Special Purpose NVIS Antennas

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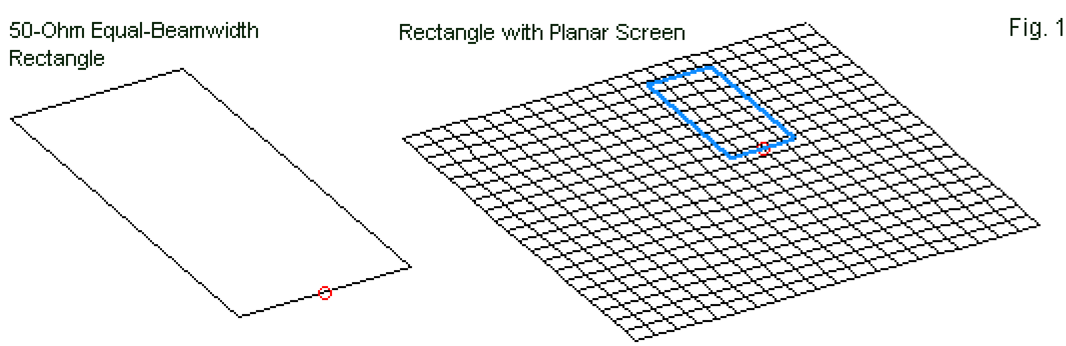
Not all NVIS missions are the same, and so not all antenna requirements are the same. In this set of notes, we shall examine a few of the special requirements that some missions might impose upon antennas and look at a few samples ways to fulfill the needs. Not all of the antennas that we shall explore fall in the category of basic NVIS antennas, but they are all buildable by experienced radio amateurs.

We shall, somewhat arbitrarily, divide the effort into three sections. The first part of our work will be to design a good NVIS antenna that has as circular a pattern as possible. In other words, the beamwidth ratio will be within the limits from 0.9:1 to 1.1:1. Our goal will also be to ensure that the zenith gain of the antenna matches or exceeds the gain of a dipole at the same height above ground. The second section will explore ways of maximizing zenith gain regardless of the beamwidth ratio. Ultimately, we shall aim for a gain of perhaps 12 dBi over average ground, compared to a dipole's maximum zenith gain of about 6.4 dBi over the same ground.

A perfectly vertical pattern is not always the best fit for a station's mission. In the third and final part of our work on special purposes NVIS antennas, we shall examine some ways in which we might reliably tip the pattern of a NVIS antenna in a desired direction while maintaining adequate zenith gain. In fact, we shall begin with a tempting proposal that simply does not work. Then we shall examine a few workable ideas, exploring along the way the parameters of any antenna that we might use to do the job. As always, the final part of this set of notes is in no way the final word on the many possibilities for NVIS antennas.

Nearly Perfectly Circular NVIS Pattern Production

Suppose that the NVIS mission includes a requirement for a perfectly circular pattern in which the broadside and endwise beamwidths are the same—or as close to the same as we may achieve. The lowest value of beamwidth ratio achieved by any of the basic antennas was about 1.25:1 for some of the square loops. Still, that value is far from the 1:1 goal of the present hypothetical requirement. We can do better. **Fig. 1** outlines a relatively basic way to attain the desired beamwidth ratio, increase zenith gain, and provide a direct match to the standard 50-Ω amateur feedline. We simply create a rectangle, fed on a narrow side, either alone or with a ground-level screen.



General Outline of a Special-Purpose Rectangular 1-Wavelength Loop

The development of vertically and horizontally polarized rectangular antenna shapes has a long history, and we may easily adapt those designs to NVIS service by laying out the wires parallel to the ground. If the ratio of long side wires to the fed wire (and its opposite) is about 2.29 to 2.30 to 1, several beneficial consequences emerge (along with one limitation as well). First and most relevant to our project, the radiation from the side wires increases, widening the beamwidth relative to the broadside beamwidth that we measure from the feedpoint through the center of the opposing wire. In fact, the suggested ratio (applicable to the AWG #14 wire antennas that we are modeling) produces a nearly perfect 1:1 ratio, depending upon the antenna height and the ground quality beneath the antenna. **Fig. 2** shows a set of typical patterns for a rectangle with the specified dimensions.

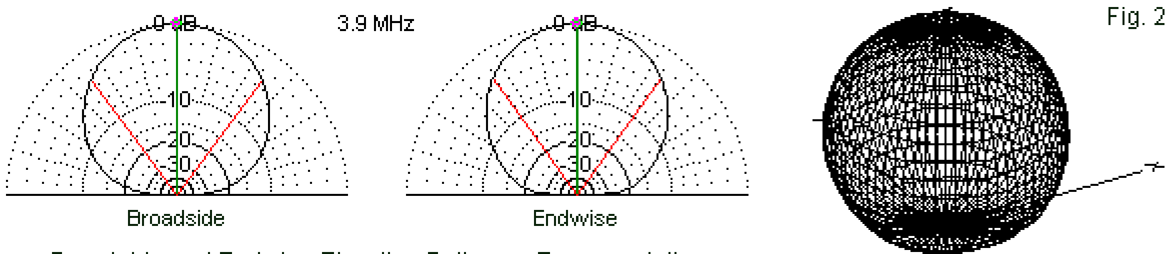


Fig. 2

Broadside and Endwise Elevation Patterns: Representative 50-Ohm Equal-Beamwidth NVIS Rectangle

The broadside and endwise elevation patterns are virtually indistinguishable. The 3-dimensional version of the radiation pattern is about as close to a sphere as one may achieve with a ground-based antenna system. The second consequence of constructing a rectangle of the suggested dimensions and fed at the center of one of the short wires is that the feedpoint impedance changes its value relative to the impedance value for a square loop. Instead of an impedance level greater than 100 Ω at resonance, the impedance value decreases as we elongate the rectangle. At the proportions necessary for a circular pattern, the feedpoint impedance is approximately 50 Ω, the value we need for our coaxial cable.

The third consequence of elongating a square loop into a rectangle is increased zenith gain for the 1-λ loop. (Like square loops, the rectangle will actually have a circumference that is slightly greater than 1-λ at resonance. The circumference values for our samples will be between 1.03 λ and 1.033 λ.) In NVIS service, the additional gain may not be enough to be truly decisive in deciding to install a rectangle. However, the combination of advantages may have more weight than the simple sum of the three individually.

An AWG #14 copper wire rectangle for 75 meters will require side wires about 0.358-λ long, with end wires about 0.157-λ long. For the numerical data in **Table 1**, I first resonated the loop at a height of 0.175-λ above average ground and then sought the height of maximum zenith gain over our three standard soil varieties: very good, average, and very poor. (See the first set of notes for soil quality specifications in terms of conductivity and relative permittivity.) For each soil quality, I recorded the zenith gain, beamwidths, and feedpoint impedance between 0.145-λ and 0.235-λ above ground in 0.01-λ increments. The table indicates by italics the heights of maximum zenith gain for each soil quality. For this class of antennas, there is no difference between zenith gain and maximum gain, since the patterns are so circular. BS BW and EW BW indicate the broadside and endwise beamwidth values respectively, while the ratio is always broadside over endwise. Hence, where the endwise beamwidth is greater than the broadside value, it is possible to obtain ratios less than 1.00. The Feed R and Feed X columns show the feedpoint impedance based on the initial resonance of the sample model.

75-Meter 1-WL Rectangle							Table 1
AWG #14 Copper Wire: Circumference = 1.030 WL					3.9 MHz		
Very Good Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	36.57	8.13	68.6	69.8	0.98	39.89	10.60
0.155	39.09	8.20	69.4	70.4	0.99	42.46	9.29
0.165	41.61	8.25	70.2	70.8	0.99	45.04	7.91
0.175	44.13	*8.27*	71.1	71.6	0.99	47.58	6.42
0.185	46.66	*8.27*	72.1	72.4	1.00	50.03	4.82
0.195	49.18	8.25	73.2	73.2	1.00	52.38	3.08
0.205	51.70	8.21	74.5	74.2	1.00	54.60	1.20
0.215	54.22	8.16	75.8	75.2	1.01	56.65	-0.81
0.225	56.74	8.09	77.4	76.6	1.01	58.51	-2.95
0.235	59.27	8.00	79.1	77.8	1.02	60.17	-5.20
Average Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	36.57	7.03	70.9	70.6	1.00	45.66	5.10
0.155	39.09	7.18	71.7	71.0	1.01	47.32	3.50
0.165	41.61	7.29	72.7	71.4	1.02	49.02	1.92
0.175	44.13	7.36	73.6	72.0	1.02	50.73	0.32
0.185	46.66	7.41	74.7	72.6	1.03	52.40	-1.33
0.195	49.18	*7.42*	76.1	73.4	1.04	54.00	-3.04
0.205	51.70	*7.42*	77.4	74.4	1.04	55.50	-4.82
0.215	54.22	7.39	79.0	75.4	1.05	56.88	-6.68
0.225	56.74	7.34	80.7	76.4	1.06	58.11	-8.60
0.235	59.27	7.27	82.7	77.8	1.06	59.19	-10.59
Very Poor Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	36.57	5.77	74.8	72.8	1.03	49.94	-4.70
0.155	39.09	5.95	75.8	72.8	1.04	50.54	-6.22
0.165	41.61	6.09	76.8	73.0	1.05	51.23	-7.65
0.175	44.13	6.20	78.0	73.2	1.07	51.97	-9.02
0.185	46.66	6.27	79.2	73.6	1.08	52.72	-10.38
0.195	49.18	6.31	80.8	74.2	1.09	53.45	-11.74
0.205	51.70	*6.33*	82.3	74.8	1.10	54.14	-13.11
0.215	54.22	*6.33*	84.0	75.6	1.11	54.77	-14.50
0.225	56.74	6.30	85.9	76.6	1.12	55.31	-15.91
0.235	59.27	6.24	88.1	77.6	1.14	55.77	-17.34

At 3.9 MHz, for all soil types and without the field adjustments that would bring the feedpoint impedance to resonance, the radiation pattern is circular within about 10% or better at the heights of maximum gain. Only over very poor soil would adjustments to resonate the rectangle at precisely 50 Ω likely increase the beamwidth ratio from the listed figure.

