Some Facts of Life About Modeling 160-Meter Vertical Arrays—Part 4: A Potpourri of 160-Meter Vertical Antennas and Modeling Issues

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So far, I have drawn some tentative conclusions about the inadequacies involved in using the *MININEC* no-radial system as a substitute for models employing radials, and of similar inadequacies of above-ground radial system models as substitutes for buried-radial system models. The converse of these negatively stated ideas is the following: For radial systems, (usually) only radial-system models will suffice, and for buried-radial systems, (usually) only buried radial-system models will suffice. As general propositions, these statements need further grounding. Although one might resort profitably to an examination of the mathematics of ground calculations, we shall stay with our present mode of demonstrating both the scope and the limits of these propositions by the use of demonstration models. In this way, we can also gain some appreciation of the likely properties of these antennas—or at least of these antenna models.

The Venerable Inverted L

One of the most popular "beginners" antennas for 160 is the inverted **L**. When the total length is approximately $^1/_4$-λ, the inverted **L** is simply a vertical monopole with the top bent over for structural convenience. The implementations of this antenna are as varied as the circumstances in which they are constructed. However, let's settle for test purposes on a 2-mm diameter wire that is 40 meters long.

Inverted-**L**s vary in shape depending upon the vertical and horizontal territory and supports that are available to the builder. Some are quite tall, with only a small horizontal portion. Others are quite low, in the 10-meter height range (about 33 feet), with the remainder spread horizontally. Therefore, let's test the three versions shown in **Figure 1** as a reasonably fair sampling of the diverse forms of the **L**. As usual in this series, we shall use the *MININEC* no-radial ground system, the 32-radial above-ground system and the 32-radial buried system as test vehicles. The radial systems will use tapered-length techniques as laid out in earlier installments of this series.

Table 1 shows the results of modeling the inverted **L** in its three iterations. As

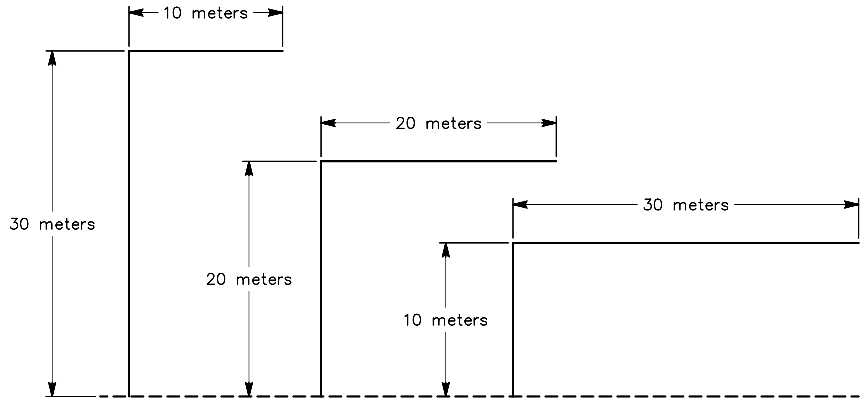
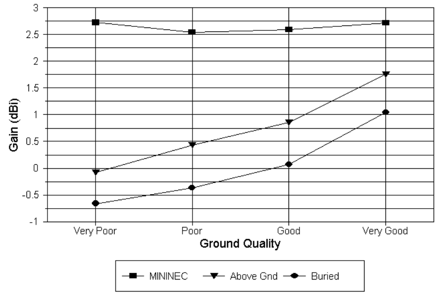


Figure 1—Three versions of the inverted L to be examined over various ground systems and soil qualities. See the text for the ground treatment.

Figure 2—Gain reports for the shortest inverted L using three different ground systems.



