Some Facts of Life About Modeling 160-Meter Vertical Arrays—Part 5: The Use of Multiple Ground Qualities in Lieu of Radials

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The final technique for simplifying the modeling of radials caught me by surprise. It consists of using the facility in *NEC* that allows two ground qualities—a set radius for an inner set of values, and from that point onward, some other values. The reasoning goes that a set of radials in effect improves the ground quality. Therefore, setting the inner radius to the length of the radial system at a high conductivity value, with a lesser value from that point outward, would largely replicate the effect of a radial system without requiring the modeling of radials.

Since the practice has some currency in various quarters, it deserves an examination, even if we know in advance that the interaction of buried radial systems is quite different from a simple soil quality improvement. We need to see to what degree the modeling technique yields something useful, even by way of indicators of antenna performance. To this end, let's go back to the very beginning of our work in this series and take a further look at the classic $^{1}/_{4}$-λ monopole.

The $^{1}/_{4}$-λ Monopole Over Various Modeled Ground Systems

We have come a long distance from our starting point of looking at $^{1}/_{4}$-λ monopoles both over radials systems and directly connected to ground with no radials in the model. We have been using the categories of soil quality in **Table 1** as our benchmarks along the way, having established the relative fairness of the spread of values in Part 2.

Table 2 reviews the modeled values in *NEC-4* of a 25-mm diameter monopole over various size radial systems and soil qualities, when the 2-mm diameter radials are buried 0.001-λ below ground (about 6.5 inches at 1.83 MHz, our test frequency). To consolidate the numbers in a different way, **Figure 1** graphs the gain in dBi of the monopoles, with each line representing a different soil quality and the individual lines tracing the numbers of radials from 4 to 128. The largest differentials appear in the region from 4 to 16 radials and over the poorest soils. We should not neglect the actual numbers for the gain values.

Figure 2 provides comparable curves for the source resistance calculated by *NEC-4* for each of the cases graphed for gain in Figure 1. As we would expect, the highest values of source resistance and the greatest rates of change occur when the radials are few and the soil is less than "Good" quality.

We have also looked at the type of model that uses no radials, but connects the $^{1}/_{4}$-λ monopole directly to ground. In earlier examinations, we looked only at the use of the *MININEC* ground. In **Table 3** are values for direct connection to both the *MININEC* and the Sommerfeld-Norton (*S-N*) ground in *NEC-4*. (The values for a *NEC-2* ground may differ, since there is a distinct difference in the treatment of wire approaching and touching ground in the two systems.

Table 1
Soil types used in the study.

Soil Type	*Conductivity (Siemans/meter)*	*Permittivity (dielectric constant)*
Very Poor	0.001	5
Poor	0.002	13
Good (Average)	0.005	13
Very Good	0.0303	20

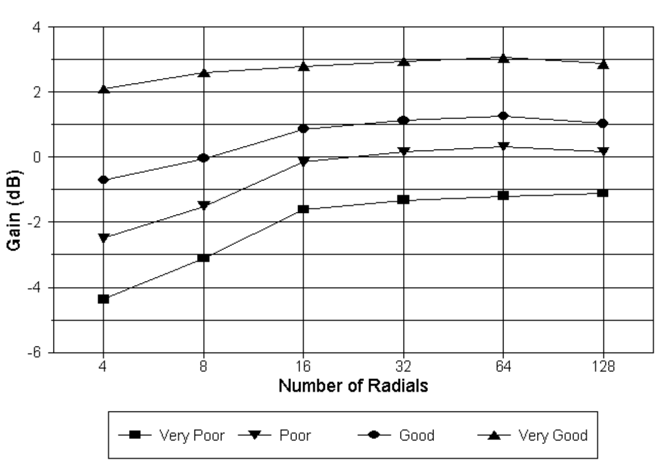

Figure 1—Gain values for a $^{1}/_{4}$-λ monopole over various size buried radial systems and different soil qualities. The radiating element is 0.25-meter in diameter. The tapered radials have a maximum diameter of 2 mm and are located 0.164-meter below ground.

