NVIS Antennas for Special Needs

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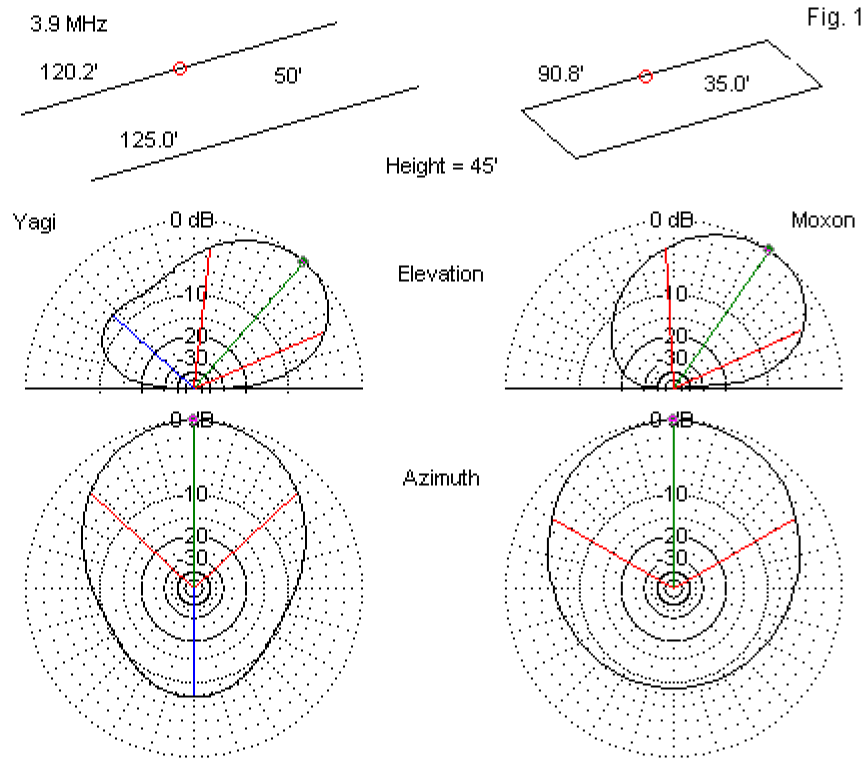
Our last episode dealt with basic and advanced monoband NVIS antennas. Although we found a number of differences among the antennas, most of them showed reasonably circular azimuth patterns as determined by the ratio of the broadside to endwise half-power beamwidth. Virtually all of the antennas achieved their maximum upward gain at heights between 0.175 wavelength and 0.2 wavelength. We also saw clearly the relationship between gain and beamwidth, especially when we compared antennas like the dipole, the inverted-V, and the 1-wavelength loop with more complex arrays based on the lazy-H configuration.

In this follow-up set of notes, we shall look at two special needs within the overall NVIS scene: a desire for directional NVIS communications and the requirement--largely a function of newer ALE potentials--for very wide-band communications. To simplify our discussions, we shall place all antennas over bare average ground (conductivity = 0.005 S/m, relative permittivity = 13).

Directional NVIS Communications

Curiously, a few years back, I received within a fairly short time period two notes via e-mail. One correspondent wished to know if there might be an effective NVIS antenna for his coastal location, since he wished to direct as much as possible of his signal inland. The second note, a few weeks later, asked is there might be an antenna for his coastal location that would allow NVIS communications out to sea with enough front-to-back ratio to quiet signals from land-based stations in the other direction. Not only do both inquiries have an affirmative response, they both might use the same antenna.



Two Directional NVIS Antennas
with Elevation and Azimuth Patterns

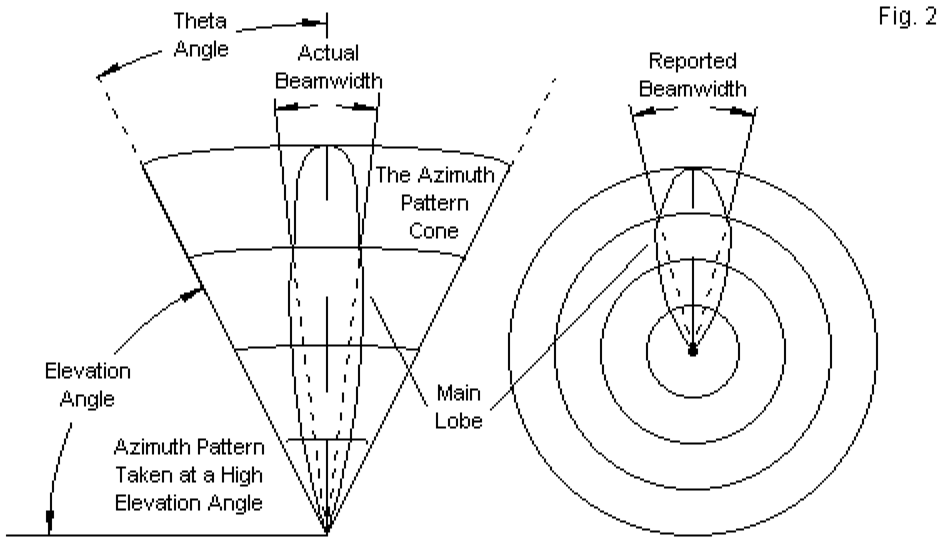
Figure 1 shows two candidates composed of AWG #12 copper wire and set at 45' about 0.175 wavelength) for 3.9-MHz operation. The upper left sketch shows a conventional 2-element driver-reflector Yagi. The element spacing provides a feedpoint impedance close to 50 Ohms. As we lower the height of a directional antenna, the main forward lobe angles ever more upward. The Yagi shown has a TO angle of about 49°, with an elevation beamwidth that extends to nearly overhead. The maximum gain approaches 8.2 dBi at the TO angle, with a 7.5-dB front-to-back ratio. The radiation directly upward from the Yagi is only down about 3.5 dB or so from the maximum gain, so NIVS communications at the shortest ranges will be similar in strength to using a dipole or inverted-V. However, receiving sensitivity to the rear of the array will be well down from maximum gain. The result is directive NVIS operation, whether out to sea or inland from the sea.

