl	Ht ft	Resist	React	Gain dBi	TO deg	Resist	React	Gain dBi	TO deg	Resist	React	Gain dBi	TO deg
0.0625	16.39	27.3	11.5	4.65	89	47.8	15.1	2.54	90	69.8	13.8	1.33	89
0.1250	32.79	44.9	29.1	7.24	88	55.9	24.1	5.89	89	67.5	15.0	4.35	86
0.1875	49.18	69.6	33.1	7.39	86	73.6	25.6	6.48	87	76.3	15.1	5.18	80
0.2500	65.57	88.9	22.9	6.83	69	87.5	16.5	6.17	63	83.9	8.9	5.25	53
0.3125	81.96	96.2	5.8	6.52	49	92.0	2.7	6.11	46	85.7	-0.1	5.47	41
0.3750	98.36	91.5	-9.5	6.74	39	87.3	-9.1	6.45	38	81.7	-7.2	5.91	35
0.4375	114.75	79.8	-16.9	7.36	33	77.3	-14.1	7.06	32	74.9	-9.7	6.47	30
0.5000	131.14	67.6	-14.9	8.12	29	67.7	-11.6	7.73	28	68.8	-7.3	7.01	26
0.5625	147.54	60.7	-6.2	8.64	25	62.8	-4.1	8.15	25	66.1	-1.9	7.32	23
0.6250	163.93	61.5	3.9	8.65	23	64.2	4.0	8.14	22	67.7	3.3	7.34	21
0.6875	180.32	68.5	10.1	8.23	21	70.3	8.5	7.81	20	72.1	5.8	7.16	19
0.7500	196.71	77.0	9.8	7.73	19	77.1	7.6	7.44	19	76.6	4.6	6.98	18
0.8125	213.11	82.5	4.1	7.42	18	81.1	2.6	7.24	17	78.9	1.0	6.90	17
0.8750	229.50	82.5	-3.2	7.41	16	80.6	-3.4	7.28	16	78.0	-3.0	6.98	15
0.9375	245.89	77.7	-8.1	7.66	15	76.3	-6.9	7.52	15	74.9	-5.0	7.20	14
1.0000	262.29	71.3	-8.3	8.04	14	71.2	-6.6	7.85	14	71.5	-4.4	7.45	14
1.0625	278.68	66.9	-4.2	8.33	13	67.8	-3.0	8.08	13	69.5	-1.8	7.63	13
1.1250	295.07	66.6	1.5	8.38	13	68.0	1.6	8.10	12	70.0	1.4	7.64	12
1.1875	311.46	70.1	5.6	8.19	12	71.2	4.7	7.94	12	72.4	3.2	7.52	12
1.2500	327.86	75.3	5.9	7.87	11	75.4	4.6	7.70	11	75.2	2.8	7.40	11
1.3125	344.25	79.0	2.7	7.67	11	78.2	1.7	7.54	11	76.9	1.0	7.30	10
1.3750	360.64	79.4	-1.9	7.62	10	78.2	-2.1	7.54	10	76.6	-1.9	7.35	10
1.4375	377.04	76.5	-5.4	7.79	10	75.6	-4.6	7.69	10	74.6	-3.4	7.46	10
1.5000	393.43	72.3	-5.8	8.01	9	72.1	-4.7	7.89	9	72.3	-3.2	7.64	9
Notes:	Ht wl = height in wavelengths; Ht ft = height in feet												
	Resist = feedpoint resistance in Ohms; React = feedpoint reactance in Ohms												
	Gain dBi = maximum gain at TO angle in dBi; TO deg = take-off elevation angle in degrees												
	Dipole length = 0.4869 wl = 127.7' based on resonance in free space at 3.75 MHz; feedpoint impedance: 73.6 - j0.4 Ohms												

As we raise the antenna from a very low level to a very high one, the numbers change, even though we have not changed the length of the antenna. We expect the elevation angle of maximum radiation (TO angle) to slowly go down with increased antenna height. Its progression is very regular, since the elevation of any horizontal antenna is a direct function of its height above ground. The other numbers move up and down in seemingly regular ways.

Fig. 2 graphs the maximum gain and TO angle of the dipole as we change height. The bottom of the graph lists the height in feet, while an upper scale shows selected heights in wavelengths for easier tracking. As we expected, the TO line shows a steady progression downward, but the rate of progression decreases as the antenna gets higher. At the backyard height of 35' above ground, the main radiation is at very high angles, useful for very short-range communications, but not so useful for long-range contacts.

The maximum gain values change with height, showing cycles with approximately ½ λ between peaks. The lowest peak gain occurs at about 3/16 λ, with successive peaks at about 5/8 λ and 1-1/8 λ. We find minimum values in the successive cycles at about 5/16 λ, 13/16 λ, and 1-5/16 λ. Note that the difference between peak and minimum values is greatest at the lowest heights and decreases with increasing antenna height. For upper HF, where antennas tend to be higher as measured in wavelengths, the variation is of no concern. Even on 80 meters, we would have difficulty detecting the differences in any one cycle operationally.


80-M Dipole over Average Ground
Gain and TO Angle vs. Height
.0625 WL
0.5 WL
1.0 WL
1.5 WL
Maximum Gain in dBi
8.5
7.5
6.5
5.5
4.5
3.5
2.5
TO Angle in Degrees Elevation
90
75
60
45
30
15
0
16.39
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Gain
TO Angle
Fig. 2

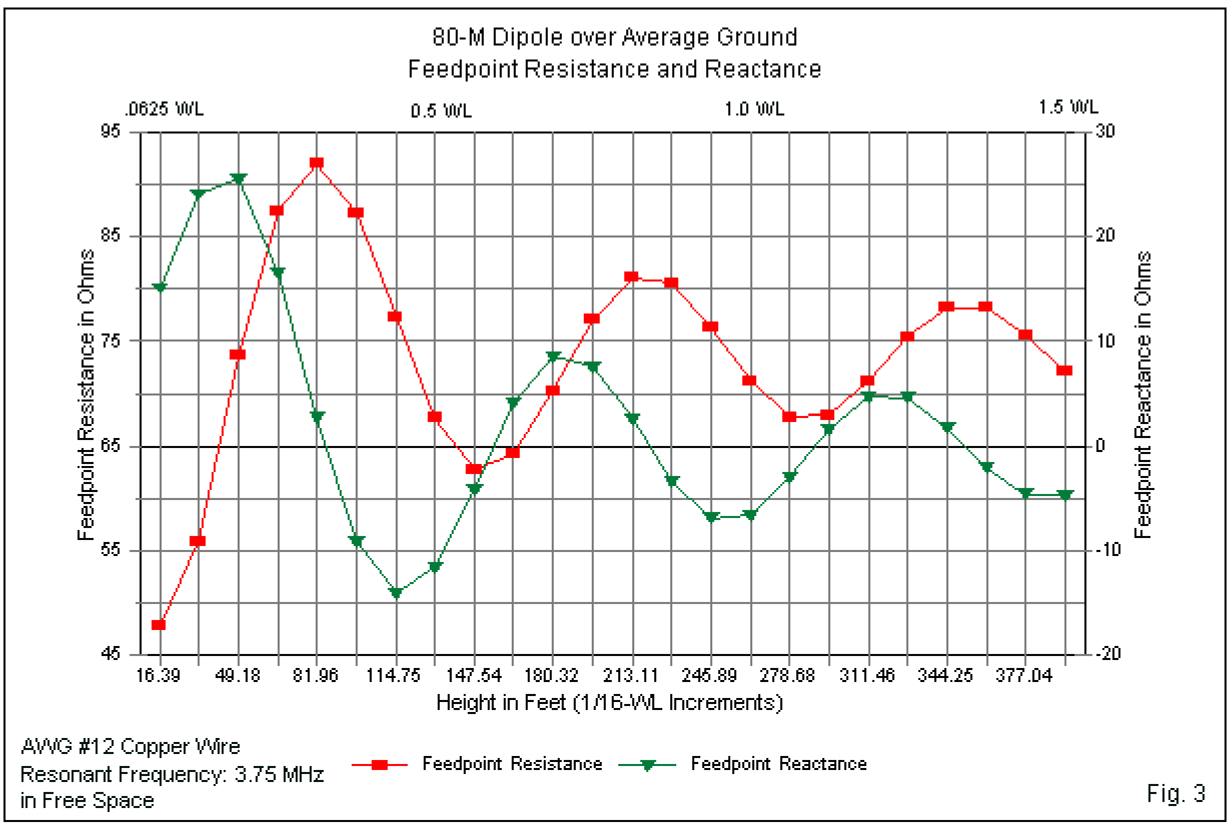

80-M Dipole over Average Ground
Feedpoint Resistance and Reactance
.0625 WL
0.5 WL
1.0 WL
1.5 WL
Feedpoint Resistance in Ohms
95
85
75
65
55
45
Feedpoint Reactance in Ohms
30
20
10
0
-10
-20
16.39
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Feedpoint Resistance
Feedpoint Reactance
Fig. 3

Fig. 3 tracks the changes in the feedpoint resistance and reactance for our constant-length dipole as we change the antenna height. Once more, we find cycles with peak and minimum resistance values and cycles of swings in reactance between maximum inductive and capacitive reactance. The two curves are synchronized in the following way. The reactance passes through the zero line approximately where the feedpoint resistance is minimum and where it is maximum in each cycle. The combination of zero reactance and minimum feedpoint resistance roughly coincides with the peak gain heights displayed in **Fig. 2**, while the maximum resistance and zero reactance points roughly coincide with minimum gain heights.

Like the gain cycles, the feedpoint resistance and reactance cycles swing most widely at lower heights, with lesser differentials as we elevate the antenna. At upper HF, where antennas are normally higher as a fraction of a wavelength, the amount of variation is almost indistinguishable from other installation site variables and tends to fall into the general category of required field adjustments. However, at the lower heights that are normal to 80-75-meter dipoles, the impedance swings are both notable and critical to planning a dipole installation.

3.75-MHz AWG #12 dipole above average ground				
Ht wl	Ht ft	Res L wl	Res L ft	Res Res
0.0625	16.39	0.4825	126.55	46.7
0.1250	32.79	0.4802	125.95	53.6
0.1875	49.18	0.4800	125.90	70.5
0.2500	65.57	0.4823	126.50	85.0
0.3125	81.96	0.4860	127.47	91.5
0.3750	98.36	0.4895	128.39	88.7
0.4375	114.75	0.4910	128.78	79.3
0.5000	131.14	0.4903	128.60	69.1
0.5625	147.54	0.4880	128.00	63.2
0.6250	163.93	0.4858	127.42	63.8
0.6875	180.32	0.4844	127.05	69.2
0.7500	196.71	0.4848	127.16	76.1
0.8125	213.11	0.4860	127.47	80.7
0.8750	229.50	0.4878	127.94	81.0
0.9375	245.89	0.4888	128.21	77.3
1.0000	262.29	0.4888	128.21	72.0
1.0625	278.68	0.4877	127.92	68.2
1.1250	295.07	0.4865	127.60	67.8
1.1875	311.46	0.4855	127.34	70.6
1.2500	327.86	0.4855	127.34	74.8
1.3125	344.25	0.4865	127.60	78.0
1.3750	360.64	0.4875	127.86	78.5
1.4375	377.04	0.4880	128.00	76.1
1.5000	393.43	0.4880	128.00	72.6
Notes:	Ht wl = height in wavelengths			
	Ht ft = height in feet			
	Res L wl = resonant length in wavelengths			
	Res L ft = resonant length in feet			
	Res Res = resonant feedpoint resistance			
		in Ohms		Table 2

Table 2 demonstrates the level of importance of taking antenna height into consideration by looking at the dipole from a slightly different perspective. In this table, we find the resonant length of the dipole for each height listed in **Table 1**. We also find the modeled resonant

impedance of the antenna over average ground. In the height range between about 50' and 115', the resonant length of a dipole for 3.75 MHz changes by over 2.5' before accounting for any influences of surrounding objects at the site. The height range that we just noted includes most of the heights used by serious 80-75-meter operators and indicates that the construction of this very basic antenna is not a casual matter.

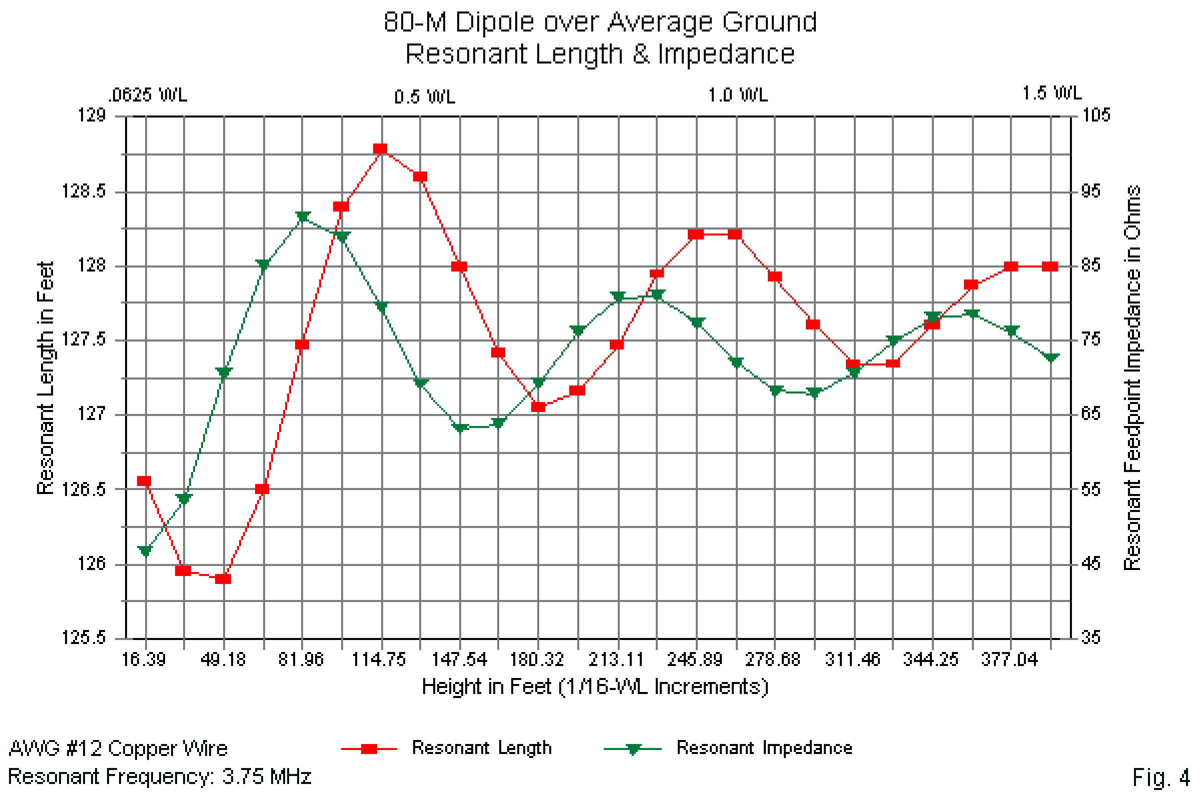
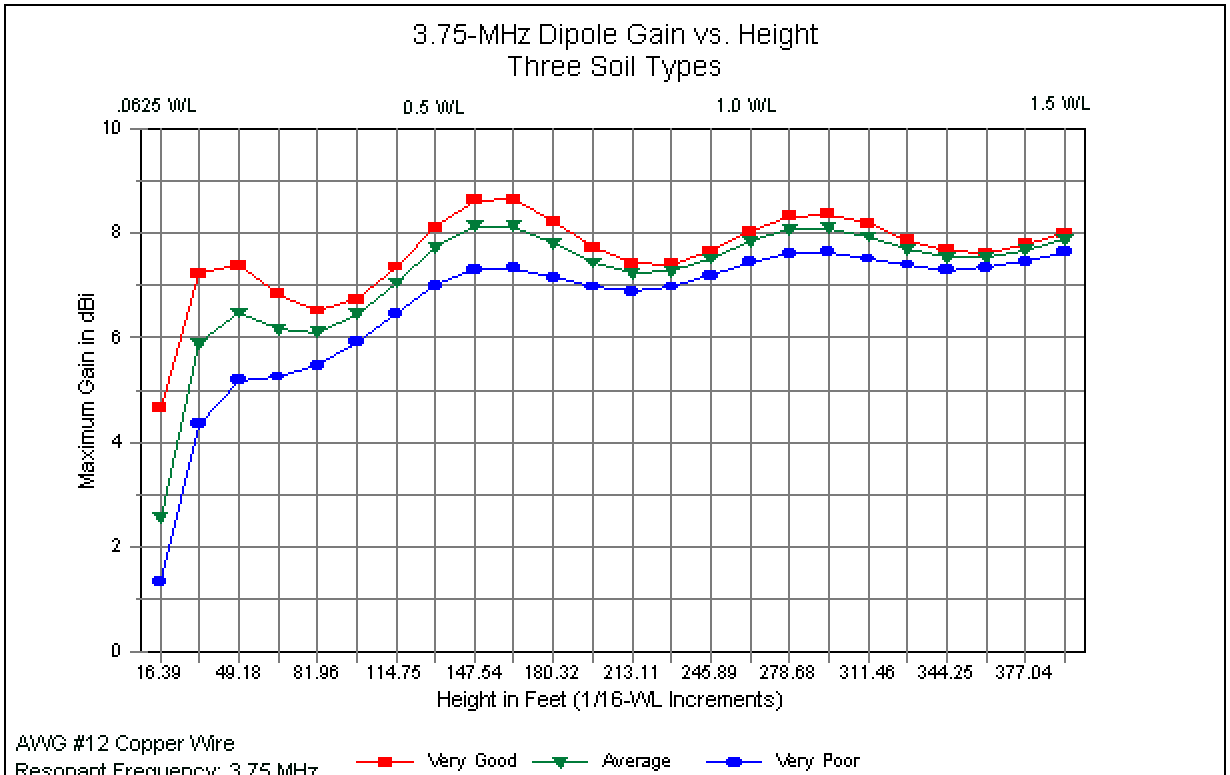