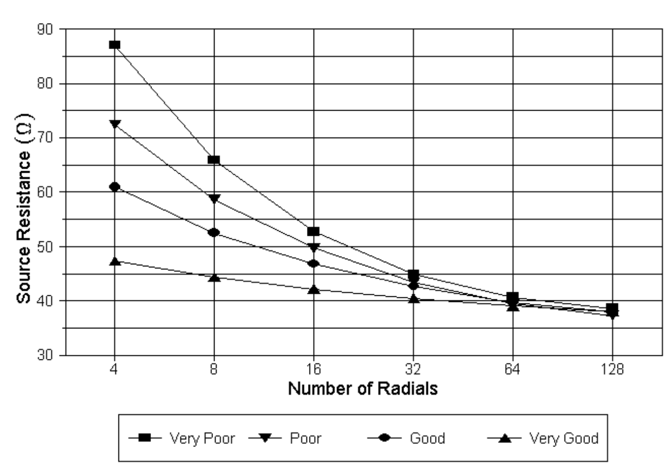

Figure 2—Source resistance values for a $^{1}/_{4}$-λ monopole over various size buried radial systems and different soil qualities. The radiating element is 0.25-meter in diameter. The tapered radials have a maximum diameter of 2 mm and are located 0.164-meter below ground.

Table 2

40-meter tall vertical monopole, 25 mm in diameter. 40.96-meter ($^{1}/_{4}$-λ) radials, 2 mm in diameter, tapered segmentation: 0.001 to 0.04-λ per wire; radials 0.001-λ below ground; *NEC-4*.

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/– jX Ω)*
4-radials: 32 wires; 62 segments			
Very Poor	–4.37	27	87.04 + *j*25.31
Poor	–2.49	25	72.45 + *j*19.47
Good	–0.71	23	60.96 + *j*20.42
Very Good	2.10	17	47.34 + *j*14.52
8-radials: 56 wires; 110 segments			
Very Poor	–3.11	28	65.90 + *j*18.09
Poor	–1.51	25	58.63 + *j*15.18
Good	–0.04	23	52.43 + *j*15.94
Very Good	2.60	17	44.34 + *j*12.60
16-radials: 104 wires; 206 segments			
Very Poor	–1.61	28	52.71 + *j*12.43
Poor	–0.16	25	49.71 + *j*12.18
Good	0.86	23	46.79 + *j*12.83
Very Good	2.79	16	42.20 + *j*11.18
32-radials: 200 wires; 398 segments			
Very Poor	–1.32	27	44.89 + *j*7.54
Poor	0.17	25	43.44 + *j*9.55
Good	1.12	22	42.67 + *j*10.46
Very Good	2.94	17	40.48 + *j*10.03
64-radials: 392 wires; 782 segments			
Very Poor	–1.19	27	40.68 + *j*4.11
Poor	0.32	25	39.43 + *j*7.08
Good	1.26	22	39.73 + *j*8.50
Very Good	3.05	17	39.06 + *j*9.07
128-radials: 776 wires; 1550 segments			
Very Poor	–1.12	28	38.60 + *j*2.18
Poor	0.17	25	37.32 + *j*5.29
Good	1.03	23	37.91 + *j*6.99
Very Good	2.87	17	37.94 + *j*8.27

Table 3

Direct connection values. 40-meter tall vertical monopole, 25 mm in diameter, direct connection to ground (no radials), fed at the lowest segment; *NEC-4*.

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/– jX Ω)*
A. *MININEC* ground			
Perfect			37.08 + *j*6.12
Very Poor	–1.00	27	
Poor	0.31	25	
Good	1.41	23	
Very Good	3.16	17	
B. Sommerfeld-Norton ground			
Very Poor	–2.26	27	49.32 + *j*8.11
Poor	–0.89	25	48.78 + *j*10.52
Good	0.31	22	47.65 + *j*11.48
Very Good	2.48	17	43.36 + *j*10.21

NEC-2 does not permit buried wires, although *NEC-4* handles buried wires routinely so long as certain modeling conventions are met.) **Figure 3** graphs the pair of gain curves that result from one soil quality to the next. The *NEC-4* S-N curve roughly tracks the values from the 4-radial portion of Table 2. However, the *MININEC* curve reaches values not achieved by even the 64- and 128-radial portions of Table 2.