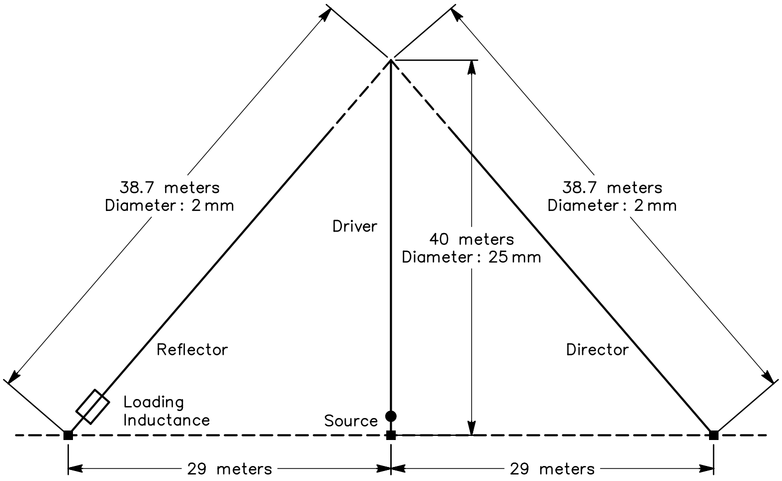


Figure 3—Outline of the 3-element parasitic array to be examined over various ground systems and soil qualities. See the text and Figure 4 for the ground treatment.

Table 1

Inverted L, 40-meter vertical total length, 2 mm in diameter. 40.96-meter (1/4-λ) radials, 2 mm diameter, tapered segmentation: 0.001- to 0.04-λ per wire (where used).

NEC-4

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/–jXΩ)*
A. Vertical, 30 meters; horizontal, 10 meters			
MININEC (no-radial) ground			
Very Poor	–0.79	28	31.64 – j13.76*
Poor	0.38	27	
Good	1.40	24	
Very Good	3.01	17	
32 Radials, 0.001-λ above ground			
Very Poor	–1.23	29	31.18 – j21.22
Poor	0.12	25	30.91 – j18.78
Good	1.09	23	31.54 – j17.62
Very Good	2.80	17	32.26 – j16.85
32 Radials, 0.001-λ below ground			
Very Poor	–1.12	29	35.76 – j7.66
Poor	–0.01	26	36.34 – j6.96
Good	0.86	23	36.19 – j7.09
Very Good	2.60	17	34.82 – j8.00
B. Vertical, 20 meters; horizontal, 20 meters			
MININEC (no-radial) ground			
Very Poor	0.26	33	20.32 – j22.33*
Poor	1.01	30	
Good	1.73	25	
Very Good	2.92	19	
32 Radials, 0.001-λ above ground			
Very Poor	–0.60	32	21.04 – j27.51
Poor	0.45	29	20.64 – j25.79
Good	1.22	26	20.75 – j24.94
Very Good	2.61	19	21.02 – j24.87
32 Radials, 0.001-λ below ground			
Very Poor	–0.61	33	25.07 – j14.62
Poor	0.17	29	25.30 – j14.33
Good	0.86	26	24.80 – j14.56
Very Good	2.30	19	23.38 – j15.90
C. Vertical, 10 meters; horizontal, 30 meters			
MININEC (no-radial) ground			
Very Poor	2.72	45	7.73 – j23.91*
Poor	2.54	39	
Good	2.59	33	
Very Good	2.71	24	
32 Radials, 0.001-λ above ground			
Very Poor	–0.08	49	10.22 – j24.59
Poor	–0.43	41	9.62 – j24.11
Good	0.86	34	9.23 – j23.83
Very Good	1.75	24	8.78 – j24.92
32 Radials, 0.001-λ below ground			
Very Poor	–0.65	46	14.57 – j12.34
Poor	–0.37	39	13.98 – j12.95
Good	0.07	34	12.86 – j13.55
Very Good	1.04	23	11.09 – j15.97

**MININEC* impedance is over perfect ground.

we saw in Part 3 when working with tilted verticals, the *MININEC* no-radial system results diverge from the radial systems in an ever-more radical manner as we shorten the vertical portion and extend the horizontal portion of the antenna. The pattern of the antenna is stronger away from the horizontal wire by a small amount (1 to 2 dB) so that the patterns are not perfectly circular. The table shows the maximum gain figures.