Fig. 4

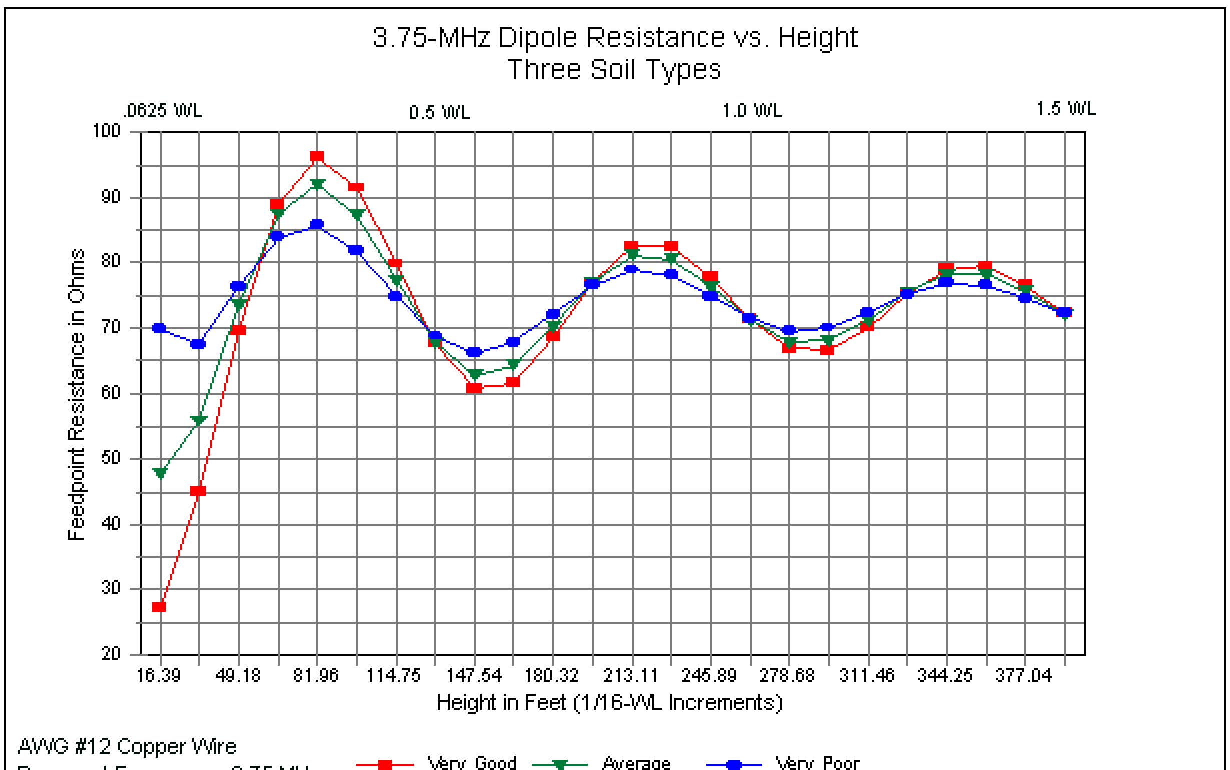
The resonant feedpoint (resistive) impedance also undergoes cyclical swings, but the curves do not directly overlay the changes in length to achieve resonance at the test frequency. In the lowest region of antenna height, the impedance ranges from less than 50 Ω at near-ground level to over 90 Ω at a height of 5/16 λ (about 82'). The region from 70' to about 110' presents the highest impedances that are favorable to certain types of broadband matching schemes that use calculated lengths of transmission line. However, some of those techniques fail to work beyond the listed range because the resonant impedance of the dipole is too low. As we have experienced with other graphed properties of the dipole, the differentials between cyclical maximum and minimum values grow smaller as we increase the dipole height. This exercise in readjusting the dipole length for resonance is one of those options that we can only sample. As we change the focus of the tests, we shall work mainly with fixed length antennas resonated in free space. However, you can replicate every exercise in these notes and create your own additions to the scrapbook.

Table 1 also includes data for our basic dipole over very good and very poor soil to go together with the basic average ground values that we have used so far. How the ground quality affects dipole performance appears in separate graphs for gain (**Fig. 5**), feedpoint resistance (**Fig. 6**), and feedpoint reactance (**Fig. 7**). As the graphs will show, the comparison of each property with varying soil type is more significant than a full profile for each level of ground quality.



3.75-MHz Dipole Gain vs. Height
Three Soil Types
.0625 WL
0.5 WL
1.0 WL
1.5 WL
Maximum Gain in dBi
10
8
6
4
2
0
16.39
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Very Good
0.0303; 20
Average
0.005; 13
Very Poor
0.001; 5

Fig. 5



3.75-MHz Dipole Resistance vs. Height
Three Soil Types
.0625 WL
0.5 WL
1.0 WL
1.5 WL
Feedpoint Resistance in Ohms
100
90
80
70
60
50
40
30
20
16.39
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Very Good
0.0303; 20
Average
0.005; 13
Very Poor
0.001; 5

Fig. 6

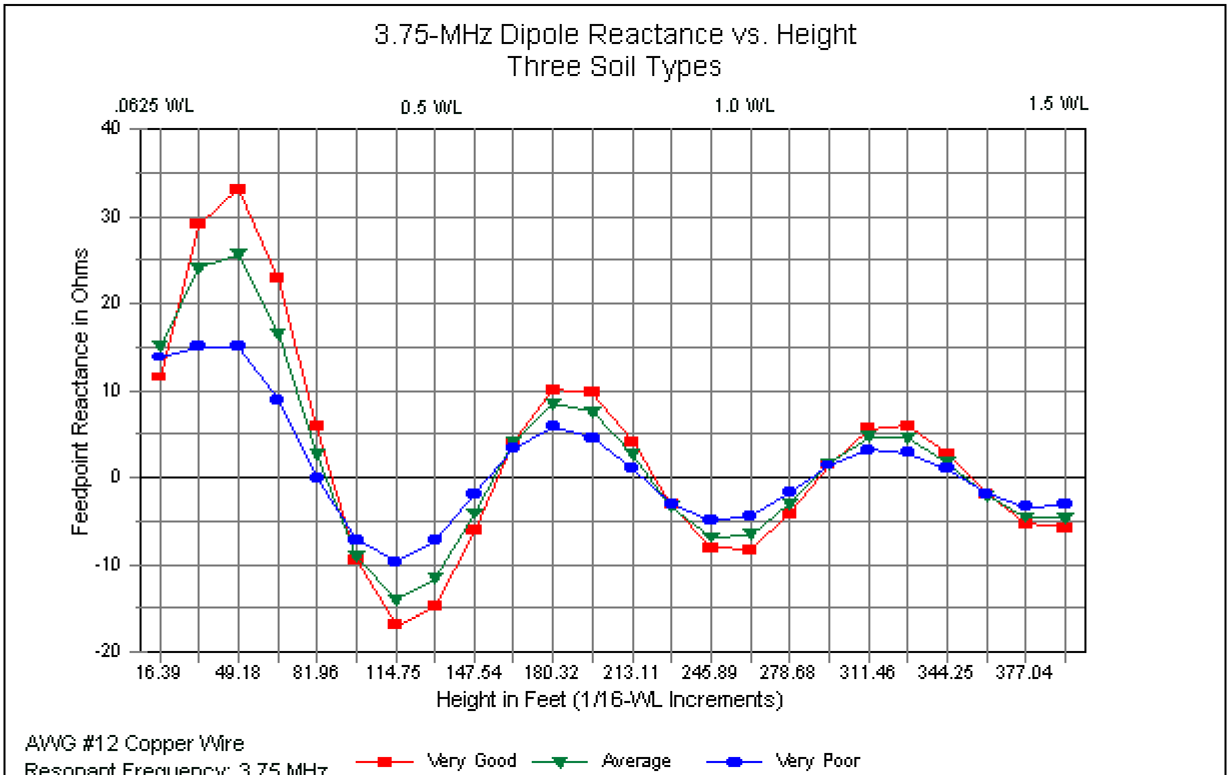


Fig. 7

As revealed by **Fig. 5**, the soil quality does not affect the heights at which we find maximum and minimum gain values. It does affect the actual values, with the curves showing slightly better gain at any height with improved ground quality. The level of gain improvement with ground quality is most dramatic at the lowest heights, where the antenna interacts most strongly with the ground. As we elevate the antenna, the amount of difference decreases. We should remember that the differences even at low heights are functions of radiation reflection from ground that lies well outside the area of the installation and therefore beyond the range of any soil or ground amendments we might make in hopes of improving performance,

Fig. 6 informs us that the feedpoint resistance will vary more with better ground quality—and less with poorer soils. Once again, the degree of variation decreases with antenna height increases. In some regions, soil quality can change with local weather (for example, in some parts of the U.S. desert southwest). A relatively low 80-75-meter dipole may therefore show some variation of its impedance with the weather, independently of the consequences of precipitation coating the antenna and its feedpoint assembly. **Fig. 7** shows a similar situation for the feedpoint reactance. The better the ground quality, the greater will be the changes in reactance with changes in antenna height.

Soil quality has some subtler effects on dipole performance. **Fig. 8** provides a small gallery of dipole elevation patterns at different heights above each soil quality. The basic development of elevation lobes is a function of antenna height, as the similarity of patterns at each level shows. There are differences, some of which are more vivid in the pattern for a height of 5/8 λ. The depth of the nulls between lobes is greater with better ground quality and is shallower over worse soil. As the pattern for 1-1/8 λ reveals, the effect is strongest between a vertically oriented lobe and the next lower one than it is between two adjacent lower lobes.

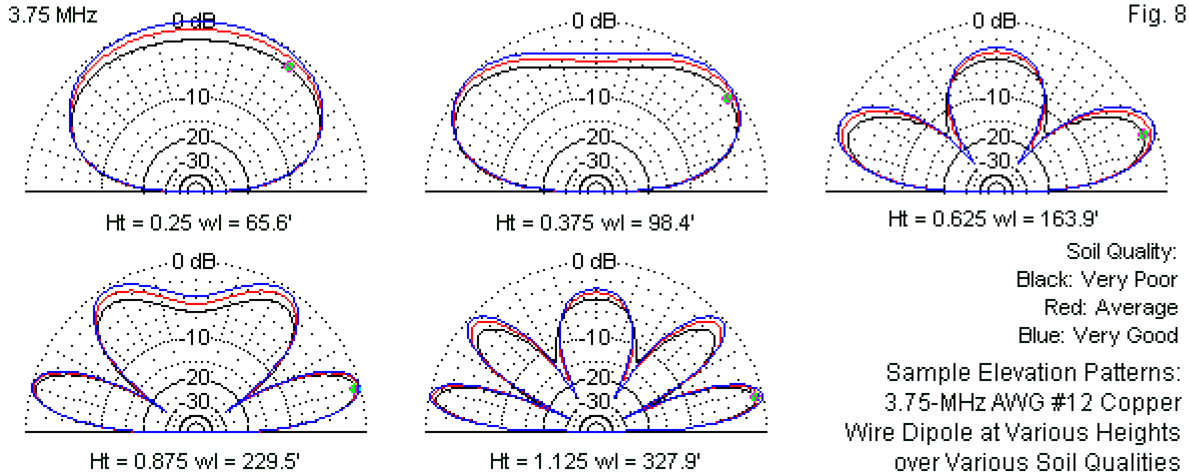


Fig. 8

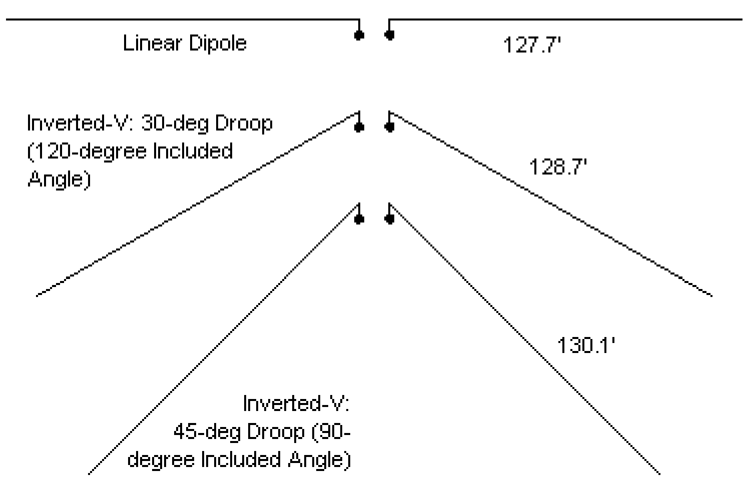
Sample Elevation Patterns: 3.75-MHz AWG #12 Copper Wire Dipole at Various Heights over Various Soil Qualities

When a new lobe first appears, it shows up as a vertically oriented lobe. In the two cases of a new lobe shown in **Fig. 8**, the difference in lobe strength is not very great over the range of soils. Under those conditions, we tend to find the greatest difference in strength in the next lower lobe as the soil quality changes. When the upper lobe splits into two distinct lobes—for example, in the pattern for 7/8 λ—we find much less difference in the strength of the next lower lobe with differences in soil quality.

Like the exercise involving readjusting dipoles to resonance at each new height, our foray into the effects of soil quality is only a sample. You may carry out a similar exercise for any of the antenna situations to come using any level of ground quality that may suit your existing or proposed installation.

The Basic Properties of Inverted-Vs at Relatively Low Heights

Fig. 9



Three 1/2-Wavelength AWG #12 Copper Wire Center-Fed Antennas Resonant in Free Space at 3.75 MHz

A very commonly used variation on the linear dipole for use on the lower HF bands is the inverted-V. Reasons for using it include the requirement for a single tall center support rather than two end supports and space restrictions that will not allow the construction of a full-length linear dipole. We should include at least the variations on the inverted-V theme shown in **Fig. 9** if only to see if their behavior tracks with the behavior of linear dipoles. We do not have time or space for every variation on the V, but we can look at two representative samples. One drops the element angle 30° below the level line for a total included angle between legs of 120°. A second common version drops the legs to 45°, for an included angle of 90°.

We may retrace our steps with each inverted-V individually. **Table 3** presents the data for the 30° V over average ground (only). Two of the lowest heights are missing so that the tip of each leg exceeds 1/16 λ above ground level. The total wire-length required for free-space resonance is 128.7', about 1' longer than the linear dipole. The droop of each leg at the tip is about 32.2', which sets the lowest height in the table at 3/16 λ.

3.75-MHz AWG #12 30-degree inverted-V above average ground					
Ht wl	Ht ft	Resist	React	Gain dBi	TO deg
0.1875	49.18	61.4	35.6	4.86	89
0.25	65.57	70.5	23.1	5.56	84
0.3125	81.96	76.6	10.5	5.52	56
0.375	98.36	75.8	-1.7	5.74	43
0.4375	114.75	69.0	-9.8	6.27	35
0.5	131.14	60.0	-11.7	6.98	30
0.5625	147.54	52.9	-7.8	7.63	27
0.625	163.93	50.5	-1.0	7.93	24
0.6875	180.32	53.0	5.1	7.80	22
0.75	196.71	58.5	7.6	7.43	20
0.8125	213.11	63.7	5.7	7.09	18
0.875	229.50	65.9	1.2	6.96	17
0.9375	245.89	64.5	-3.3	7.06	16
1	262.29	60.7	-5.3	7.34	15
1.0625	278.68	56.9	-4.3	7.65	14
1.125	295.07	54.9	-1.0	7.84	13
1.1875	311.46	55.8	2.5	7.80	12
1.25	327.86	58.6	4.3	7.60	12
1.3125	344.25	61.8	3.6	7.39	11
1.375	360.64	63.4	1.0	7.26	11
1.4375	377.04	62.8	-1.9	7.32	10
1.5	393.43	60.5	-3.4	7.48	10
Notes:	Ht wl = height in wavelengths				
	Ht ft = height in feet				
	Resist = feedpoint resistance in Ohms				
	React = feedpoint reactance in Ohms				
	Gain dBi = maximum gain at TO angle in dBi				
Table 3	TO deg = take-off elevation angle in degrees				

The tabulated data seems to show the same sorts of variations in gain and feedpoint impedance that we experienced with the linear dipole. **Fig. 10** graphs the maximum gain and TO-angle information, while **Fig. 11** tracks the feedpoint resistance and reactance values. In both cases, we find the same sorts of cyclical variation (except for the TO angle, of course) that we saw in the graphs for the dipole. For reference, the free-space 30° V showed a gain of 1.79 dBi (about 0.25 dB less than the dipole) with a feedpoint impedance of 59.6 + j0.1 Ω. The V's resonant impedance is about 14 Ω less than the comparable dipole impedance. Nevertheless, the variations in 30° V behavior appear to parallel those of the linear dipole.

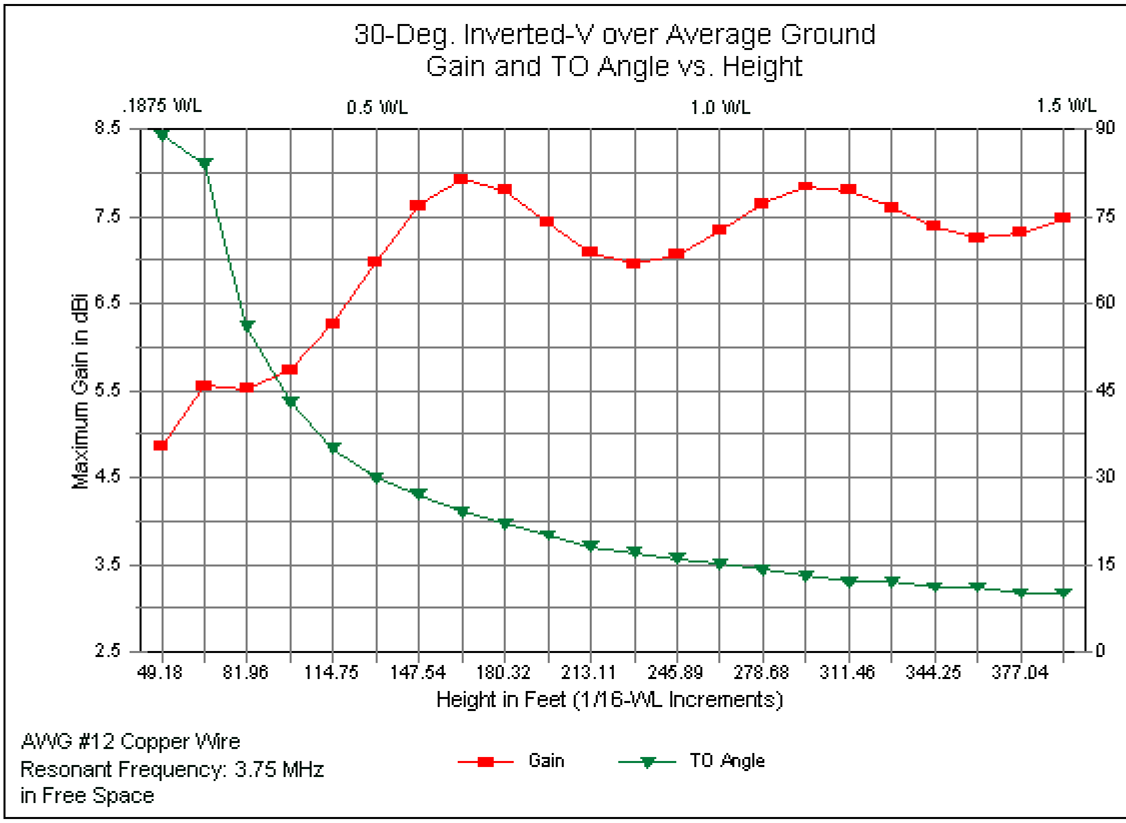

30-Deg. Inverted-V over Average Ground
Gain and TO Angle vs. Height
.1875 WL
0.5 WL
1.0 WL
1.5 WL
Maximum Gain in dBi
TO Angle in Degrees Elevation
8.5
7.5
6.5
5.5
4.5
3.5
2.5
90
75
60
45
30
15
0
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Gain
TO Angle