Fig. 3 provides a graphic view of the gain curves for the three soil qualities. They are quite shallow and selecting a mounting height that differs a bit from the optimum height would yield undetectable differences in performance. In fact, the optimum heights for maximum zenith gain for the rectangle are uniformly slightly higher (by about 0.01-λ) than those for the square loop. We may note in passing that the fed wire and the opposite wire are significantly farther apart in the rectangle than the corresponding wires are in the square loop. Although not very significant relative to building a loop, this fact will take on more importance when we examine other types of antennas in these notes. We should remember that we may analyze the square loop and the rectangle as two dipoles in phase, bent so that the ends join at the center of the side wires.

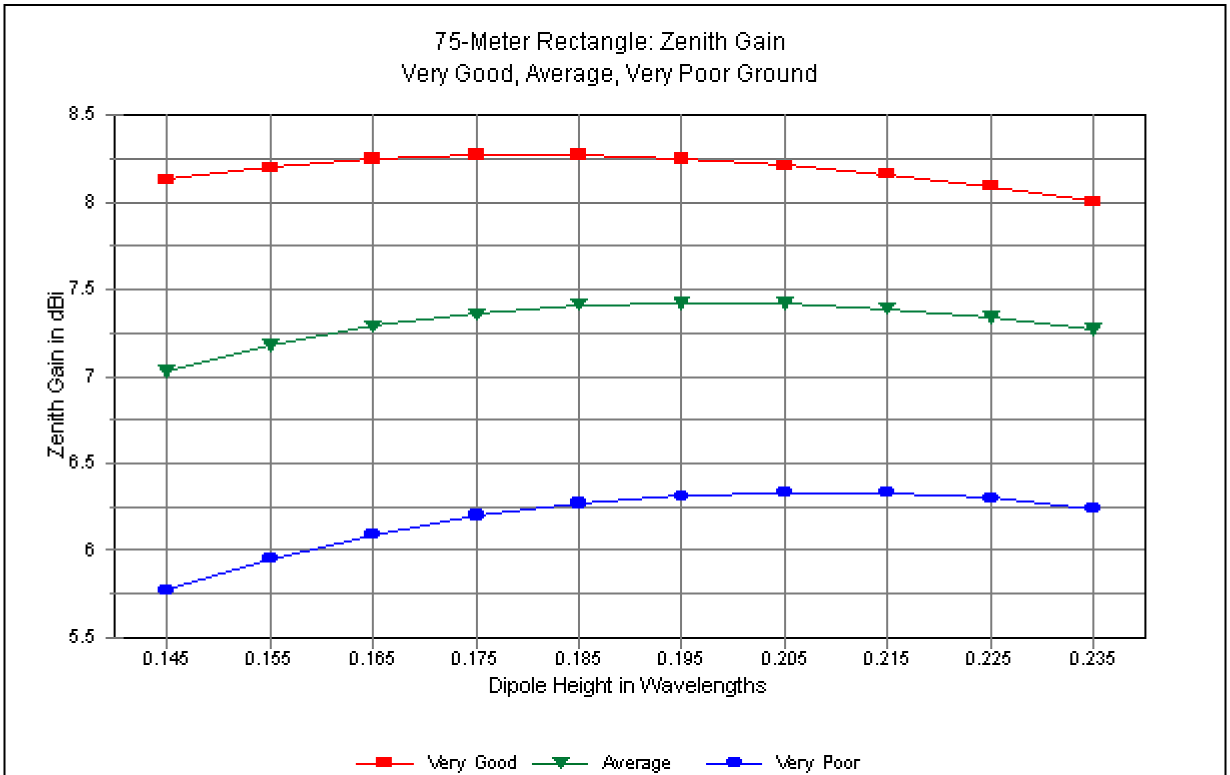


Fig. 3

Besides having circular patterns and 50-Ω feedpoint impedance values, rectangles also show very good gain over each soil type. However, they have one limitation relative to a square loop. The SWR bandwidth is much narrower. **Fig. 4** shows overlaid SWR curves relative to the respective resonant impedance of a square loop and a rectangle. The 2:1 bandwidth is about 1/3 the width achieved by the square loop. As a consequence, the rectangle will likely require considerably more field adjustment effort than a dipole or square loop.

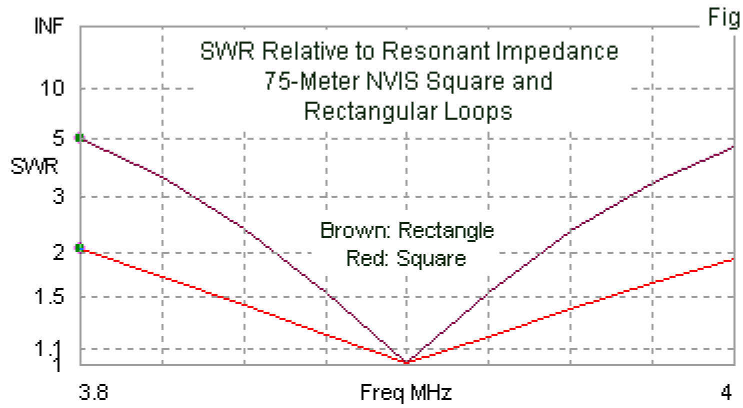


Fig. 4

We may retrace our steps on 40 meters (7.2 MHz) to assure ourselves that the trends that apply to 75 meters are quite general. **Table 2** provides data over the same span of heights (in wavelengths) and the same soil types that we applied to 75 meters. Because ground losses at 40 meters are slightly higher than at 75 meters, we expect a slight reduction in gain values for comparable heights. The rectangle is 0.36-λ by 0.157-λ using AWG #14 copper wire.

40-Meter 1-WL Rectangle							Table 2
AWG #14 Copper Wire: Circumference = 1.033 WL					7.2 MHz		
Very Good Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	19.81	7.94	69.0	70.0	0.99	40.59	11.56
0.155	21.17	8.03	69.9	70.6	0.99	42.91	10.13
0.165	22.54	8.09	70.7	71.2	0.99	45.24	8.65
0.175	23.91	8.13	71.5	71.6	1.00	47.54	7.10
0.185	25.27	*8.14*	72.5	72.4	1.00	49.76	5.45
0.195	26.64	8.12	73.8	73.4	1.01	51.89	3.68
0.205	28.00	8.09	75.0	74.4	1.01	53.90	1.80
0.215	29.37	8.04	76.4	75.4	1.01	55.74	-0.20
0.225	30.74	7.98	78.0	76.6	1.02	57.41	-2.31
0.235	32.10	7.89	79.7	78.0	1.02	58.89	-4.51
Average Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	19.81	6.72	71.5	70.4	1.02	44.90	4.26
0.155	21.17	6.90	72.2	70.6	1.02	46.23	2.77
0.165	22.54	7.03	73.2	71.0	1.03	47.63	1.33
0.175	23.91	7.13	74.1	71.4	1.04	49.05	-0.12
0.185	25.27	7.19	75.3	72.0	1.05	50.47	-1.60
0.195	26.64	7.22	76.6	72.8	1.05	51.84	-3.13
0.205	28.00	*7.23*	78.0	74.6	1.05	53.13	-4.72
0.215	29.37	7.22	79.4	74.4	1.07	54.33	-6.38
0.225	30.74	7.18	81.1	75.6	1.07	55.42	-8.09
0.235	32.10	7.12	83.0	76.8	1.08	56.36	-9.86
Very Poor Soil							
Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
0.145	19.81	5.56	74.9	72.6	1.03	46.91	-4.92
0.155	21.17	5.76	75.8	72.4	1.05	47.44	-6.23
0.165	22.54	5.91	76.8	72.4	1.06	48.04	-7.43
0.175	23.91	6.03	77.8	72.6	1.07	48.71	-8.58
0.185	25.27	6.12	79.0	72.8	1.09	49.39	-9.70
0.195	26.64	6.18	80.3	73.2	1.10	50.07	-10.83
0.205	28.00	6.21	81.8	73.8	1.11	50.73	-11.96
0.215	29.37	*6.22*	83.4	74.6	1.12	51.33	-13.12
0.225	30.74	6.21	85.1	75.4	1.13	51.88	-14.30
0.235	32.10	6.17	87.1	76.4	1.14	52.35	-15.49

In general, the heights required for maximum zenith gain are about one step higher on 40 than on 75. In addition, they are equivalently higher than for the square loop on 40 meters. **Fig. 5** provides a graphic view of the gain curves for each soil type in the table. Like the curves for 75 meters, the 40-meter gain graphs show very slow changes in the zenith gain in the general height region of maximum gain, a fact that allows the user to vary the physical height of the antenna with no perceptible difference in operational performance.

The feedpoint impedance values remain tame in the sense that small changes of the rectangle's dimensions can easily yield a precise 50-Ω impedance. Since resonance is a function of the circumference, every modification to either the long or the short sides will require a comparable modification to the other sides. Elongating the long sides will reduce the resistive component value, while increasing the length of the short sides will raise the value. Since the amount of change for the side lengths will be small, the beamwidth ratio will not change much.

