An 80-Meter LPMA: A Design Idea and a Modeling Dilemma
Part 2. The Adequacy of the LPMA Design

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Everything that has been said so far about the 10-element 3.5-4.0 MHz LPMA design, whether using 1, 2, or 3 arrays, is based upon models in NEC-4 using a MININEC ground. The use of NEC-4 is not essential, since the same results appear using NEC-2. Unfortunately, the requirement to use a mathematical phase line precludes modeling the array wholly in MININEC 3.13, since public domain MININEC does not have the TL facility. Physically modeling the transmission line would require an exceptional number of segments, since the number of right-angle junctions would be very high.

However, the real question that we must raise is whether the MININEC ground is adequate to provide an accurate model whose performance can be transferred to a physical antenna. On the surface, the LPMA has none of the features previously identified as invalidating the use of a MININEC ground. (A study of such invalidating factors appeared in the *National Contest Journal* series on "Some facts of Life About Modeling 160-Meter Vertical Arrays" during 2000 and 2001.) All of those array types that resulted in faulty MININEC-ground models used elements that were not completely vertical. They had to one or another degree a horizontal component to their radiated fields, and at close proximity to ground, the performance reports were erroneous.

In contrast to the faulty models, the 80/75-meter LPMA consists of entirely vertical elements. Since the phase line is a mathematical and not a modeled physical entity, it does not modify the radiation patterns except by current magnitude and phase variations of predictable sorts. Consequently, the model based on the use of a MININEC ground should be reliable.

Whatever we may expect at first sight, there is a test that we can make to determine whether or not the MININEC-ground model provides enough confidence for us to build the LPMA (assuming that we have the resources to build it). For every adequate MININEC ground model, there is a purely NEC-4 model that uses a buried ground plane/radial/grid system that achieves results that are very closely akin to those reported by the MININEC-ground model. For example, consider monopole that is 1/4 wavelength long at 2 MHz and intended for use until it is about 5/8 wavelength long at 5 MHz.

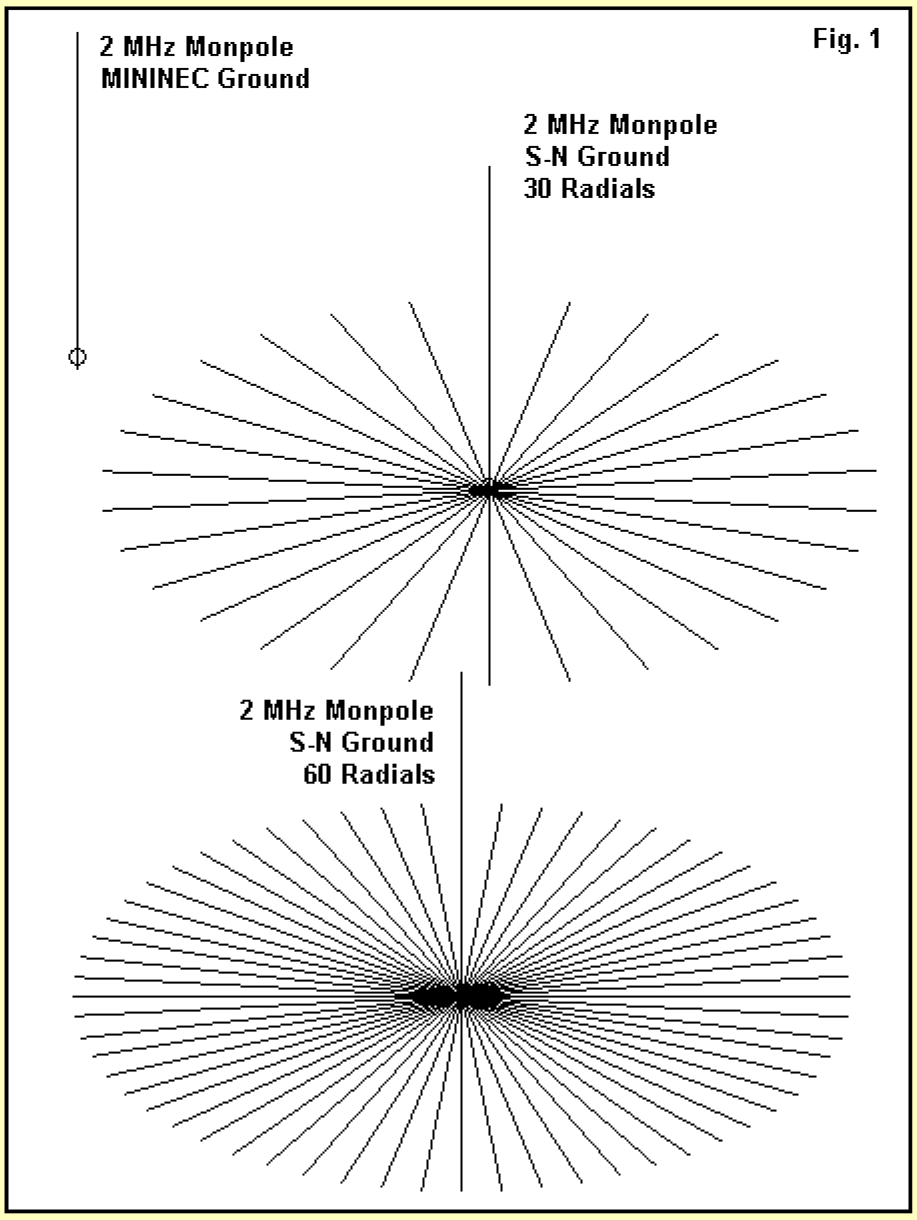


Fig. 1 shows the outline of a monopole for 2-5 MHz (where its height varies from 1/4 wavelength to 5/8 wavelength). The monopole is 118' tall and 6" in diameter to simulate a tower structure. The monopole was run on NEC-4 over a MININEC ground and over a Sommerfeld-Norton ground with radials buried 0.5' beneath the ground surface using recommended modeling techniques. Radial systems of 30 and 60 125'-radials of 0.1" diameter were tested. Throughout, the ground quality was set at "good" (cond.: 0.005 S/m; D.C.: 13). Since take-off angles did not vary at any given frequency by more than 1 degree between the two ground systems, they are omitted from the following table of results. As the table shows, when compared to the MININEC-ground results, the results for the NEC-4 buried radial systems are very sensible--and vice versa.

