How High is My Antenna?

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The question of antenna height in the HF region mysteriously remains somewhat a mystery to many amateurs. We know some basic facts about the antenna, like its height in feet or meters. But many of us fail to realize what the physical height implies about performance. So let's spend some time looking at a couple of standard cases--where the antenna is all at one height--to find out what height means to performance. Then, let's look at a few antennas that have multiple heights of interest. For example, the inverted-V has a peak height at the center and an end height. The quad beam has an upper and lower height. Finally, a stack of two or three Yagis has a top beam and a bottom beam.

Notice that our discussion will involve only antennas that are essentially horizontal. The height of vertical antennas is another discussion entirely, and we shall reserve it for another occasion.

The 1-Height Antenna

The basic height of an antenna is only indirectly connected with the physical height. The more important question is how high the antenna is as measured in wavelengths at the operating frequency. We can perform an easy approximation. Take the height in feet and convert it to meters by multiplying the height by 0.3048. Now check the operating band. If your height works out to 10 meters and you are using the antenna on 20 meters, then the height is roughly 1/2 wavelength. I call the value "rough" because the band designators for amateur allocations are only approximate. But the exercise will get you started in the right direction.

The next stage is to figure out what the antenna height in wavelengths tells us that might be important. Basically, the antenna height tells us what the angle will be for our elevation pattern. Since the elevation pattern determines the skip angle for our antenna, we shall soon discover whether the antenna is good for DX or only for local and/or regional communications. (Remember that propagation can do funny things, and even an antenna that is mostly useful for shorter range contacts can sometimes let us contact the rare DX station.)

There is an equation for determining the elevation angle of each lobe in the pattern of a horizontal antenna:

$$A_{LN} = \arcsin \frac{N}{4h}$$

A_{LN} is the elevation of the lobe or null above the horizon. We count for this equation by assigning lobes odd numbers (N). So the first lobe is 1, while the second lobe (if it exists) is 3. (Nulls get even numbers, and ground level--0--is the first null.) The antenna height (h) is in wavelengths or fractions of a wavelength. **Table 1** lists the values for the ideal first-lobe elevation angle based on the equation.

Table 1. Equation-based elevation angles for the first lobe of a horizontal antenna.

Height (h) λ	Elevation angle (A_{LN}) degrees
0.5	30.0
1.0	14.5
2.0	7.2

We shall discover that these values are a bit too high. The equation presumes perfect ground and a simple dipole. Real ground and the antenna structure will slightly modify these values. However, as a rule of thumb, these values are good ones to memorize as an easy reference. Note, of course, that as we raise the height of the antenna, the first elevation lobe has its peak gain at a lower angle. Since propagation angles for long-distance communication tend to favor lower angles, we can see the wisdom of the old advice that with a horizontal antenna, height comes before almost any other concern.

Let's start our survey of real antennas with a 1/2-wavelength dipole made from wire, and let's place it over average ground. Our main modeling tests will be at 20 meters (14.175 MHz), which is about in the middle of the amateur HF region. Let's see what happens when we run a dipole with heights or 0.5, 1.0, and 2.0 wavelengths. **Fig. 1** shows the antenna and the elevation patterns, while **Table 2** provides the numerical data.

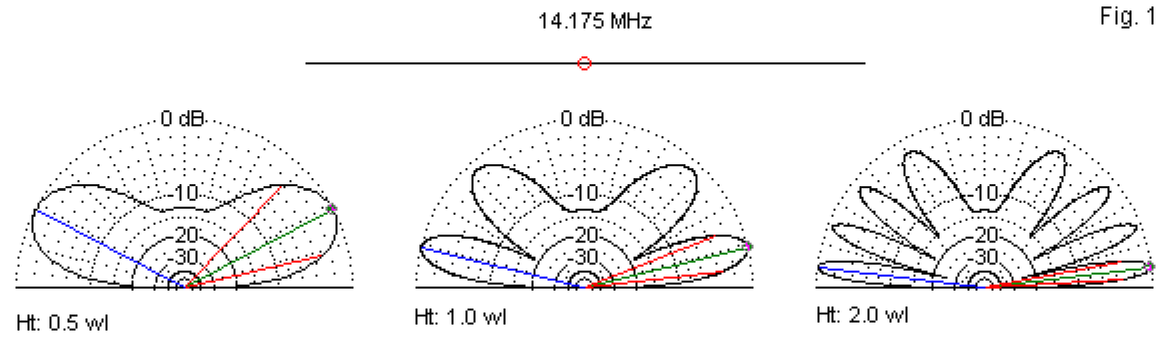


Fig. 1

Elevation Patterns for a 20-Meter Dipole at Various Heights

Table 2. First-lobe elevation angle of a 20-meter dipole at various heights.

Height (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	7.30	27.5	33.1
1.0	7.64	13.7	14.7
2.0	7.85	6.9	7.2

First, we notice that the elevation angle of the first lobe is lower than predicted by the equation for each of our sample heights. Second, there is no magic in the exact number for that angle. Terrain will make a difference to its real value. As well, I have recorded the vertical beamwidth value for the lobe to illustrate that there is a span of angles (and not simply a single angle) that marks the range of angles of strong radiation (and equally strong sensitivity for reception). Third, take note of the fact that as we raise the antenna, we obtain slightly more gain.

To establish that these phenomena are quite general, let's substitute a 10-meter dipole for our original 20-meter antenna. The 10-meter dipole will have half the physical height of the longer antenna in order to establish our test heights from 0.5 wavelength to 2 wavelengths. **Fig. 2** and **Table 3** provide the patterns and the data.