Fig. 10

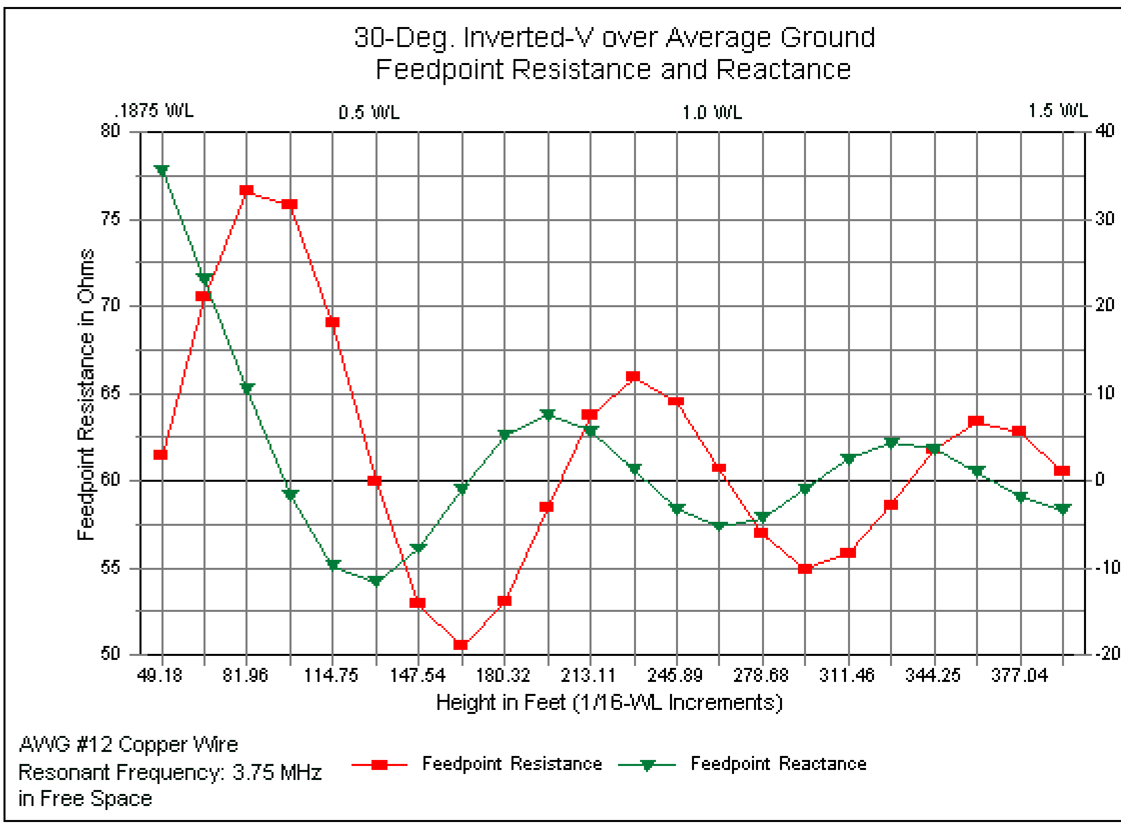

30-Deg. Inverted-V over Average Ground
Feedpoint Resistance and Reactance
.1875 WL
0.5 WL
1.0 WL
1.5 WL
Feedpoint Resistance in Ohms
Feedpoint Reactance in Ohms
80
75
70
65
60
55
50
40
30
20
10
0
-10
-20
49.18
81.96
114.75
147.54
180.32
213.11
245.89
278.68
311.46
344.25
377.04
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Feedpoint Resistance
Feedpoint Reactance

Fig. 11

The 45° V saves more lateral space that the 30° V, but requires more vertical room. In addition, as we close the included angle, the required total wire length becomes longer. For a free-space resonant 45° V, we need about 130.1' of AWG #12 copper wire. The array provides 1.49 dBi of free-space gain, about 0.3 dB less than the 30° V. The feedpoint impedance is lower: 43.6 + j0.0 Ω. Due to the 46' vertical dimension, we must remove one more step from our survey and begin with a minimum peak height of 0.25 λ (65.57' at 3.75 MHz) in order to leave at least 1/16 λ between the V tips and the ground.

3.75-MHz AWG #12 45-degree inverted-V above average ground					
Ht wl	Ht ft	Resist	React	Gain dBi	TO deg
0.25	65.57	53.8	24.9	4.67	86
0.3125	81.96	57.1	11.8	4.93	59
0.375	98.36	57.0	1.5	5.19	45
0.4375	114.75	52.7	-5.8	5.69	37
0.5	131.14	46.2	-8.6	6.40	32
0.5625	147.54	40.3	-7.0	7.10	28
0.625	163.93	37.3	-2.5	7.53	25
0.6875	180.32	38.0	2.3	7.53	22
0.75	196.71	41.4	5.0	7.23	20
0.8125	213.11	45.3	4.7	6.88	19
0.875	229.50	47.7	2.0	6.68	17
0.9375	245.89	47.6	-1.3	6.71	16
1	262.29	45.4	-3.5	6.94	15
1.0625	278.68	42.5	-3.4	7.24	14
1.125	295.07	40.7	-1.6	7.46	13
1.1875	311.46	40.6	0.9	7.49	12
1.25	327.86	42.2	2.6	7.36	12
1.3125	344.25	44.4	2.7	7.15	11
1.375	360.64	46.0	1.3	7.00	11
1.4375	377.04	46.1	-0.7	7.00	10
1.5	393.43	44.8	-2.1	7.13	10
Notes:	Ht wl = height in wavelengths				
	Ht ft = height in feet				
	Resist = feedpoint resistance in Ohms				
	React = feedpoint reactance in Ohms				
	Gain dBi = maximum gain at TO angle in dBi				
Table 4	TO deg = take-off elevation angle in degrees				

Within the limits we have set, including the overall lower gain and the base height, the 45° V replicates the same cyclical behavior that we observed with both the linear dipole and the 30° V. **Fig. 12** graphs the maximum gain and the TO angles for the tighter inverted-V. The TO portion of the graph lacks the plateau of high elevation angles, due to the unavoidable missing steps in the survey. However, the curve displays the same kind of curves as we have seen for the other antennas. The gain curve (minus the dipole's first three steps) exhibits peaks and valleys in just about the right places.

The graph of feedpoint resistance and reactance in **Fig. 13** also appears completely normal. The inductive reactance reaches it peak value a height that is about 1/8 λ lower than the nearest peak in the resistive component of the impedance. As well, each cycle—gain, resistance, and reactance—repeats itself about every halve wavelength of height increase. Moreover, the differential between highest and lowest values decreases as we increase the height of the antenna.

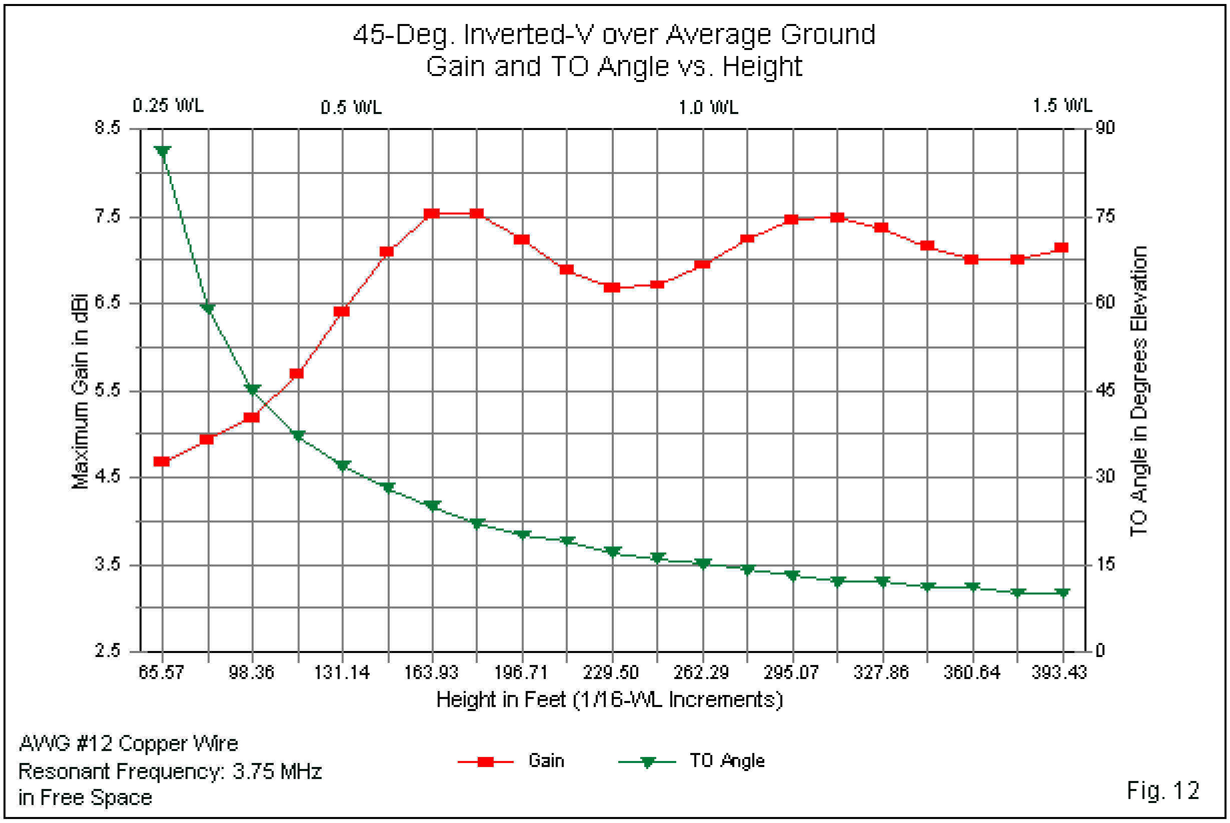

45-Deg. Inverted-V over Average Ground
Gain and TO Angle vs. Height
0.25 WL
0.5 WL
1.0 WL
1.5 WL
8.5
7.5
6.5
5.5
4.5
3.5
2.5
90
75
60
45
30
15
0
Maximum Gain in dBi
TO Angle in Degrees Elevation
65.57
98.36
131.14
163.93
196.71
229.50
262.29
295.07
327.86
360.64
393.43
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Gain
TO Angle

Fig. 12

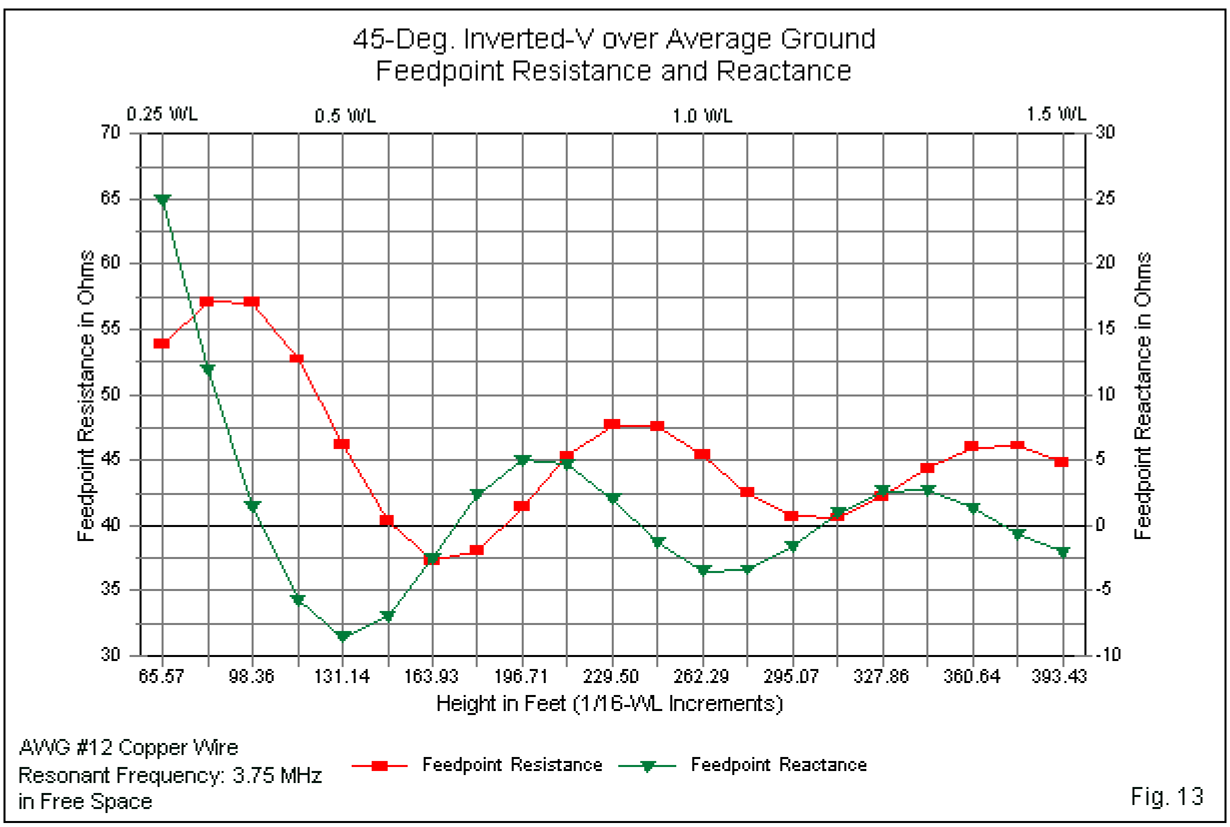

45-Deg. Inverted-V over Average Ground
Feedpoint Resistance and Reactance
0.25 WL
0.5 WL
1.0 WL
1.5 WL
70
65
60
55
50
45
40
35
30
30
25
20
15
10
5
0
-5
-10
Feedpoint Resistance in Ohms
Feedpoint Reactance in Ohms
65.57
98.36
131.14
163.93
196.71
229.50
262.29
295.07
327.86
360.64
393.43
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Feedpoint Resistance
Feedpoint Reactance

Fig. 13

The individual profiles of the two types of inverted-V establish that these antennas behave like the linear dipole, but not necessarily just like the dipole. To determine whether the coincidence is exact or not, we must create a set of comparative graphs of the properties that we have been tracking. **Fig. 14** overlays the three sets of gain values, beginning at a minimum peak antenna height of 0.25 λ. As the curves plainly show, the linear dipole reaches its peak gain values (and its minimum values) at a slightly lower height than the 30° V, which in turn reaches its peaks and valleys at a lower height than the 45° V. The displaced waves deserve an explanation.