Monopole Performance

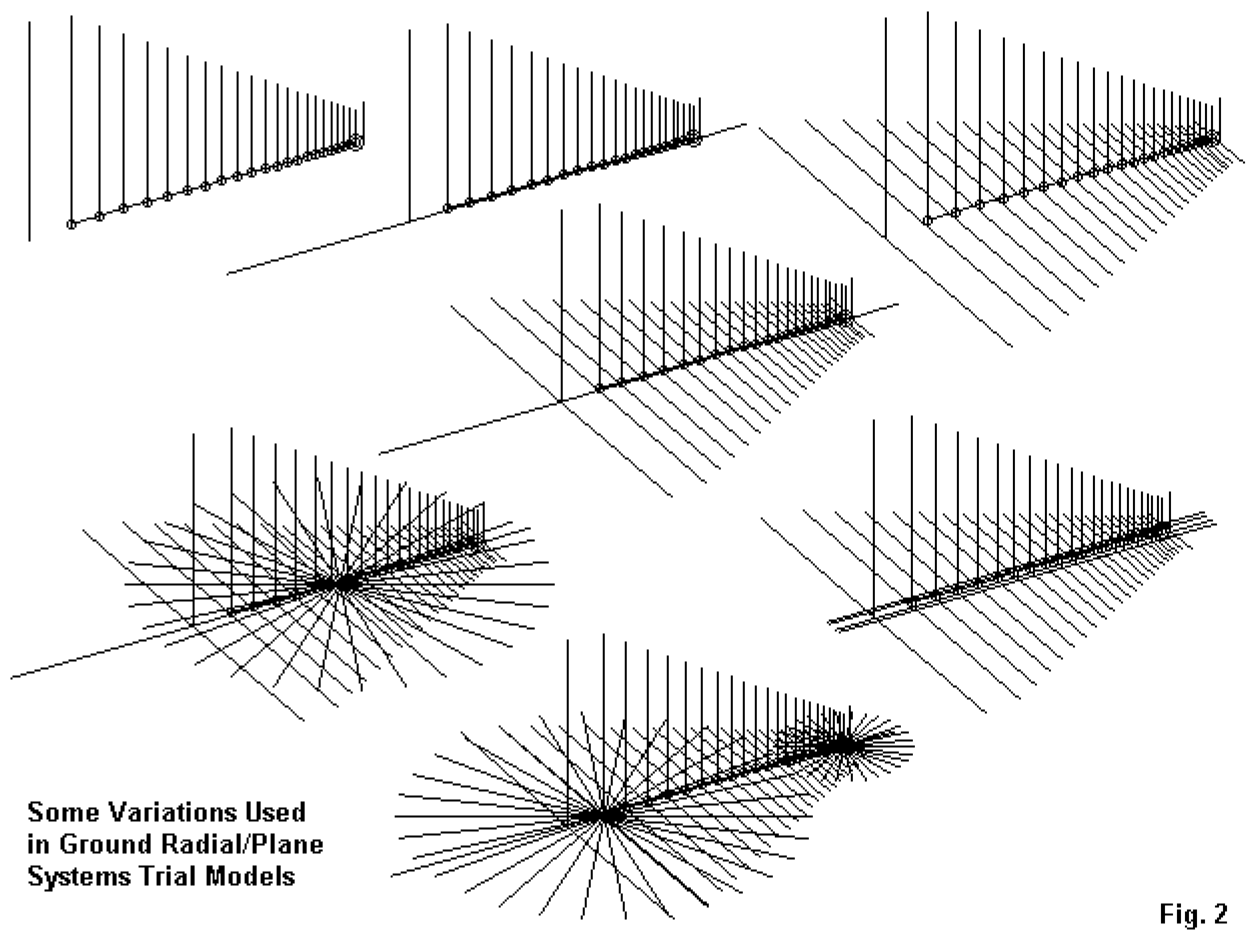
1. 2-7 MHz 118' monopole

Freq.	a. MININEC ground Gain	Source Z	b. S-N Ground, 30 radials Gain	Source Z	c. S-N Ground, 60 radials Gain	Source Z
2	1.31	36 + j 2	0.94	41 + j 10	1.25	37 + j 8
3	0.66	175 + j287	0.75	245 + j319	1.04	232 + j325
4	0.44	1064 - j 85	0.70	672 - j489	0.93	658 - j493
5	1.00	118 - j318	0.68	78 - j251	0.77	79 - j252

The progression shows a few notable variations from a fully adequate correlation of MININEC and buried-radial models. The S-N radial systems show a consistent increase in gain and a consistent reduction of the resistive component of the feedpoint impedance with the increase in the size of the radial system. In short, the S-N buried radial model is capable of showing the decreasing ground losses with increases in the field size, in contrast to the single value returned by the MININEC-ground model. Moreover, the changes in gain with changes in frequency are not completely consistent between the MININEC ground and the S-N radial systems. For the test monopole, the gain progression is steadily downward from the low frequency to the high. The MININEC system is variable.