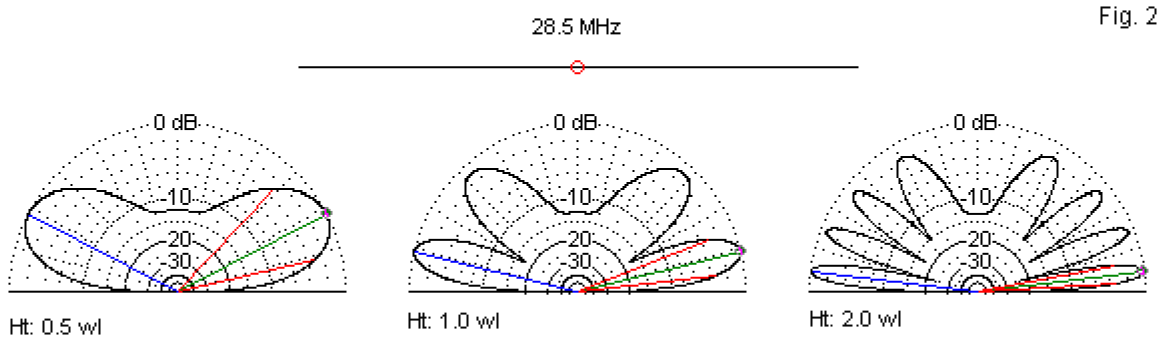


Fig. 2

Elevation Patterns for a 10-Meter Dipole at Various Heights

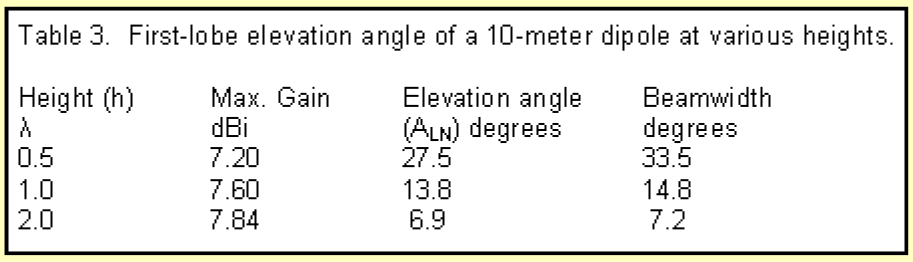


Table 3. First-lobe elevation angle of a 10-meter dipole at various heights.

Height (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	7.20	27.5	33.5
1.0	7.60	13.8	14.8
2.0	7.84	6.9	7.2

The values for the elevation angle of the first lobe and the lobe's vertical beamwidth are virtually identical to those for the 20-meter dipole. Almost incidentally, we can note the slight differences in the maximum gain values. The lower the antenna, the lower the 10-meter gain relative to the 20-meter gain. The amount is far too low to make an operational difference, but the fact that the lower gain shows up is a function of the fact that ground losses increase with frequency. As we raise the antenna farther from ground, it has less effect on a horizontal antenna. By a height of 2 wavelengths, the effect is nearly completely gone.

Many amateurs (erroneously) believe that making a horizontal antenna longer may improve the radiation angle. To test this belief, let's create a 20-meter 1-wavelength center-fed wire. It is twice as long as the original 20-meter dipole. If length does make a difference to the elevation angle, the effect should show up. Now let's examine **Fig. 3** and the data in **Table 4**. The representation of the antenna carries the current distribution curves to establish that it is not just another 1/2-wavelength dipole.

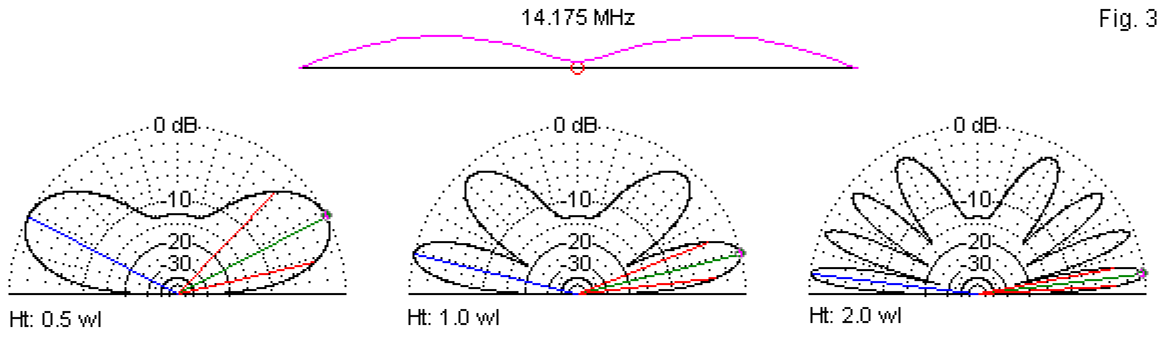


Fig. 3

Elevation Patterns for a 20-Meter 1-Wavelength Center-Fed Wire at Various Heights

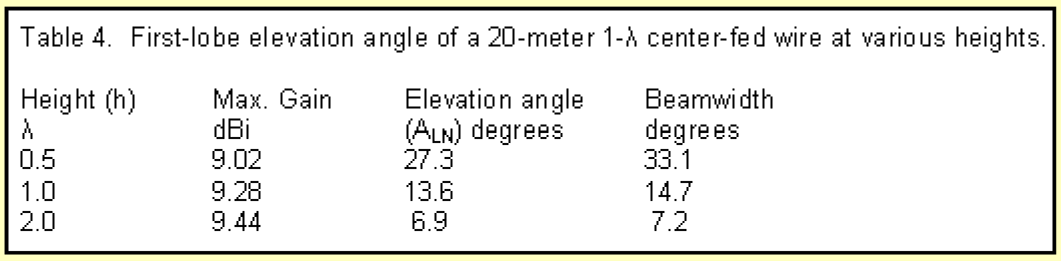


Table 4. First-lobe elevation angle of a 20-meter 1-λ center-fed wire at various heights.