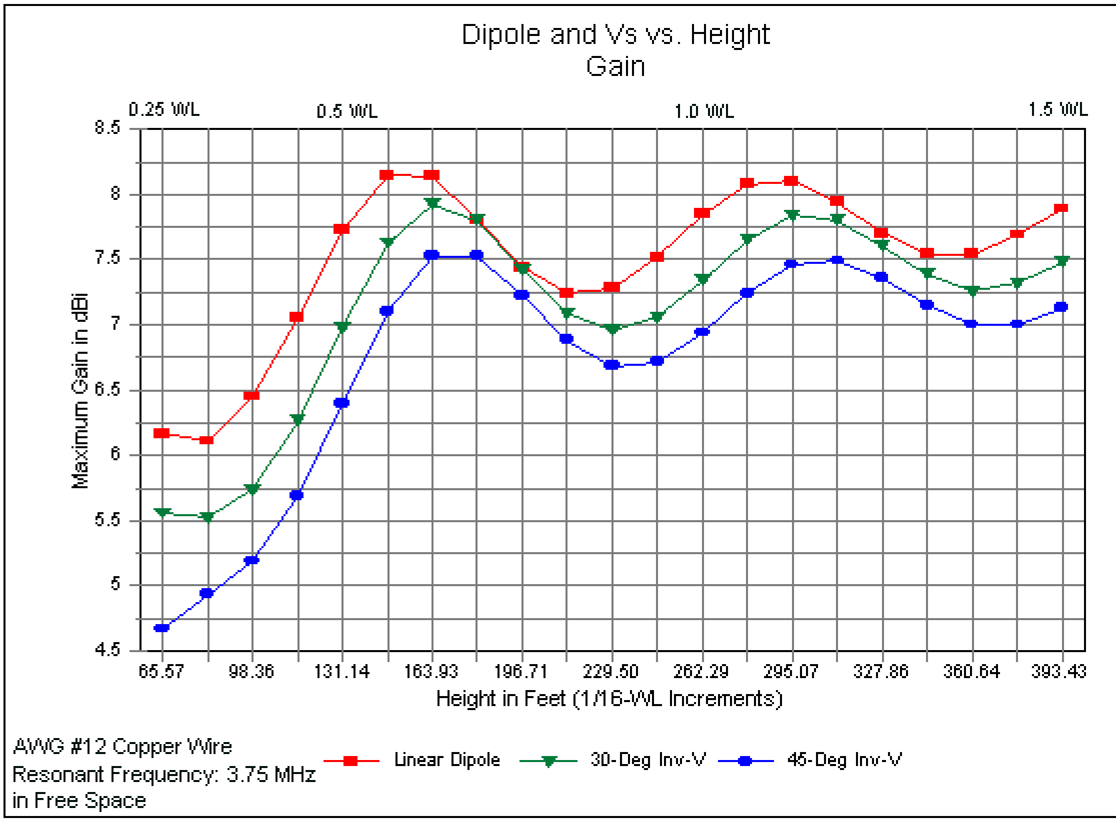
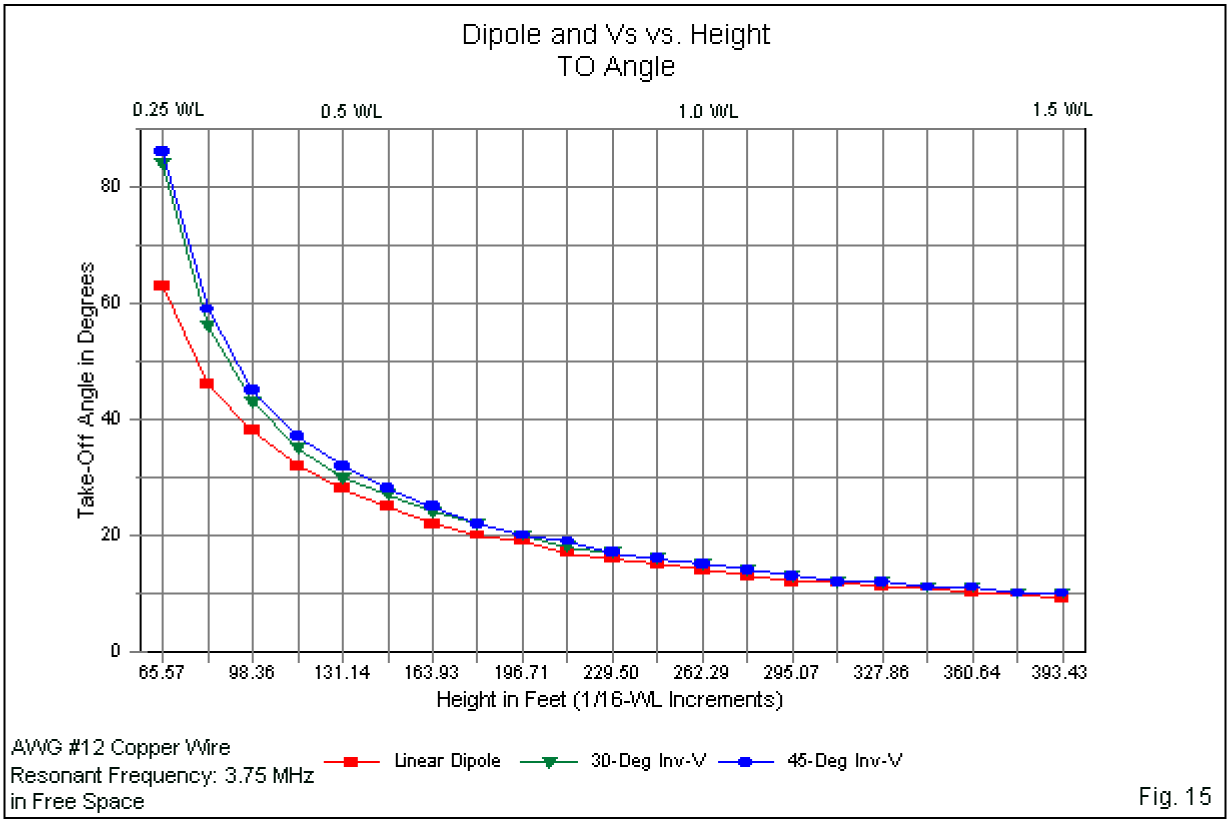
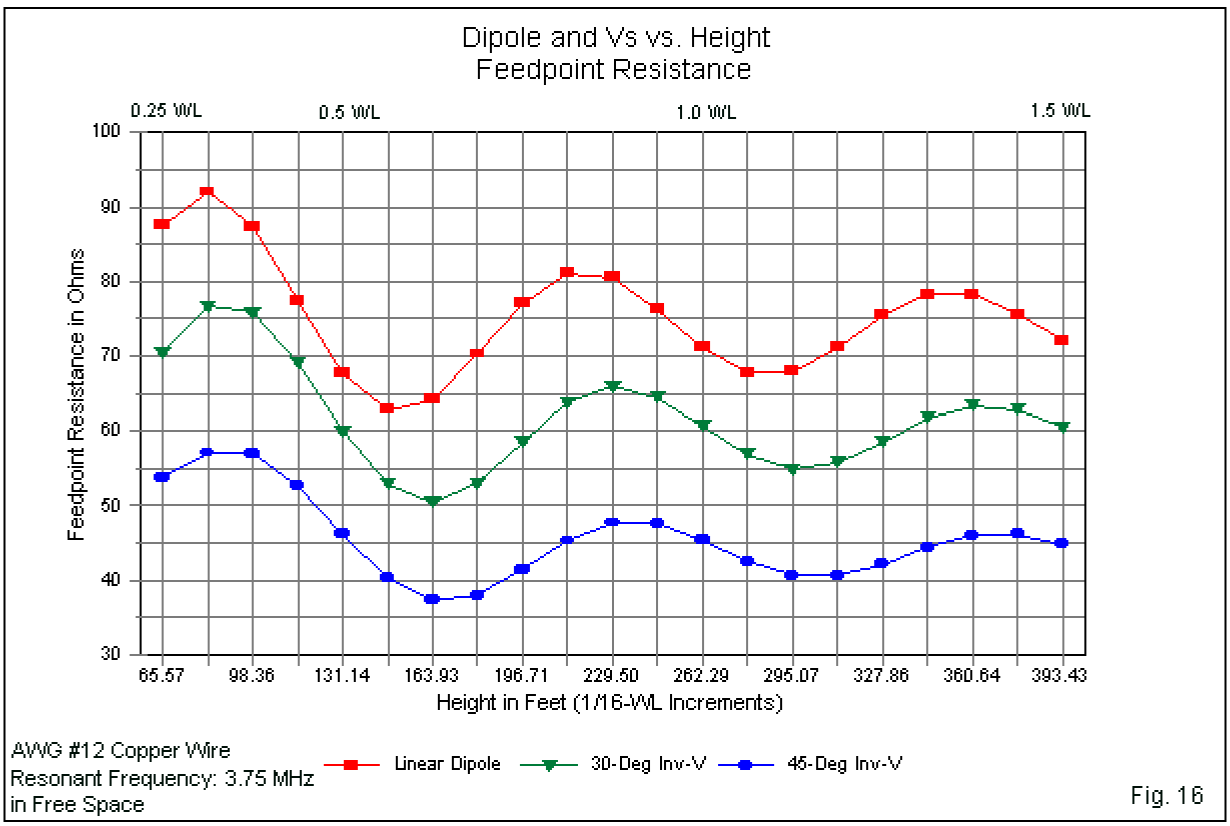


Fig. 14

The reason for the displacement becomes apparent once we create a similar comparative graph for the TO angles for the three antennas. Even though the resolution of the TO angle is to the nearest degree so that the lines often overlap, we can see the general trend. The drooping legs of the inverted-Vs give the antenna a lower effective height than the linear dipole that is exactly horizontal. Hence, the smaller the enclosed angle of the V—while still maintaining dipole-like behavior—the higher will be the TO angle. In fact, the gain curves are a more sensitive registry of the effective height differences, since they record the height delay until the antenna achieves peak gain. The 45° V effective height is about 1/16 λ lower than the physical peak antenna height.

Fig. 16 shows the feedpoint resistance curves, while **Fig. 17** provides the reactance graphs. Even though the resistance curves represent quite different value groups, based on the free-space resonant impedance differences among the three antennas, we find the same degree of difference in the heights for peak values that we saw in the collection of gain curves. The effective height of the 45° V is about 1/16 λ lower than the peak physical height, which corresponds to the height of every part of the linear dipole. The 30° V shows an intermediate value.


Dipole and Vs vs. Height
TO Angle
0.25 WL
0.5 WL
1.0 WL
1.5 WL
Take-Off Angle in Degrees
0
20
40
60
80
65.57
98.36
131.14
163.93
196.71
229.50
262.29
295.07
327.86
360.64
393.43
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Linear Dipole
30-Deg Inv-V
45-Deg Inv-V
Fig. 15


Dipole and Vs vs. Height
Feedpoint Resistance
0.25 WL
0.5 WL
1.0 WL
1.5 WL
Feedpoint Resistance in Ohms
30
40
50
60
70
80
90
100
65.57
98.36
131.14
163.93
196.71
229.50
262.29
295.07
327.86
360.64
393.43
Height in Feet (1/16-WL Increments)
AWG #12 Copper Wire
Resonant Frequency: 3.75 MHz
in Free Space
Linear Dipole
30-Deg Inv-V
45-Deg Inv-V
Fig. 16

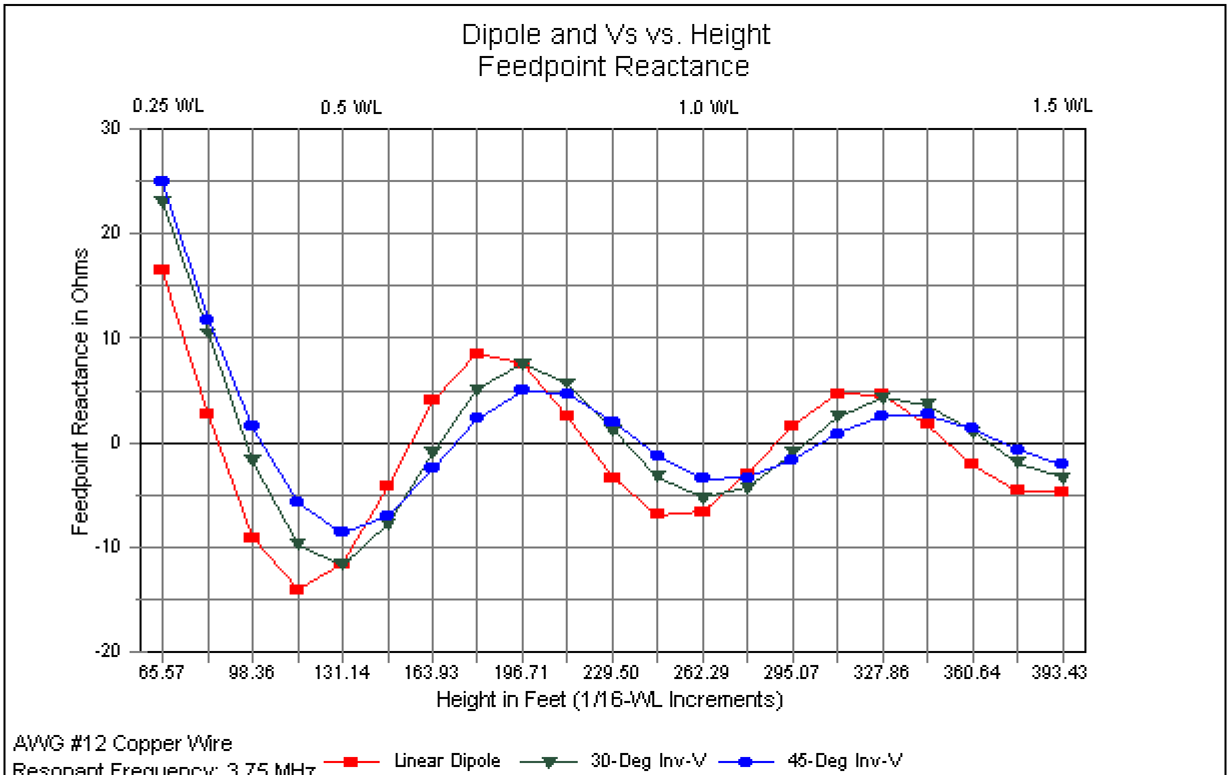


Fig. 17

The reactance curves provide us with multiple bits of information. We can find a further confirmation of the lower inverted-V effective height. As well, we also see that the difference between peak inductive reactance and peak capacitance reactance decreases as we move from the linear dipole through the 30° V to the 45° V. The smaller differences coincide with the lower average values of the feedpoint resistance as we create Vs with smaller included angles.

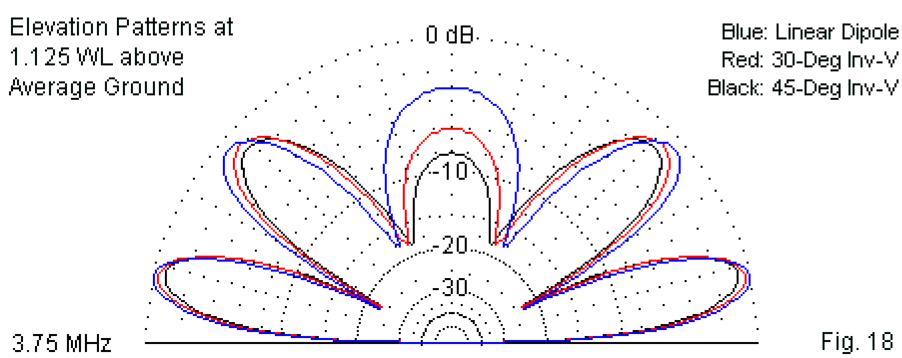


Fig. 18

Fig. 18 gives us a somewhat different view of the lower effective height of the Vs by showing the lobe development at a particular height. I selected 1-1/8 λ for the peak height (the height of the antenna feedpoint) because it displays multiple lobes that more readily reveal the lobe development stages. The lowest lobes not only show the dipole's higher gain (by a small margin), but as well the slightly lower TO angle. The second elevation lobes are perhaps more revealing, since we can more readily see the higher central angle of each lobe as we move from the dipole toward the 45° V. The development (or the lack thereof) of the emerging vertically oriented lobe provides the highest level of differentiation. The 30° V requires more height before the new lobe reaches a level close to that of the dipole. The 45° V requires even more height.

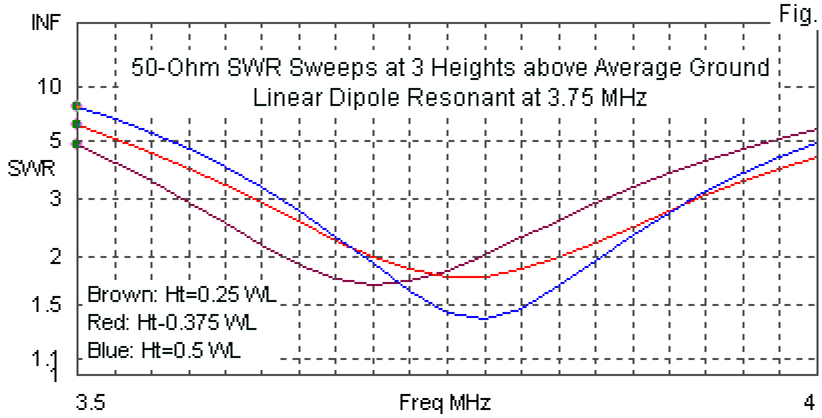


Fig. 19

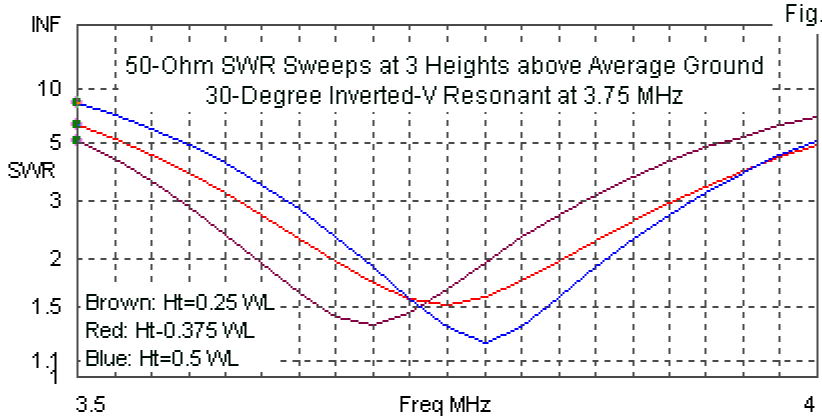


Fig. 20

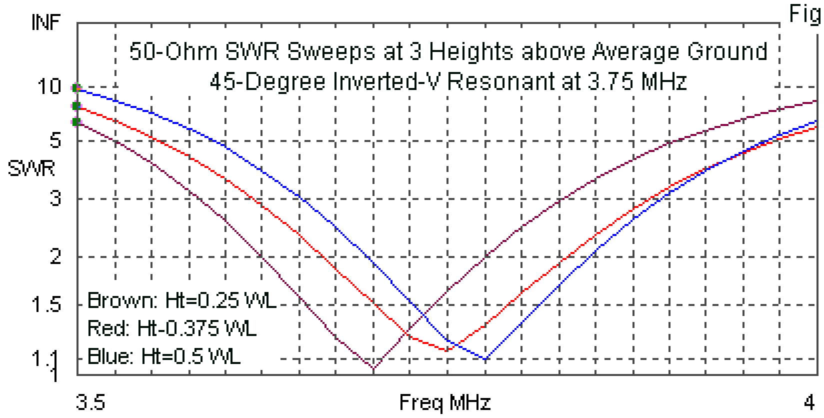


Fig. 21

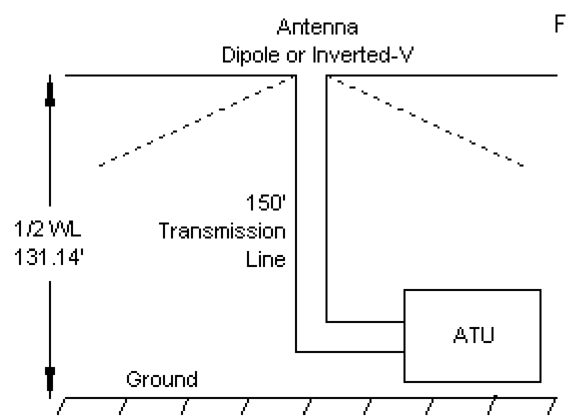
If we require even further confirmation, we can examine the 50-Ω SWR sweeps for the antennas. **Fig. 19** presents the dipole data; **Fig. 20** shows the 30° V information; and **Fig. 21** is for the 45° V. In all three cases, the 3/8-λ curves show an SWR minimum at or very close to 3.75 MHz, with the dipole minimum a bit closer to 3.8 MHz. The revelatory part of the graphs appears in the relative depths of the curves for ¼ λ and for ½ λ. As we move from the dipole toward the 45° V, the minimum SWR value for the lower height decreases, while the corresponding value for the upper height increases. (The actual SWR values vary according to the different resonant impedance values; hence, only the relative positions of the two curves within each graph are significant here.) If we use the dipole as a standard, then the minimum SWR impedances show a displacement lower in frequency as we move toward the 45° V, coinciding with the slight retardation of the test-frequency resistance and reactance data.

The SWR curves also demonstrate another feature that will become important as we proceed down our exploratory path. For any minimum SWR frequency, the SWR value rises more rapidly below that frequency than above it. For the relatively well-centered curves at a 3/8-λ height, the passband edge values tell the story: the SWR is higher at 3.5 MHz than at 4 MHz. The visual difference may not seem great in the graphs, but we must keep in mind that the Y-scale is logarithmic.

Basic Antenna Performance with Attached Transmission Lines

Unfortunately, most amateurs using the 80-75-meter band cannot practically attach their equipment directly to the antenna feedpoint. There must be some form of transmission line between the equipment and the antenna. An additional limitation of our safari is that is cannot (for both modeling and space reasons) include a discussion of methods by which we may broaden the operating bandwidth of the antenna. As the SWR curves show, even with careful matching at the feedpoint to a 50-Ω feedline, the maximum bandwidth at the antenna will be only about 150-200 kHz. Losses in the cable itself may widen the operating bandwidth slightly, but the antenna will still fall far short of covering the entire band. Rather than examining broadbanding techniques per se, let's take another tack.

Fig. 22



Outline of Loss-Analysis Models

Regardless of which of our three antennas may be in use or proposed, let's simply take a length of transmission line and connect it to an antenna tuner (or ATU for antenna tuning unit). Here we shall have to take a highly restricted sample, using only one height and one soil type. We shall place the antenna ½ λ above ground, as shown in **Fig. 22**. To reach the ATU, we shall use 150' of transmission line. We shall suppose that the ATU is highly efficient—and many are on the 80-75-meter band. Our goal is to discover what level of performance we may expect of the three antennas with the transmission line connected, compared to the basic performance of the antenna itself with no line attached. Our interest will focus especially on the band-edge performance, where we might expect higher losses due to the higher SWR values.