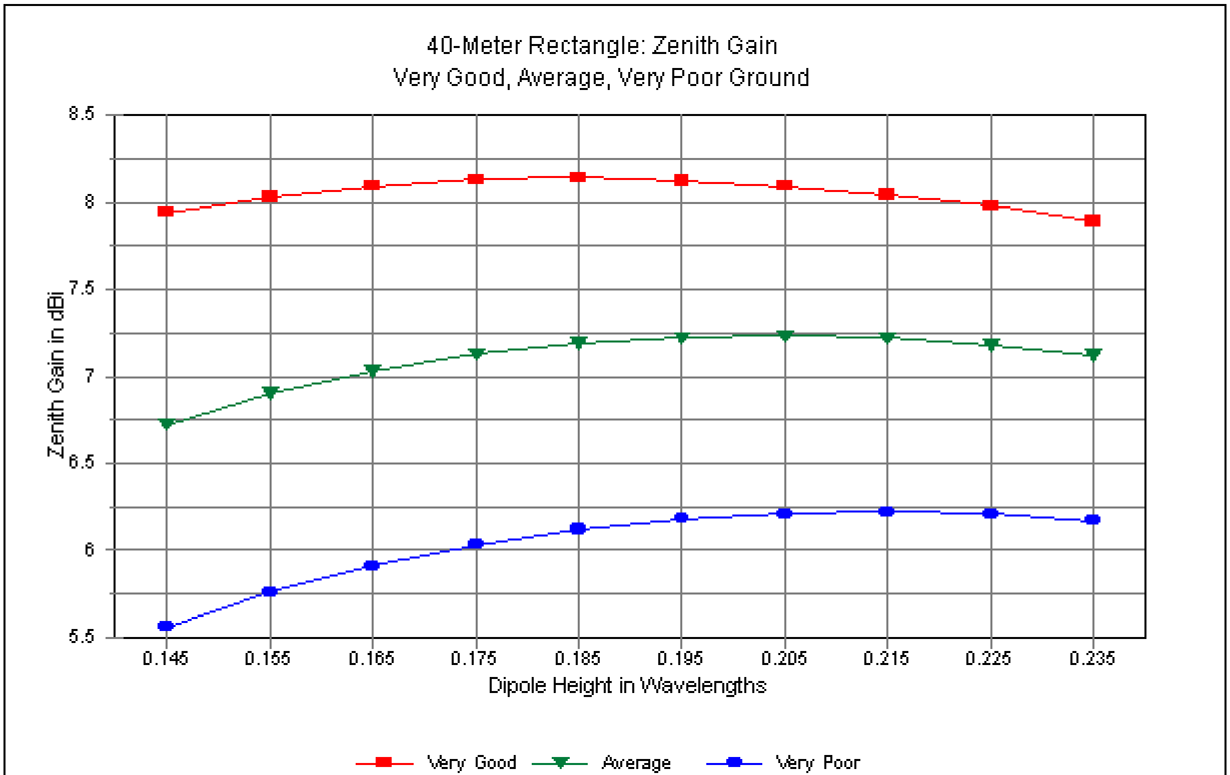


Fig. 5

Like the 75-meter rectangle, the 40-meter version also displays a narrower SWR bandwidth than a square loop, as measured relative to the resonant impedance of each type of antenna. **Fig. 6** displays the narrowing on 40 meters by superimposing loop and rectangle SWR curves. The rectangle's 2:1 SWR bandwidth is about 1/3 the value for a square loop.

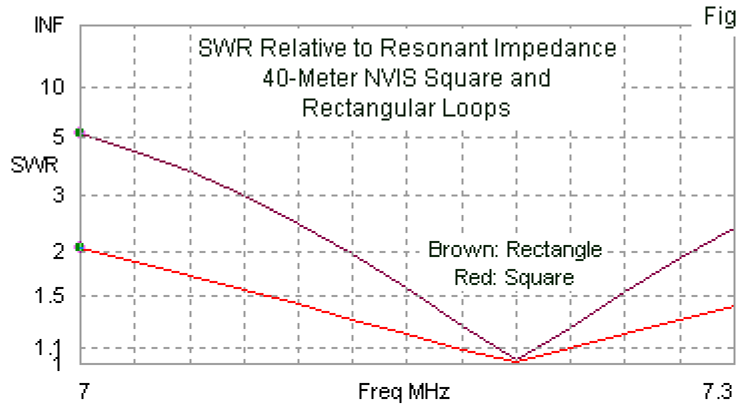


Fig. 6

The tables have shown zenith gain values that may seem high compared to those we developed in the second set of these notes for the dipole and the square loop. To confirm this impression, **Table 3** presents maximum zenith gain data for each type of antenna over each type of soil, along with the height above ground at which the maximum zenith gain occurs. The heights of maximum gain for both the dipole and the square loop are almost identical, but the rectangle requires about 0.01-λ greater height to reach maximum gain. As noted earlier, this is a fact worth remembering for the moment.

Summary of Maximum Zeith Gain Values and Heights					Table 3
Antenna	Very Good		Average		Very Poor	
	Max Gain	Height	Max Gain	Height	Max Gain	Height
	Zenith	WL	Zenith	WL	Zenith	WL
75 m						
Dipole	7.40	0.165	6.42	0.185	5.13	0.200
1-wl Loop	7.96	0.165	7.04	0.185	5.85	0.200
Rectangle	8.27	0.180	7.42	0.200	6.33	0.21
40 m						
Dipole	7.15	0.170	6.09	0.195	4.86	0.205
1-wl Loop	7.74	0.175	6.76	0.195	5.64	0.210
Rectangle	8.14	0.185	7.23	0.205	6.22	0.215
Notes:	Max Gain Zenith = maximum zenith gain in dBi					
	Height WL = maximum zenith gain height in wavelengths					

The rectangle provides an added increment of gain over the square loop with any soil type. The increment is not as great as the increment of the square loop over the dipole. However, the rectangle provides an average of about 1 dB higher gain than the dipole when both are at optimal heights above ground. The increase is highest over very poor soil and least over very good soil and slightly higher on 40 meters than on 75 meters. Whether the gain increase offsets the narrower SWR bandwidth of the rectangle is a complex judgment that requires consideration of all mission and resource information applicable to a given installation site.

Fig. 1 provided the outlines of the rectangle in isolation, the case with which we have been working, and of the rectangle with a near-ground screen. The screen is 0.001-λ above ground to allow the modeled wires to avoid ground penetration. It uses openings that are 0.05-λ per side to simulate better the sorts of screening that might actually find use at a site. For uniformity over the three soil types, the antenna is fixed at 0.175-λ above ground and uses the dimensions set for resonance without a screen. **Table 4** presents the results of the screen test.

1-Wavelength Rectangle + !-wl by 1-WL Screen						Table 4
Rectangle at 0.175-Wavelength; Screen at Near-Ground Level						
Ground	Zen Gain	BS BW	EW BW	BW Ratio	Feed R	Feed X
75 Meters						
Vy Good	8.64	70.1	71.0	0.99	46.42	8.69
Average	8.57	69.9	69.8	1.00	48.79	8.18
Vy Poor	8.67	69.0	67.4	1.02	50.63	8.14
40 Meters						
Vy Good	8.71	70.1	70.8	0.99	46.06	10.71
Average	8.69	69.3	68.8	1.01	48.25	10.08
Vy Poor	8.82	68.5	66.5	1.03	49.77	10.11
Notes:	Zen Gain = maximum zenith gain in dBi					
	BS BW; EW BW = broadside & endwise beamwidths in degrees					
	Feed R; Feed X = feedpoint resistance and reactance in Ohms					

Although the screen is 1 λ by 1 λ, making it a bit short for the broadside dimension of the loop, the supplement does improve gain, even over very good soil. More significant is the uniformity of both gain and feedpoint impedance values over all three soil types. The total variation in feedpoint impedance on either band is about 4 Ω of resistance. As we saw with the dipole and the square loop in past notes, the gain value over very poor soil is (by an insignificant operational amount) the highest on both bands. Over very poor soil, installation of a ground screen may be a worthy investment, since the gain improvement can be up to about 2.5 dB over the same antenna without the screen.

Our exercise has been largely hypothetical, since it rests on the assumption that for some given mission, a circular beamwidth pattern is required or desired. The rectangle proves to be one of the simplest means for achieving the goal—and for obtaining slightly more gain than the other basic antennas and for achieving a feedpoint impedance close to 50 Ω. The cost, as we have seen, is a major narrowing of the SWR bandwidth of the resulting antenna.

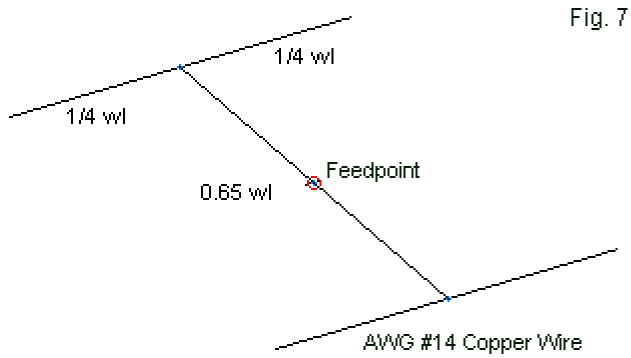
Maximum Zenith Gain

In theory, we may produce much higher gain than we obtained even with the rectangle. One very basic way to achieve this goal is to create a large array of parallel dipoles spaced ½-λ apart and fed in phase. The net gain will be a function of the number of dipoles in the array. The array achieves its increased gain by reducing the beamwidth of the zenith lobe. A very long collection on in-phase collinear sections can achieve similar ends by the same beamwidth-narrowing means.

Within the realm of practical antennas for NVIS work, most suggested high-gain arrays have restricted themselves to 2 elements fed in phase. Past suggestions have acquired some odd names, but all of the 2-element arrays are variations on the lazy-H. In this section, we shall look at two of the past arrays and then create a third version of the lazy-H with superior gain. Along the way, we shall acquire a better understanding of the relationship of an array's broadside dimension and the required height above ground for maximum zenith gain.

One of the earliest antennas in this group has carried the label "Shirley" array. As shown in **Fig. 7**, it is a form of lazy-H that uses relatively short (1/2-λ) elements with a wide spacing (0.65-λ) between them. The lines joining the elements are transmission line sections. To achieve in-phase feeding of the elements, we use equal length sections to a central feedpoint.