Height (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	9.02	27.3	33.1
1.0	9.28	13.6	14.7
2.0	9.44	6.9	7.2

We can easily see the added gain that the 1-wavelength wire gives is. As with all horizontal antennas, the gain increases slowly with increasing antenna height. However, we do not find any difference in the elevation angle or the vertical beamwidth. (The decimal place in the values for the angles is not operationally significant. It will only play a role a bit later on in this discussion, when we look at antennas having more than one height of interest to us.)

While we are looking at antennas that have only one height, let's see what we obtain for values from antennas having gain in a favored direction. We can begin with a 3-element Yagi of fairly standard design. **Fig. 4** and **Table 5** tell the essential story.

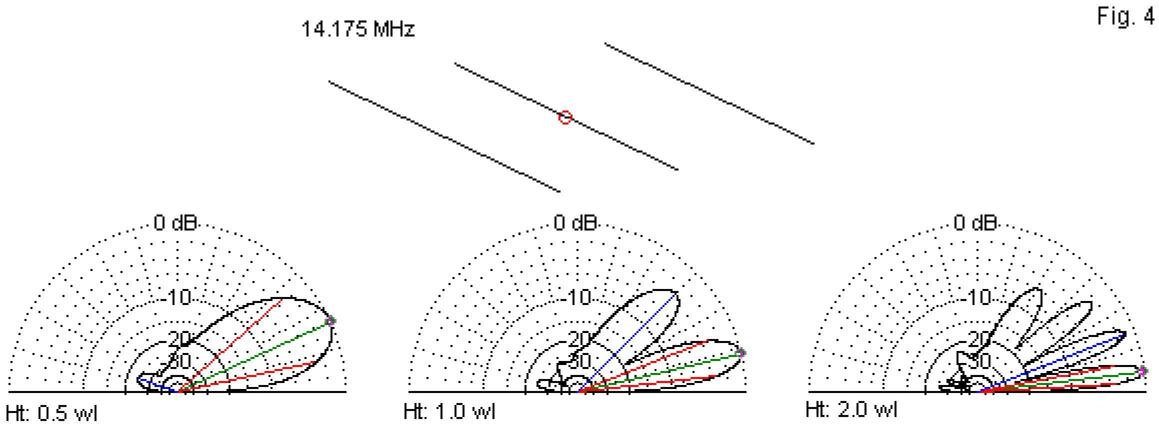


Fig. 4

Elevation Patterns for a 20-Meter 3-Element Yagi at Various Heights

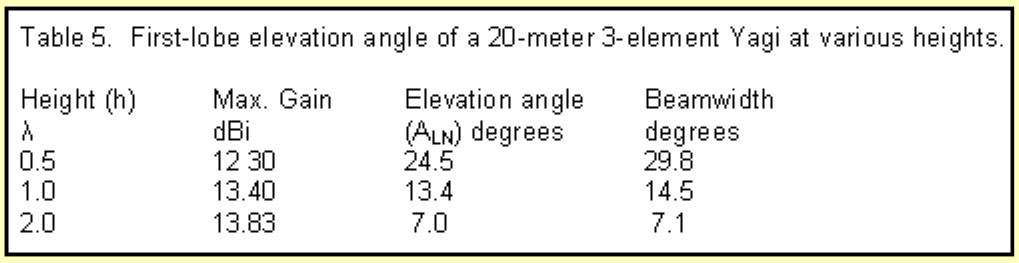


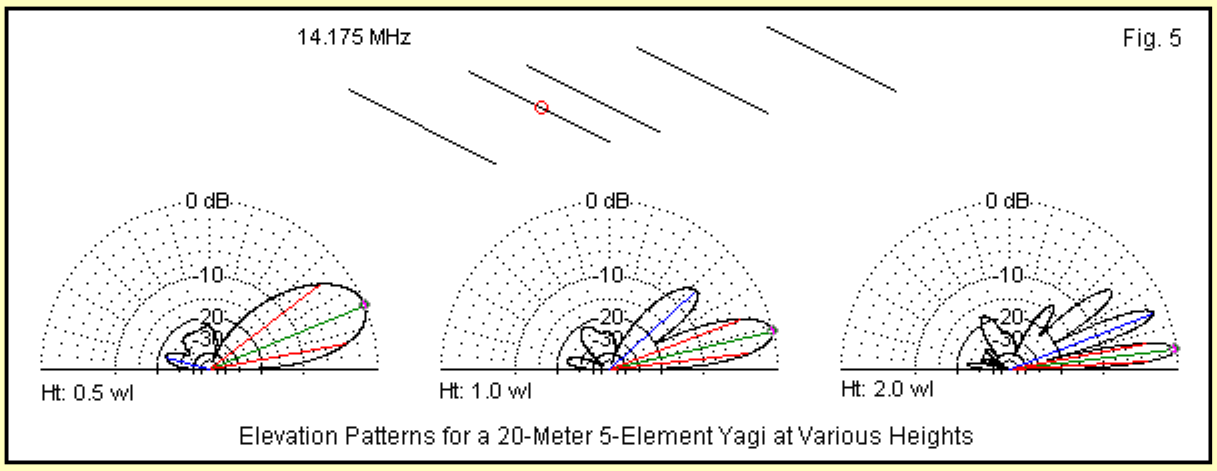
Table 5. First-lobe elevation angle of a 20-meter 3-element Yagi at various heights.