The investigation would not be especially useful if we used only a single type of transmission line. Initially, we shall employ three types of 50 Ω lines, along with a 450 Ω window line. The coaxial cables will include RG-8X, a lightweight cable that has become very popular. The set will also use RG-213, a post-World-War-II improved version of RG-8, with better shielding in a standard 0.4"-diameter shell. Finally, we shall look at LMR500, a very modern low-loss cable with a 0.5" outer diameter. **Table 5** lists the critical specifications for the cables and for the 450 Ω parallel line. The data comes from a table in *The ARRL Antenna Book*. There can be slight variations in the specifications, depending upon the cable maker.

Table 5. Transmission-Line Specifications

Line Type	Characteristic Impedance	Velocity Factor	Loss (dB)/100' @ 10 MHz
RG-8X	50	0.82	0.9
RG-213	50	0.66	0.6
LMR500	50	0.85	0.3
Window	450	0.91	0.08

(from *The ARRL Antenna Book*, p.24-19)

For each cable, we shall scan the 80-75-meter band in 0.05-MHz increments and record the maximum gain at each frequency. Each listing will include the data for the no-line case as a reference. For example, **Table 6** provides the scan data for the linear dipole under the prescribed conditions for each type of line.

Performance of a linear dipole plus 150' of transmission line					
Height: 1/2-wavelength = 131.14' above average ground					
	Maximum Gain in dBi --				
Freq MHz	No Line	RG-8X	RG-213	LMR500	450-Ohm
3.5	7.34	5.02	5.48	6.46	7.02
3.55	7.42	5.51	5.95	6.72	7.11
3.6	7.50	5.96	6.36	6.96	7.20
3.65	7.58	6.35	6.70	7.16	7.29
3.7	7.66	6.65	6.96	7.32	7.38
3.75	7.73	6.86	7.13	7.44	7.46
3.8	7.80	6.96	7.21	7.52	7.54
3.85	7.87	6.97	7.20	7.57	7.62
3.9	7.94	6.87	7.11	7.58	7.69
3.95	8.00	6.68	6.95	7.54	7.76
4	8.06	6.41	6.74	7.47	7.83
Notes:	Antenna AWG #12 copper wire				
	See Table 5 for line specifications				Table 6

The table indicates, and the graph in **Fig. 23** confirms, that each of the coaxial cables shows a peak gain at or near 3.8 MHz, with decreasing gain toward the band edges. Only the parallel line yields a curve that is parallel to the rising gain curve of the antenna alone. In addition, the coaxial cables show the effects of line losses on performance, with the RG-8X showing the highest losses. The low-loss LMR500 has a shallower curve that is partly due to the fact that the band-edge SWR represents a multiplier upon the basic matched loss value of a line. Lines with lower match losses also show less additional loss due to SWR.

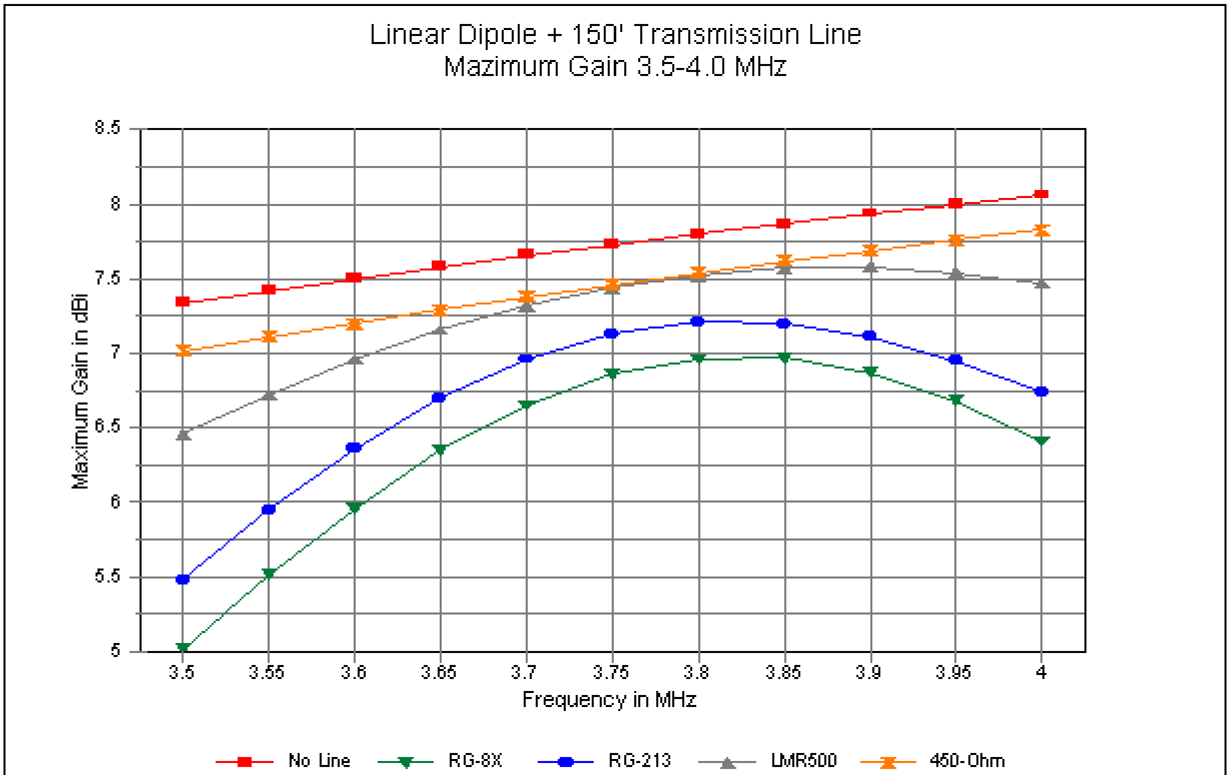


Fig. 23

We can obtain similar results for the 30° inverted-V with each of the selected transmission lines. **Table 7** provides the numerical data, while **Fig. 24** gives the numbers some visual impact. The curves are similar to those for the linear dipole, but the 30° V begins with lower antenna-only gain values. As well, it begins with a lower feedpoint resistance. Nonetheless, we still see the peak gain values for the coaxial cables clustered near 3.8 MHz. The LMR500 curve is shallower than the curves for the other cables. The window line still provides a track that is essentially parallel to the curve for the antenna alone.

Performance of a 30-degree inverted-V + 150' of transmission line					
Height: 1/2-wavelength = 131.14' above average ground					
	Maximum Gain in dBi ---				
Freq MHz	No Line	RG-8X	RG-213	LMR500	450-Ohm
3.5	6.61	4.14	4.63	5.66	6.25
3.55	6.69	4.67	5.13	5.94	6.33
3.6	6.76	5.15	5.56	6.19	6.42
3.65	6.83	5.56	5.93	6.39	6.51
3.7	6.91	5.89	6.21	6.56	6.59
3.75	6.98	6.11	6.39	6.69	6.68
3.8	7.06	6.23	6.48	6.78	6.76
3.85	7.13	6.24	6.47	6.83	6.84
3.9	7.20	6.14	6.37	6.84	6.92
3.95	7.27	5.94	6.21	6.81	7.00
4	7.34	5.66	5.99	6.74	7.08
Notes:	Antenna AWG #12 copper wire				
	See Table 5 for line specifications				Table 7

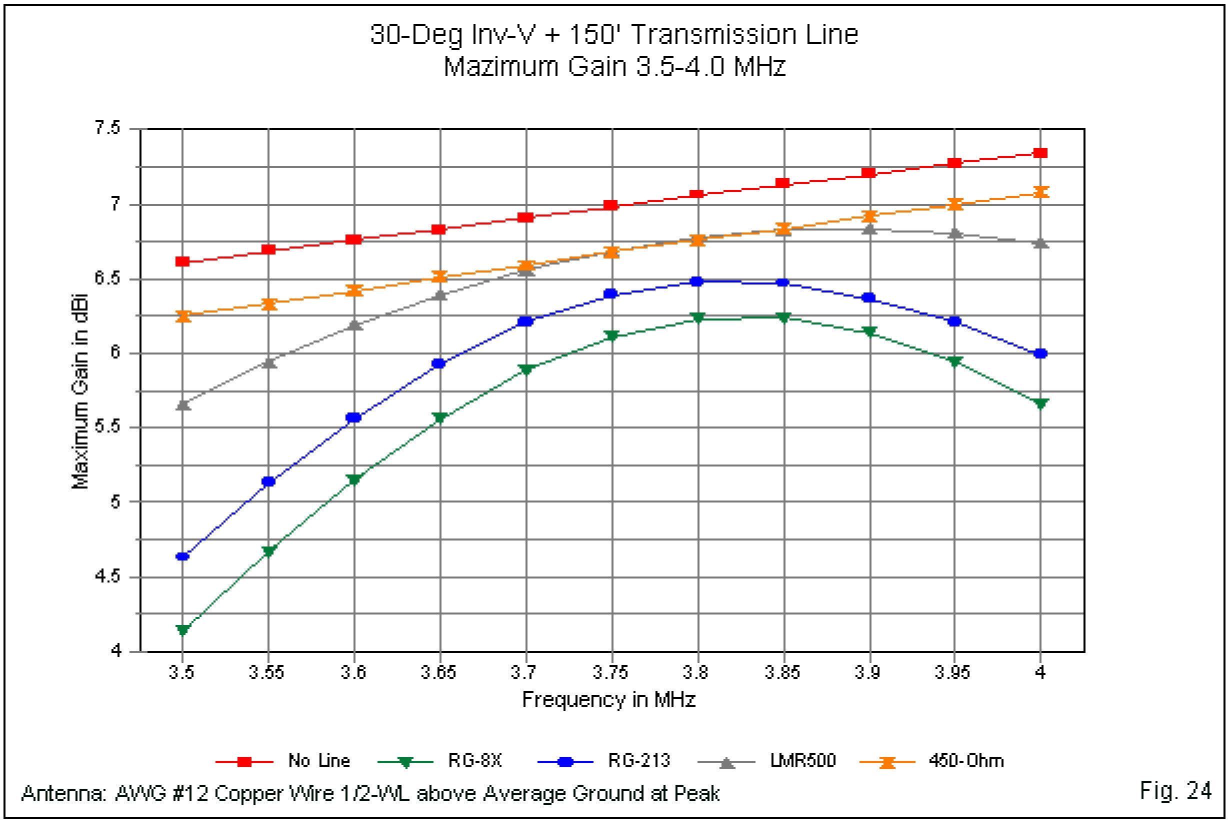


Fig. 24

Despite the similarity between the curves for the linear dipole and the 30° V, there are slight differences. These differences become more apparent when we turn to the data and graphs for the 45° V. See **Table 8** and **Fig. 25**. As we reduce the resistive impedance of the antenna, the peak values of the set of coaxial cables rise toward the antenna-alone value. In fact, several gain values for the LMR500 actually exceed the gain values for the window line. Part of this situation stems from the fact that the 450 Ω line shows a higher SWR with each antenna change, since each shows a lower impedance. Therefore, the window line losses increase with the 45° V, just as the coaxial cable losses decrease.

Performance of a 45-degree inverted-V + 150' of transmission line					
Height: 1/2-wavelength = 131.14' above average ground					
	Maximum Gain in dBi ---				
Freq MHz	No Line	RG-8X	RG-213	LMR500	450-Ohm
3.5	6.08	3.23	3.78	4.95	5.61
3.55	6.14	3.85	4.36	5.27	5.69
3.6	6.20	4.41	4.88	5.55	5.77
3.65	6.27	4.89	5.31	5.79	5.85
3.7	6.33	5.27	5.63	5.97	5.92
3.75	6.40	5.53	5.83	6.10	6.00
3.8	6.46	5.64	5.90	6.19	6.08
3.85	6.52	5.61	5.84	6.22	6.16
3.9	6.59	5.45	5.69	6.20	6.24
3.95	6.65	5.17	5.45	6.13	6.31
4	6.72	4.80	5.15	6.02	6.39
Notes:	Antenna AWG #12 copper wire				
	See Table 5 for line specifications				Table 8

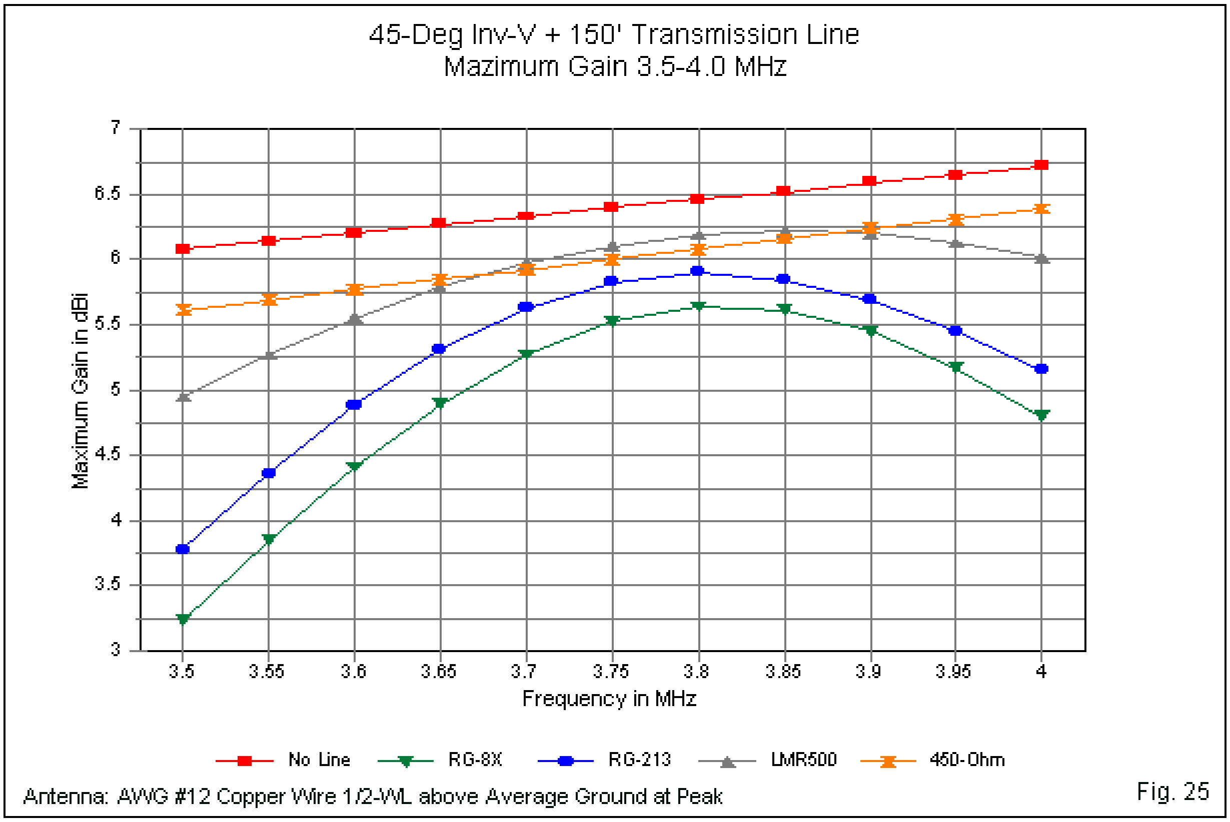


Fig. 25

The lessons of this exercise are notable. If we choose to use a coaxial cable between the antenna and the ATU, we assure the highest gain across the band by using the lowest loss cable that we can find and afford. Some 80-75-meter operators have been known to find a way to use CATV hardline in order to squeeze slightly more gain from the antenna at the band edges. Alternatively, even with a very high SWR on the line, 450 Ω window line provides the highest band-edge gain of any sampled lines in this exercise. As shown in **Table 9** and in **Fig. 26** for the linear dipole, we may turn over the data and directly examine the losses across the band compared to the antenna-only situation.

Linear Dipole: relative loss with 150' transmission line				
	Loss Relative to No Line ------------------------			
Freq MHz	RG-8X	RG-213	LMR500	450-Ohm
3.5	2.32	1.86	0.88	0.32
3.55	1.91	1.47	0.70	0.31
3.6	1.54	1.14	0.54	0.30
3.65	1.23	0.88	0.42	0.29
3.7	1.01	0.70	0.34	0.28
3.75	0.87	0.60	0.29	0.27
3.8	0.84	0.59	0.28	0.26
3.85	0.90	0.67	0.30	0.25
3.9	1.07	0.83	0.36	0.25
3.95	1.32	1.05	0.46	0.24
4	1.65	1.32	0.59	0.23
Notes:	Antenna AWG #12 copper wire			
Table 9	See Table 5 for line specifications			