The way to improve the NVIS directional pattern is not with more antenna gain, but with less. The more compact Moxon rectangle--consisting of AWG #12 copper wire--has a lower maximum gain value: about 7.9 dBi. However, the TO angle is about 55°, with a smoother pattern curve from front-to-rear. Hence, the zenith angle falls within the elevation pattern's beamwidth. As well, the rectangle's configuration provides an additional 2-dB of front-to-back ratio, resulting in further quieting in the unwanted direction. We might obtain similar results from the Yagi by lowering its height somewhat.

Because both antennas are horizontal directional beams, even at low heights, we have a limited horizontal beamwidth. NEC-4 reports a value of 94° for the Yagi and 120° for the Moxon rectangle. These reports derive from the azimuth patterns that we took using the TO angle as the pattern elevation angle. Since both TO angles are quite high, we must use caution in accepting the reported values.

Every azimuth pattern over ground specifies an elevation angle for the pattern. Only if the elevation angle is 0° (illicit in NEC-2) will the pattern itself be circular. Azimuth-equivalent patterns in free-space may use 0° elevation and also yield a far-field tracing that is flat and circular. Every non-zero elevation angle entry in fact produces a pattern based on a conical surface, as suggested by the radically high elevation angle in **Figure 2**. Let's assume that the figure has sliced the cone from tip to base and therefore shows only the main forward lobe and not the rearward lobes. The actual half-power beamwidth on the surface of the cone is the angular distance between the points on the lobe that are 3 dB down from the peak gain value.

Fig. 2



The Azimuth Pattern Cone Sliced to Show Only the Main Forward Lobe

Conical Section with the Main Forward Lobe Transferred to a Flat Circular Plane

Understanding Azimuth Patterns and Their Projections onto Plotting Forms

Unfortunately, limitations of software force us to project the pattern onto a flat circular plotting form. World maps suffer a similar problem when we project the features of a globe onto a flat page. The problem is distortion. With azimuth patterns, we do not notice the problem with antennas that we use for long-distance communication, because we normally us fairly low elevation angles. Hence, the cone and the plotting form are very similar. However, for NVIS operations, we are interested in high to very high angles, that is, elevation angles from 45° to 90°. At these angles, the distortion can be high, and it increases as we increase the elevation angle. The right side of **Figure 2** may seem to create only mild distortion, but the sketches show a 2:1 ratio between the angles on a flat surface and on the conical surface at the left.

We may quickly calculate an approximate corrected horizontal beamwidth value using a simple equation:

BWa = BWr * cos(elevation angle) or BWa = BWr * sin(theta angle)

BWa is the actual horizontal beamwidth, BWr is the NEC report of the beamwidth, and the indicated angles are the elevation or theta angles at which we take the phi/azimuth pattern. The use of an elevation angle or a theta angle will depend on the operative convention of your antenna modeling software. NEC operates using theta angles counting from the zenith downward. We convert theta angles to elevation angle by subtracting from 90°. The equation is only a handy approximation because it does not account for the fact that the pattern has side-to-side curvature on the surface of the cone, but it provides results that are as close as we need for virtually all applications.

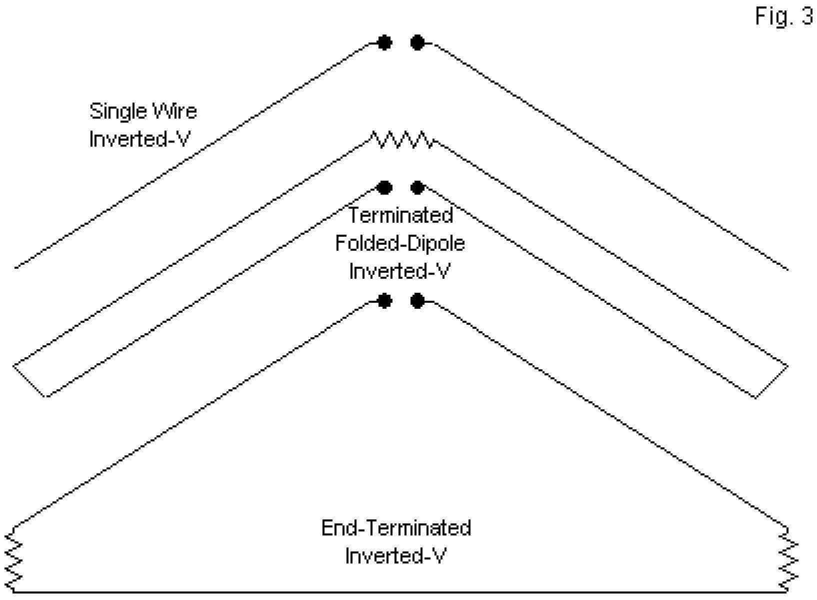
One reason that we do not question beamwidth reports for lower angle azimuth patterns relative to the values that occur in free-space patterns is that the cosine of the elevation angle is 0.9 or higher for all such angles that are 25.8° or lower. However, the cosine of the elevation angle decreases ever more rapidly toward zero as we raise the elevation angle. The Yagi reported a beamwidth of 94° at a TO angle of 49°. The cosine of 49° is 0.646 and so the adjusted beamwidth is about 62°. The Moxon reported a beamwidth of 120° at an elevation angle of 55°. The corrected value is about 69°. Although the initial reports seemed to give the Moxon a large horizontal beamwidth advantage over the Yagi, the corrected values tell us that there is not much difference. Since wire NVIS directional antennas require aiming, correcting the high-angle azimuth beamwidth reports is essential if we are to know what coverage we can expect from it. Of course, coverage does not suddenly end beyond the beamwidth limit, but it may weaken rapidly.