Height (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	12 30	24.5	29.8
1.0	13.40	13.4	14.5
2.0	13.83	7.0	7.1

The gain increase with increasing height once more shows up. In fact, the phenomenon is so universal to horizontal antennas that we shall only mention it one more time from this point forward. More significant is the elevation angle behavior. If we look at the table from the bottom up, which means from the highest level down, we see that the numbers gradually depart from the dipole values. The lower that we place the Yagi, the lower its elevation angle becomes relative to the standard values for the dipole. Again, we have the ground to thank for the variation. A Yagi radiates from its entire structure, not just from the driver. Each element has a set of "rays" that intercept the ground at very slightly different angles due to the physical displacement of the elements from each other. The closer to the ground that we bring the antenna, the more that these differences show up in the antenna's radiation pattern. The complex interactions show up as a lower elevation angle at the lowest sample height. As we move the antenna upward, the effect grows less noticeable. By a height of 2 wavelengths, the effect is virtually gone.

At the same time, note that the vertical beamwidth of the lowest lobe generally tracks with the elevation angle. At lower mounting heights, the beamwidth is slightly greater than the elevation angle of the lobe. The difference decreases as we raise the antenna and lower the elevation angle of the lowest lobe. For VHF antennas that we normally mount quite a few wavelengths above ground, we can equate the two numbers without fearing any error.

Let's increase the antenna size and forward gain a bit more. A 5-element Yagi at 20 meters often serves as a big antenna for the DXer. **Fig. 5** and **Table 6** show us what happens.



Elevation Patterns for a 20-Meter 5-Element Yagi at Various Heights

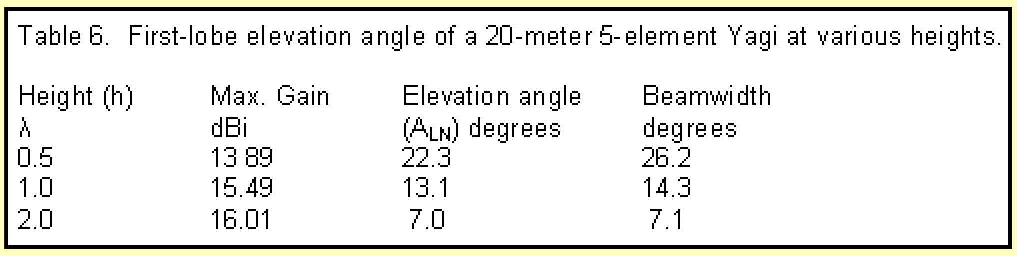


Table 6. First-lobe elevation angle of a 20-meter 5-element Yagi at various heights.

Height (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	13 89	22.3	26.2
1.0	15.49	13.1	14.3
2.0	16.01	7.0	7.1

The long-boom Yagi shows a further lowering of the elevation angle when we mount it at the unlikely height of 1/2 wavelength above ground. Ground effects still show up--although not to an operationally significant degree--when the antenna is 1 wavelength above ground. However, by the time we move the antenna to 2 wavelengths above ground, those effects have completely disappeared.

Our last mention of the antenna gain-vs.-height situation requires that we look at the tables for all of the 20-meter antennas. For the single wire antennas, the total gain difference between heights of 0.5-wavelength and 2.0 wavelengths is only about 0.5 dB. That difference grows to about 1.5 dB for the 3-element Yagi and to 2.1 dB for the 5-element Yagi. The difference is becoming not only noticeable, but also significant. For this reason, many DXers like to mount their long-boom Yagis as high as they can safely maintain.

Our small survey gives us a fairly good foundation in knowing what to expect from a horizontal antenna at any height above ground, when we measure the height in wavelengths. More significant to the rest of our work in these notes is the fact that the demonstrations show what significance we place on the height of horizontal antennas in terms of our anticipations of performance for long-distance communications. Height correlates to the elevation angle of the lowest lobe, and that factor relates to the propagation angles that most usually come into and go out of our antenna. (Note that in many circumstances, incoming and outgoing angles of propagating signals may differ with respect to the ionospheric conditions between my antenna and yours.)

The net result is this: we may equate the height of two antennas if they have the same elevation angles for the lowest lobe in the pattern. The equation cannot be exact, since--as we have seen--the antenna may have some structural factors that affect the elevation angle at lower mounting heights. However, we can come close.

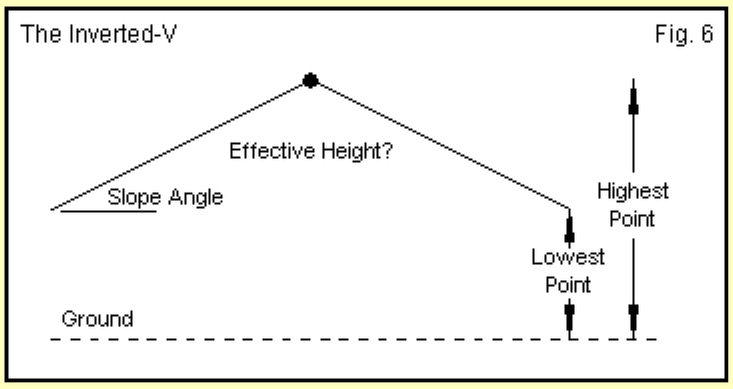
Six Sample Multi-Level Antennas

The equation for estimating the elevation angle of the first lobe of a horizontal antenna applies only when the elements are linear relative to the ground and when we have only one X-Y plane for the elements. The equation does not guide us when we have sloping elements, such as the ones we find in an inverted-V. As well, the equation fails us when we have an antenna with multiple X-Y planes, that is, when we have a vertical stack of antennas.

There is a rule of thumb: the *effective height* of an antenna with multiple height considerations is about 2/3 of the distance between the lowest height and the highest height for the antenna. Like the human thumb, which varies in size and shape from one person to the next, this rule of thumb varies in its accuracy depending on the type of antenna and the actual lowest and highest heights. If we look at several types of antennas and place them at various heights above ground, we might be able to refine the rule. Of course, once we run the exercise, we likely shall no longer need the rule, since we shall have some data that will allow more precise interpolations.