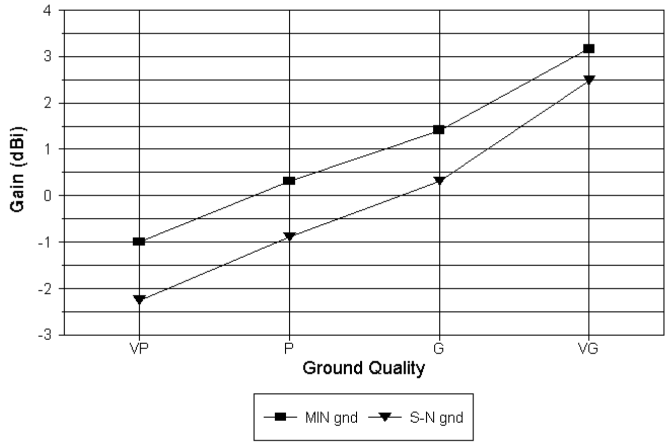

Figure 3—Gain values for a $^{1}/_{4}$-λ monopole over *MININEC* and S-N grounds without modeled radials.

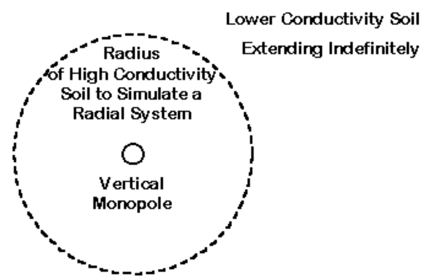

Figure 4—A monopole over a dual ground-quality system used to simulate radials. The area inside the circle is modeled as high conductivity soil to represent the effect of radials. The area outside of the circle is lower conductivity soil that corresponds to the actual ground quality.

The technique that we shall try to compare to these modeled results appears in **Figure 4**. We set the monopole touching ground. Beneath the antenna and for a radius of $^{1}/_{4}$-λ (40.96-meter), we set the soil quality to some higher value. In these tests, we shall use a conductivity of about 0.03 S/m, corresponding to Very Good soil. From that radius outward, we shall use Very Poor soil for the contrast.

Theoretically, *NEC* calculates the source impedance and currents from the inner radius soil quality, and would do so even had we specified the dividing boundary radius as zero. The far field is calculated using the second or outer ground quality. For the sake of this test, I used *EZNEC Pro*, which permitted runs using either *NEC-2* or *NEC-4* and gave access to the *MININEC* ground as well as to the standard *NEC* grounds (the high accuracy Sommerfeld-Norton ground calculation system and the "fast" or reflection coefficient calculation system). The results appear in **Table 4**.

The values shown for the *NEC* ground calculation systems are in the table largely for reference. They are not considered usable by most modeling software experts. Tradition has used the *MININEC* ground as a basis for simplified modeling. However, the gain figures for both cores using a *MININEC* ground exceed the highest value of far-field gain found in Table 2 for all but Very Good Soil. Note that the far-field gain is supposed to be a function of the outer soil quality, which was set at Very Poor. As well, the dual ground quality system

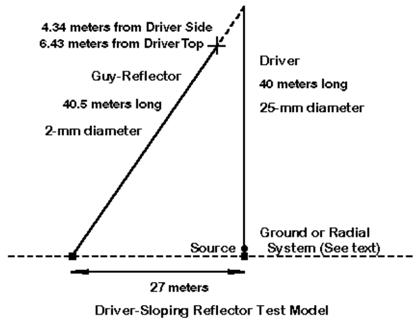

Figure 5—The 2-element sloping-reflector array used as a test model.

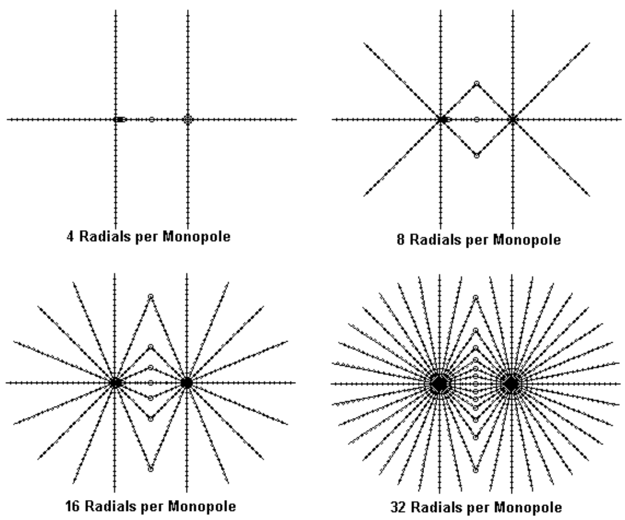

Figure 6—The four configurations of intersecting buried radial systems surveyed with the 2-element sloping-reflector array.