It appears that the MININEC ground system is based throughout on image calculations whenever the lower end of an element has a Z-axis value of zero, that is, touches the ground. Impedance with a MININEC ground is always calculated for a perfect ground. It appears that with a MININEC ground, gain and other performance figures are also calculated for a perfect ground--which uses image techniques--and then adjusted for wire and ground quality losses. In contrast, when not using a perfect ground but instead using the Sommerfeld-Norton system, NEC-4 calculates the actual ground losses entering into the antenna performance. Hence, although the MININEC ground system and calculating technique provides a ballpark estimate of values for a highly refined radial field (more than about 70 radials), its performance calculating technique falls short of perfection relative to modeling a full buried radial system. However, the MININEC values are sufficiently close to those emerging from the large radial systems to account the simplified model adequate for many purposes.

When I started work on the 80-meter LPMA, I was also working on designs for larger LPMAs, larger in terms of the number of elements (17-24), larger in terms of frequency range (2 to 7 MHz), and larger in terms of overall size (boom length: 220'). Arrays of this size almost defy efforts to provide buried ground radial, grid, or treatment systems, since the number of segments required can easily run to 10,000 or more. Consequently, the search for a simplified system to serve the entire array was a natural direction of effort.



Some Variations Used in Ground Radial/Plane Systems Trial Models

Fig. 2

Fig. 2 shows some of the configurations explored. The results of none of the systems were anywhere close to satisfactory. No buried radial model in the sequence has approached closely the performance predictions supplied by the MININEC-ground model of an LPMA. Depending upon the buried ground system design, gain has ranged from 2 to 10 dB below values reported with a MININEC ground. In fact, the monopole model shown earlier as an example of good coincidence between MININEC-ground and buried radial results provides more gain in the 3.5-4.0 MHz region than do any of the buried-radial LPMA models that I tried.

The following table summarizes only some of the trial models. It will be useful to help isolate a few of the temptations that proved simply not to work.

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Reference Table of Gain Ranges with Types of Ground Systems

No.	System Type	Gain Range dBi 1.8 MHz	Gain Range dBi 7.3 MHz
1	No radials, S-N ground	2.88	1.02
2	Pair of radials, same length as elements, 2 per element (called SW for "side-wires" in further entries), 1' deep	-6.20	-15.55
3	Revised SW system, with 1' feed segment per element	-6.06	-15.48
4	System 3 with tapered segment length elements	-6.40	-15.84
5	System 4 with 4' spaced longitudinal grid lines at 1.5'	-2.03	-17.73
6	System 4 with a connecting line between SW junctions (Note: variations of this system with extensions beyond towers yielded no better results.)	-0.40	- 5.49
7	Single buried wire connecting elements 1' below ground	-5.12	-11.98
8	System 6 with a centered radial system at -1.5' of 30 140' radials	0.27	- 5.43
9	System 6 with 2 sets of 30 radials: 140' set at 82' mark, 47' set at 214' mark (most active elements at 1.8 and 7.3 MHz, respectively)	0.32	- 4.13
10	System 9 radial sets connected to nearest SW junction	0.96	- 4.52
11	SW system only, all wires elevated 1' above ground	0.58	0.53
12	SW system only, towers touch ground, phased elements elevated 1'	1.21	- 0.35

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The attempt to provide "side-wires" for each element is a natural temptation. The spacing of wires in the array does not permit full radial systems at the same level without a multitude of intersections. Indeed, it is difficult to provide any given element in the array with more than one radial without intersections among the radials that are not at perfect right angles to the boom line. None of these systems yielded worthy results. One temptation that seemed to improve results slightly was running a buried model wires between the intersections of the side-wires along the boom line. In fact, this line would ultimately prove more problematical as the correct solution to the problem emerged.

Combining side-wires with spot radial systems had some ameliorative affect on the array gain. However, the array gain appeared to peak in certain frequency regions and to decline rapidly in others. System 10 proved the most promising, although better results would be needed.

To achieve better results, it would be necessary to initially work with a smaller model. The 24-element LPMA that defied simplified buried radial systems was replaced with a version of the 80/75-meter LMPA in Part 1. The model used had only the 8 0.1" diameter elements and omitted the 2 parasitic support towers. For the validation work at hand, it was considered legitimate to presume that the 0.1" wires could be self-supporting. The following model description provides the essential physical and electrical details.

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80-m t=.92 s=.05 3.3-4.5 Frequency = 3.5-4.0 MHz.
Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

--------------- WIRES ---------------

Wire	Conn.	End 1 (x,y,z : ft)	Conn.	End 2 (x,y,z : ft)	Dia(in)	Segs
1		0.000, 0.000, 75.500	G	0.000, 0.000, 0.000	1.00E-01	27
2		15.494, 0.000, 69.500	G	15.494, 0.000, 0.000	1.00E-01	25
3		29.771, 0.000, 64.563	G	29.771, 0.000, 0.000	1.00E-01	23
4		42.928, 0.000, 60.000	G	42.928, 0.000, 0.000	1.00E-01	21
5		55.050, 0.000, 55.500	G	55.050, 0.000, 0.000	1.00E-01	19
6		66.221, 0.000, 51.500	G	66.221, 0.000, 0.000	1.00E-01	17
7		76.515, 0.000, 48.000	G	76.515, 0.000, 0.000	1.00E-01	17
8		86.000, 0.000, 44.500	G	86.000, 0.000, 0.000	1.00E-01	15

-------------- SOURCES --------------

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	15	8 / 96.67	(8 /100.00)	0.707	0.000	V