Fig. 7



General Outline: NVIS Shirley Array
(Wide-Space, Short-Element Lazy-H)

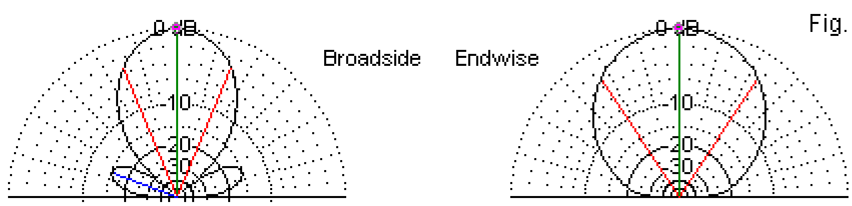
In our notes, shall omit feedpoint impedance values. The feedpoint impedance depends upon the length of the elements, the characteristic impedance and velocity factor of the phasing lines, along with the length of the lines. Because the ½-λ elements are still within a range that permits mutual coupling, the impedance of ½-λ elements will not be identical to the impedance of each element in isolation. As well, different installations may opt for different feedpoint positions, some using an elevated feedpoint, others using longer lines for a feedpoint at or near the ground. With judicious element pruning, one might develop the array to use ¾-λ (electrical-length) sections of phasing line with a 70-75-Ω impedance to transform element 50-Ω impedance values to 100 Ω. In parallel, the array might then be fed with a 50-Ω coaxial cable.

The lazy-H configuration with two elements fed in phase increases the broadside gain relative to a single element. The particular configuration used in the Shirley array employs ½-λ elements with a spacing that approaches maximum gain for the element length. **Table 5** summarizes the potential performance of the array over each ground type. We may omit the scanning of many heights with the understanding that for the height region around maximum zenith gain, the change per height increment is relatively small. The table lists only the heights of maximum gain and the zenith gain value for each soil on each of our two bands.

Shirley Array (Short-Element, Wide-Space Lazy-H)						Table 5
Ground	Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters						
Vy Good	0.180	45.40	10.70	43.0	65.8	0.65
Average	0.205	51.70	9.95	44.2	67.8	0.65
Vy Poor	0.210	52.96	8.95	45.4	68.4	0.66
40 Meters						
Vy Good	0.190	25.96	10.52	43.4	66.6	0.65
Average	0.210	28.69	9.71	44.6	67.4	0.66
Vy Poor	0.220	30.05	8.76	45.6	68.2	0.67
Notes:	75 Meters = 3.9 MHz; 40 Meters = 7.2 MHz					
	Zen Gain = maximum gain in dBi at zenith angle					
	BS BW, EW BW = broadside and endwise beamwidth in degrees					

The phased dipoles at wide spacing produce an average of about 3.5 dB over single dipoles. The required height for maximum zenith gain averages about 0.02-λ higher than for the single dipole. The height values are about 0.01-λ higher than for the rectangle. Note that the Shirley array uses a spacing between dipoles that is close to twice the spacing of the broadside wires in the rectangle. The increased height of maximum gain from the reflective surface—in this case, the ground—is also noticeable with planar reflector arrays. In fact, the required height increase of the array over a single dipole is less with very poor soil, a relatively poor reflector.

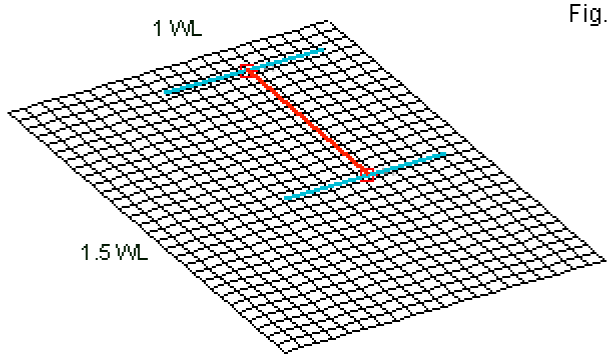
Fig. 8



Typical Broadside and Endwise Elevation Patterns
for a Shirley NVIS Array

Fig. 8 in conjunction with the beamwidth ratios shows other interesting facts about the performance of two dipoles spaced more than ½-λ apart. First, the broadside beamwidth narrows considerably to yield the higher gain levels. However, the endwise beamwidth remains close to the value for individual dipole elements. As a consequence, the array has beamwidth ratios well under 1.00. Still, the motivation for employing a phased array to obtain higher gain is the gain itself. In most such cases, designers are not concerned with the beamwidth ratio. The higher-gain NVIS antennas tend to focus solely upon NVIS effectiveness, to the exclusion of almost all other missions. The second interesting fact about the present array is the development of secondary broadside lobes. Such lobes are typical of any phased array in which the element spacing exceeds ½-λ.

Fig. 9



Shirley Array with Ground-Level Screen

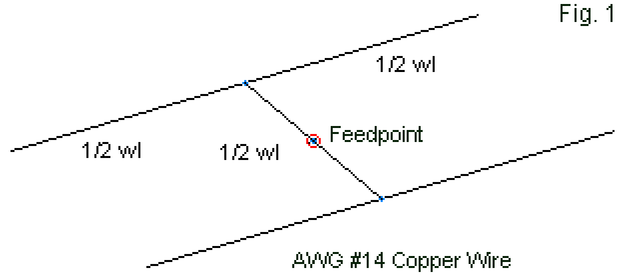
Fig. 9 shows Shirley array over a ground-level screen. Because the spacing between elements is so wide, the modeled screen uses a broadside dimension of 1.5 λ. The results of modeling the antenna at a height of 0.2-λ above ground with the screen beneath appear in **Table 6**.

Shirley Array above Near-Ground Screen				Table 6
Screen: 1.5 wl Broadside x 1.0 wl Endwise				
Ground	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters				
Vy Good	10.95	43.4	67.0	0.65
Average	10.88	43.4	66.2	0.66
Vy Poor	10.95	43.0	64.4	0.67
40 Meters				
Vy Good	10.95	43.4	66.8	0.65
Average	10.92	43.2	65.4	0.66
Vy Poor	11.03	42.8	63.6	0.67
Notes:	See Table 5			

With a ground screen, the array provides only a very small gain improvement over very good ground, but about 2-dB of improvement over very poor soil. The reported gain values are insignificantly different as we change soil types once we add the screen. Indeed, the uniformity of operating characteristics tends to apply to all of the antenna parameters.

The second of our older antenna systems bears the label “Jamaica” array. In fact, as shown by the outline sketch in **Fig. 10**, the array is nothing more or less than a traditional lazy-H. The elements are 1 λ long, which presents to the individual phase lines a very high impedance value. Normally, a lazy-H builder uses equal lengths of parallel transmission line to a central feedpoint. Again, the precise impedance at the feedpoint is the parallel combination of individual impedance values, as transformed by the lines. The transformation will depend upon the characteristic impedance, velocity factor, and length of the lines employed. In many cases, the net feedpoint impedance will consist of a relatively low resistive component and a high reactance. As a result, matching at the feedpoint generally results in lower losses than using a long run of parallel transmission line.

Fig. 10



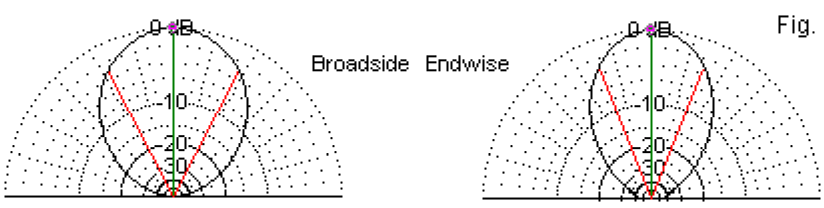
General Outline: NVIS Jamaica Array
(Standard/Traditional Lazy-H)

Because the Jamaica or standard lazy-H uses longer elements, its gain potential is higher than we can obtain from the Shirley array. **Table 7** summarizes the heights and values of maximum zenith gain from the standard lazy-H configuration.

Jamaica Array (Standard/Traditional Lazy-H)						Table 7
Ground	Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters						
Vy Good	0.165	41.61	11.53	54.0	43.6	1.24
Average	0.185	46.66	10.88	56.2	44.2	1.27
Vy Poor	0.195	49.18	10.00	58.6	44.8	1.31
40 Meters						
Vy Good	0.170	23.22	11.38	54.6	43.8	1.25
Average	0.190	25.96	10.65	56.8	44.2	1.29
Vy Poor	0.200	27.32	9.80	59.0	44.6	1.32
Notes:	75 Meters = 3.9 MHz; 40 Meters = 7.2 MHz					
	Zen Gain = maximum gain in dBi at zenith angle					
	BS BW, EW BW = broadside and endwise beamwidth in degrees					

The Jamaica array provides about a dB higher gain than the Shirley. However, it is more notable for what it reveals about array performance in general. The longer elements result in a narrower endwise beamwidth, as shown in **Fig. 11**. The broadside beamwidth exceeds the endwise beamwidth, resulting in beamwidth ratio values greater than 1.00. Still, the values average only about 1.25:1, indicating a fairly circular NVIS pattern. In addition, because the spacing between the elements does not exceed 1/2-λ, the broadside pattern has no secondary lobes. Finally, the closer element spacing also produces maximum zenith gain heights that are very similar to those for a single dipole.

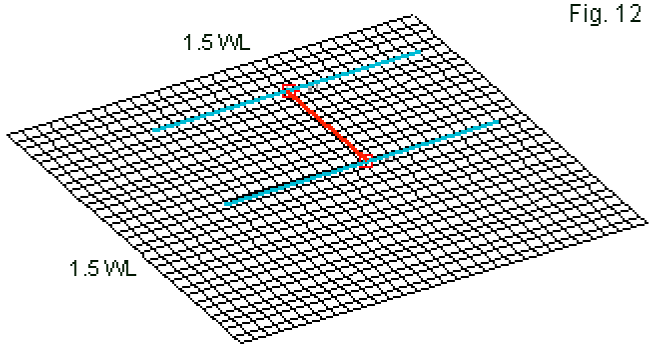
Fig. 11



Typical Broadside and Endwise Elevation Patterns
for a Jamaica NVIS Array

As we did for the Shirley array, we may place a ground-level screen below the Jamaica array. The greater element length requires a screen enlargement. For this exercise, I used a screen that is 1.5 λ per side. All of the screens used in these notes use 0.05-λ openings. **Fig. 12** shows the general outline of the Jamaica array and its screen. The results of the modeling appear in **Table 8**.