Figure 2 shows the maximum gain values for the shortest of the inverted **L**s over various soil qualities for each of the three modeled ground systems. The nearly level gain—and its elevated value—for the *MININEC* no-radial system are once more unrealistic as approximations of the gain values for either radial system. Over poor soil, the difference between the *MININEC* ground result and the buried radials system result is nearly 3.5 dB.

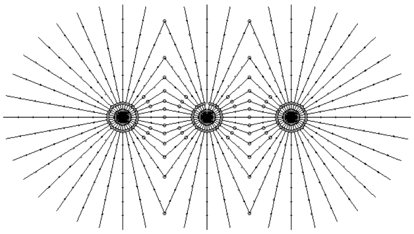


Figure 4—Sketch of three intersecting radial systems, 32 radials each, used with the 3-element parasitic array.

Similar divergences show up in the source resistance values. For the tallest **L**, the differences among all three systems are minor. However, for the shortest version, the *MININEC* value becomes a poor indicator of what a buried-radial system model will show. Whatever the parameter, the different models of ground once more prove inadequate approximations of each other.

A 3-Element Parasitic Array Using Sloping Guys

Since the inverted **L** requires only a single radial set, models are simple to construct. In contrast, a 3-element parasitic array of the sort shown in **Figure 3** is a far more tedious project. Again, the array is an adaptation of a fairly standard arrangement. The 40-meter long driver is 25 mm in diameter. Each 2-mm diameter guy is 38.7 meters long and slopes 54 degrees relative to the ground (or 36 degrees relative to the driver). In this array, a loading inductor serves to increase the electrical length of the reflector. Our interest in this particular array stems not only from the differences in reports from using different radial systems, but as well, differences that may emerge in the required value of the loading inductor to achieve maximum front-to-back ratio.

Each element base is centered in a radial system for other than the *MININEC* no-radial test runs. **Figure 4** is a screen "grab" of the length-tapered intersecting 32-radial system used with the model for the test runs. There are 26 intersections. The initial model with uniform segmentation required 99 wires and 1559 segments. With length-tapering, the model has shrunk to 1015 segments, but needs 619 wires. The obvious question is whether the added work of setting up the model over a radial system is worth the effort.

The results appear in **Table 2**. The divergence in gain among the three ground systems is perfectly in parallel with results obtained for other arrays with sloping parasitic guys. Over Very Poor soil, the *MININEC* system shows over 4.5 dB of excess gain, although this shrinks to about 1.1 dB over Very Good soil. Interestingly, the above-ground radial system shows better gain than the buried system when over Very Poor soil, but less gain over Very Good soil.

The most dramatic differences occur in the front-to-back reports, as summarized in **Figure 5**. Two facets of the front-to-back ratio are significant. First, the maximum obtainable ratios for the radial systems are mediocre (although operationally usable) compared to the reports of the *MININEC* no-radial system. The no-radial and the buried-radial systems show parallel curves, but the above-ground system curve does not join the parallel until the transition from Good to Very Good soil.

It is impossible to ignore all comparisons to reality, and the front-to-back ratios of the 2-element (in Part 3) and the 3-element parasitic arrays are a case in point. The values reported by the radial system models for both cases are in line with typical 2- and 3-element horizontal parasitic beams. For the 3-element array, only the most highly optimized 3-element horizontal beams show the level of front-to-back ratio reported by the *MININEC* no-radial model. Yet, it would be difficult to assert that the vertical array uses dimensions that approach any degree of optimization, with the possible exception of refining the loading coil.

Table 2

3-element parasitic array. Driver: 40-meter tall vertical monopole, 25 mm diameter. Reflector and director: sloping 2-mm diameter guy, 38.7 meters long; intersecting 32 40.96-meter ($^{1}/_{4}$-λ) radial system, 2 mm diameter, tapered segmentation: 0.001- to 0.04-λ per wire (where used).