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/98.1	(1/100.)	2/98.0	(2/100.)	Actual dist	75.0	1.00	R
2	2/98.0	(2/100.)	3/97.8	(3/100.)	Actual dist	75.0	1.00	R
3	3/97.8	(3/100.)	4/97.6	(4/100.)	Actual dist	75.0	1.00	R
4	4/97.6	(4/100.)	5/97.4	(5/100.)	Actual dist	75.0	1.00	R
5	5/97.4	(5/100.)	6/97.1	(6/100.)	Actual dist	75.0	1.00	R
6	6/97.1	(6/100.)	7/97.1	(7/100.)	Actual dist	75.0	1.00	R
7	7/97.1	(7/100.)	8/96.7	(8/100.)	Actual dist	75.0	1.00	R

Ground type is Real, MININEC-type analysis
Conductivity = .005 S/m Diel. Const. = 13

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The performance of the array with a MININEC ground can be summarized by using 3.5, 3.75, and 4.0 MHz checkpoints. In the following table, TO angle is the elevation angle of maximum radiation. The front-to-rear ratio is the worst case ratio of gain forward to rear taken from an elevation plot. The 180-degree front-to-back ratio is taken from an azimuth plot at the TO angle. The beamwidth refers to the angle between -3 dB points on the azimuth pattern. The 75-Ohm phase line yield a reasonable match for 50-Ohm coaxial cable and the 50-Ohm SWR is given in the last column.

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8-Element 80/75 MHz LPMA with MININEC Ground

Freq. MHz	Gain dBi	TO deg	F-R Ratio dB	F-B Ratio dB	B/W deg	Feed Z R+/-jX	50-Ohm SWR
3.5	4.44	22	16.11	18.97	132	50.3-j 3.5	1.07
3.75	4.12	22	13.80	15.32	136	54.7+j 4.4	1.13
4.0	4.39	22	16.59	19.94	128	44.7-j 6.5	1.20

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In attempting to validate this model, it is not necessary to produce the exact figures. However, the patterns and general levels should be consistent with the values given. For example, the model shows a small gain decline mid-band, accompanied by a similar small decline in the F-R and F-B values. The mid-band region also shows a rise in the resistive component of the feedpoint impedance.

Providing this model with sundry simplified ground-treatment systems all failed to yield acceptable results. For example, placing a single 60-radial buried system beneath the array, using 140' radials and a connection to the center element of the LPMA yielded no better gain -1.84 dBi and that only at one frequency. The key move was proving 3 radial systems of differential lengths connected to the end and the middle elements. Gain rose to a peak of 1.34 dBi, but again, only at one frequency.

The key to a satisfactory radial system for the array did not arise from the differential radial lengths used in the last trial, but from the connections to elements. The more elements that had a radial system directly and independently tied to them, the better the response. Hence, the final system provided an independent radial system for each element in the array.