Fig. 12

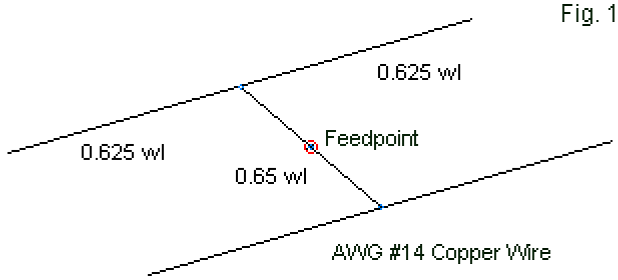


Jamaica Array with Ground-Level Screen

Jamaica Array above Near-Ground Screen				Table 8
Screen: 1.5 wl Broadside x 1.5 wl Endwise				
Ground	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters				
Vy Good	11.68	55.2	44.4	1.24
Average	11.63	55.0	44.2	1.24
Vy Poor	11.70	54.4	43.8	1.24
40 Meters				
Vy Good	11.67	55.2	44.4	1.24
Average	11.65	54.8	44.0	1.25
Vy Poor	11.75	54.0	43.4	1.24
Notes:	See Table 7			

The table provides no surprises. The screened array over very good soil provides very little added gain, but about 1.7 dB more gain over very poor soil. Across all soil types, the performance values a very consistent, with very poor soil showing again the highest numerical gain values. Indeed, for all implementations, the standard lazy-H provides high-gain NVIS service compared to the basic antenna. The remaining question is whether we can further improve zenith gain without adding further elements to the lazy-H configuration.

Fig. 13



General Outline: NVIS Extended Lazy-H

There is a version of the lazy-H, sometimes called the extended or expanded lazy-H, that uses 1.25 λ elements with a spacing value of about 0.65-λ (sketched in **Fig. 13**). The individual elements are called extended double-Zepps, which provide about the maximum gain possible from a simple length extension before the pattern breaks into multiple lobes with a reduced broadside lobe. The elements are spaced as far apart as possible to yield maximum gain when fed in phase with each other. The combination produces the maximum possible broadside gain (measured from the plane of the element pair). **Table 9** provides a glimpse into the gain and other performance attributes of the extended lazy-H when pressed into NVIS service.

Extended Lazy-H Array						Table 9
Ground	Height wl	Height ft	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters						
Vy Good	0.210	52.96	13.45	43.8	31.3	1.40
Average	0.225	56.74	12.68	45.0	31.6	1.42
Vy Poor	0.230	58.01	11.66	46.2	31.8	1.45
40 Meters						
Vy Good	0.215	29.37	13.27	44.2	31.4	1.41
Average	0.230	31.42	12.44	45.4	31.6	1.44
Vy Poor	0.240	32.79	11.50	46.2	31.8	1.45
Notes:	75 Meters = 3.9 MHz; 40 Meters = 7.2 MHz					
	Zen Gain = maximum gain in dBi at zenith angle					
	BS BW, EW BW = broadside and endwise beamwidth in degrees					

The maximum zenith gain of the extended lazy-H array averages about 6 dB more than we can obtain from a single dipole. However, the antenna height at which the array reaches maximum gain averages about 0.04-λ higher than the maximum gain heights for the dipole. The increases spacing between elements explains only part of the required heights, for the extended lazy-H has the same spacing distance as the Shirley, which has lower maximum gain heights. The extended lazy-H shrinks both the broadside and endwise beamwidths to achieve its gain. As a result, it shows secondary lobes for both types of elevation patterns, as is evident in **Fig. 14**.

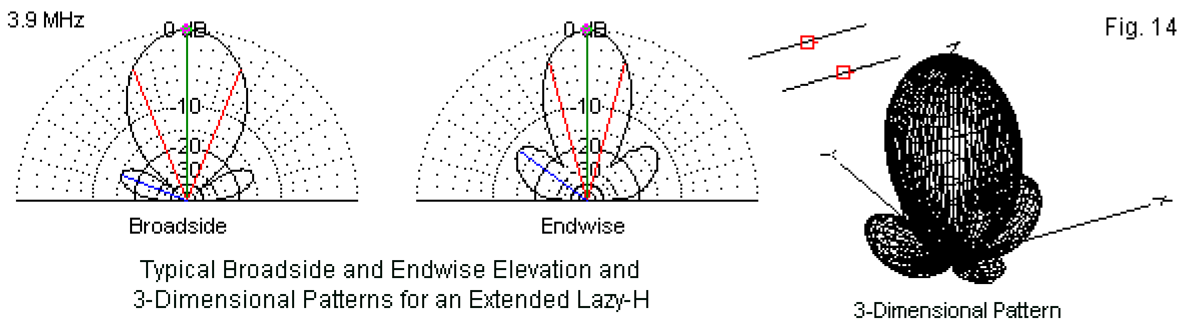
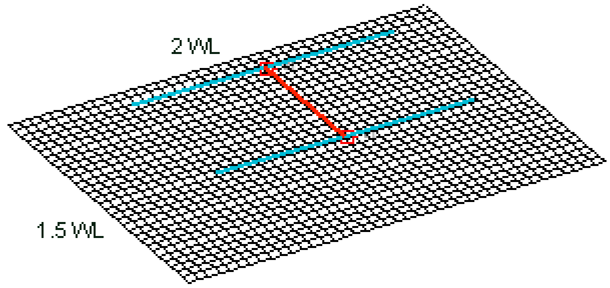


Fig. 14

Typical Broadside and Endwise Elevation and 3-Dimensional Patterns for an Extended Lazy-H

The patterns not only show secondary lobes along both axes, but as the 3-dimensional view of the pattern reveals, the secondary lobes are separate. An elevation pattern along an axis at 45° to the broadside and endwise directions would show virtually no secondary lobe structure. The strongest secondary lobe is about 12 dB lower in strength than the main lobe and would normally not constitute a problem for NVIS operation. However, strong atmospheric noise at medium elevation angles in certain (mostly endwise) directions may raise the overall background noise level. Perhaps a more interesting problem is the fact that, at the endwise half-power beamwidth angle, the communications radius is less than about 150 miles, rather than the 200-300 mile range we expect of more basic antennas. (Broadside, the radius is over 200 miles.) The situation reveals that, so long as NVIS gain comes at the expense of radiation pattern beamwidth, there are limits to the gain that we should expect from NVIS arrays.

Fig. 15



Extended Lazy-H with Ground-Level Screen

As shown in **Fig. 15**, we may place a ground level screen below the extended lazy-H. The increased element length and spacing distance of the array requires a screen that is 2 λ endwise and 1.5 λ broadside. As in all of the screen tests in this section, the antenna is 0.2-λ above ground. **Table 10** provides the test results.

Laxy-H Array above Near-Ground Screen				Table 10
Screen: 1.5 wl Broadside x 2.0 wl Endwise				
Ground	Zen Gain	BS BW	EW BW	BW Ratio
75 Meters				
Vy Good	13.79	43.4	31.0	1.40
Average	13.73	43.4	30.6	1.42
Vy Poor	13.83	43.0	30.0	1.43
40 Meters				
Vy Good	13.80	43.4	30.8	1.41
Average	13.77	43.2	30.4	1.42
Vy Poor	13.90	43.0	29.8	1.44
Notes:	See Table 9			

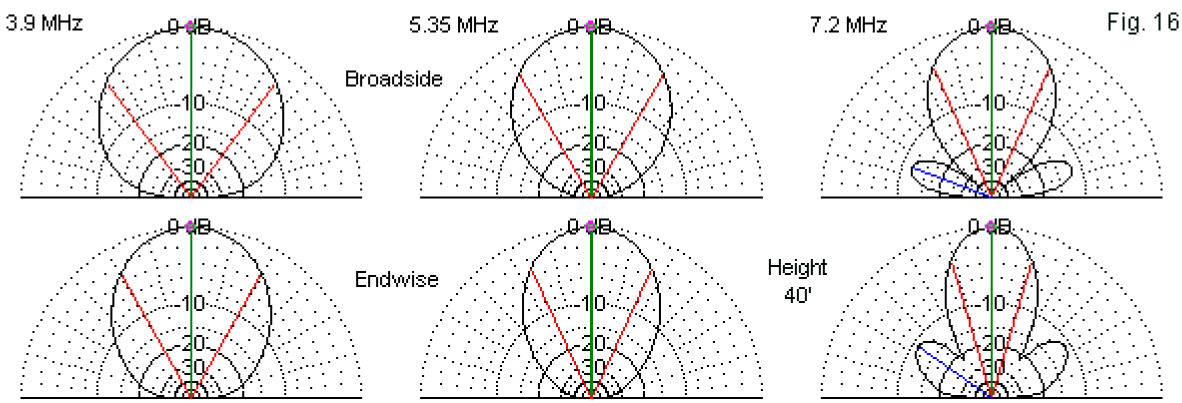
The consequences of adding an adequate ground screen below the lazy-H parallel previous results for the Shirley and Jamaica arrays. Gain improvement over very good ground is negligible, while over very poor ground, we improve gain by just over 2 dB. The gain figures are almost uniform over the range of soil qualities, with very poor soil showing its now typical numerical edge. The beamwidth values and the ratio between them show virtually no change.