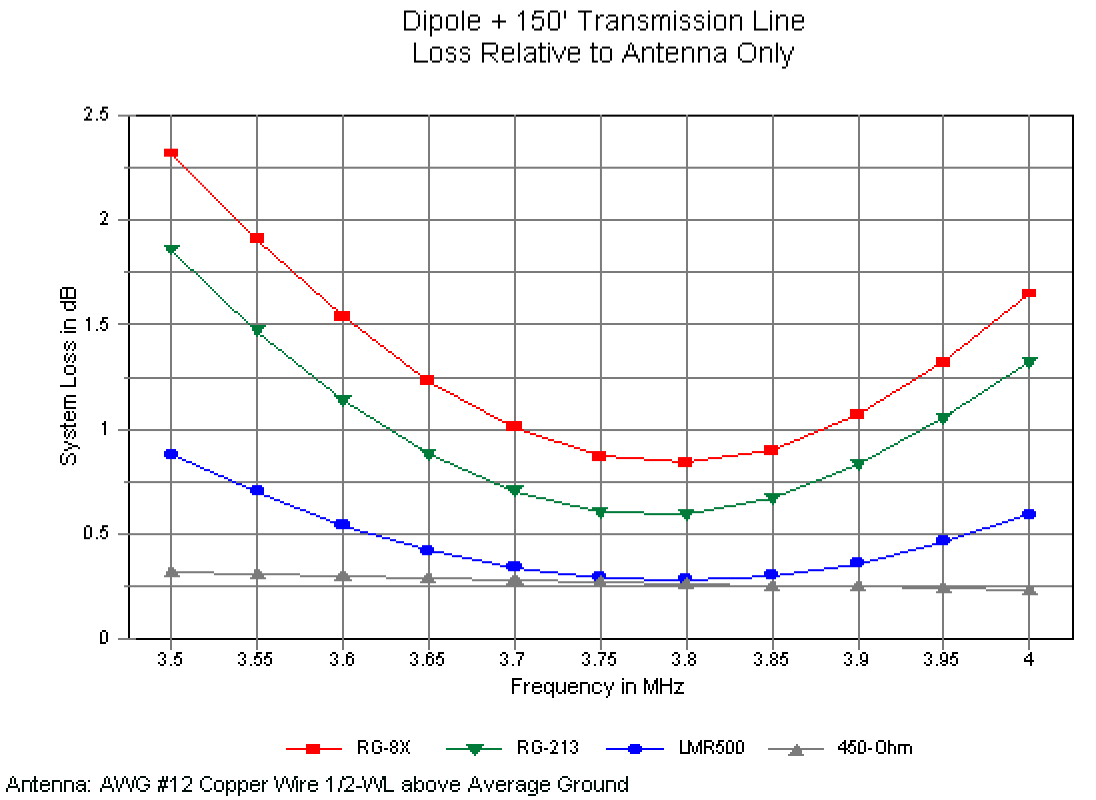
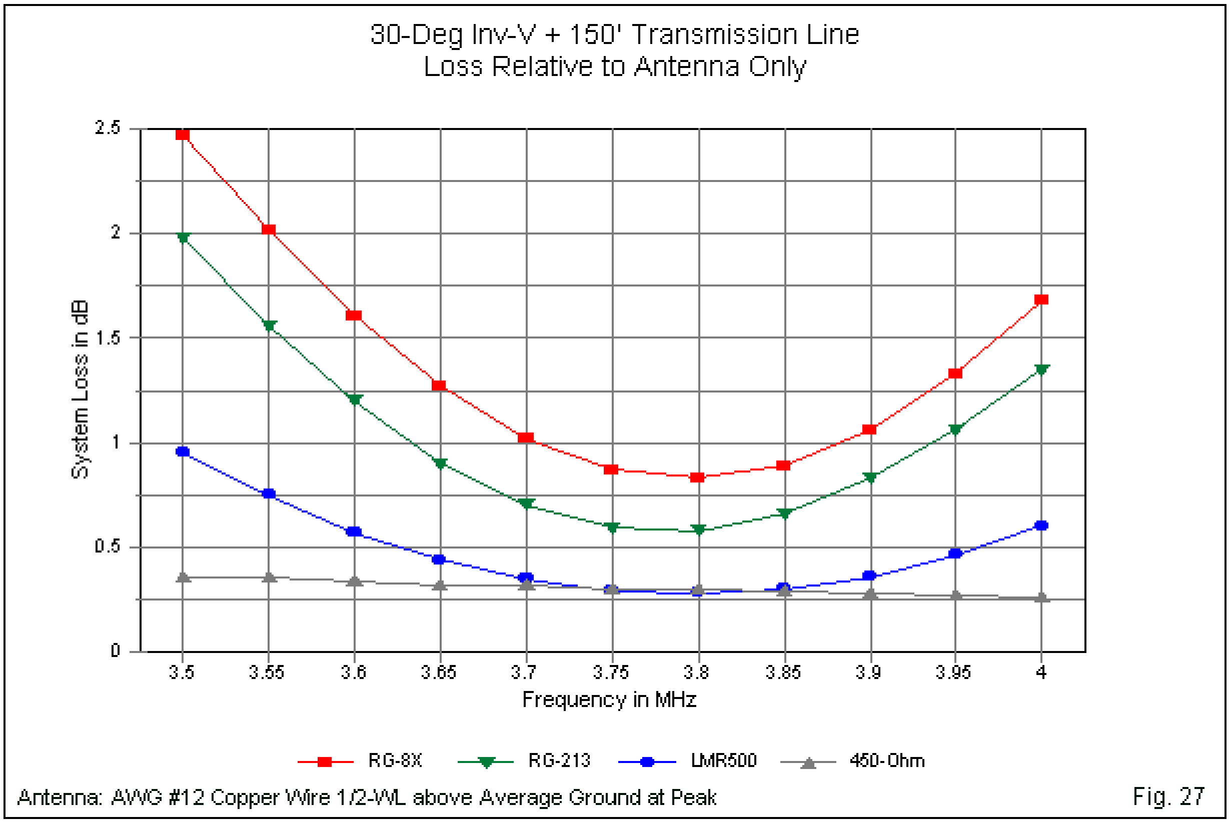


Fig. 26

The window line shows a nearly constant loss level, but all of the coaxial cables show higher losses at the band edge the ear the mid-band point. If we use 1 dB as the hypothetical minimum detectable loss level, only the low loss LMR500 (or its equal) has relatively undetectable losses.

The situation is not much different for the coaxial cables when used with a 30° inverted-V, as shown in **Table 10** and **Fig. 27**. Although not troublesome, we do see a rise in the losses of the 450 Ω window line due to the decreasing impedance values associated with the inverted-V form.

30-Deg Inv-V: relative loss with 150' transmission line				
	Loss Relative to No Line ------------------------			
Freq MHz	RG-8X	RG-213	LMR500	450-Ohm
3.5	2.47	1.98	0.95	0.36
3.55	2.02	1.56	0.75	0.36
3.6	1.61	1.20	0.57	0.34
3.65	1.27	0.90	0.44	0.32
3.7	1.02	0.70	0.35	0.32
3.75	0.87	0.59	0.29	0.30
3.8	0.83	0.58	0.28	0.30
3.85	0.89	0.66	0.30	0.29
3.9	1.06	0.83	0.36	0.28
3.95	1.33	1.06	0.46	0.27
4	1.68	1.35	0.60	0.26
Notes:	Antenna AWG #12 copper wire			
Table 10	See Table 5 for line specifications			



Despite the a seemingly better match between the 30° V and the coaxial cables, we do find slightly increased losses at the lower band edge (3.5 MHz), especially when using RG-8X. The rise in the capacitive reactance offsets the lesser departure from 50 Ω.

The coax loss curves grow steeper with the 45° V, as revealed by **Table 11** and **Fig. 28**. At 3.5 MHz, RG-8X losses approach 3 dB, and even the low-loss LMR500 shows a loss of over 1 dB. At the same time, the losses in the window line increase due to the further lowering of the antenna impedance across the band. The increasing steepness of the coaxial cable curves allows the MLR500 cable to show lower losses than the window line over part of the band.

45-Deg Inv-V: relative loss with 150' transmission line				
	Loss Relative to No Line ------------------------			
Freq MHz	RG-8X	RG-213	LMR500	450-Ohm
3.5	2.85	2.30	1.13	0.47
3.55	2.29	1.78	0.87	0.45
3.6	1.79	1.32	0.65	0.43
3.65	1.38	0.96	0.48	0.42
3.7	1.06	0.70	0.36	0.41
3.75	0.87	0.57	0.30	0.40
3.8	0.82	0.56	0.27	0.38
3.85	0.91	0.68	0.30	0.36
3.9	1.14	0.90	0.39	0.35
3.95	1.48	1.20	0.52	0.34
4	1.92	1.57	0.70	0.33
Notes:	Antenna AWG #12 copper wire			
Table 11	See Table 5 for line specifications			

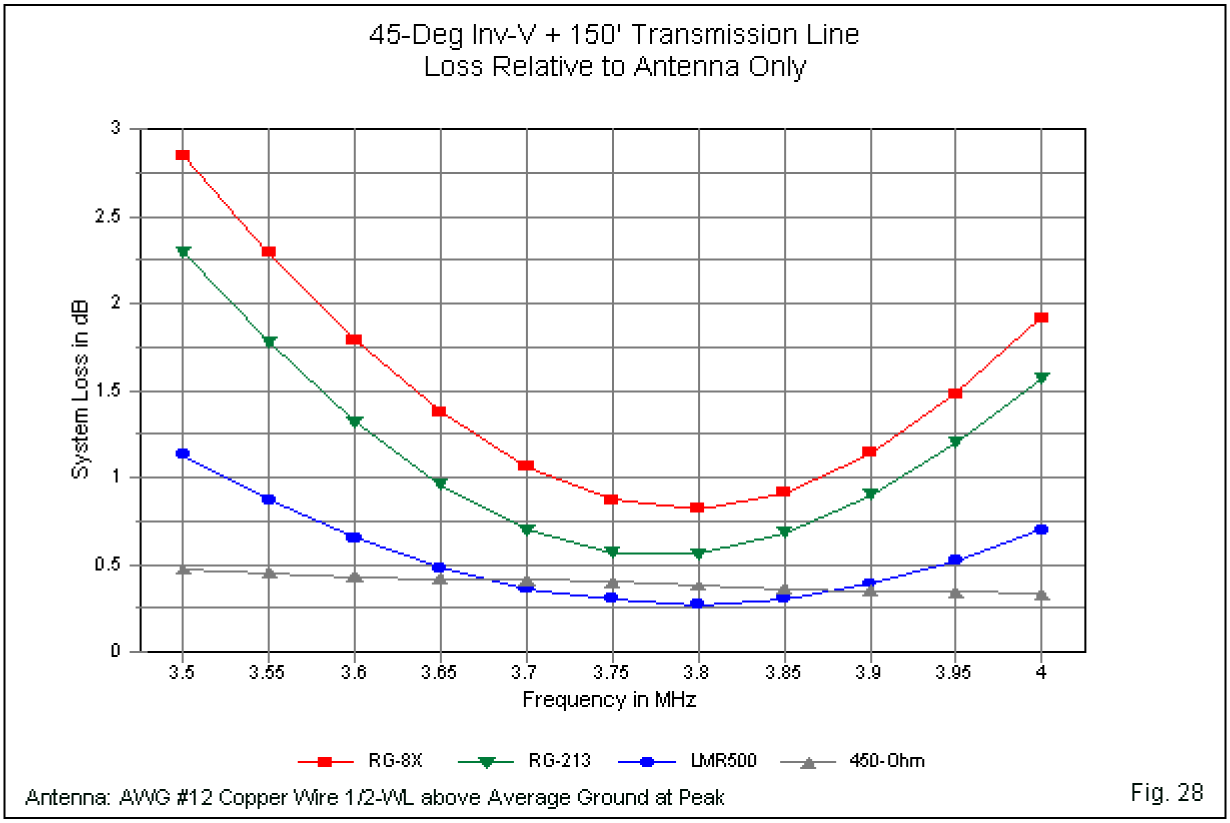


Fig. 28

Part of the reason for the relatively high losses at the low end of the 80-75-meter band is the fact that the maximum gain and minimum loss occur above the band's midpoint. If we lengthen each antenna to resonate about 90 kHz lower in the band, we may better equalize the situation. For example, if we lengthen the dipole to about 130.8' from its original length of 127.7', the free space resonant frequency becomes about 3.66 MHz. We may note in passing, subject to later discussion, that this strategy works for the dipole at its pre-set height of ½ λ (131.14') as measured at 3.75 MHz.

Revised linear dipole plus 150' of transmission line				
Height: 1/2-wavelength = 131.14' above average ground				
	Maximum Gain in dBi ----------------------------			
Freq MHz	No Line	RG-8X	RG-213	LMR500
3.5	7.36	5.77	6.14	6.80
3.55	7.45	6.17	6.50	7.00
3.6	7.53	6.49	6.79	7.18
3.65	7.61	6.72	6.99	7.31
3.7	7.68	6.85	7.09	7.41
3.75	7.76	6.89	7.11	7.47
3.8	7.83	6.82	7.05	7.49
3.85	7.90	6.66	6.91	7.47
3.9	7.97	6.43	6.72	7.42
3.95	8.03	6.13	6.48	7.33
4	8.09	5.78	6.22	7.22
Notes:	Antenna AWG #12 copper wire			
	Free-space resonance at 3.66 MHz			
Table 12	See Table 5 for line specifications			

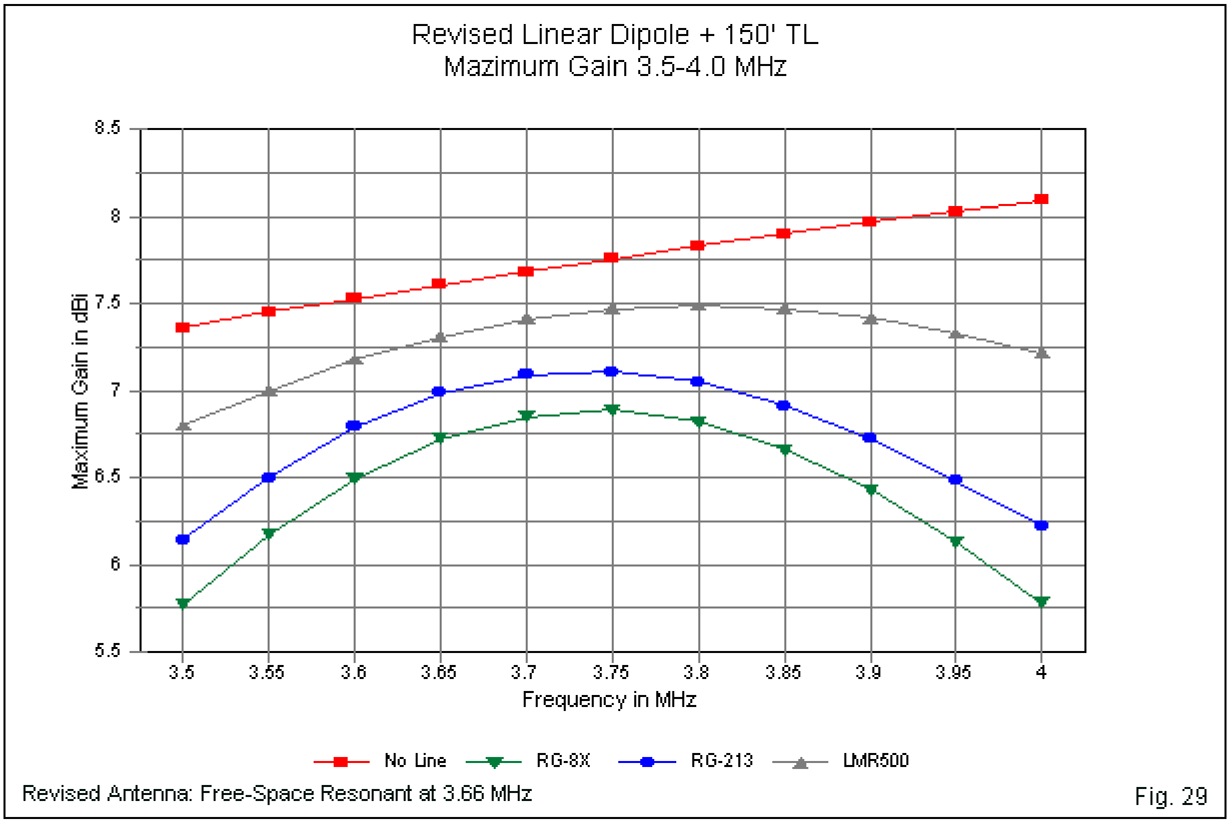


Fig. 29

Omitting the window line from our consideration of the revised dipole, we obtain the data in **Table 12**, with a corresponding graph in **Fig. 29**. The higher-loss coaxial cable show good gain equality at both ends of the band, but the low-loss cable still shows a 0.4 dB difference between band-edge values. The same tactic also works with the 30° V, which increases its length from 128.7' to 131.9'. **Table 13** and **Fig. 30** together provide us with the results. Like the dipole, the lowest-loss coaxial cable shows about a 0.4 dB difference in band-edge values across the 80-75-meter band.

Revised 30-degree inverted-V + 150' transmission line				
Height: 1/2-wavelength = 131.14' above average ground				
	Maximum Gain in dBi -----------------------------			
Freq MHz	No Line	RG-8X	RG-213	LMR500
3.5	6.61	4.96	5.34	6.02
3.55	6.68	5.37	5.72	6.23
3.6	6.78	5.71	6.02	6.40
3.65	6.83	5.96	6.23	6.54
3.7	6.91	6.09	6.34	6.64
3.75	6.98	6.12	6.35	6.69
3.8	7.05	6.05	6.28	6.71
3.85	7.13	5.88	6.13	6.69
3.9	7.20	5.62	5.92	6.64
3.95	7.27	5.31	5.67	6.55
4	7.34	4.95	5.39	6.44
Notes:	Antenna AWG #12 copper wire			
	Free-space resonance at 3.66 MHz			
Table 13	See Table 5 for line specifications			

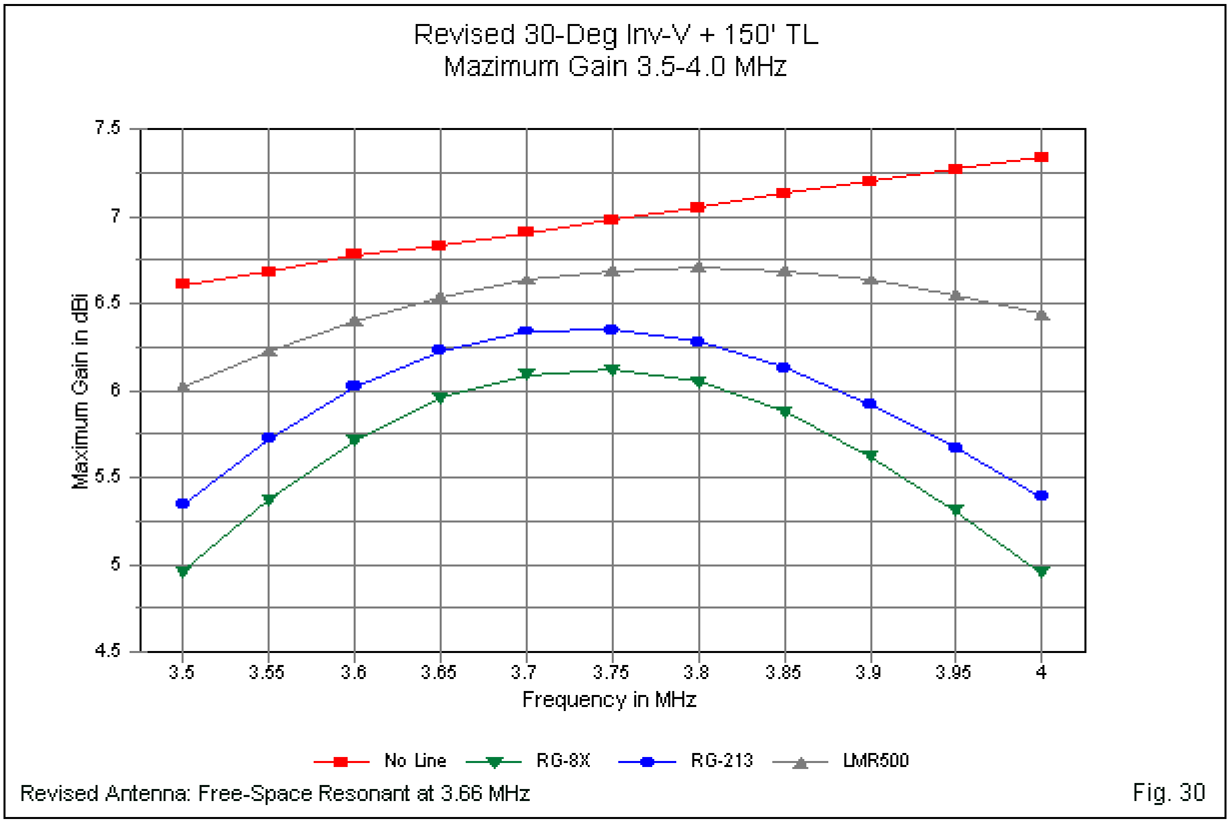
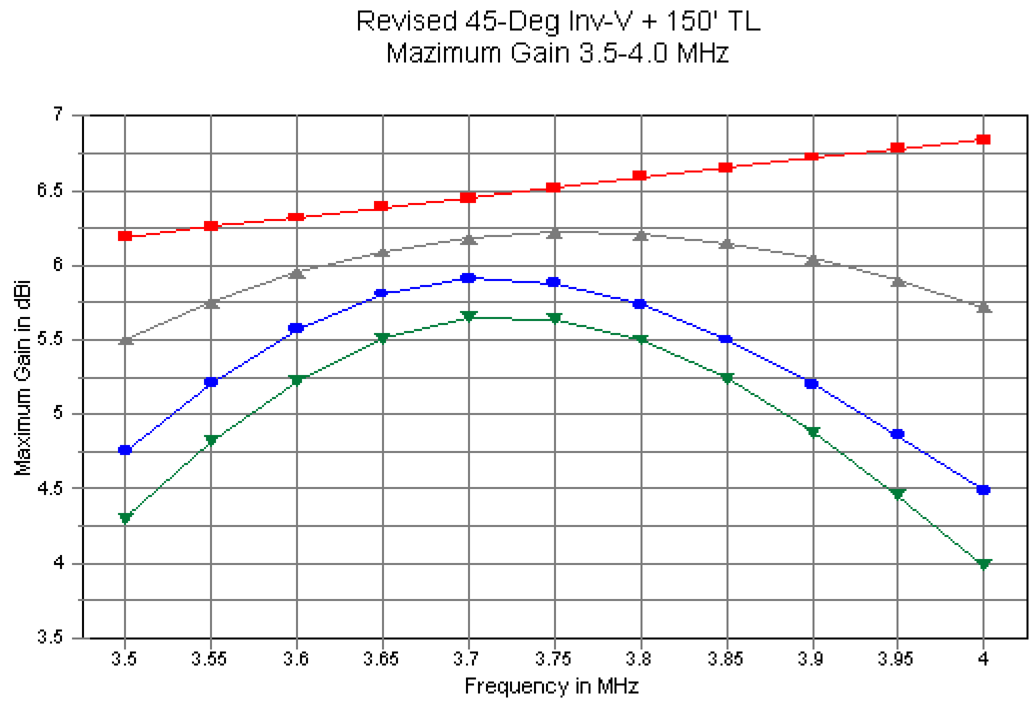