NEC-4

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Front-to Back Ratio (dB)*	*Source Impedance (R +/– jXΩ)*
MININEC (no-radial) ground: Load = 2.87 μH, Q = 300				
Very Poor	4.85	29	20.85	15.11 + *j*32.45*
Poor	5.73	26	23.53	
Good	6.75	23	24.92	
Very Good	8.15	17	27.55	
32 Radials, 0.001-λ above ground: Load = 2.78 μH, Q = 300				
Very Poor	1.53	28	16.74	16.95 + *j*43.54
Poor	2.69	26	16.02	15.77 + *j*43.78
Good	3.71	22	15.45	14.98 + *j*43.57
Very Good	6.14	16	18.20	14.56 + *j*40.27
32 Radials, 0.001-λ below ground: Load = 1.91 μH, Q = 300				
Very Poor	0.15	27	12.23	14.46 + *j*32.44
Poor	2.16	25	12.99	11.93 + *j*31.72
Good	4.06	22	13.62	10.12 + *j*31.10
Very Good	6.98	16	15.36	8.62 + *j*27.93

**MININEC* impedance is over perfect ground.

Table 3

Two 40-meter tall, 25-mm diameter monopoles, separated 84 meters, fed in phase. 40.96-meter ($^{1}/_{4}$-λ) radials, 2 mm diameter, tapered segmentation: 0.001- to 0.04-λ per wire (where used).

NEC-4

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/– jXΩ)*
MININEC (no-radial) ground			
Very Poor	2.96	27	29.05 – *j*7.60*
Poor	4.27	25	
Good	5.37	23	
Very Good	7.11	16	
32 radials, 0.001-λ above ground			
Very Poor	2.95	27	26.40 – *j*22.70
Poor	4.27	25	26.95 – *j*11.40
Good	5.21	22	28.00 – *j*10.80
Very Good	6.98	17	28.90 – *j*10.30
32 radials, 0.001-λ below ground			
Very Poor	2.36	27	35.25 – *j*2.93
Poor	3.84	25	33.71 + *j*1.78
Good	4.90	22	32.80 – *j*1.50
Very Good	6.79	17	31.32 – *j*2.74

The loading inductor in the models is the second important area of divergence among the models. To obtain the highest values of front-to-back ratio, the loading inductors were assigned a Q of 300. In other words, the load uses a series value of resistance about 1/300 of the required inductive reactance and its associated inductance at the 1.83 MHz test frequency. The difference in required loading coil between the no-radial and the above-ground radial system represent about 1 Ω of reactance: 33 Ω for the *MININEC* ground model and 32 Ω for the above-ground radial system. However, to obtain the best front-to-back ratio of which the model was capable with the buried radial system, the loading inductance had to be reduced to about 1.9 μH or 22 Ω reactance.

Figure 6 shows the elevation patterns for the three models over Good soil. The differences in the predicted patterns among the three ground systems are clearly evident. It is well to be reminded at this point that the data and patterns apply only to the modeled radial systems and that some variance will become apparent with changes in the model. For example, changing radial length and number will likely alter the reported data to some degree, in line with expectations that might emerge from our survey of system ranging from 4 to 128 radials in Part 1.

Where the *MININEC* Ground System Works

So far we have examined cases in which the results of using the *MININEC* no-radial system diverge in very significant ways from results obtained from using modeled radial systems. Not all models exhibit such large levels of deviation among models. For example, let's examine a pair of $^{1}/_{4}$-λ monopoles, each 40 meters tall and 25 mm in diameter and positioned as shown in **Figure 7**. We shall space them 84 meters apart, which is just over $^{1}/_{2}$-λ. The selected separation is intentional so that the $^{1}/_{4}$-λ radials that we place under each monopole for certain tests do not overlap. Therefore, we end up with elementary though large models for the above-ground and buried radial systems—about 400 wires and 795 segments for length-tapered models. Of course, the *MININEC* no-radial model is simple by comparison.