Wide-Band Terminated NVIS-ALE Antennas

Automatic Link Establishment (ALE) equipment has become almost standard in military circles. By very rapid scanning and synchronization of codes and return codes, the central station can select the most promising frequency for successful communications. Other governmental agencies have seen a potential for adapting this system to emergency communications. Since the scanning central transceiver does its work so rapidly, it does not have time for the delays associated with changing matching networks to effect a match between the equipment and the antenna. As a result, antennas that exhibit a constant impedance over a very wide frequency range have once more become very popular government acquisition items.

Unfortunately, radio amateurs have also become enamored with these antennas. One of the most common misconceptions associated with these antennas is that they perform in all respects as smoothly across the frequency spectrum as the very low SWR value suggests. In general, we can rarely obtain such smooth performance over a 2:1 frequency range using an inverted-V configuration. Let's perform a small experiment. We can use the 3 antennas shown in **Figure 3** as samples. Each antenna is 42.5' high at the center and 2.5' above average ground at the ends. The distance between the center pole and the wire end is 50'. Each leg is therefore 64' long, for a total AWG #12 wire length of 128'. These dimensions apply to all three variations on the inverted-V installations. The operating range is 3.75 MHz to 7.5 MHz. Each antenna is initially a bit shorter than ½ wavelength electrically so that we may obtain adequate NVIS patterns throughout the passband.

Fig. 3



Antennas for Comparison

The single-wire unterminated V forms a performance baseline for our comparisons. At the antenna feedpoint, we shall expect (and ignore in this context) a wide set of excursions for the resistive and reactive components. The resistance will begin quite low and reach a very high value at or near the upper frequency limit. The reactance begins as a moderate capacitive value and climbs to a very high inductive value. These progressions are normal for an antenna that begins at just under ½ wavelength and reaches about 1 wavelength at the upper frequency limit.