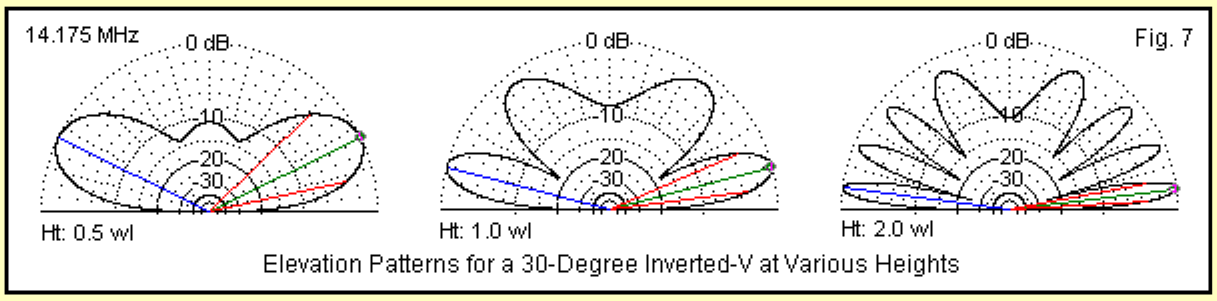
Case 1: the Inverted-V

Inverted-V antennas are less common on 20 meters than they are on 160, 80, and 40 meters. However, to be consistent in our comparisons, we shall use a 20-meter wire inverted-V as the subject antenna. We shall seek out the effective height of an inverted-V to see if it corresponds with the lowest point, the highest point, or some other point between the two. **Fig. 6** shows the outline of our project.



One useful way to find an effective height is to compare the inverted-V to a linear dipole. The V is simply a sloping version of the dipole, although the slope does modify the antenna's performance characteristics. Suppose that we take the TO angles for the dipole and move the V up and down until it yields about the same TO angle (within a few tenths of a degree). Then the lowest and highest points of the V will tell us something about how the 2 antennas are related. However, inverted-Vs come in many angles of slope, where the angle of slope is the angle of each half element relative to flat ground. We cannot cover every possible angle, but we can sample inverted-Vs with slope angles of 30 degrees and 45 degrees.

The 30-Degree V: The data for the 30-degree V appear in **Table 7**, while the pattern are in **Fig. 8**.



Elevation Patterns for a 30-Degree Inverted-V at Various Heights

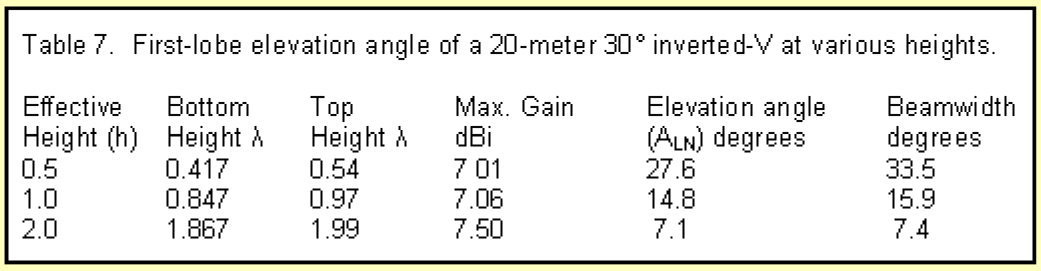


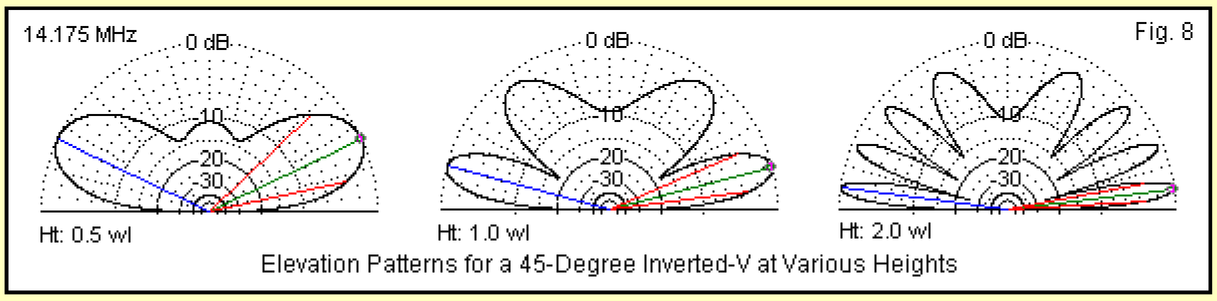
Table 7. First-lobe elevation angle of a 20-meter 30° inverted-V at various heights.

Effective Height (h)	Bottom Height λ	Top Height λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	0.417	0.54	7 01	27.6	33.5
1.0	0.847	0.97	7.06	14.8	15.9
2.0	1.867	1.99	7.50	7.1	7.4

In the table, note that the left-most column shows the effective height, that is, the physical height that most closely approximates a linear dipole at 0.5, 1.0, or 2.0 wavelengths above ground. The next 2 columns list the lowest and upper heights of the 30-degree V. The remaining data provides a basis for making comparisons with **Table 2**, the data for the linear dipole. We may instantly notice that the 30-degree V has slightly less gain than a linear dipole at the same effective height, but not enough less to be operationally noticeable. As well, if we compare the pattern in **Fig. 7** with those in **Fig. 1**, we can see some small differences, but again, not sufficient to worry us in the least.