The extended lazy-H has an additional potential. It provides usable gain over a 2:1 frequency ratio, counting downward from the frequency at which the elements are about 1.25 λ long. The gain, however, is not constant as we reduce the operating frequency. At lower frequencies, the elements are shorter as a fraction of a wavelength. On 60 meters, the 40-meter extended lazy-H elements are about 0.9-λ long, while on 75 meters, the length shrinks to about 0.7-λ. In addition, the space between the elements undergoes an equally proportional reduction. (For example, on 60 meters, the antenna is close to the Jamaica array proportions.) Both decreases in effective array size combine to reduce gain on the lower bands. The user question is whether the remaining gain is adequate to the mission assigned to the antenna.

Table 11 provides data for all three bands over the surveyed soil types. As the best compromise among the bands, the antenna is set 40' above ground, which is somewhat high for 40 meters, somewhat low for 75 meters, and nearly optimal for 60 meters. However, element and spacing reductions yield lower gain on the 60-meter band than on the 40-meter band.

3-Band Lazy-H (Extended 40-Meter Lazy-H at 40')						Table 11
Ground	Zen Gain	BS BW	EW BW	BW Ratio	Sample R	Sample X
75 Meters						
Vy Good	9.21	70.4	58.6	1.20		
Average	8.37	73.0	59.0	1.24	191	-468
Vy Poor	7.26	77.2	59.8	1.29		
60 Meters						
Vy Good	10.78	59.0	49.4	1.19		
Average	10.17	60.6	49.2	1.23	36	-35
Vy Poor	9.32	62.4	49.2	1.27		
40 Meters						
Vy Good	12.81	48.0	33.2	1.45		
Average	12.09	48.8	33.2	1.47	81	459
Vy Poor	11.24	49.0	32.8	1.49		
Notes:	75 M = 3.9 MHz; 60 M = 5.35 MHz; 40 M = 7.2 MHz					
	Zen Gain = maximum gain in dBi at zenith angle					
	BS BW, EW BW = broadside and endwise beamwidth in degrees					

As we lower the operating frequency, the broadside and endwise bandwidth values both increase, as suggested by the tabular entries. However, the rates of increase are not identical in both directions, as the beamwidth ratio values show. We may glean a further understanding of the changes by examining the broadside and endwise elevation patterns in **Fig. 16**. With the shortening of the elements and of the space between elements, the patterns for bands below 40 meters show no secondary lobes.



Typical Broadside and Endwise Elevation Patterns
3-Band NVIS Extended Lazy-H

Of the bands covered, 75 meters shows the lowest gain. Before discounting the performance on this band, compare the values with those for a rectangle. The 40-meter extended lazy-H on 75 meters still provides an added full dB of gain.

A more significant problem perhaps is the range of feedpoint impedance values offered by the 3-band extended lazy-H. The numbers cited in the table only show the possible range and are not actual values. The actual values would depend upon the characteristic impedance, velocity factor, and length of the two phasing lines. In most cases, a 3-band extended lazy-H would employ lines running to near-ground level with a remote antenna tuner installed at that point. A parallel transmission line from the feedpoint to the equipment room may well suffer significant loss on one or more bands, especially where the reactance at the feedpoint is very high relative to the resistance.

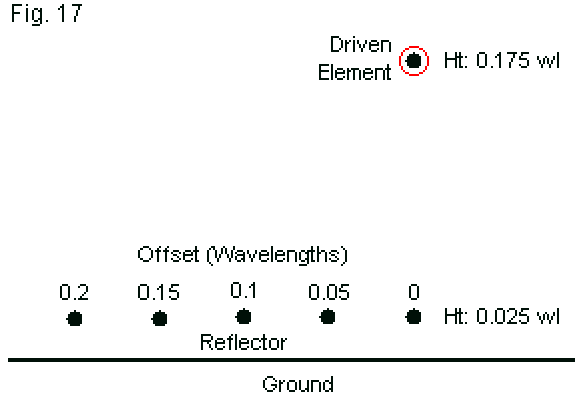
Despite its limitations, the extended lazy-H—either as a monoband or a multi-band array—offers high gain for NVIS operations. It requires only 4 corner tall supports and possibly a short center support for the remote antenna tuner. The smaller versions of the lazy-H might also serve as monoband antennas with slightly lower gain but generally wider beamwidth values for a larger calculated communication radius. If we expect effective NVIS communications with a prescribed radius, the family of lazy-H configurations may approach the practical gain limits for NVIS work.

Tilting the NVIS Radiation Pattern

Thus far, we have presumed that the zenith angle is best for virtually all missions. However, some stations have indicated a need for tilted NVIS patterns. The primary examples both come from near-shore locations. In one case, the goal was for maximum inland coverage; in the other instance, the aim was for over-water coverage. The design question that emerges is whether we can not only tilt the NVIS pattern, but also maintain gain directly upward at least at dipole levels.

One method that suggests itself to many is to use a dipole and reflector wire. In the third set of notes, we examined this arrangement in perfect vertical alignment to find the combination of antenna height and reflector height that provided the best performance. To tilt the radiation pattern, perhaps we need only displace the reflector wire to some position behind the driven dipole without materially altering the wire relationships relative to ground. **Fig. 17** shows the general outline of what we might do. The driver remains fixed while we offset the reflector to various positions. Theoretically, the pattern should tilt to the right relative to the sketch.

Fig. 17

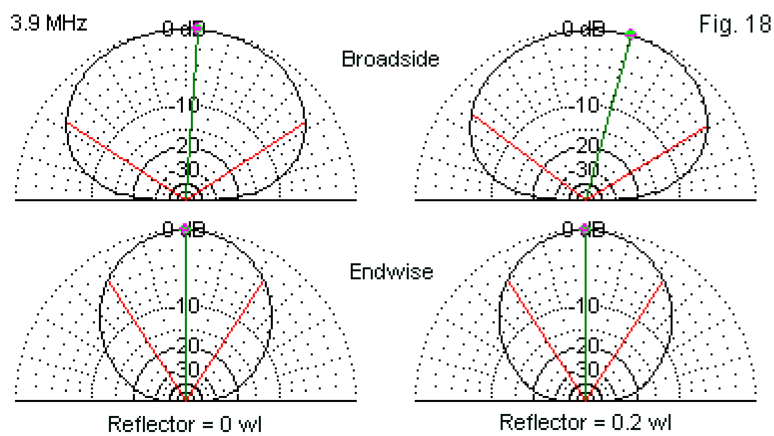


Moving the Reflector Wire to Tilt a NVIS Pattern

Unfortunately, the plan fails to account for an important fact about NVIS antennas with single element parasitic reflectors. The reflector element is only one of two major sources of radiation reflection. The ground itself is the other major reflective element, and in many ways, it can override the effects of a parasitic element. **Table 12** provides comparative results between a vertically aligned pair of elements and a driver with the reflector offset to the rear by 0.2-λ. (Intermediate positions for the reflector show intermediate results between the two parts of the table.)

Performance of Aligned and 0.2-WL Offset Dipole Plus Reflector									Table 12
Antenna at 0.175-WL			Reflector at 0.025-WL						
Ground	Max Gain	TO Angle	BS BW	Forward	Rearward	Zen Gain	EW BW	Feed R	Feed X
75 Meters: Vertically Aligned									
Vy Good	7.48	90	108.6	54.3	-54.3	7.48	66.2	51.27	2.40
Average	6.88	90	113.6	56.8	-56.8	6.88	66.4	52.79	0.21
Vy Poor	6.11	90	120.8	60.4	-60.4	6.11	66.8	52.62	-2.25
75 Meters: Reflector 0.2-WL behind Dipole									
Vy Good	7.39	80	108.2	56.1	52.1	7.34	66.4	59.32	6.09
Average	6.59	74	111.6	58.6	-53.0	6.49	66.8	65.05	1.73
Vy Poor	5.67	70	115.1	62.4	-52.7	5.42	67.6	71.21	-4.89
Notes:	Max Gain = maximum gain at TO (take-off) angle in dBi								
	BS BW = broadside beamwidth in degrees								
	Forward, Rearward = angle from zenith in degrees of forward (positive) and rearward (negative)								
		half power (-3 dB) points							
	Zen Gain = maximum gain at the zenith (90 degree elevation) angle in dBi								
	EW BW = endwise beamwidth in degrees at the zenith angle								
	Feed R, Feed X = feedpoint impedance								

Although the offset reflector versions of the array show a take-off angle that is less than 90°, the amount of overall pattern offset is disappointingly small. Operationally, the difference would not be noticeable. **Fig. 18** compares patterns for the two cases over average ground. In effect, the reflector element cannot overcome the greater influence of the ground itself in reflecting signals straight upward.

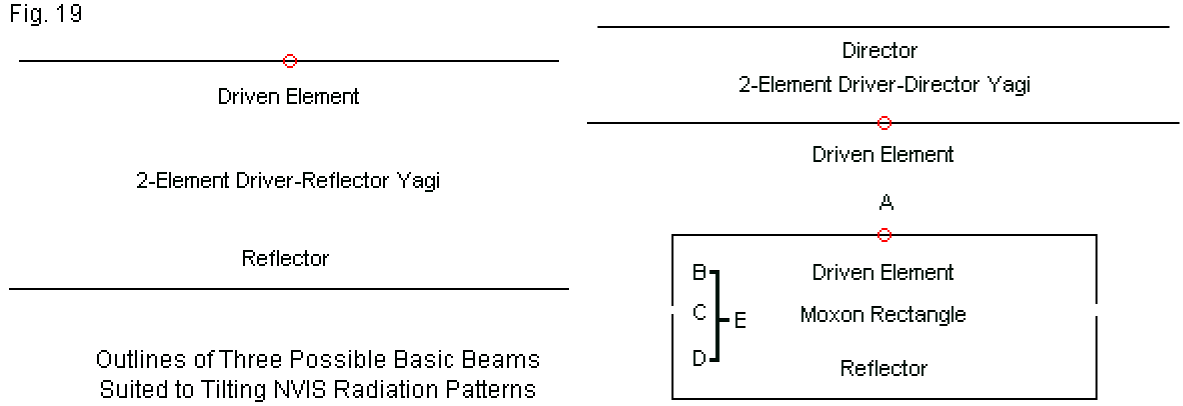


Broadside and Endwise Elevation Patterns: Dipole + Reflector
Vertically Aligned and Offset by 0.2-Wavelengths

The goal of having a tilted radiation pattern is significantly to reduce signal strength to a defined rearward area while preserving signal strength overhead and in the defined forward direction. One way to achieve this goal is reorient the 2-element array into a horizontal position and to place it in a relatively low position over the ground. We shall employ 0.175-λ as the beam height as a reasonable compromise height among the precisely optimum heights over each of the soil types.