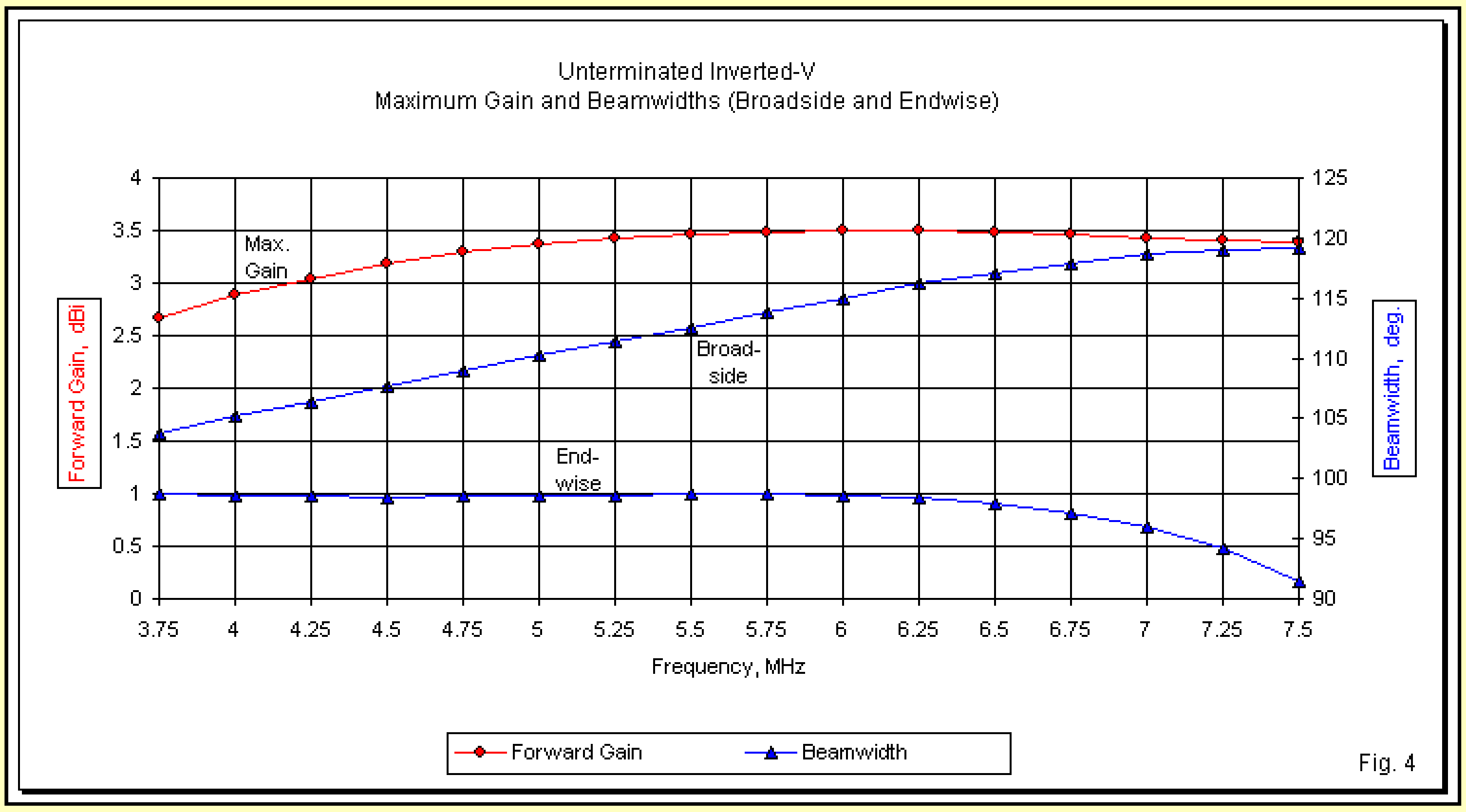


Fig. 4

More significant for the present context are the data in **Figure 4**, which graphs the maximum gain and the broadside and endwise beamwidth values. The gain declines at the lower end of the spectrum as the antenna reaches ½ wavelength and then becomes even shorter. Otherwise, the gain level is relatively smooth and consistent with values that we saw for the inverted-V in the last episode. The broadside beamwidth shows a continuous climb with increasing frequency. In contrast, the endwise beamwidth remains relatively constant until we near the upper end of the passband.

The middle sketch in **Figure 3** shows perhaps the most popular terminated wide-band antenna used by amateurs: the terminated folded dipole. There are many versions and a number of myths surrounding the antenna. The spacing between the AWG #12 conductors can vary from an inch to a foot or two with no modelable difference in the basic performance. Far more critical to any application is the length. An ideal terminated wide-band folded dipole antenna will be at least ½ wavelength long at the lowest operating frequency to remain above the performance "knee." The knee represents an electrical length below which performance falls off precipitously as the antenna feedpoint resistance without the termination would decrease from about 70 Ohms toward zero. The series termination would provide a stable feedpoint impedance, but also dissipate more and more of the energy. In the inverted-V configuration, the baseline non-terminated impedance would be closer to 50 Ohms. Above the knee region, the impedances undulate around the value of the terminating resistor. A resistor in the vicinity of 800 to 900 Ohms tends to yield the smoothest SWR curve. Of course, the antenna must include an effective method of converting the high terminal impedance down to a conventional coaxial-cable value.