Perhaps the most interesting fact to emerge from the data is that the 30-degree V has an apex that is above the dipole height only for the lowest version. As we increase the V's height, the apex height and the effective height come together. (The very slight differences between the top height and the effective height are well within the boundaries for calling them equal, since the TO angles do not change fast enough to allow for greater precision.) Therefore, the rule of thumb, if it applies at all, works only for inverted-Vs with top heights below 1/2 wavelength. Of course, most 30-degree inverted-Vs for 160 through 40 meters tend to be well below 1/2-wavelength at the top, and their ends are much closer to the ground as a fraction of a wavelength. Hence, the 2/3-rule is more likely to be accurate for Vs on the lower HF bands. Higher Vs tend to act almost exactly like linear dipoles with respect to their TO angle.

The 45-Degree V: For smaller spaces, amateurs often give the inverted-V a slope angle of up to 45 degrees. What happens with this version of the inverted-V appears in **Fig. 8** and in **Table 8**.



Elevation Patterns for a 45-Degree Inverted-V at Various Heights

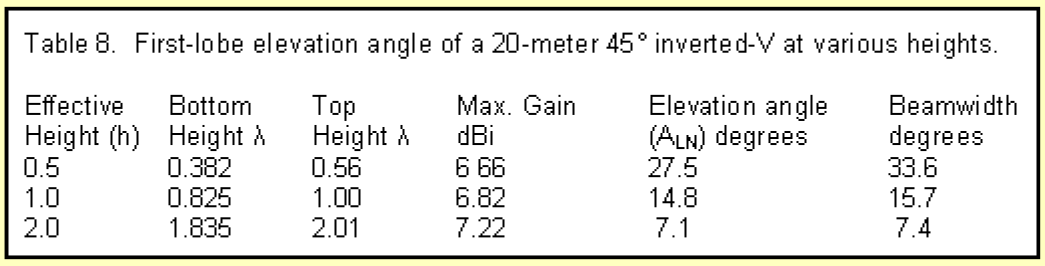


Table 8. First-lobe elevation angle of a 20-meter 45° inverted-V at various heights.

Effective Height (h)	Bottom Height λ	Top Height λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	0.382	0.56	6 66	27.5	33.6
1.0	0.825	1.00	6.82	14.8	15.7
2.0	1.835	2.01	7.22	7.1	7.4

Since the 45-degree inverted-V patterns are for their effective heights relative to the TO angle of a comparable dipole, they show virtually no difference from the 30-degree V patterns. The clues to the effects of the higher slope angle appear in the numerical data, especially in the gain column. Relative to a dipole, the 45-degree V loses the better part of a dB of gain at every height. The lost gain would reappear in radiation along the axis of the wire. Otherwise, the 45-degree V replicates what we discovered for the 30-degree V. If the height is low, then the apex of the V is above the effective height. The lower the height as a function of a wavelength, the higher the apex will be with respect to the effective height. However, if we raise the 45-degree V to a wavelength, then the apex and the effective height are just about equal. Once more, the 2/3-rule of thumb is applicable only to those low inverted Vs for 160 through 40 meters that we see in backyards.

Note that we are separating the TO angle from the overall pattern shape for the inverted Vs. The maximum gain value is an indicator that an inverted-V's azimuth pattern is likely to be more oval than the azimuth pattern for a linear dipole when both patterns have the same TO angle, that is, are at the same effective height. In a different exercise, we might easily confirm this fact. However, the direction of radiation at the TO angle does not itself effect (and is not affected by) the TO angle to any significant degree. With very low inverted-Vs, the ground can get into the overall sum of influences, but for higher Vs, the TO angle is relatively independent of the gain.

In this exercise, we are working with inverted-V antennas used on their fundamental frequency, that is, when they are about 1/2 wavelength long and close to being resonant. Under these conditions, we see only small differences in performance between the 30-degree and the 45-degree V. Multi-band use of the inverted-V is another matter. In this application, the slope angle may make a big difference in performance on bands well above the fundamental operating frequency. For notes on this subject, see "The Multi-Band Inverted-V from Many Angles".

Case 2: the Quad Beam

A quad loop consists of two dipoles that are in phase. Because they are only 1/4-wavelength apart, the ends can fold down and touch, forming a continuous loop with a single feedpoint. A single quad loop has a gain advantage over a linear dipole of about 1.15 dB. When we add one or more parasitic loops, we end up with a beam whose principles are the same as for a Yagi with the same number of elements. In this case study, we shall look at 2-element quad beams.

The procedures will be the same as those used with the inverted-V. We need to make two adjustments. The first is to add one more measurement to the list of heights with which we are concerned. Besides the lowest and highest points of the quad loops, we shall also note the height of the boom or the hub. This point is halfway between the upper and lower elements. See **Fig. 9** for an outline of this situation.

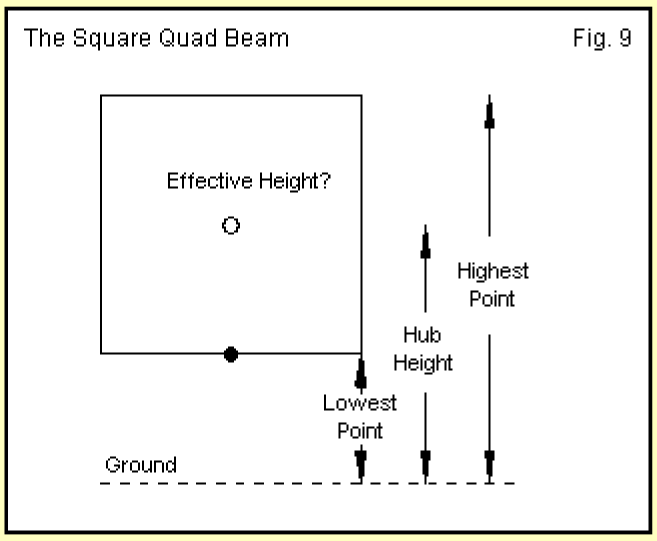

The Square Quad Beam

Fig. 9

The square quad beam: Commonly we find two forms of the quad: the square shape and the diamond. (The delta is also a form of quad with 3 sides instead of 4. As well, we can make many-side quad loops, including perfect--or imperfect--circles.) In general, we shall follow the inverted-V procedure, but we also need a new comparator. A quad beam has front-to-back structure. Therefore, we shall use the TO values for the 3-element Yagi as the most similar single-plane antenna. We shall move the quad beam up and down until the TO angle is about the same as we obtained from the Yagi. **Fig. 10** and **Table 9** show the results of our juggling.