We shall feed each monopole in phase with the other and examine the results, as we have for each test case so far. **Table 3** lays out the numbers. **Figure 8** graphs the gain figures in order to show that there is little difference among the three modeling systems. In fact, for this particular antenna, the *MININEC* and the above-ground systems yield figures that are closer than those of the buried-radial system. **Figure 9** compares the *MININEC* no-radial azimuth pattern with the buried-radial model pattern to show that there would be little or no operationally significant difference in the numbers.

The one arena in Table 3 in which we find a difference that may be significant is the source impedance figures. Of course, the *MININEC* values show no variation, while the above-ground radial system figures show only small variations (with the exception of the reactance over Very Poor Soil). The values are for each of the two feedpoints of the 2-element array. As we have noted before, the buried radial system shows a wider range of variation with changes in soil quality and generally higher values than for each of the other ground systems. For this antenna, the variation carries over into the reactance column, where the array appears to be closer to resonance at 1.83 MHz than with either of the other ground modeling systems.

Despite these differences, all three ground modeling systems would generally be adequate for analyzing the array in question. Where the elements are perfectly vertical, they do not encroach on the error-producing aspects of the *MININEC* ground. As well, the model lacks potential complications that might be introduced by the use of intersecting radial systems. As a result, we have a type of case in which the simplification of the ground system to a *MININEC* no-radial model yields reasonable results.

A $^1/_4$-λ Monopole Over 32 Radials Buried at Three Depths

I have shown exemplary applications of overlapping radial systems, but have not yet shown an example that uses the technique of sloping the first two sections of each radial in order to model either a “fat” monopole or a shallow buried radial system. To rectify this gap, let’s consider a monopole that is 250 mm in diameter. As always, we shall leave the top height at 40 meters. In addition to working with the fat monopole, let’s consider whether the depth of the buried radial system makes a difference to performance. With a 32-radial system, we shall use depths of 0.0005-λ (0.082-meter or 3.23 inches), 0.001-λ (0.164-meter or 6.46 inches), 0.002-λ (0.328-meter or 12.91 inches), 0.003-λ (0.492-meter or 19.37 inches), and 0.004-λ (0.656-meter or 25.82 inches).

Figure 10 shows the general modeling setup for the areas of the antenna nearest the junction. Only the first of the 32 radials is shown, but the separate values for the X and the Z axes appear on the sketch. The objective was to keep the shortest wire or segment length at 1-meter, which is 4 times the diameter of the monopole. As well, the length of segments adjacent to the source wire are equal to its length. The models consisted of 164 wires and 460 total segments and were run over the usual span of Very Poor to Very Good Soil.

The results of the runs yield operationally insignificant but numerically interesting differences for any soil quality. As with the other models which we have surveyed, the results over Very Poor soil strongly suggest the need for more radials. See Part 1, which has some data for some systems up to 128 radials. For Very Good soil, 32 radials may suffice.

The gain figures represent the most interesting facet of the runs. As shown in the graph in **Figure 11**, the radial systems