Before we model a beam under these conditions, we may wish to consider which beam to use. The beam should be basic, perhaps limited to 2 elements. We might construct larger beams, but the net effect would be greater gain at lower angles, a feature that falls outside of the project specifications. We need only enough gain to provide good signal reduction to the rear while maintaining the highest possible gain in the zenith and high-angle forward directions.

Fig. 19



Outlines of Three Possible Basic Beams Suited to Tilting NVIS Radiation Patterns

Fig. 19 presents 3 candidate beams for the role. All happen to be parasitic beams, but one might as easily employ a 2-element phased horizontal array. The outlines are in proper proportions to each other. The driver-reflector array uses wide element spacing, while the driver-director version uses much closer spacing. The Moxon rectangle requires the least endwise space of the three beams. **Table 13** provides the 75-meter and 40-meter dimensions of each modeled beam in feet.

Table 13. Dimensions of sample beams for tilting NVIS radiation patterns

2-element driver-reflector Yagi: AWG #14 copper wire

	75 Meters	40 Meters
Reflector length	125.0’	67.48’
Driver length	120.2’	64.98’
Element spacing	50.4’	27.32’

2-element driver-director Yagi: AWG #14 copper wire

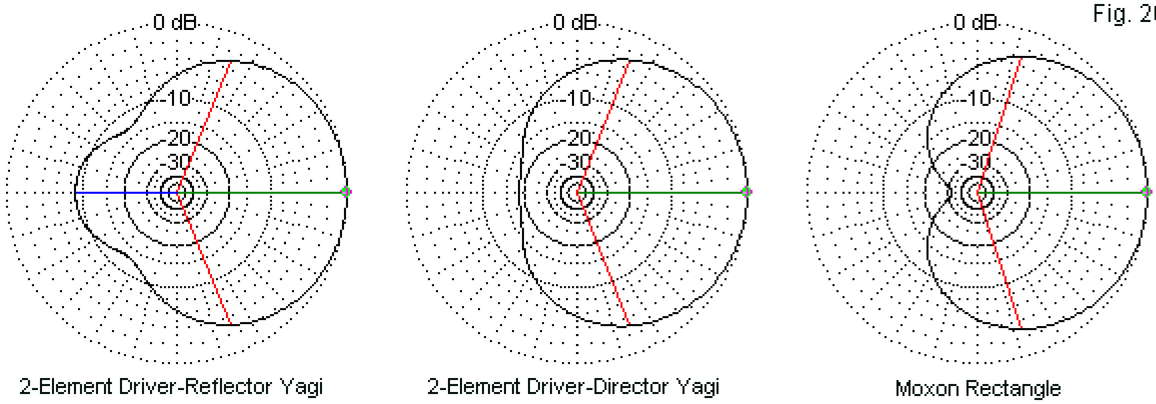
	75 Meters	40 Meters
Driver length	126.1’	68.30’
Director length	121.1’	65.67’
Element spacing	20.2’	10.93’

2-element Moxon rectangle: AWG #12 copper wire (see Fig. 19 for dimension designations)

	75 Meters	40 Meters
A (Endwise length)	90.86’	49.22’
B (Driver tail)	14.69’	7.95’
C (Gap)	2.44’	1.32’
D (Reflector tail)	17.66’	9.56’
E (Total broadside dimension)	34.79’	18.83’

Prior to any practical modeling, we may estimate the relative probabilities among the candidates of fulfilling the radiation pattern specification. Free-space E-plane patterns, such as those shown in **Fig. 20**, provide excellent guidance in selecting a beam for the task. These patterns approximate—with the correct interpretation—the shape of the final pattern above ground, with adjustments for ground reflections.

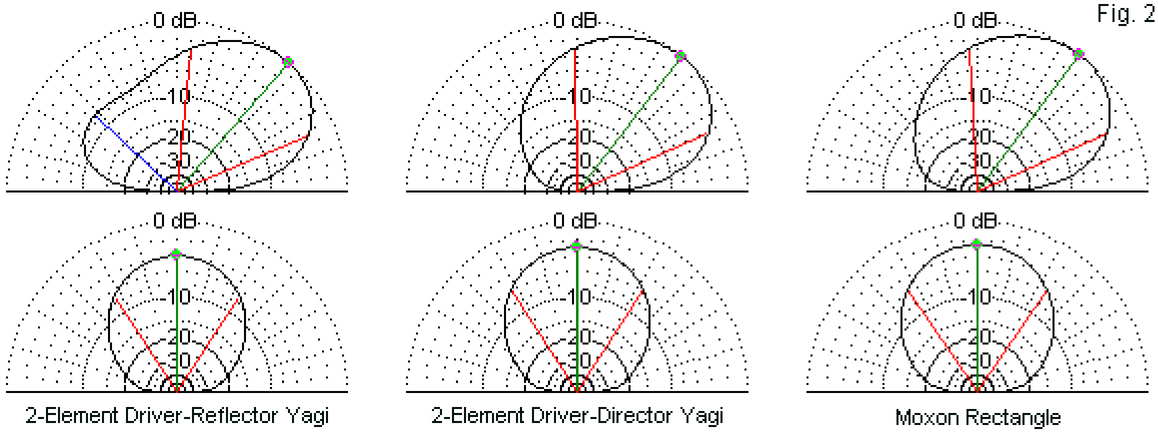
Fig. 20



Free-Space H-Plane Patterns of Three Basic Beams
Suited to Tilting NVIS Radiation Patterns

The driver-reflector Yagi shows a narrower beamwidth than the other beams. As well, its shape shows less width along the plot's vertical axis. In contrast, the driver-director Yagi and the Moxon rectangle have wider beamwidths and more gain along the plot's vertical axis. These rapidly read comparisons will translate into distinctive features in patterns over real ground. **Fig. 21** presents samples of the broadside and endwise patterns of each beam at a height of 0.175-λ above average ground.

Fig. 21



Broadside and Endwise Elevation Patterns of Three Basic Beams
0.175-Wavelength above Average Ground

The upper row of patterns provides broadside views of the radiation patterns. The two more promising beam designs show less medium-angle gain to the defined rearward side of the antenna. In contrast, the driver-reflector Yagi has a considerable rearward elevation lobe. The lower row of patterns are the endwise plots at the zenith angle, with the limit of the plot scaled to the overall maximum gain of each beam. In all cases, the maximum gain is greater than the zenith gain. Of the three candidates, the driver-reflector Yagi has the weakest zenith gain compared to its maximum gain. The driver-director Yagi and the Moxon rectangle show only small differences in the relative strength of zenith gain.

The remaining step is to compare numerical data to determine is there is a clear winner among the three candidate beams. **Table 14** supplies the values for both 75 and 40 meters.

Performance of 2-Element Beams 0.175-WL above Ground									Table 14
Driver-Reflector Yagi									
Ground	Max Gain	TO Angle	BS BW	Forward	Rearward	Zen Gain	EW BW	Feed R	Feed X
75 Meters: 3.9 MHz									
Vy Good	8.81	51	61.7	65.5	3.8	5.22	66.4	34.40	1.80
Average	8.01	49	61.3	66.9	5.6	4.10	66.8	39.99	0.14
Vy Poor	7.04	46	61.0	69.1	8.1	3.69	67.6	46.94	-2.76
40 Meters: 7.2 MHz									
Vy Good	8.72	49	60.4	66.2	5.8	4.73	66.6	43.20	2.82
Average	7.74	48	60.3	67.6	7.3	3.49	66.4	39.63	-0.11
Vy Poor	6.70	45	60.6	69.7	9.1	2.12	67.0	45.76	-2.98
Driver-Director Yagi									
Ground	Max Gain	TO Angle	BS BW	Forward	Rearward	Zen Gain	EW BW	Feed R	Feed X
75 Meters: 3.9 MHz									
Vy Good	8.49	55	68.7	64.6	-4.1	6.03	66.1	31.83	-4.31
Average	7.76	52	67.5	66.4	-1.1	4.91	66.3	30.99	-1.31
Vy Poor	6.80	48	66.2	68.9	2.7	3.43	66.8	29.93	1.78
40 Meters: 7.2 MHz									
Vy Good	8.53	52	65.6	65.6	0.0	5.53	66.2	25.39	0.80
Average	7.62	50	65.2	67.3	2.1	4.30	65.8	25.71	1.86
Vy Poor	6.59	47	64.7	69.6	4.9	2.85	66.4	25.41	4.33
Moxon Rectangle									
Ground	Max Gain	TO Angle	BS BW	Forward	Rearward	Zen Gain	EW BW	Feed R	Feed X
75 Meters: 3.9 MHz									
Vy Good	8.62	56	70.5	63.8	-6.7	6.47	68.8	36.36	-9.54
Average	7.87	53	69.1	65.7	-3.4	5.32	69.2	41.04	-8.40
Vy Poor	6.90	49	67.5	68.4	0.9	3.78	70.4	47.31	-7.21
40 Meters: 7.2 MHz									
Vy Good	8.49	55	70.1	64.3	-5.8	6.23	69.0	37.74	-3.19
Average	7.58	52	69.1	66.2	-2.9	4.96	68.8	43.05	-2.91
Vy Poor	6.55	49	68.3	68.8	0.5	3.48	69.8	49.12	-2.08
Notes:	Max Gain = maximum gain at TO (take-off) angle in dBi								
	BS BW = broadside beamwidth in degrees								
	Forward, Rearward = angle from zenith in degrees of forward (positive) and rearward (negative)								
		half power (-3 dB) points							
	Zen Gain = maximum gain at the zenith (90 degree elevation) angle in dBi								
	EW BW = endwise beamwidth in degrees at the zenith angle								
	Feed R, Feed X = feedpoint impedance								

The maximum gain varies by only a small amount among the three beams for any given frequency and soil quality. Where we find more important differences is in the zenith gain columns, with the Moxon providing the strongest values. (However, the margin is not so great as to rule out use of the driver-director Yagi.) As well, the wider free-space beamwidth of the Moxon translates into rearward half-power points that extend over most soils just to the rear of the zenith angle, thereby assuring adequate radiation in the immediate vicinity of the antenna location. (Negative values in the rearward column indicate radiation to the rear within 3 dB of maximum gain within the specified angular distance. A positive value in this column indicates that the –3-dB point occurs forward of the zenith angle.)