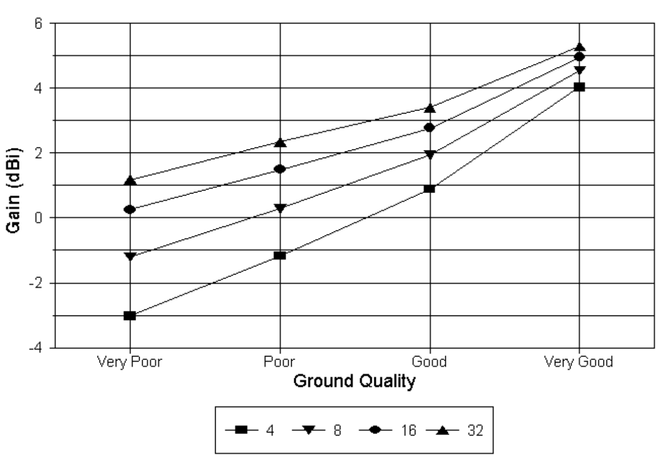

Figure 7—Gain values for 2-element sloping-reflector arrays employing 4, 8, 16 or 32 buried radials over a range of soil qualities.

Table 4

Direct Connection Values: 40-meter tall vertical monopole, 25 mm in diameter, direct connection to ground (no radials), fed at the lowest segment. Dual ground: inner to 40.96-meter radius, Very Good; outer, Very Poor.

Ground System	*Gain (dBi)*	*TO Angle (degrees)*	*Source Impedance (R +/–jX Ω)*
A. *MININEC* Ground			
NEC-4	3.16	27	37.08 + *j*6.12
NEC-2	1.89	29	37.08 + *j*6.12
B. “Fast” *NEC* Ground			
NEC-4	2.12	29	35.14 + *j*5.37
NEC-2	–5.07	29	179.5 – *j*163.0
C. Sommerfeld-Norton *NEC* Ground			
NEC-4	1.21	29	43.36 + *j*10.21
NEC-2	0.04	29	56.79 + *j*9.58

Table 5

Two-element parasitic array. Driver: 40-meter tall vertical monopole, 25 mm in diameter. Reflector: sloping 2-mm guy, 40.4 meters long; intersecting 40.96-meter ($^{1}/_{4}$-λ) radial system, 2 mm in diameter, 0.001-λ below ground, uniform segmentation; *NEC-4*.

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Front-to Back Ratio (dB)*	*Source Impedance (R +/–jX Ω)*
4 radials per element				
Very Poor	–3.03	28	5.89	102.8 + *j*53.58
Poor	–1.17	26	6.14	86.89 + *j*44.75
Good	0.88	23	7.04	75.31 + *j*47.33
Very Good	4.03	17	8.84	62.11 + *j*46.58
8 radials per element				
Very Poor	–1.20	29	7.58	82.12 + *j*50.16
Poor	0.29	26	7.96	73.99 + *j*45.63
Good	1.94	23	8.62	68.17 + *j*47.52
Very Good	4.54	17	9.73	59.75 + *j*47.78
16 radials per element				
Very Poor	0.25	29	9.40	67.75 + *j*49.90
Poor	1.49	26	9.54	65.74 + *j*48.23
Good	2.77	23	9.96	63.06 + *j*48.75
Very Good	4.95	18	10.54	57.70 + *j*48.95
32 radials per element				
Very Poor	1.18	29	10.43	60.03 + *j*48.96
Poor	2.34	27	10.61	59.34 + *j*49.10
Good	3.40	23	11.04	58.66 + *j*49.77
Very Good	5.29	17	11.26	55.72 + *j*50.06

of modeling does nothing to correct the fact that *MININEC* ground forces the source impedance to be calculated over perfect ground. At best, the Sommerfeld-Norton ground using *NEC-4* yields values of gain and source impedance similar to those for Good soil and 32 buried radials (from Table 2). However, there is a significant difference in the calculated take-off angle for the two models.