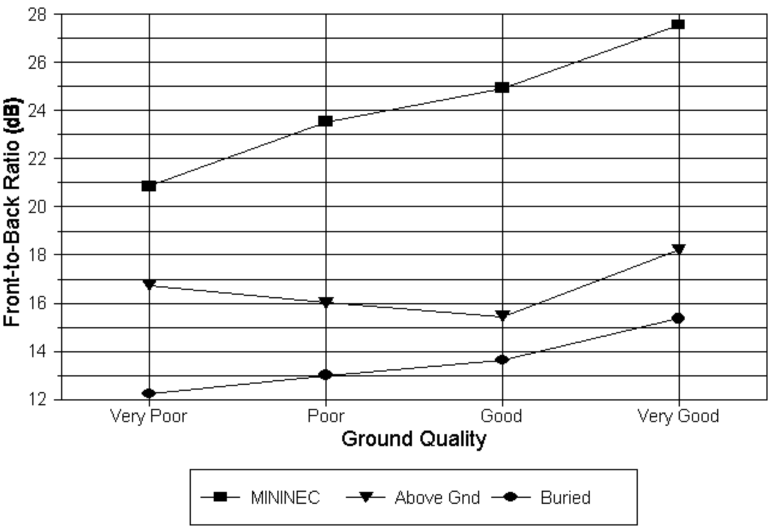


Figure 5—Front-to-back ratio reports of the 3-element parasitic array over various grounds.

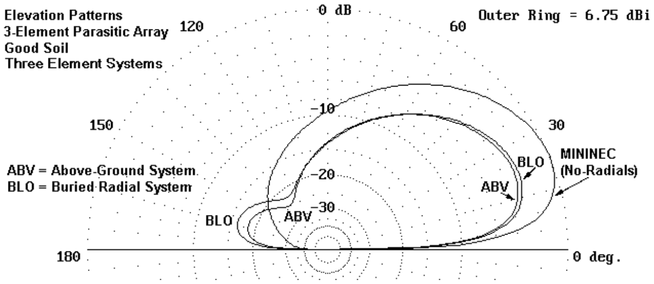


Figure 6—Elevation patterns of the 3-element parasitic array as modeled over a *MININEC* (no-radial) ground and over intersecting radial systems both above and below ground.

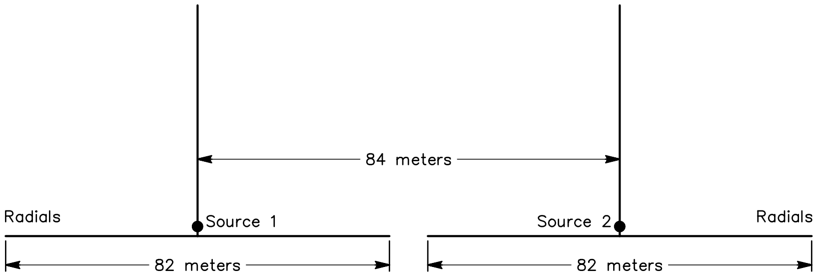


Figure 7—Two $^1/_4$-λ monopoles spaced $^1/_2$-λ apart and fed in phase (with non-intersecting radial systems).

at depths of 0.0005- and 0.001-λ are even numerically insignificantly different. The question raised by these two runs is whether the maximum 0.01-dB gain difference over any one soil represents a trend or a mere artifact of rounding. Deepening the radial system to 0.002- through 0.004-λ shows that there is indeed a trend. For the depths modeled, the deeper the radial system, the higher the gain.

What these runs do not establish is whether there is a maximum depth below which the performance of the monopole would decrease. The rate of gain increase itself decreases as we move from 0.003- to 0.004-λ, suggesting that there is indeed a limit. The differences are not artifacts of the changing radius of the portions of the slanting radials that are above ground. This fact was established by modeling the 25-mm monopole using a single vertical wire below ground to the radial junction. The results of model runs with the radials wholly buried and between 0.001- and 0.004-λ below ground appear in **Table 5**. For the thinner monopole, maximum numerical gain reports appear at different depths of the radial field for each soil type, as indicated by the "+" notations in the table. Although the results of these studies do not yield any particular construction recommenda-tions, since the differences are very small, the trends have their own fascination.

Other buried-radial questions abound and are ripe for detailed and systematic modeling. For example, we have examined only 1/4-λ radials: other radial lengths have been recommended for various reasons. Moreover, this set of runs was made for 1.83 MHz only. The runs do not tell us what the modeling reports would be for various depths on

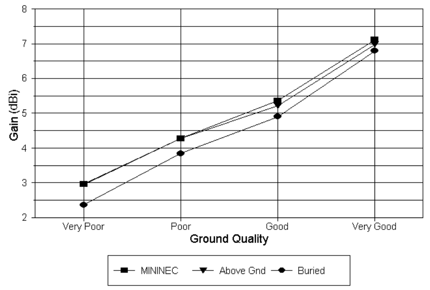


Figure 8—Gain reports of the two 1/4-λ monopoles spaced 1/2-λ apart and fed in phase.