Fig. 30

If we use RG-8X or RG-213, we obtain equalized band-edge gain values, although both of those cables result in an overall greater loss of gain relative to the antenna-only curve. If we use a 45° V, the total wire length increases to 133.3'. As well, we improve the band-edge equalization for the low-loss cable, but the lossier cables now show slightly higher gain values at the low end of the band. No single adjustment will be suitable for all cables within the limits set for this exercise. Hence, it is critical that an antenna builder repeat the exercise using the antenna type, height, cable type, and cable length anticipated for the overall system.

Revised 45-degree inverted-V + 150' transmission line				
Height: 1/2-wavelength = 131.14' above average ground				
	Maximum Gain in dBi ----------------------------			
Freq MHz	No Line	RG-8X	RG-213	LMR500
3.5	6.19	4.30	4.75	5.50
3.55	6.26	4.82	5.21	5.75
3.6	6.32	5.22	5.57	5.95
3.65	6.39	5.51	5.81	6.09
3.7	6.45	5.65	5.91	6.18
3.75	6.52	5.64	5.88	6.22
3.8	6.59	5.50	5.74	6.21
3.85	6.65	5.24	5.50	6.15
3.9	6.72	4.88	5.20	6.05
3.95	6.78	4.46	4.86	5.90
4	6.84	3.99	4.49	5.72
Notes:	Antenna AWG #12 copper wire			
	Free-space resonance at 3.66 MHz			
Table 14	See Table 5 for line specifications			



Revised Antenna: Free-Space Resonant at 3.66 MHz

Fig. 31

We may have noticed that for all three antennas, the antenna-only curve in the graphs showed a rising gain value from the low end of the band to the high end. The nature of the antenna-only gain curve implies that to achieve equalized band-edge gain values, the revised antenna lengths result in greater losses at 4 MHz than at 3.5 MHz. The implication is correct as shown by the linear dipole data in **Table 15** and **Fig. 32**. The data for both the table and the graph are easily automated on any spreadsheet program. The inference that we may draw from the loss information is this: if we are dissatisfied with the loss at either band edge, we may select an antenna length that will equalize band-edge losses rather than band-edge gain.

Linear Dipole: relative loss with 150' TL			
	Loss Relative to No Line ----------		
Freq MHz	RG-8X	RG-213	LMR500
3.5	1.59	1.22	0.56
3.55	1.28	0.95	0.45
3.6	1.04	0.74	0.35
3.65	0.89	0.62	0.30
3.7	0.83	0.59	0.27
3.75	0.87	0.65	0.29
3.8	1.01	0.78	0.34
3.85	1.24	0.99	0.43
3.9	1.54	1.25	0.55
3.95	1.90	1.55	0.70
4	2.31	1.87	0.87
Notes:	Antenna AWG #12 copper wire		
	Free-space resonan: 3.66 MHz		
Table 15	See Table 5 for line specs		

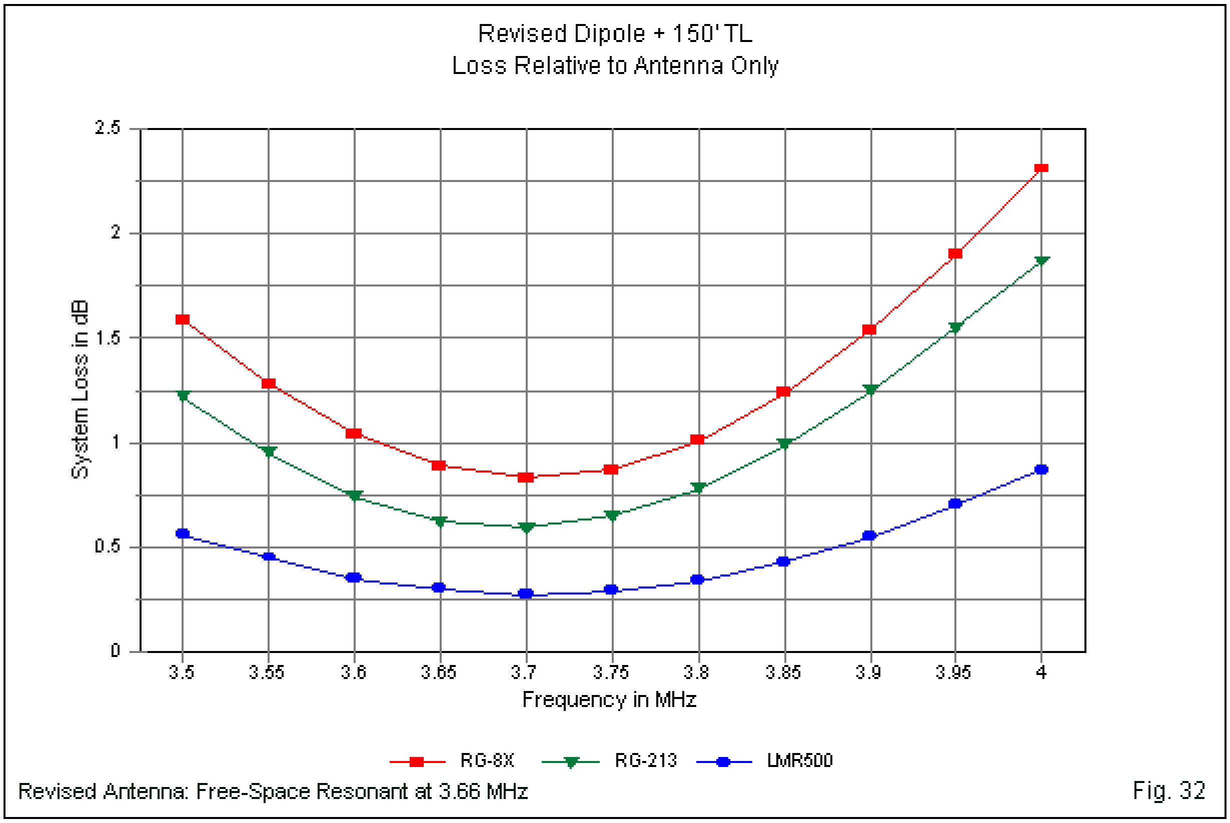


Fig. 32

Comparable loss data for the 30° V appears in **Table 16** and in **Fig. 33**. The cable loss is creeping toward a full dB at 4 MHz for the lowest-loss cable. RG-213 shows a maximum loss of gain that approaches 2 dB, while RG-8X shows a maximum loss of about 2.4 dB. The lossier cables may be of some concern, despite the relatively equalized band-edge gain values that we previously observe. Still, the loss level is in the vicinity of losses exhibited by some broadbanding schemes that involve relatively complex and carefully calculated antenna structures. The antennas with which we are working are simple, with the complex matching problems shifted to the ATU.

30-Deg Inv-V: relative loss with 150' TL			
	Loss Relative to No Line ----------		
Freq MHz	RG-8X	RG-213	LMR500
3.5	1.65	1.27	0.59
3.55	1.31	0.96	0.45
3.6	1.07	0.76	0.38
3.65	0.87	0.60	0.29
3.7	0.82	0.57	0.27
3.75	0.86	0.63	0.29
3.8	1.00	0.77	0.34
3.85	1.25	1.00	0.44
3.9	1.58	1.28	0.56
3.95	1.96	1.60	0.72
4	2.39	1.95	0.90
Notes:	Antenna AWG #12 copper wire		
	Free-space resonan: 3.66 MHz		
Table 16	See Table 5 for line specs		

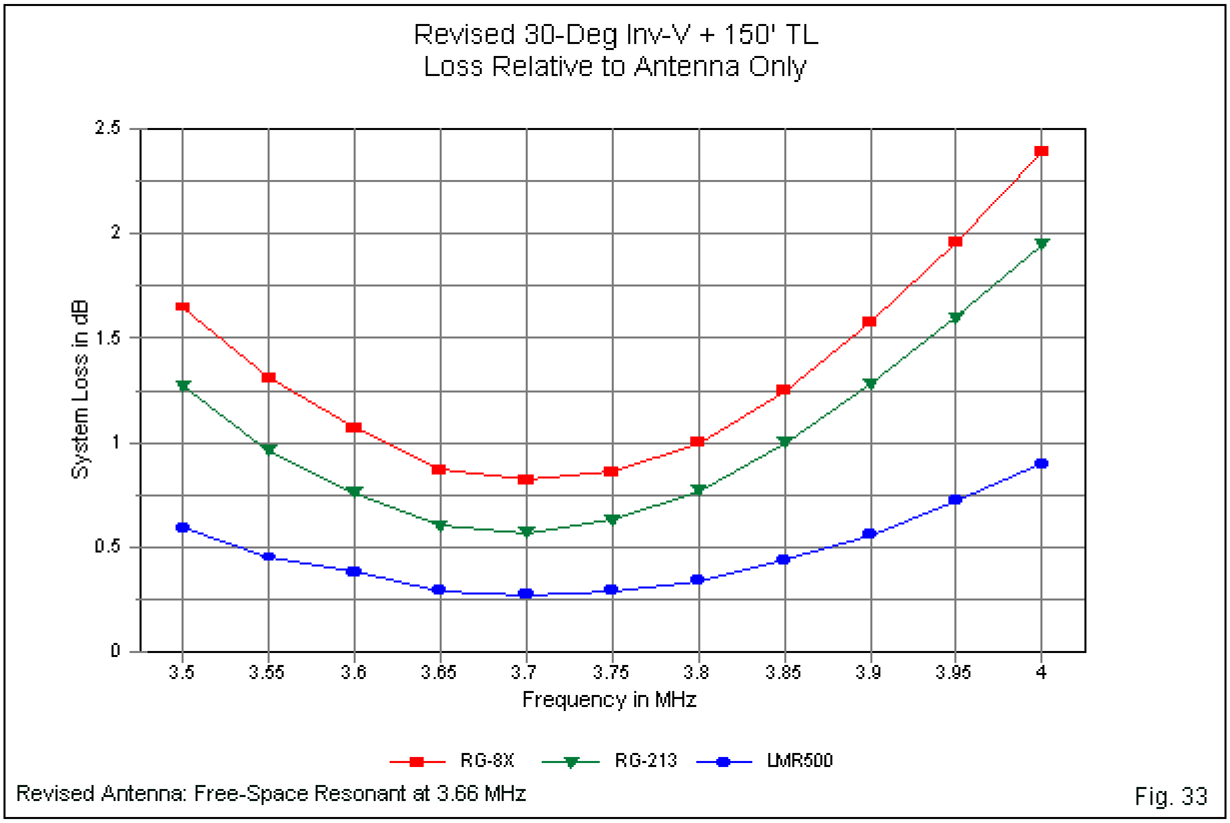


Fig. 33

Our final check on losses of gain relative to the antenna alone—which shows only the resistive losses of AWG #12 copper wire—applies to the 45° V. The data are in **Table 17** and in **Fig. 34**. As expected from the gain data, the losses at 4 MHz continue to increase for all types of cable. The overall lesson of the exercise is that for most cases (but not all, as we shall see), we cannot achieve both band-edge gain equality and band-edge loss equality by the same maneuver. Equalizing the band-edge gain values required a larger increase in the length of each type of antenna than we would need for band-edge loss equality. Still, for the given antenna height, some change of length is necessary to achieve either goal.

45-Deg Inv-V: relative loss with 150' TL			
	Loss Relative to No Line ----------		
Freq MHz	RG-8X	RG-213	LMR500
3.5	1.89	1.44	0.69
3.55	1.44	1.05	0.51
3.6	1.10	0.75	0.37
3.65	0.88	0.58	0.30
3.7	0.80	0.54	0.27
3.75	0.88	0.64	0.30
3.8	1.09	0.85	0.38
3.85	1.41	1.15	0.50
3.9	1.84	1.52	0.67
3.95	2.32	1.92	0.88
4	2.85	2.35	1.12
Notes:	Antenna AWG #12 copper wire		
	Free-space resonan: 3.66 MHz		
Table 17	See Table 5 for line specs		

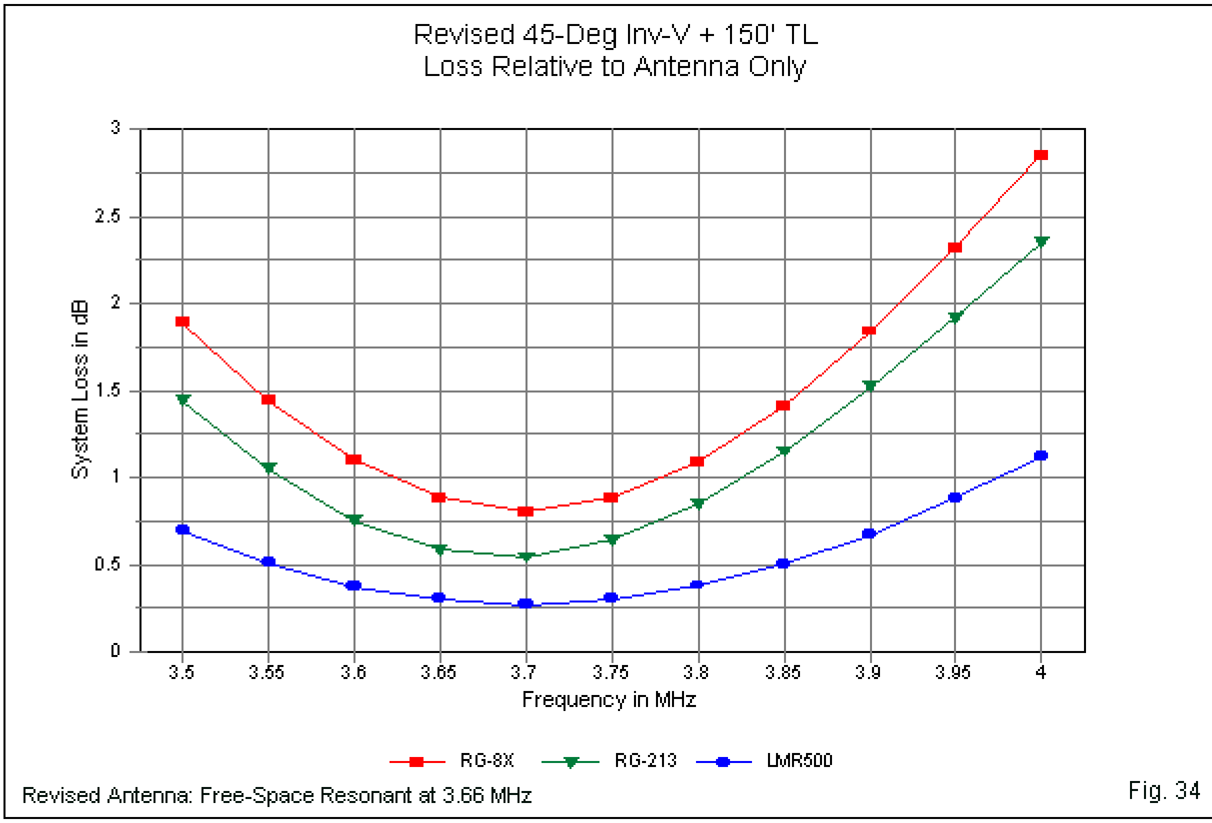


Fig. 34

Although a host of tables and graphs may create the illusion that the data represents a general case, it strictly applies only to the specified situation upon which it rests. The dipole, for instance, is at a height of 131.14', or ½ λ at 3.75 MHz above average ground. The initial dipole exhibited a resonant free-space impedance at the test frequency of 3.75 MHz, but at the noted height above ground, the 3.75-MHz impedance is 67.6 – j11.6 Ω. (The impedance values for the two Vs are also capacitively reactive.) Hence, resonance at ½ λ above ground does not occur until we reach a frequency closer to 3.78 MHz. When we revised the antenna length to equalize gain values, the resonant frequency dropped to about 3.69 MHz, below the mid-band point (with the free-space resonance at 3.66 MHz). The disparity between the numbers and possible expectations we might have raises a number of questions, all of which suggest that the sample is just that—a sample case and not a general case.