With respect to the simple $^{1}/_{4}$-λ monopole, at least, there is nothing in the data calculations to suggest that a dual ground system in any way provides usable data as a substitute for a buried radial system of any size. Since the closest correlation appeared in a *NEC-4* S-N run, which presumes that one has *NEC-4* at hand, one might as well model the buried radials in the first place.

A 2-Element Sloping-Parasitic Vertical Array Test

To determine whether the results for a $^{1}/_{4}$-λ monopole, as interpreted, represent a case of excessive finickiness, I went back to a model first examined in Part 3 of this series: a 2-element vertical array in which the reflector is a sloping guy wire. The outline of the array appears in **Figure 5**. Both the 25-mm diameter driven element and the 2-mm diameter reflector guy are connected to ground—or to a radial system.

Because we wish to discover if there is a usable correlation between a dual ground quality system and a buried radial system, I extended the analysis of the array over buried radials. The $^{1}/_{4}$-λ length radial systems for the individual elements intersect—how many times being dependent on the number of radials in each system. I used 4, 8, 16 and 32 radials per element, and the resulting radial systems are sketched in **Figure 6**.

The results of the model runs appear in **Table 5**, which provides values for each of our soil qualities for each level of radial system. **Figure 7** provides curves for the gain values, where each line represents a different size radial system. The curves are unexceptional. We should note that the gain barely reaches 5.3 dBi with 32 radials per element over Very Good soil.

Figure 8 graphs in a similar way the modeled front-to-back ratios achieved by the array variations. The 4-radial-per-element system benefits most from soil quality improvements. However, even over Very Good soil, the model does not achieve an 11.3 dB front-to-back ratio.

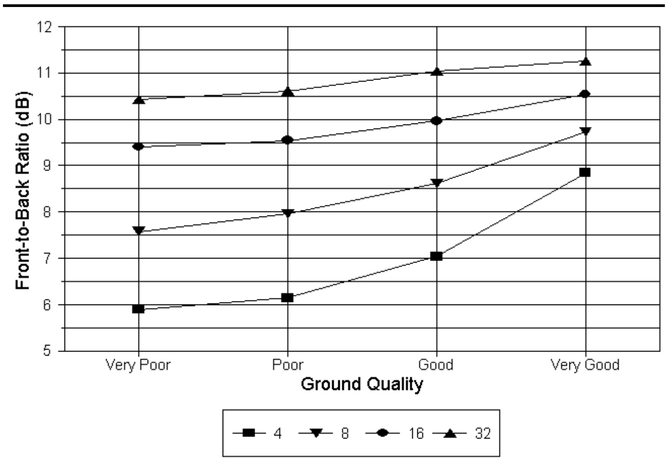

Figure 8—Front-to-back ratio values for 2-element sloping-reflector arrays employing 4, 8, 16 or 32 buried radials over a range of soil qualities.

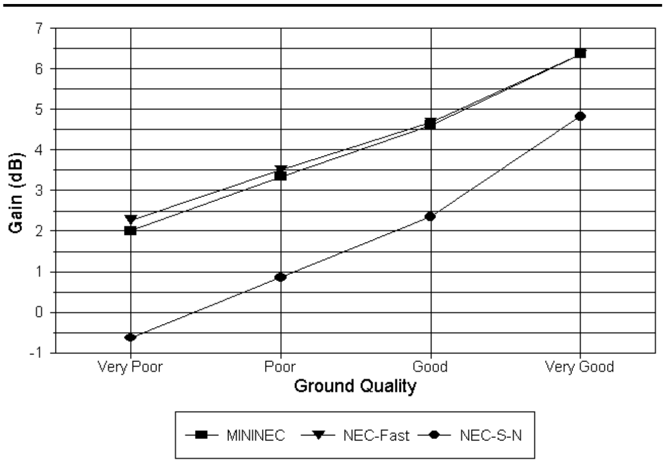

Figure 9—Gain values for the 2-element sloping-reflector array over *MININEC*, "fast" and S-N grounds without modeled radials.