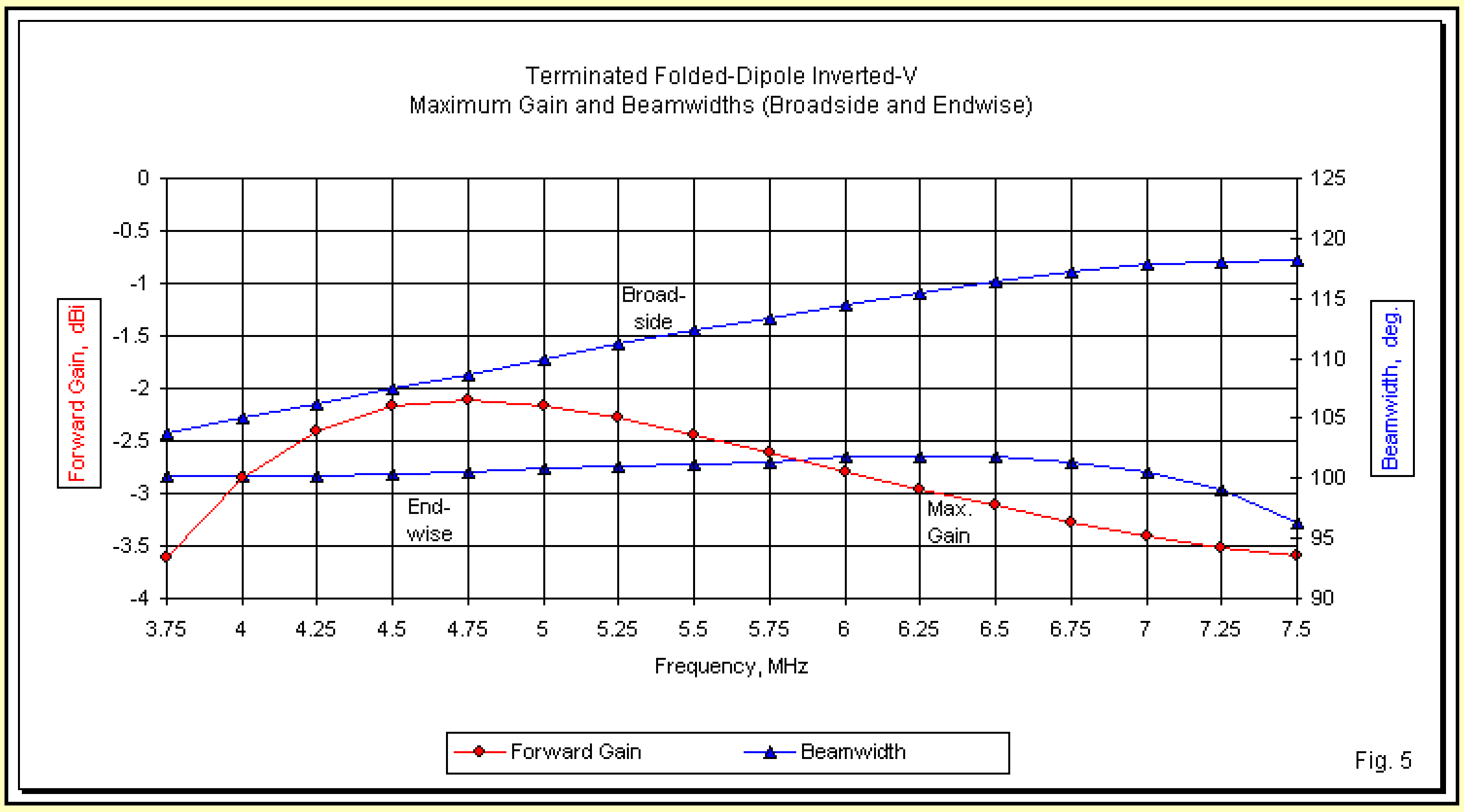


Fig. 5

Like the single wire unterminated inverted-V, the terminated folded version is slightly short relative to the knee in order to produce acceptable patterns for NVIS operation within the 3.75- to 7.5-MHz passband. Because the amount of shortening below ½ wavelength is small, we should see only the start of the gain decline below about 4.5 MHz. The graph in Figure 5 confirms this suspicion. Below about 4.5 MHz, the curve takes a sharper downward direction than the corresponding gain curve for the unterminated inverted-V. Equally significant in **Figure 5** are the beamwidth curves for broadside and endwise directions from the wire antenna. Compare these curves to the corresponding set in **Figure 4**. The fundamental similarity is inescapable.

An alternative method of developing a wide-band terminated antenna is to place the terminating resistors at the wire ends. These resistors require a ground-return line to provide them with a low impedance common point. The model for this basic configuration uses a wire that is 0.001 wavelength above ground so that the model will run on both NEC-2 and NEC-4.1 Commercial versions of the antenna show variations on the basic theme. Some use fans of different-length elements joined at the terminated ends. Others bring the common line back up to the feedpoint. Most of the variations tend to yield somewhat smoother SWR curves. The modeled basic version uses a 500-Ohm resistor at each end of the wire, with a 1000-Ohm reference impedance. As with the folded dipole type of terminated antenna, the system needs an effective impedance transformation device to allow a coaxial feedline. One difference between the end-terminated system and the folded-dipole type occurs with the SWR performance below the knee region. Whereas the folded version shows a smoother SWR curve, the end-terminated version tends to show a rise in SWR. Hence, the SWR provides a warning apart from gain performance to tell the user when the antenna is too short.