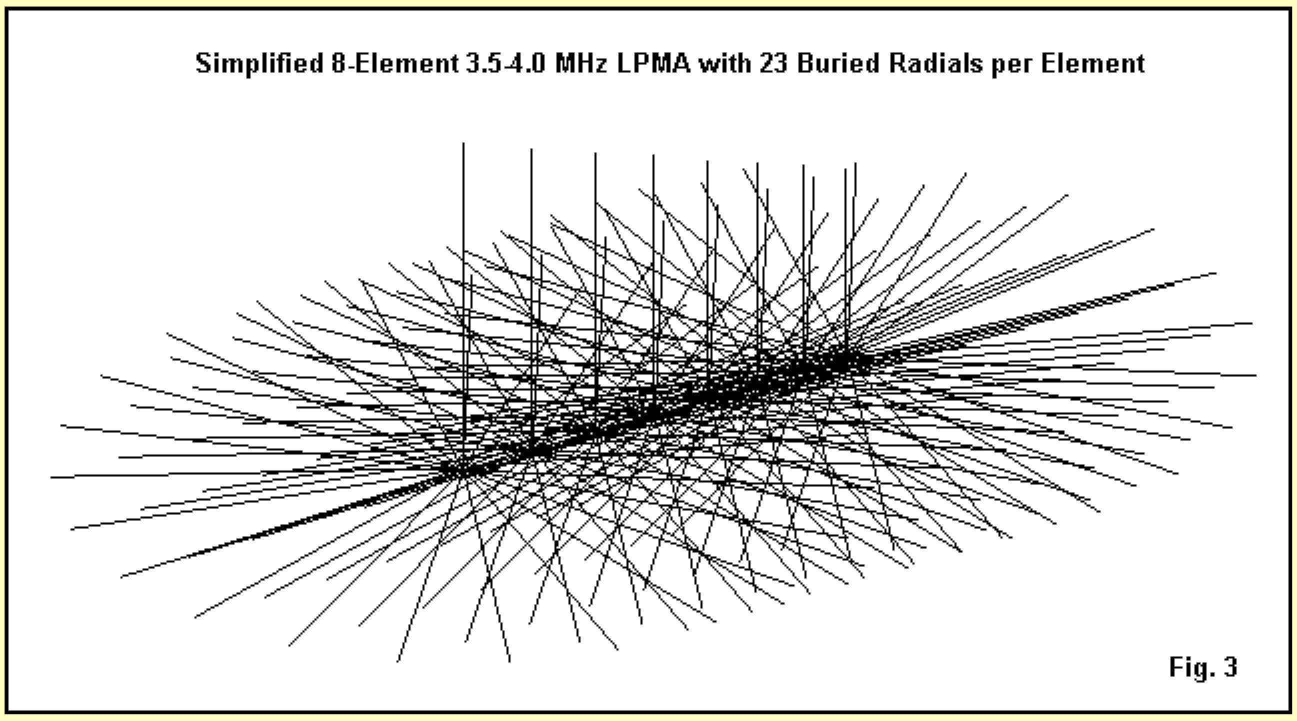
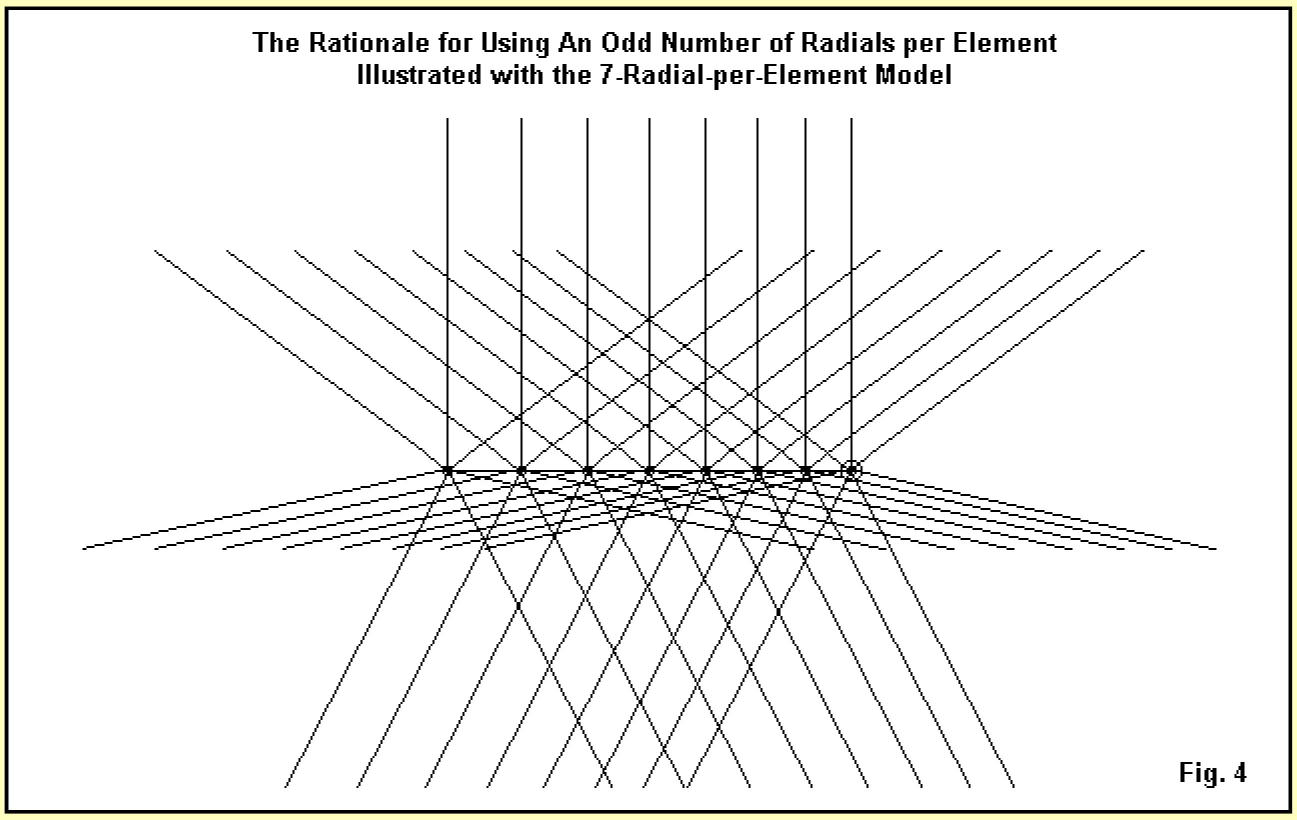
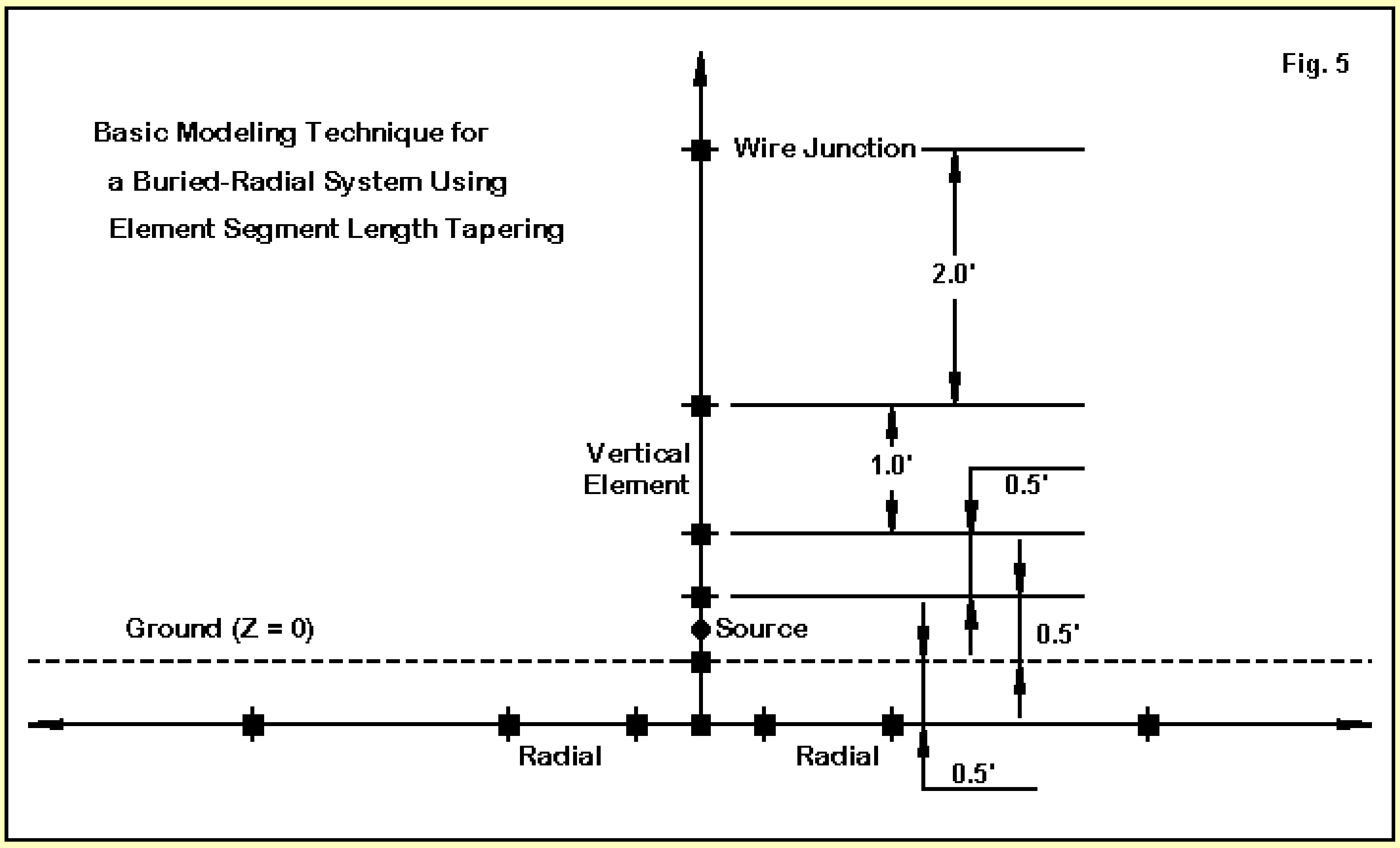