Table 6

Two-element parasitic array. Driver: 40-meter tall vertical monopole, 25 mm in diameter. Reflector: sloping 2-mm guy, 40.4 meters long; direct connection to ground (no radials); *NEC-4*.

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Front-to Back Ratio (dB)*	*Source Impedance (R +/–jX Ω)*
A. *MININEC* Ground				
Very Poor	2.00	30	11.36	40.19 + *j*53.02*
Poor	3.34	26	14.25	
Good	4.62	24	17.11	
Very Good	6.36	18	19.50	
**MININEC* impedance is over Perfect ground.				
B. "Fast" *NEC* Ground				
Very Poor	2.27	28	6.37	50.40 + *j*29.73
Poor	3.50	26	8.63	50.14 + *j*36.48
Good	4.67	23	10.82	51.25 + *j*42.49
Very Good	6.35	18	14.66	46.64 + *j*49.99
C. Sommerfeld-Norton *NEC* Ground				
Very Poor	–0.63	29	10.31	69.16 + *j*38.46
Poor	0.85	26	10.78	65.61 + *j*42.24
Good	2.35	23	11.81	62.44 + *j*45.83
Very Good	4.82	18	13.44	53.33 + *j*48.39

Note: Use of *NEC-2* and the S-N ground will yield reports that differ considerably from the values produced by *NEC-4*. The following listing is simply to display the differential.

D. Sommerfeld-Norton *NEC* Ground—*NEC-2*				
Very Poor	–11.0	28	0.58	342.3 – *j*169.9
Poor	–7.06	26	1.46	180.3 – *j*77.60
Good	–3.60	23	3.55	122.5 + *j* 4.20
Very Good	2.94	18	10.16	61.57 + *j*38.79

If we use a direct connection to ground and no radials, the calculated numbers derived from *NEC* diverge from those yielded by the buried radial systems. **Table 6** gives the modeling results of placing the two elements alone over the range of available grounds, including the *MININEC* ground, the "fast" *NEC* ground, and the S-N ground. Once more, the latter two are for reference and the general advice not to use these grounds for such purposes remains applicable.

Figure 9 graphs the gain values for the three sets of *NEC-4* runs. Interestingly, the reflection coefficient ground in *NEC-4* correlates very well to the *MININEC* ground. The S-N ground, when used in *NEC-4*, provides values that coincide roughly with a 12-radial-per-element system, if one can interpolate fairly from the data in Table 5.

The correspondence in gain figures between the *MININEC* ground and the "fast" ground in *NEC-4* disappears if we move to the front-to-back column. Although the "fast" ground curve is roughly congruent with the *MININEC* curve, the "fast" ground values are 5 dB lower. The S-N ground curve is much shallower, but the values are high, even when compared to the front-to-back values for the 32-radial-per-element buried radial system model.

Table 6 provides S-N ground data for *NEC-2*, the version used by most hams. Once more, there is a very large difference in the values reported from those yielded by *NEC-4* under identical modeling parameter conditions. The values would hardly be useful as anything but artifacts. However, the remaining numbers in Table 6 have equally misleading data values and should also be set aside if one is modeling a buried radial system attached to the array in question.

The final step in our test is whether using a dual soil-quality

Table 7

Two-element parasitic array. Driver: 40-meter tall vertical monopole, 25 mm in diameter. Reflector: sloping 2-mm guy, 40.4 meters long; direct connection to ground (no radials), fed at the lowest segment. Dual ground: inner to 61.43-meter radius (3/8-λ from array center line), Very Good; outer, Very Poor.

Soil Type	*Gain (dBi)*	*TO Angle (degrees)*	*Front-to Back Ratio (dB)*	*Source Impedance (R +/–jX Ω)*
A. *MININEC* Ground				
NEC-4	6.36	18	19.50	40.19 + *j*53.02
NEC-2	6.82	11	18.58	40.21 + *j*53.02
B. "Fast" *NEC* Ground				
NEC-4	6.03	25	14.43	46.64 + *j*49.99
NEC-2	No usable values			
C. Sommerfeld-Norton *NEC* Ground				
NEC-4	4.45	25	14.04	53.33 + *j*48.39
NEC-2	3.51	11	9.58	61.57 + *j*38.79