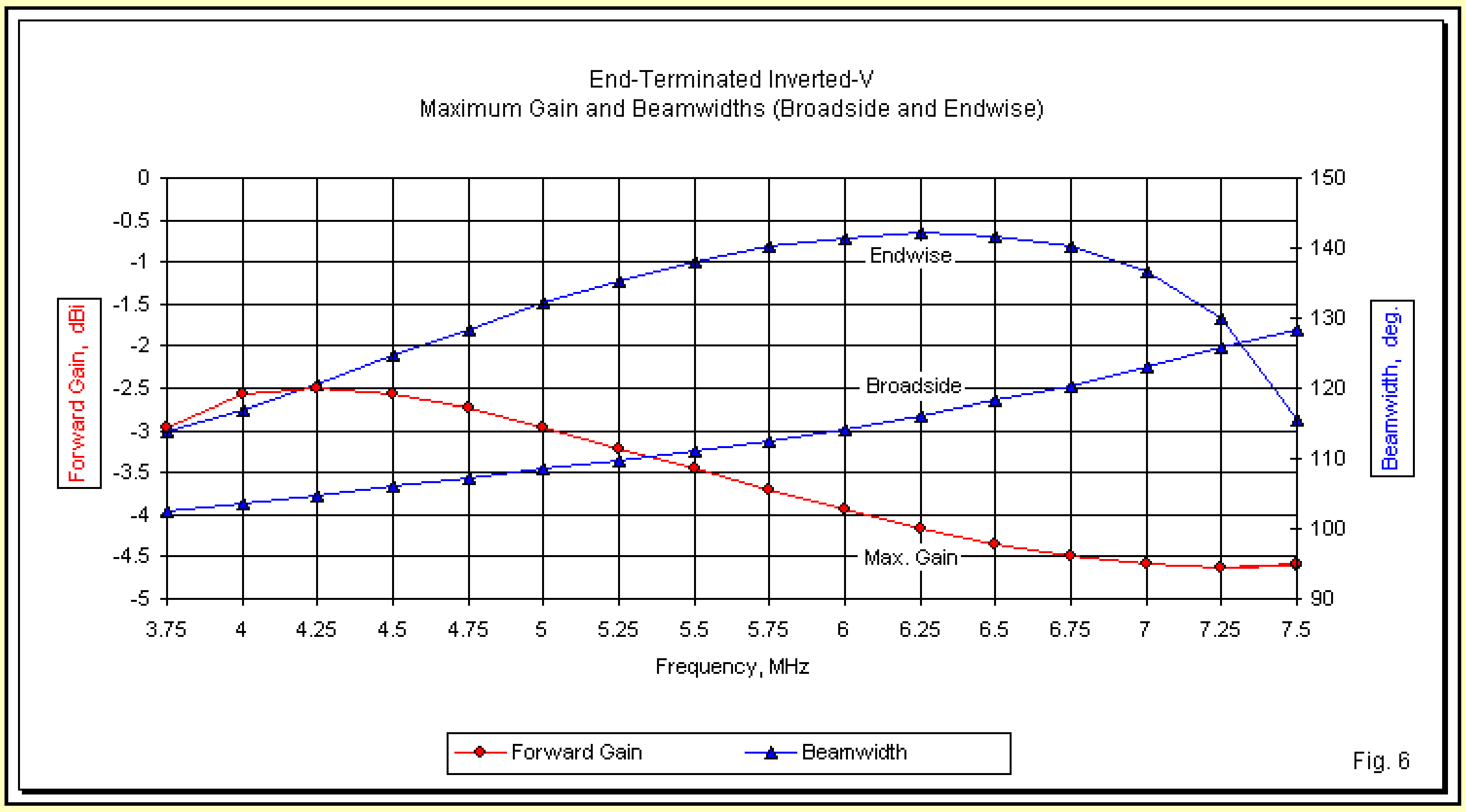


Fig. 6

Figure 6 graphs the maximum gain and the beamwidth values for the end-terminated antenna in its simplest form. The gain curve roughly parallels the folded-dipole curve, but with a slightly lower knee-frequency region--closer to 4 MHz than to 4.5 MHz. More interesting are the beamwidth curves. The broadside beamwidth is very close to what we found for the unterminated and the folded-dipole antenna types. However, the endwise beamwidth shows a greater variation across the passband than we found with the other two antennas. As well, the average endwise beamwidth is perhaps 25° greater and exceeds the broadside beamwidth throughout the passband. One consequence of this behavior difference is that commercial versions of the antenna tend to favor flatter installations than the 38° slope of the wires in these test models. The more level the wire, the lower the endwise beamwidth of the end-terminated wire, with a resulting equalization of beamwidths for NVIS operation.

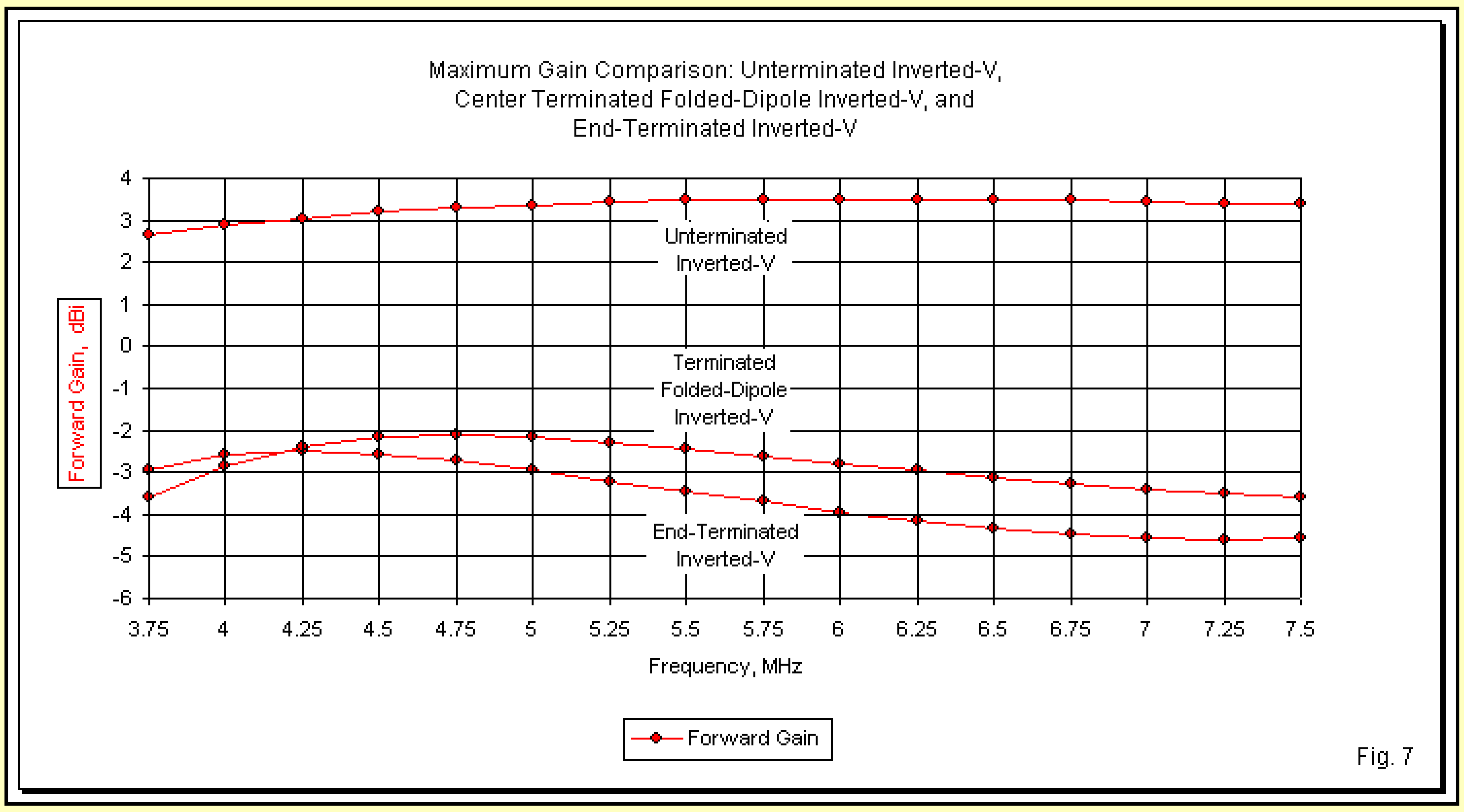


Fig. 7

We cannot escape an ultimate comparison of the gain curves for the 3 sample antennas. See **Figure 7**. The gain differential between the two terminated antennas is inconsequential compared to the deficit relative to the unterminated wire. The gain difference runs from a minimum of 5+ dB up to over 6.5 dB across the 2:1 frequency span. Since NVIS operations often call for working at the margins of acceptable transmitted and received signals, a central station using a terminated antenna loses ¾ of its transmitted power and over an S-unit of received signal strength compared to a simple unterminated wire. While terminated antennas might be used at field installations to simplify operation, they do not appear to offer the amateur operator any significant benefits for a durable installation.