In fact, all three candidate beams (and many other basic arrays that we might select for the task) tilt the pattern in the defined forward direction. The driver-director Yagi and the Moxon rectangle provide better reduction of signal strength to the rearward areas. The numbers and the pattern shapes that we have so far observed do not quite complete the information that we need in order to make a decision.

The wide spacing of the elements in the driver-reflector Yagi assures a broad SWR bandwidth (relative to the resonant impedance). The Moxon rectangle also has a relatively wide SWR bandwidth. However, on 75 meters, as shown by the superimposed SWR curves in **Fig. 22**, the driver-director Yagi reveals its typically narrow operating bandwidth. Unlike 2-element arrays with reflectors, the presence of the director reverses the SWR trend so that it rises more steeply above the resonant frequency than below it. Nevertheless, the region with an SWR of less than 2:1 is scarcely 60 kHz wide.

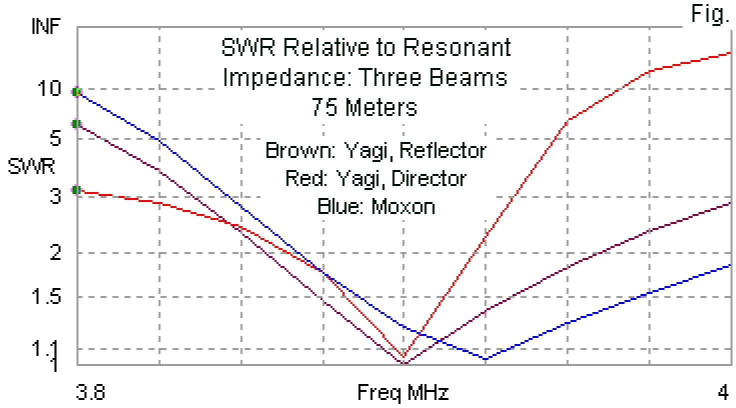


Fig. 22

On 40 meters, we find a similar situation, as revealed by **Fig. 23**. The wide-spaced driver-reflector Yagi and the Moxon rectangle have relatively wide operating bands. The values are not as great as would be the case for a single linear dipole, but they are wide enough to allow easy tuning of the arrays to the SSB portions of the band. On both bands, the Moxon bandwidth is slightly greater than the driver-reflector Yagi bandwidth. In contrast, the driver-director Yagi SWR bandwidth is not wholly adequate to cover the upper half of the 40-meter band. Adjusting the narrow-spaced Yagi for both the correct frequency and optimum performance might be a somewhat daunting task.

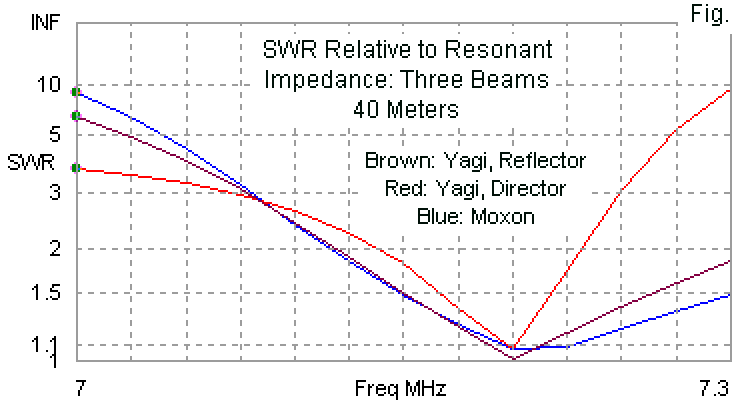
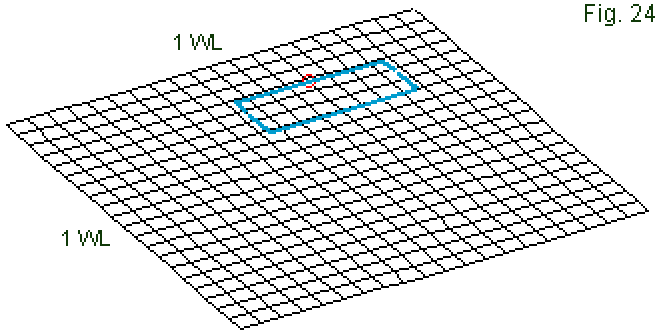


Fig. 23

If we add up the total information provided by the models, then the Moxon rectangle might be the best candidate for pattern tilting among the three candidates. However, our samples have covered only some of the possible directional antennas that we might consider in this regard. Nevertheless, the goals definitely rule out tilting vertically aligned arrays. Low horizontal directional arrays of the types considered hold the most promise of performing well in this specialized task.

Before we close the book on the Moxon rectangle, let's add one more test by placing a 1-λ-by-1-λ near-ground screen below it, similar to tests that we have performed with other antennas in this overall collection of notes. Since the dimensions of the Moxon rectangle are modest, when measured in terms of wavelengths, the smaller screen—outlined in **Fig. 24**—will suffice.

Fig. 24



Moxon Rectangle with a Ground-Level Screen

The results of our test appear in **Table 15**, which may hold a surprise for the unwary. In all other tests, we found that the gain over very poor soil exceeded the gain over other soils with the screen in place. While this trend holds true for the zenith gain values, it does not hold true for the maximum gain values. Maximum gain at the take-off angle involves ground reflection not only in the immediate vicinity of the antenna, but also well beyond the screen limits in the forward direction. As a result, some major components of the reflected rays that combine with the incident rays are reflected from bare soil and hence show heavier losses. The amounts are not operationally significant, but are just enough to show up in the lack of parallelism between the progressions of maximum gain and zenith gain values.

Performance of a Moxon Rectangle with a 1-WL by 1-WL Ground-Level Screen									Table 15
Ground	Max Gain	TO Angle	BS BW	Forward	Rearward	Zen Gain	EW BW	Feed R	Feed X
75 Meters: 3.9 MHz									
Vy Good	8.87	57	72.1	63.4	-8.7	6.94	68.2	34.57	-9.65
Average	8.70	57	73.0	64.1	-8.9	6.81	67.2	35.41	-8.08
Vy Poor	8.56	59	75.6	64.8	-10.8	6.92	65.2	35.60	-6.71
40 Meters: 7.2 MHz									
Vy Good	8.89	57	72.1	63.5	-8.6	6.96	68.0	34.96	-3.23
Average	8.71	58	73.5	64.1	-9.4	6.90	66.6	35.80	-1.72
Vy Poor	8.64	60	75.6	64.4	-11.2	7.06	54.4	35.82	-0.50
Notes:	Max Gain = maximum gain at TO (take-off) angle in dBi								
	BS BW = broadside beamwidth in degrees								
	Forward, Rearward = angle from zenith in degrees of forward (positive) and rearward (negative)								
		half power (-3 dB) points							
	Zen Gain = maximum gain at the zenith (90 degree elevation) angle in dBi								
	EW BW = endwise beamwidth in degrees at the zenith angle								
	Feed R, Feed X = feedpoint impedance								

Apart from the small surprise in numbers, the Moxon's performance over a sufficiently large ground screen is remarkably consistent across the entire span of soil qualities. As in virtually all other trials, the screen has negligible effect over very good soil, makes a marginal improvement over average soil, and improves performance noticeably over very poor soil. As always, its implementation depends not only upon soil quality, but as well upon the time, energy, and monetary resources available for the antenna installation.

Conclusion

In out exploration of some special purpose NVIS antennas, we have had occasion to suggest the use of some antenna types not usually considered by radio amateurs (or many others): rectangles, extended lazy-Hs, and horizontal beams. The special needs that we have explored may not match the special needs of your particular installation. However, they do illustrate that fact that the possible antennas for NVIS operations go well beyond the basic dipole, inverted-V, and square or diamond loop. For every need, there likely is an antenna type that we can adapt to the application.

These notes have not covered all possible special needs. One fairly obvious omission is the need for rapid frequency changes, such as those demanded by automatic link establishment (ALE) techniques. Antennas to meet these needs, such as terminated antennas with relatively constant feedpoint impedance values over a very large frequency range, are the subject extensive notes elsewhere at this site. The gain deficits that are inherent in these antennas have spurred investigation in two directions. One is the development of an antenna without the loss of gain but with the uniform feedpoint impedance. The other is the employment of high-speed antenna tuner switching to allow the use of common antennas with higher gain to do the job. In addition, for non-military, non-governmental applications, such as the wide range of type of emergency communications, the situation has raised the question of whether we need frequency change times in the microsecond range or whether we might ably use change times in milliseconds, of which many ATUs are capable.

Moreover, we have not addressed the special needs of mobile and field antennas. Many new commercial offerings are appearing in this arena, and a few of them actually offer some incremental improvements. Obviously then, these scant closing notes only function to say that the subject of NVIS antennas is far from concluded with this set of observations on special purpose NVIS antennas.