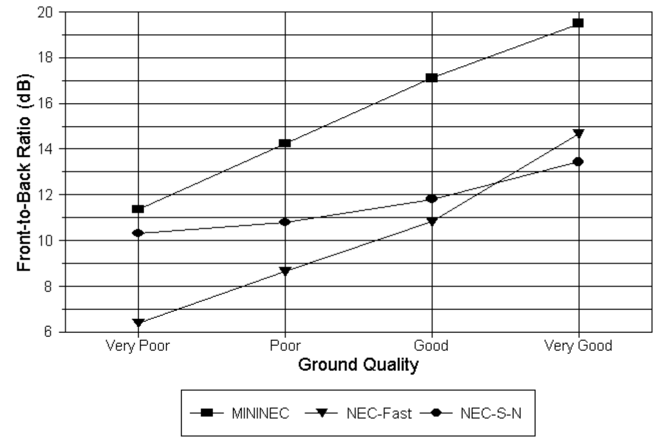

Figure 10—Front-to-back ratio values for the 2-element sloping-reflector array over *MININEC*, "fast" and S-N grounds without modeled radials.

system fares any better than the simple *MININEC* ground. To examine this question, I altered the model to include Very Good ground under the antenna and Very Poor ground at a distance. Since the model involves radial systems that intersect, with about 1/8-λ between element bases, I chose a radius of 3/8-λ for the inner ground quality (61.43 meters at 1.83 MHz). The results of the modeling appear in **Table 7**.

Using the normal *MININEC* ground for the exercise produced excessively high values of gain and front-to-back ratio relative to the buried-radial models—in both *NEC-4* and *NEC-2*. As well, *NEC-2* depressed the TO (*take off*) angle by 7 degrees relative to any other report. Although the "fast" and S-N numbers are provided, once more they are no more than reference reports. The end result, however, is that the dual-ground system provides no usable data or even indicators of data for the array in question.

Conclusion

As expected, the dual-ground modeling technique can be as misleading as any other substitute for a direct and detailed model of a buried radial system. The calculations for the way in which radials interact with a given soil quality when buried is quite different from the calculations for the soil alone. As a result, a radial system is not equivalent with respect to antenna performance to a simple improvement of the soil quality.

Thinking of a radial system as an improvement in soil quality may have some utility when the concern is the overall RF ground for a station and its antenna(s). However, that mode of thought can be highly misleading when it comes to calculations that yield potential antenna performance figures. We have looked in review at the results for the standard techniques of simplifying models by placing them without radials over a *MININEC* ground, and the result is simply that both systems of simplification are equally but separately misleading. The only type of modeling that seems adequate to a buried radial system is a buried radial model. Any suggested simplification would require that we first test the simplified model against a full model with all buried radials modeled. If a reliable correlation appears—and it might, as illustrated in Part 4—then we can use the simplification. However, once we have the full model, the rationale for simplifying seems largely to disappear.

As one step in the direction of developing more adequate models of vertical antennas and arrays for 160 meters (or any other band, for that matter), this series has tried to set forth some basics of the varied results that different kinds of models produce, as well as to give some perspective on the divergence in reports yielded by the range of ground qualities that we can model. If any theme emerges from these notes, it should be this: to the degree possible, let us model accurately and without shortcut every possible aspect of a 160-meter vertical antenna or array and begin from the ground up. ■

WRTC USA Youth Fund

The Boring (Oregon) Amateur Radio Club is happy to announce the establishment of a tax-deductible fund intended to help defray the travel costs of young USA competitors to the WRTC events. This fund is being administered by the ARRL Foundation.

To be eligible, an applicant must be a US citizen, no more than 25 years old at the time of the WRTC event, and must be selected as a competitor.

Up to $1000 of the actual travel expenses will be reimbursed per WRTC event, depending on fund availability. If funds are left over, they will be applied to the next WRTC event.

The Boring ARC will verify eligibility and request fund disbursements. You can send your request to the club's mailing address: 15125 SE Bartell Road, Boring, OR 97009. Include a copy of your receipts.

To contribute to the fund, send your check to the ARRL Foundation Inc, 225 Main Street, Newington, CT 06111. Make your check out to "The ARRL Foundation" and include a note indicating the name of the fund that you are contributing to (WRTC USA Youth Fund, in this case). All contributions of $25 USD or more will be recognized in *QST*.

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