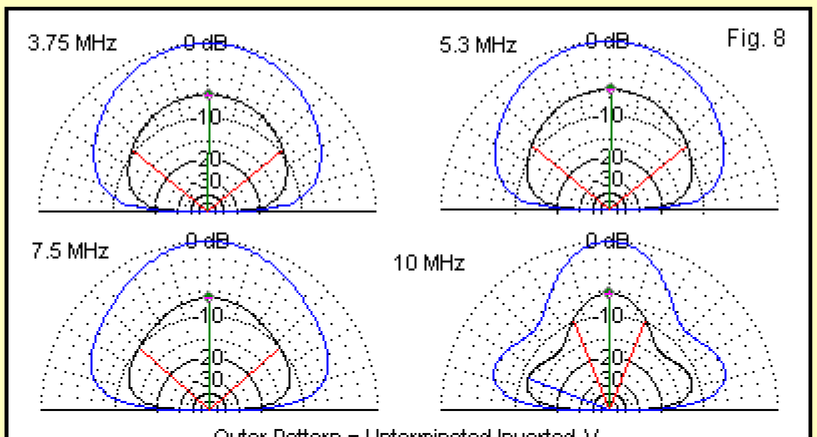


Fig. 8

Outer Pattern = Unterminated Inverted-V
Inner Pattern = Terminated Folded-Dipole Inverted-V

Endwise Elevation Patterns: Unterminated Inverted-V
and Terminated Folded-Dipole Inverted-V

The reason for limiting the 3 antennas to a 2:1 frequency span results from the fact that terminating a given length antenna does not change the far-field pattern shape. To illustrate this basic fact, **Figure 8** presents some samples of overlaid endwise elevation patterns. Only the terminated folded-dipole antenna appears as the lower-gain entry for comparison with the unterminated antenna. Adding the end-terminated antenna would only create murky pattern outlines for the inner or weaker patterns. The essential feature of these patterns is the strict congruence between the stronger and the weaker patterns across the passband. Termination affects the radiated energy of an antenna, but not its patterns. I have included a pattern for 10 MHz to establish the reason for limiting the antenna passband. However smooth the SWR curve may be for a given terminated design, the bell-shaped pattern at 10 MHz indicates an endwise beamwidth that is usually too narrow for most NVIS operations.

The Search for a Wide-Band Unterminated NVIS Antenna

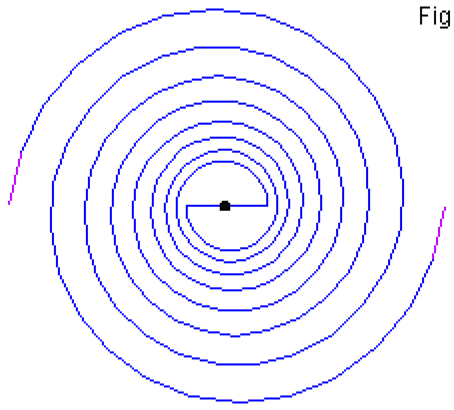
ALE has added a fresh incentive to find a NVIS antenna that provides full unterminated wire antenna gain but with an exceptionally wide operating bandwidth. A more ideal antenna would exhibit relatively uniform gain directly upward with equal beamwidth values, that is, with a virtually circular azimuth pattern at any elevation angle. The half-power beamwidth values should fall within a range from 70° to perhaps 110° to assure adequate energy and receiving sensitivity at about a 45°-elevation range to allow intermediate as well as short-range communications by this mode. The search for such an antenna has taken two basic directions--one relatively futile, the other more promising.

Both directions share a common feature: the use of frequency-independent design techniques. The most obvious technique is to apply LPDA design equations to a dipole array that points straight upward (or downward). In general, an LPDA design with linear elements fails to achieve the desired results due to a conflict between LPDA design criteria and the height range within which NVIS antennas perform best. For any number of elements covering any frequency range, the best height falls within the 0.125-wavelength and the 0.225-wavelength range. To obtain the best LPDA performance in terms of gain and feedpoint impedance we must increase the value of one of the calculation constants (sigma) to a value higher than we find in most horizontally oriented arrays. For the 2.5-11-MHz range (a 4.4:1 frequency span), the result would be an exceptionally tall array. As well, the gain would yield beamwidths well below the desired 70° minimum value.

If we shorten the array by reducing the value of sigma and reduce the number of elements, then LPDA performance over wide frequency range tends to collapse. Numerous anomalous frequencies will appear. At these frequencies, the pattern will show multiple lobes in unwanted directions and the main lobe will not be upward. As well, the impedance curve tends to vary widely. In general, the wider the frequency span for an LPDA, closer that the design constants of tau and sigma must come to the highest permissible values. As a result, if we try to place each element at a height that favors NVIS operation, we end up with an array that fails completely in its mission.

An alternative array that also uses basic LPDA principles in an expanded format has become popular among some commercial antenna makers for the corporate and government market: the log-spiral doublet array. **Figure 9** shows the general outline for one such design. The spiral uses a factor of a^{theta} to define the rate of radius increase with each wire segment. The design shown uses a pair of 4-turn spirals 180° apart to end up with the full structure.