Fig. 3 shows the outline sketch of the largest model in the final test group, with 976 wires and 2690 segments. However, it only achieves 23 radials per element. In fact, the radial systems themselves are interesting in terms of the techniques used to ensure their independence, where independence means that no wire from one system touches a wire from another system. The 8 individual radial systems are at different levels, separated by 3". This technique held the lowest level, used for the rear element, at the 2' level below ground. Other test models have shown that in the lower HF region, there is insignificant difference among models with buried radials in the 6" to 24" range below ground.

Since each radial system has a connecting wire to the element that it serves, it was necessary to ensure that no radial passed though a connecting wire. Therefore, I chose to use an odd number of radials, beginning with a set of 7 per element, as shown in **Fig. 4**.



By setting the initial radial at right angles to the boom line, all of the subsequent radials would take angles so that none would be parallel to the boom. By increasing the sequence in 8-radial steps (7-15-23-31-etc.), the same condition would exist and avoid model crashes.



Modeling a buried radial system requires adherence to several NEC guidelines which will explain the modeling structure shown in **Fig. 5**. A segment junction--usually a wire end-- must be a Z=0, that is, at ground level. Since the connector wires to the radials would be short, and since angular junctions are best served by segment lengths that are equal, a form of segment length tapering for the radials was in order. As well, the segments on either side of the source segment should equal the length of the source segment. For a vertical element, the source (or phase line connection for an LPMA) should be on the lowest segment. To achieve this and to have the first segment above the source segment be of the same length, a separate "source wire" was constructed, with the vertical element above that point also tapered in terms of segment length.

The resulting model results in wire junctions quite different from those of the MININEC model. Therefore, a second MININEC-ground model was constructed with the elements tapered exactly as they would be in the buried-radial model. The results are extremely close to the version using standard segmentation techniques.

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8-Element 80/75 MHz LPMA with MININEC Ground (Segment Tapered Elements)

Freq. MHz	Gain dBi	TO deg	F-R Ratio dB	F-B Ratio dB	B/W deg	Feed Z R+/-jX	50-Ohm SWR
3.5	4.48	22	16.10	18.98	132	49.7-j 3.7	1.08
3.75	4.17	22	13.79	15.30	136	54.2+j 3.9	1.12
4.0	4.44	22	16.59	19.96	128	44.2-j 6.6	1.21

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The only differences occur in the last decimal column for any entry, indicating a very tight correlation with the original model.

The buried radial model was run using 7, 15, and 23 radials per element. These runs produced interesting results, and further runs with higher numbers of radials per element would be useful. However, the run time increases exponentially with increases in wires and segments, so tests were limited to data gathering that required less than 1.5 hours per check point. (We shall see an indirect validation technique shortly.) The results for the runs are in the following table.