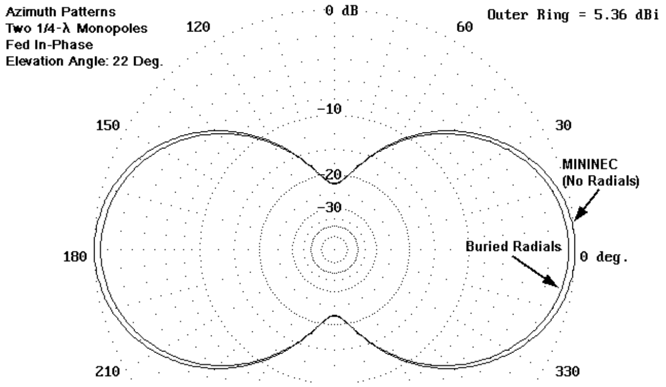


Figure 9—Azimuth patterns for an in-phase fed pair of 1/4-λ monopoles over *MININEC* (no-radial) ground and over a buried radial system.

Table 4

Vertical monopole, top at 40 meters, 250 mm in diameter, 32 40.96-meter (1/4-λ) radials, 2 mm diameter, tapered with interior wires slanted, depth: 0.0005- to 0.004-λ.

NEC-4

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/– jXΩ)*
Depth: 0.0005-λ (0.082-meter)			
Very Poor	–1.31	28	43.08 + *j*13.11
Poor	–0.07	25	44.68 + *j*14.49
Good	0.86	22	44.86 + *j*14.64
Very Good	2.72	17	43.41 + *j*14.34
Depth: 0.001-λ (0.164-meter)			
Very Poor	–1.30	27	43.91 + *j*13.33
Poor	–0.06	25	44.71 + *j*14.56
Good	0.87	23	44.85 + *j*14.63
Very Good	2.72	17	43.40 + *j*14.26
Depth: 0.002-λ (0.328-meter)			
Very Poor	–1.21	27	43.36 + *j*13.66
Poor	0.01	25	44.15 + *j*14.68
Good	0.94	22	44.24 + *j*14.65
Very Good	2.78	17	42.79 + *j*14.09
Depth: 0.003-λ (0.492-meter)			
Very Poor	–1.14	28	43.06 + *j*14.10
Poor	0.06	25	43.94 + *j*14.95
Good	0.99	22	43.92 + *j*14.88
Very Good	2.82	17	42.46 + *j*14.07
Depth: 0.004-λ (0.656-meter)			
Very Poor	–1.09	28	42.83 + *j*14.73
Poor	0.11	25	43.68 + *j*15.54
Good	1.03	23	43.71 + *j*15.32
Very Good	2.85	17	42.25 + *j*14.24

Table 5

Vertical monopole, top at 40 meters, 25 mm in diameter, 32 40.96-meter (1/4-λ) radials, 2 mm diameter, tapered with single wire to junction, depth: 0.001- to 0.004-λ.

NEC-4

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/– jXΩ)*
Depth: 0.001-λ (0.164-meter)			
Very Poor	–1.61	27	44.89 + *j*7.54
Poor	–0.16	25	43.44 + *j*9.55
Good	0.86	22	42.67 + *j*10.46
Very Good	2.79+	17	40.48 + *j*10.03
Depth: 0.002-λ (0.328-meter)			
Very Poor	–1.29	27	42.07 + *j*12.38
Poor	–0.04+	25	42.48 + *j*13.30
Good	0.91+	22	42.36 + *j*13.32
Very Good	2.75	16	40.87 + *j*12.49
Depth: 0.003-λ (0.492-meter)			
Very Poor	–1.25+	27	41.98 + *j*15.48
Poor	–0.04+	25	42.75 + *j*16.20
Good	0.89	22	42.75 + *j*16.01
Very Good	2.70	17	41.48 + *j*14.89
Depth: 0.004-λ (0.656-meter)			
Very Poor	–1.25+	27	42.28 + *j*18.41
Poor	–0.06	25	43.23 + *j*19.00
Good	0.85	22	43.27 + *j*18.68
Very Good	2.62	16	42.24 + *j*17.24