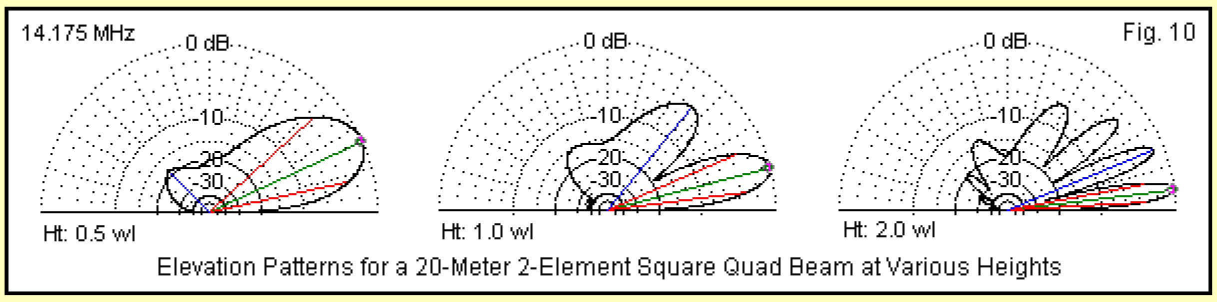


Fig. 10

Elevation Patterns for a 20-Meter 2-Element Square Quad Beam at Various Heights

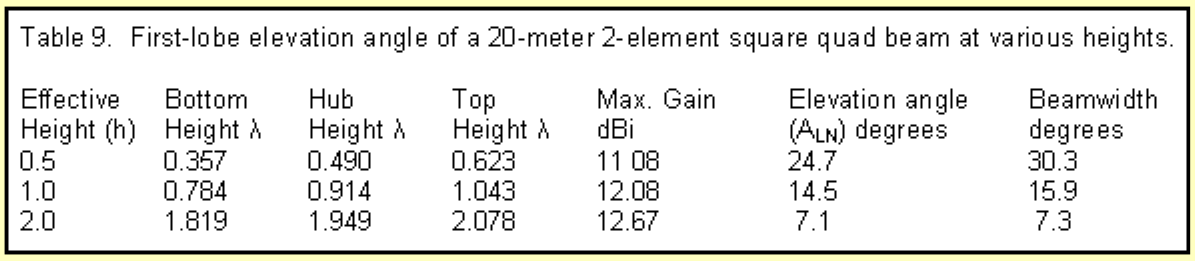


Table 9. First-lobe elevation angle of a 20-meter 2-element square quad beam at various heights.

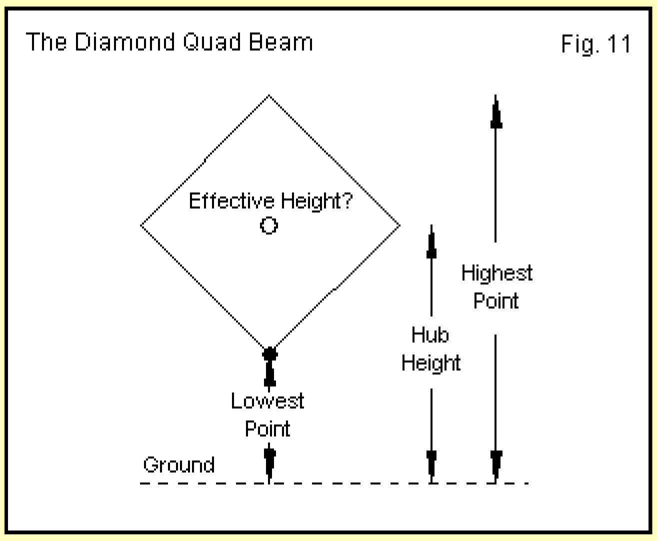
Effective Height (h)	Bottom Height λ	Hub Height λ	Top Height λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	0.357	0.490	0.623	11 08	24.7	30.3
1.0	0.784	0.914	1.043	12.08	14.5	15.9
2.0	1.819	1.949	2.078	12.67	7.1	7.3

The patterns for the 2-element square quad resemble those for the 3-element Yagi, but not perfectly. Most of the differences are in the rear quadrants and at the highest angles. The maximum gain of the quad is a little more than 1 dB under the Yagi's capabilities. The physical height midpoint--the hub--is always below the effective height by a few per cent. Otherwise expressed, the effective height is a little more than halfway up the distance between the lower and the upper wires. Had we used the dipole as the comparator for marking effective heights, the difference would have been greater--perhaps enough to approach the 2/3-rule of thumb.

The diamond quad beam: The most common alternative structure for a quad is the diamond, which gives us somewhat different upper and lower points for measurement. Still, as shown in **Fig. 11**, the hub remains at the center of the structure and provides a good point to compare with the effective height.