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8-Element 80/75 MHz LPMA with 7 Buried Radials per Element

Freq. MHz	Gain dBi	TO deg	F-R Ratio dB	F-B Ratio dB	B/W deg	Feed Z R+/-jX	50-Ohm SWR
3.5	0.87	22	13.75	15.07	135	48.5-j 1.4	1.04
3.75	0.99	22	15.80	18.26	130	54.8-j 4.7	1.14
4.0	1.34	23	14.91	15.95	129	45.3-j 2.5	1.12

8-Element 80/75 MHz LPMA with 15 Buried Radials per Element

Freq. MHz	Gain dBi	TO deg	F-R Ratio dB	F-B Ratio dB	B/W deg	Feed Z R+/-jX	50-Ohm SWR
3.5	2.81	22	13.38	14.51	138	50.5-j 2.7	1.06
3.75	2.98	22	13.98	15.49	135	59.2-j 4.7	1.21
4.0	3.30	23	14.44	15.56	133	45.3-j 1.6	1.11

8-Element 80/75 MHz LPMA with 23 Buried Radials per Element

Freq. MHz	Gain dBi	TO deg	F-R Ratio dB	F-B Ratio dB	B/W deg	Feed Z R+/-jX	50-Ohm SWR
3.5	3.53	23	12.99	14.03	140	51.1-j 4.2	1.09
3.75	3.61	23	13.25	14.41	137	60.4-j 1.6	1.21
4.0	3.85	23	14.42	15.59	133	45.8-j 1.5	1.10

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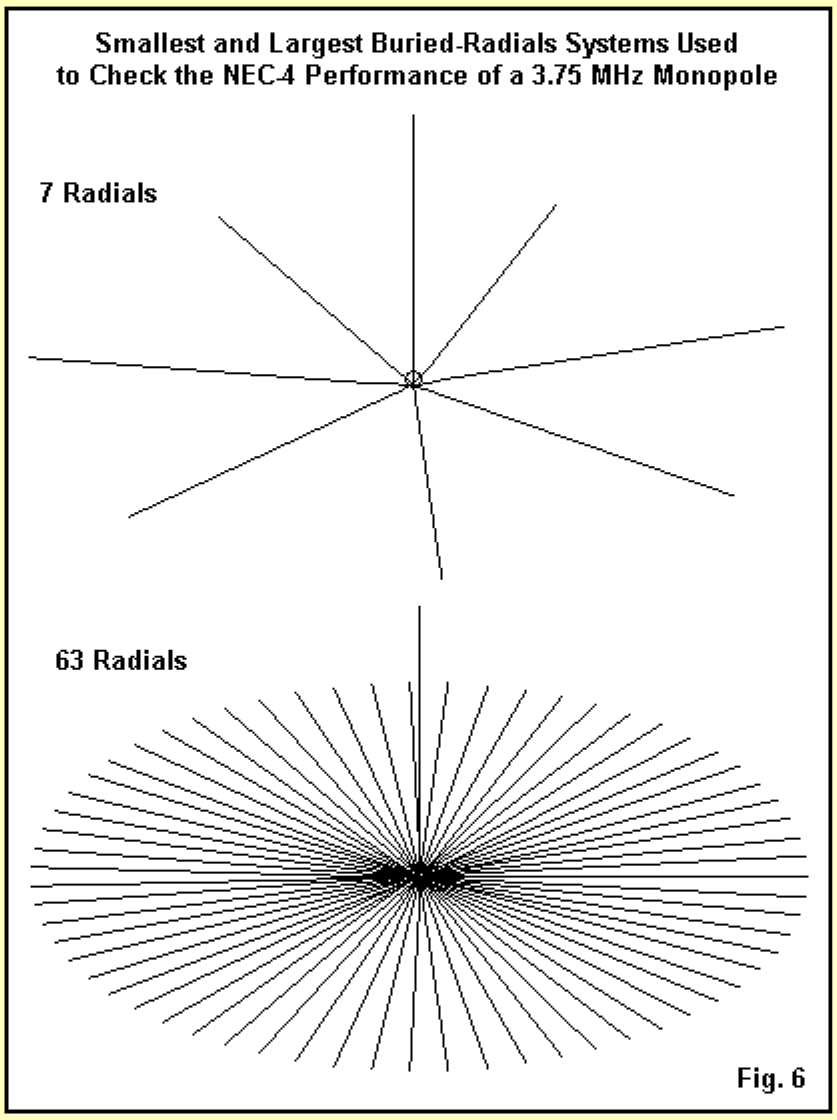
The progression of values with increasing numbers of radials per element is promising, and the impedance values are especially attractive, since even with the lowest number of radials per element, they track the MININEC model very closely. Performance has smoothed out across the passband of the array to a level that is not only higher, but is as well more equal at every checkpoint than in any of the simplified ground treatments. The question that remains is whether there is a radial count level per element that will likely yield array results equal to or better than those predicted by the MININEC model.

By fiat, I declared the 23-radial system to be the largest that I would run with the full 8-element array. This foreclosed direct determination of an answer to the remaining quandary. However, there is an indirect route to an answer. I modeled a simple monopole for 3.75 MHz using radial systems in increments of 8 but starting with 7. **Fig. 6** shows the smallest (7 radials) and the largest (63 radials) of the sequence. Each monopole and radial system used the same structure as an individual element in the LPMA model.



The following table summarizes the results of the test model.

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3.75 MHz Monopole Performance with Various Radial Systems

No. of Radials	Gain dBi	TO Angle degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
7	-1.08	24	54.8 + j 16.2	1.38
15	-0.25	25	46.5 + j 13.1	1.33
23	0.13	25	43.1 + j 11.9	1.34
31	0.36	25	41.1 + j 11.2	1.37
39	0.51	25	39.7 + j 10.6	1.39
47	0.61	25	38.7 + j 10.2	1.41
55	0.69	25	37.9 + j 9.8	1.43
63	0.74	25	37.3 + j 9.4	1.44

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The model surpasses a MININEC-ground version of the monopole in gain at the 39-radial level and equals it in impedance at the 63-radial level.

By examining the rate of change of the monopole figures throughout its range of radial systems, we can project similar rates of change to the progression of LPMA values, using average gain values for the entire array passband. The result is a projection of values above the level of radial systems explored directly.