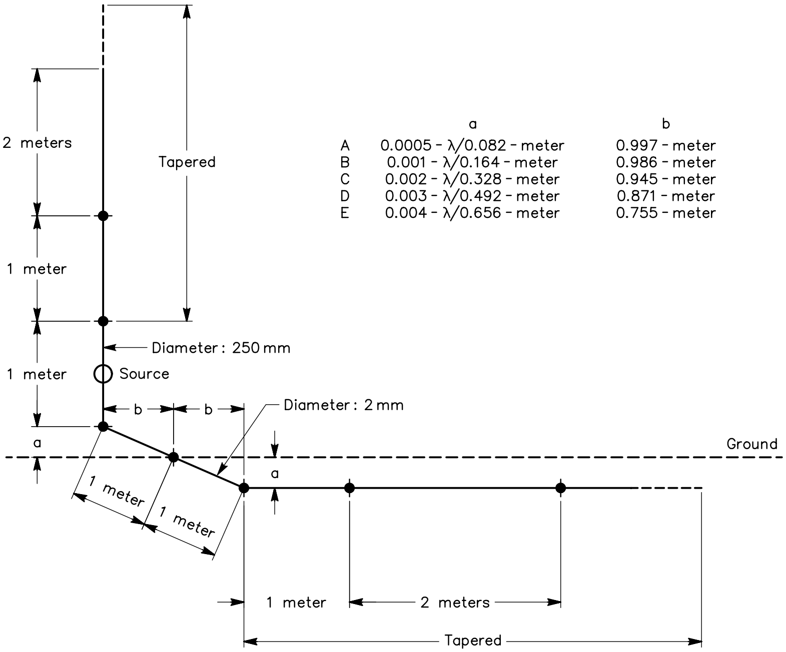


Figure 10—The model set-up for testing a vertical monopole over a 32-wire radial system buried at 5 depths.

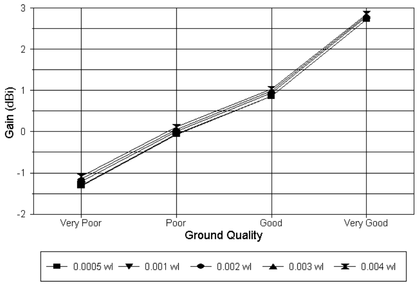


Figure 11—Gain reports for a 1/4-λ vertical monopole over 32 radials buried at 5 depths.

other amateur bands on which the use of vertical antennas and arrays is common. All of that we shall leave as unfinished business (or, as texts are fond of saying, as exercises for the reader).

There are a myriad of other modeling questions associated with verticals that we shall also have to leave unanswered. For example, there is evidence in preliminary models that the required length of phasing line required to establish a maximum rear null in 1/4-λ monopole spaced 1/4-λ apart will vary somewhat with the soil quality. How this variation itself varies with the size and depth of a radial field remains unanswered. To this question we might also add one about 1/2-λ near-ground verticals that are base fed. Preliminary models suggest that only minor changes in performance occur with various types of radial systems beneath the antenna, a result that is at odds with user experiential reports. However, what remains to be developed are models that adequately handle all of the aspects of the antenna system, including the usual source-matching system that places a network between the base of the antenna and the ground.

To these questions, we may add any number of others that involve the development of adequate models of various arrays. One final simplification technique remains to be treated: the use of inner and outer ground qualities to simulate a radial system. We shall examine that proposal in the final episode of this series. ■