Fig. 9



A Wide-Band Log-Spiral "Doublet"
for Unterminated NVIS Service

Log-spiral antennas have their greatest use in the UHF region where the design can attend to the element diameter (or strip width on a substrate). A wire version in the HF range that uses a single wire diameter will thus be less ideal and subject to numerous finicky requirements. Most commercial designs to not use an inner limiting radius for the spiral. As well most use a conical or modified conical shape (with 4 or 6 sides). Some offerings use outer-end resistive terminations, although this practice seems to defeat the point of using such a complex structure, namely, to achieve full wire gain over a wide frequency span. Hence, the state of the art relative to log-spiral NVIS potentials remains uncertain. Nevertheless, **Table 1** shows the modeled performance of the flat log-spiral design and thus suggests what may be possible some time in the future. Note that at only 2 frequencies does the beamwidth drop to less than 70° in one of the sampled planes. Patterns do not go completely askew until we pass 10.5 MHz. The sample array used here requires a 50-meter diameter just to contain the wire, with additional space needed for supports.

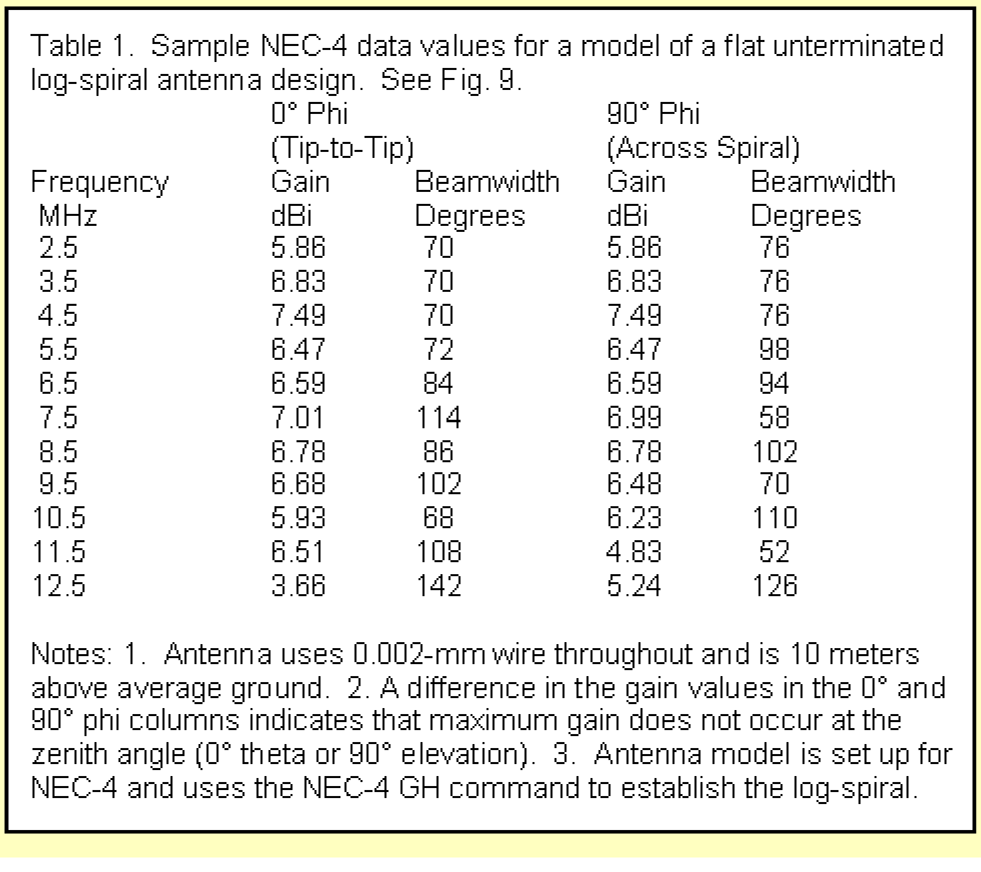


Table 1. Sample NEC-4 data values for a model of a flat unterminated log-spiral antenna design. See Fig. 9.

	0° Phi (Tip-to-Tip)		90° Phi (Across Spiral)	
Frequency MHz	Gain dBi	Beamwidth Degrees	Gain dBi	Beamwidth Degrees
2.5	5.86	70	5.86	76
3.5	6.83	70	6.83	76
4.5	7.49	70	7.49	76
5.5	6.47	72	6.47	98
6.5	6.59	84	6.59	94
7.5	7.01	114	6.99	58
8.5	6.78	86	6.78	102
9.5	6.68	102	6.48	70
10.5	5.93	68	6.23	110
11.5	6.51	108	4.83	52
12.5	3.66	142	5.24	126

Notes: 1. Antenna uses 0.002-mm wire throughout and is 10 meters above average ground. 2. A difference in the gain values in the 0° and 90° phi columns indicates that maximum gain does not occur at the zenith angle (0° theta or 90° elevation). 3. Antenna model is set up for NEC-4 and uses the NEC-4 GH command to establish the log-spiral.

Conclusion

We began by identifying two special needs sometimes associated with NVIS operation. Obtaining a directional NVIS array proved to be the simpler project, since any number of relatively low-gain horizontal arrays might meet the operational criteria for an installation. Very-wide band NVIS operation across a large frequency spread presented the more difficult challenge. If we require relatively slow frequency changes, then we can easily press an inverted-V into service over a 2:1 frequency range for acceptable NVIS patterns. However, the higher rates of ALE frequency change require an antenna that requires no alteration of the impedance matching network in the course of operation. Some typical wide-band terminated antenna types can meet the need, with 2 restrictions. First, for many antennas that we might set up as inverted-Vs or as linear doublets, the operative frequency range for acceptable NVIS patterns remains about 2:1. Second, termination yields considerable loss of gain. Achieving a wide-band unterminated antenna design capable of covering 2.5 to 10 MHz with roughly similar gain levels and acceptable NVIS patterns without a need to switch networks remains a future goal for amateurs and an expensive project for commercial and government installations.

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