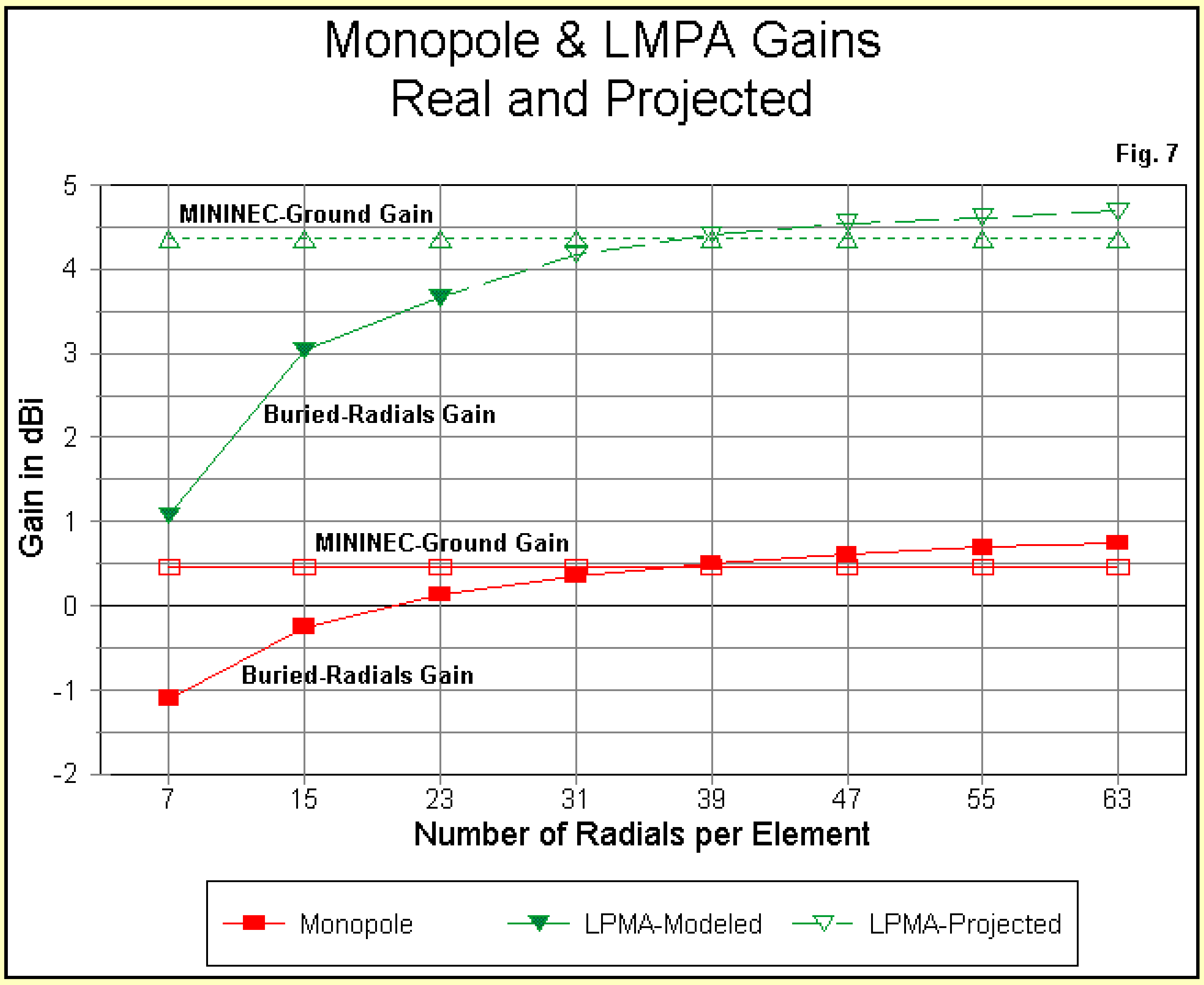

Fig. 7 provides a graph of the monopole values, the combined LPMA direct and indirect values, and reference lines for the predicted MININEC-ground models for both antennas. The LPMA projection values should be read with caution, since a number of real antenna variables may intervene to deny the array its ultimate performance levels. Obtaining the highly complex field of radials for the LMPA is a construction challenge several orders of magnitude greater than that associated with layout radials for a single monopole.

Nevertheless, the modeling and derivation techniques do establish some useful points. First is the fact that the MININEC-ground LPMA can be realized with a buried radial system. However, that system may be more extensive and of a nature not fully appreciated before this exercise. Each element needs to be supplied with a radial system of its own, independent of the radial system serving other elements. At this point, it is not certain whether one can use an interlocking grid where the radial wires make good electrical contact, although the model suggests that electrical independence is the best method so far obtained.

Second, the radial system for each element will have to be fairly extensive to obtain more than mediocre performance from the LPMA. About 39 radials per element seems called for by the model for average to good soil (conductivity: 0.005 S/m; dielectric constant: 13). Worse soils will call for more extensive radial systems per element. A full field, as defined by the AM broadcast industry, would not be out of place for a serious installation of the LPMA. It is likely that poor performance from any lower-HF LPMA can be traced primarily to a poor ground treatment system (with room for poor-design causes as an additional factor).

The use of a MININEC ground in a model, then, is legitimate and the general performance predicted by such a model can be obtained. However, the cost in terms of modeling and especially in terms of required construction is very high. Consider the following alternatives. We examined a fixed-position horizontal LPDA of the same general design as the LPMA. To arrive at roughly equivalent performance levels, The LPDA would need to by 90-100 feet high, requiring 4 support towers, appropriate non-conductive support cables, and sundry materials. The comparable LPMA would require only 2 towers, but complex and extensive treatment of the ground at the element bases. Which option might be best for a given installation makes an interesting thought project.

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