Why Samples Are Only Samples

The exercises that we have examined have had the goal of showing techniques that any 80-75-meter antenna planner may use to obtain a better anticipation of what his or her system may do once we set down as a definite antenna type, a definite height, a definite soil quality, a definite cable type, and a definite cable length. The work does not show all general trends, but only a single case among many possible cases. The numbers and graphs that apply to my case do not necessarily apply to your case. Let's go through some of the factors that may in some cases dictate an alternative strategy either for achieving equalized band-end gain values or for arriving at equal band-edge losses of gain.

SWR Curves: We noted in connection with some earlier 50-Ω SWR curves for the antenna alone that the SWR rises more rapidly below the design frequency than above it. Although we shall in this section restrict ourselves solely to dipoles, the general principle concerning SWR curves of simple elements applies to all three antenna types that we have considered. As well, it applies to all SWR curves derived from the antennas at any peak heights, regardless of the variations in the feedpoint impedance that occur with height.

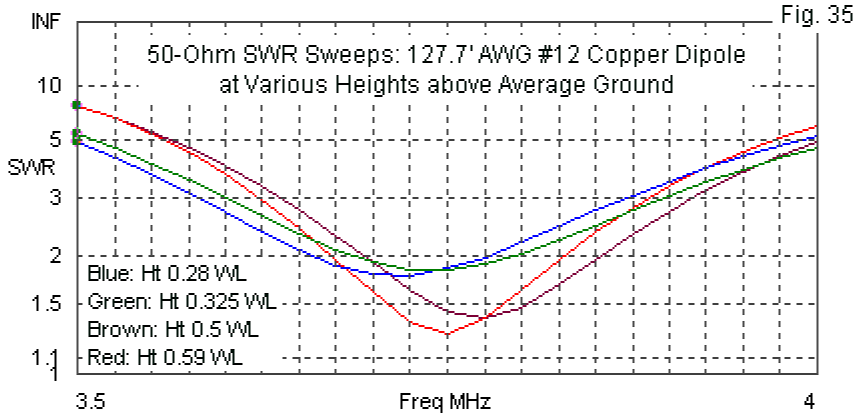


Fig. 35 presents 50-Ω SWR sweeps for four antenna height options, only one of which appears on an earlier table. At heights of 0.325 λ and 0.59 λ, the minimum SWR occurs at 3.75 MHz, the same frequency as the free-space resonance. However, neither resonant impedance is close to the free-space resonant value of about 73 Ω. The lower height impedance is close to 92 Ω, while the greater height impedance is near 66 Ω. At a height of 0.5 λ, the impedance is 67.7 – j11.6 Ω, while a height of 0.28 λ yields an impedance of 91.0 + j10.0 Ω. I selected the latter two heights to reflect roughly equal reactance magnitudes, but of opposite types.

If you examine the SWR curve closely, with an eye toward equal linear frequency amounts on each side of the minimum SWR value for each line, you will see that the SWR below the minimum rises more rapidly toward the lower end of the band. The exact rate of change will differ with the position of the SWR minimum. As we shift frequency, not only is the antenna changing its length, but as well, the antenna height above ground is changing. The difference in the amount of frequency (and therefore wavelength) change relative to the mid-band frequency is not great, but it is sufficient to create the difference in the rate of change of SWR above and below the test frequency or the frequency of minimum SWR.

The SWR curve situation automatically requires that—if this were the only variable involved—we would need always to lengthen the antenna to achieve band-edge equalization. However, the SWR curve is not the only variable involved.

Height and the Resonant Frequency: The minimum SWR value is an indicator of the antenna's resonant frequency, even if not exact if the antenna impedance and the line's characteristic impedance are not matched. Since we designed our sample antennas to be resonant in free-space, the resonant frequency will vary according to the antenna height. At some heights, the resonant frequency may already be at a frequency that provides relatively equal band-edge gain values or loss values. For example, among the curves in **Fig. 35**, the sweep for a height of 0.28 λ places the minimum SWR at a frequency below the mid-band point, while the impedance at 3.75 MHz had an inductively reactive component. This antenna-height combination at about 73' above average ground may not require further adjustment to equalize band-edge performance.

In contrast, we saw that at a height of 0.5 λ (131'), the antenna required considerable adjustment to yield equalized band-edge performance. Not only did the feedpoint impedance at 3.75 MHz have a capacitively reactive component, but as well, the SWR minimum occurs at a frequency above the mid-point of the band. Even the two heights that show a resonant impedance may require lengthening to bring the SWR curve down in frequency to achieve equalization.

Height and a Rising or Falling Gain Curve: The height of an 80-75-meter dipole (or V) gives us additional information that is useful in estimating the need for adjustment of an initial design to equalize band-edge performance. Comparing a proposed antenna height with the data in **Table 1** gives us an idea of whether the gain is rising or falling with small changes in height. This data is significant for estimating the gain behavior of the antenna alone across the wide passband.

The estimate may not be reliable without modeling the situation, since there are two variables that may either counteract each other or abet each other. One variable is the antenna length, which becomes longer as a fraction of wavelength as we increase the frequency from 3.5 to 4.0 MHz. Increasing the length of a dipole tends to increase its gain. From the perspective of length alone, we expect the gain to increase across the band. The second variable is the height, which also increases as we increase the operating frequency. If the height region shows increasing gain with increasing height, the effect adds to the gain increase that occurs by lengthening the antenna as we move up the band. However, if the height falls in a region of decreasing gain, then the two variables are at odds with each other. Since the gain of a dipole is cyclical, different heights may place the antenna in regions of either faster or slower changes with each height increment. Hence, the degree to which the height may abet or counteract the gain increase with lengthening due to frequency rise becomes a complex variable.

A comparison of gain patterns of a dipole at various heights with/without transmission line								
Antenna: AWG #12 copper wire, 127.7'			Transmission line: 150' RG-8X					
	Ht 0.28 wl = 73.44'		Ht 0.325 wl = 85.24'		Ht -.5 wl = 131.14'		Ht 0.59 wl = 154.75'	
Freq MHz	Ant only	w/RG-8X	Ant only	w/RG-8X	Ant only	w/RG-8X	Ant only	w/RG-8X
3.5	6.09	4.36	6.05	4.23	7.34	5.02	8.06	5.68
3.55	6.09	4.67	6.07	4.56	7.42	5.51	8.1	6.21
3.6	6.08	4.91	6.09	4.82	7.5	5.96	8.14	6.65
3.65	6.08	5.07	6.1	5.03	7.58	6.35	8.17	7.01
3.7	6.08	5.16	6.13	5.16	7.66	6.65	8.19	7.25
3.75	6.09	**5.18**	6.15	**5.23**	7.73	6.86	8.2	**7.37**
3.8	6.09	5.12	6.17	**5.23**	7.8	6.96	**8.21**	7.36
3.85	6.1	5.01	6.2	5.16	7.87	**6.97**	**8.21**	7.23
3.9	6.11	4.84	6.23	5.05	7.94	6.87	8.2	7
3.95	6.12	4.62	6.26	4.88	8	6.68	8.19	6.68
4	**6.13**	4.38	**6.3**	4.68	**8.06**	6.41	8.17	6.31
Z@3.75	90.98 + j10.03 Ohms		91.71 - j0.04 Ohms		73.06 - j11.6 Ohms		62.65 - -/31 Ohms	
Notes:	Ant only: no transmission line							
	w/RG8X: 150', VF 0.82, Loss 0.9 dB/100' @ 10 MHz							
	Boldface: peak gain values							Table 18

Table 18 lists the 4 antennas and the corresponding heights at 3.75 MHz that appeared in the SWR sweeps in **Fig. 35**. For the moment, we shall explore only the columns labeled "Ant only", which give us the gain of the antenna across the band for the antenna alone. All four antennas are in different situations.

The antenna at 0.28 λ above ground is resonant below mid-band. In addition, it occurs in a height region of relatively rapidly falling gain with further increases in height. As a result, the gain actually decreases slightly as we raise the frequency above the lower band edge. The increased gain that results from element lengthening with increased frequency does not override the decrease due to increased height until the mid-band point. The net result is relatively even gain across the band with a total gain change range of only 0.05 dB.

When we raise the antenna to 0.325 λ above ground, we enter a height region in which the gain rises with height, but at a very slow rate. As well, the total height range from 3.5 to 4.0 MHz is about 0.04 λ. The data show a continuous rise in gain across the band, but the total change is only 0.25 dB from one band edge to the other.

At 0.5 λ, the antenna height is in a region of relatively rapid gain change in the rising direction. As a consequence, the height increase and the length increase from 3.4 to 4.0 MHz strongly abet each other so that the total gain change is 0.72 dB.

The final case places the antenna at 0.59 λ above ground in a region of very slowly declining gain with height increases. As we move above 3.5 MHz, the dipole length increase creates a small increase in gain. As we further increase the frequency, the rate of gain decline with small increases in height itself increases. Hence we reach a peak gain value just above mid-band, and the upper end of the band shows a small gain decrease. Hence, the gain change across the band is only 0.15 dB.

Fig. 36 graphs the gain changes of each sample antenna across the band. In this context, the slope of each curve is more significant than the actual gain values, since our goal is to understand how the variables of height and antenna length interact.

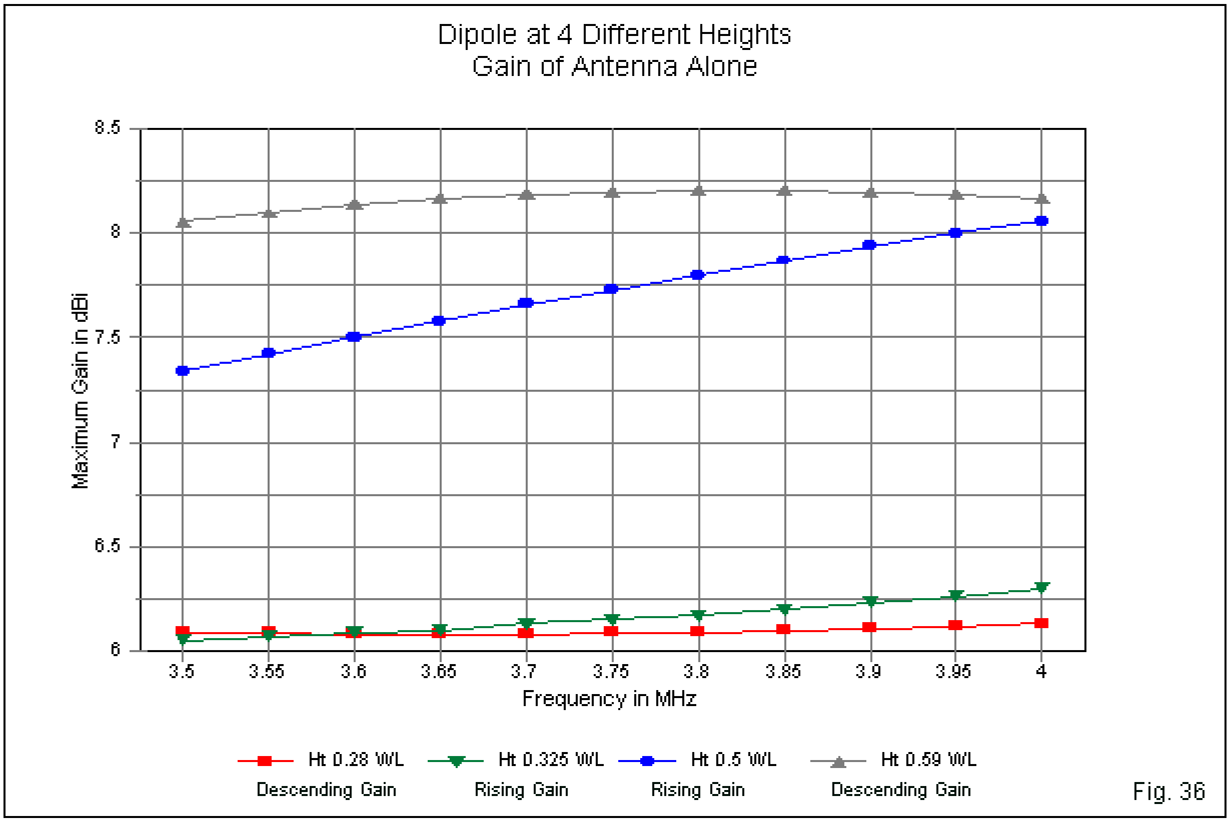


Fig. 36

Once we add 150' of cable to each antenna, we can see the net effect of all of the variables at work. For this example, I am using RG-8X. The goal is not to recommend this cable, but to create more vivid curves. The table lists the gain values that result, while **Fig. 37** presents the data visually.

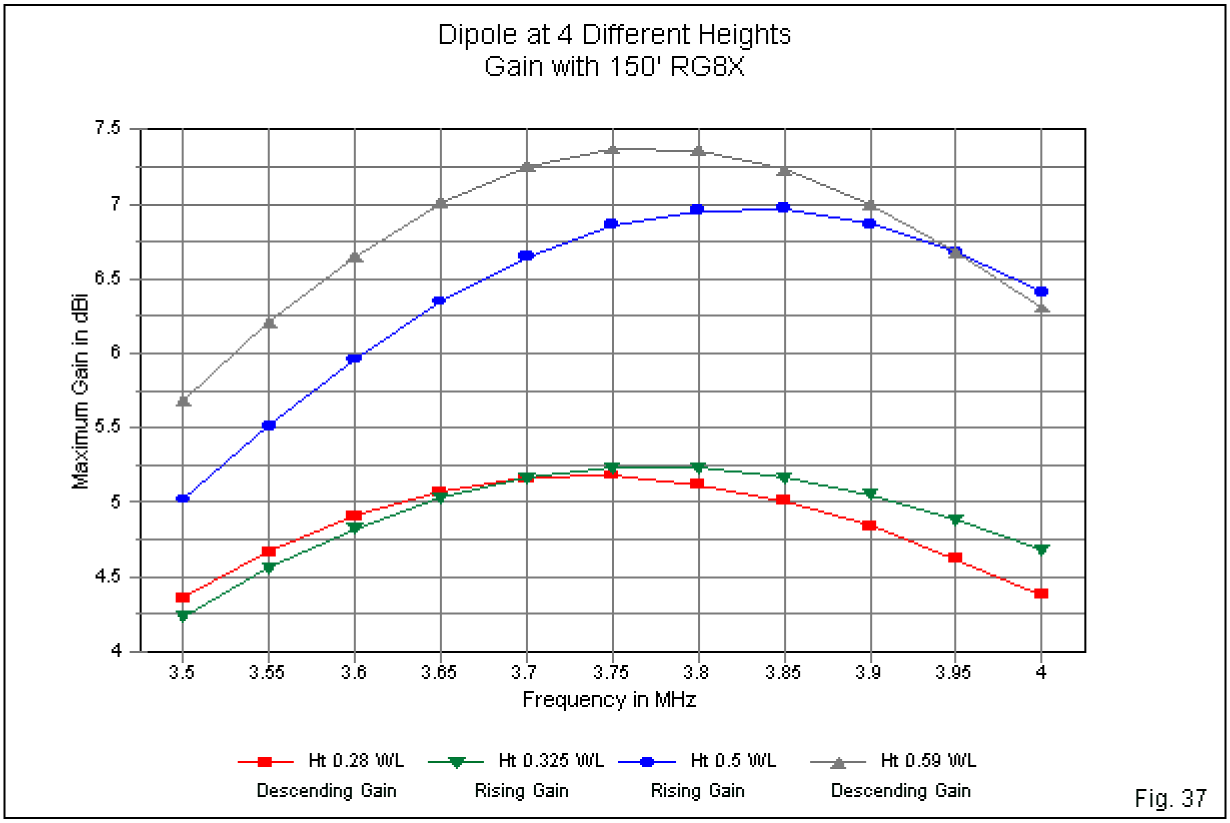


Fig. 37

The antenna at a height of 0.28 λ provides relatively equal band-edge performance in concert with the sum of the variables. The SWR curve minimum occurred below mid-band, and the antenna gain in the previous figure showed a nearly flat line across the band. In comparison, all of the other system-gain curves show lower gain values at the low end of the band than at the upper edge.

Raising the height to 0.325 λ—in the region of only slowly rising gain and with an SWR curve and resonance well-centered in the band—produces only modest differences in band-edge gain values. Lengthening the antenna a small amount to bring its resonant frequency (alone) down by perhaps 30 kHz or so should suffice to equalize band edge gain performance.

At 0.5 λ above ground, we encounter the case that we have examined in detail. Among our new collection of samples, it yields the largest difference in performance at the band edges. As a result, it requires the greatest lengthening of the antenna to equalize performance at the band edges. The case holds a lesson of some import: a single sample of dipole (or V) behavior chosen with no criteria in mind (except, perhaps for the convenience of rounded numbers) is just as likely to represent an extreme case as it is to fall in the relative center of the span of possible cases.

The final sample at 0.59 λ above ground has a well-centered SWR curve, mid-band resonance, and only a slowly declining gain value as height increases. However, the combination of variables produces a considerable difference in the band-edge gain values (about 0.65 dB). Hence, even this antenna requires that we lengthen the element to lower the resonant frequency at the given antenna height in order to bring the band-edge gain values to parity.

The curves would become shallower with the use of a very low-loss cable, such as LMR500 or its equivalent. As well the curves may change if we select a different length of cable between the antenna and the ATU that we shall use to tune the entire 80-75-meter band. They will also change if we select an antenna height that differs from the sampled values. Moreover, they will further change if we select one of the inverted-Vs rather than the linear dipole.

Conclusion

Once we passed beyond the most basic information on the behavior of dipoles and inverted-Vs with increasing height above ground, the aim of our efforts changed. The earlier parts of the graphical scrapbook presented general information. However, when we began using this information in an exercise to plan a hypothetical dipole installation, the data and graphs became just a sample case designed to show the procedures involved in the planning effort and the range of possible variations that we might expect.

Of course, our planning exercise had as its goal the use of a single transmission line that connected to an ATU so that we could use the antenna all across the 80-75-meter band. The general conclusion that we reached is that a parallel transmission line with inherent very low losses or even a suitably low-loss coaxial cable would provide overall system losses that are sufficiently low to compete with antennas and matching schemes that are far more complex than our simple AWG #12 copper wire element.

Still, achieving the goal of either equalizing band-edge gain or band-edge losses requires very specific and detailed planning in which antenna modeling software may play a useful role. Even though such software generally will omit potentially interactive objects in the installation area, it will permit modeling the system quite exactly with respect to the following variables: *antenna height, length, and diameter; ground quality; and transmission line type, velocity factor, loss, and length.* By understanding the variables and their individual consequences, one can in an evening or so design a reasonable antenna that is likely to work as planned.

We used to think that, if we grabbed a handy cutting formula and cut an antenna for use in the 80-75-meter band, we could prune it to resonance and get on the air. Actually, we still can—after a fashion. But, if we wish to obtain the best possible performance across the entire band within the limits of our installation site, we need to follow a more careful procedure for developing the antenna. The old 80-75-meter dipole or V may be a basic antenna, but its use is by no means simple.