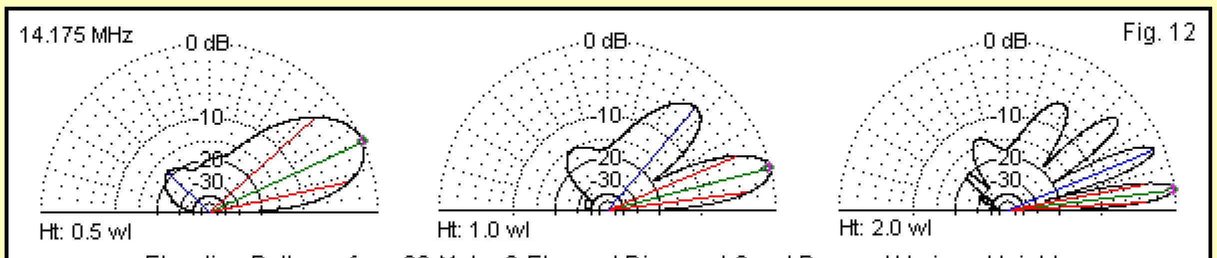
The Diamond Quad Beam

Fig. 11



In general, the performance of the square and the diamond quads are equivalent. The patterns in **Fig. 12** and the data in **Table 10** bear out this situation. The gain values for the two types of quads do not vary enough at any of the sampled heights to be detected in operation. The patterns at each height are virtually identical to those in **Fig. 10**.

Fig. 12



Elevation Patterns for a 20-Meter 2-Element Diamond Quad Beam at Various Heights

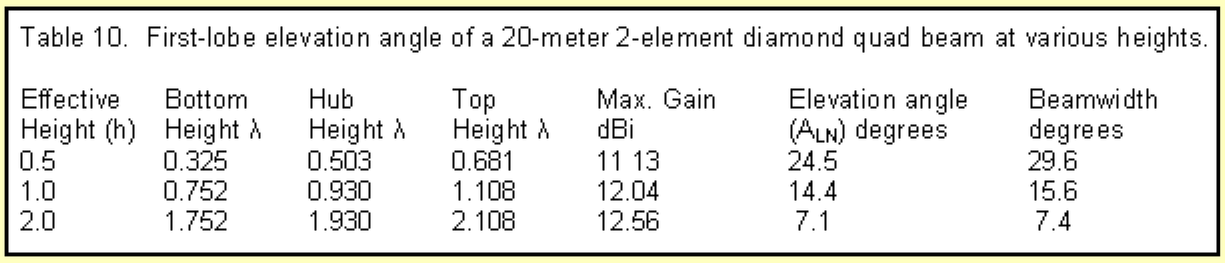


Table 10. First-lobe elevation angle of a 20-meter 2-element diamond quad beam at various heights.

Effective Height (h)	Bottom Height λ	Hub Height λ	Top Height λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees
0.5	0.325	0.503	0.681	11 13	24.5	29.6
1.0	0.752	0.930	1.108	12.04	14.4	15.6
2.0	1.752	1.930	2.108	12.56	7.1	7.4

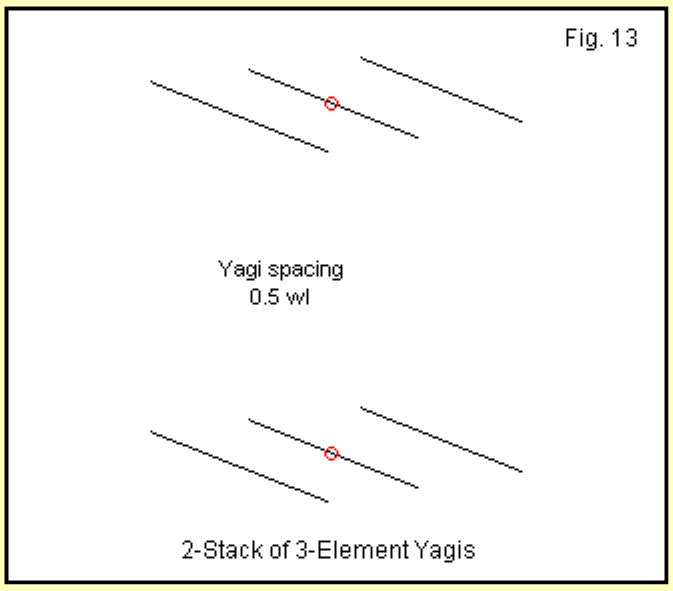
The relationship between the effective heights and the hub heights for the diamond quad also follow the pattern set by the square quad. Had we used a 2-element Yagi as the comparator, its TO angle at the lowest height would have been about midway between the TO angles for the dipole and for the 3-element Yagi. Finding the physical quad height for that slightly higher TO angle would have brought the hub height below 0.5 wavelength. Overall, the hub of the diamond quad is at or below the effective height of the antenna. The average distance from the lowest to the highest points for the effective height is about 56-57% of the total distance. The rule of thumb may use too large a value, but it serves as an indicator that the effective height of a quad is somewhat higher than the hub.

Stacked Yagis

In the past, stacked Yagis gave a misimpression. Two identical Yagis in a vertical array with both antennas fed in phase certainly yielded more gain than a single Yagi. Some folks also believed that the stack had a TO angle that was lower than the TO angle of either antenna alone. In fact, the TO angle is always lower than the bottom Yagi's solitary TO angle, but is it always higher than the TO of the top Yagi when used alone. Where in the middle the TO angle lies is what we wish to know. To sample the field, let's stack Yagis at 1/2-wavelength vertical intervals and feed them in phase. The 1/2-wavelength spacing does not yield the highest possible gain. However, it is a convenient height for our work. Once we know the TO angle of the stack, we can set up a single Yagi of the same general type and find the height at which it has the same TO angle as the stack.

A stack of 2 3-element Yagis: The 2-stack is perhaps the simplest place to begin. A 2-stack of 3-element Yagis will add a bit more than 2-dB to the array gain over a single Yagi. **Fig. 13** outlines the stack as a reference.

Fig. 13



2-Stack of 3-Element Yagis

The tables for our Yagi stacks will differ from preceding ones by listing the heights of the Yagis in the stack. In this case, we shall set the Yagis at 0.5 and 1.0, 1.0 and 1.5, and finally 1.5 and 2.0 wavelengths above ground. The height at which a single Yagi yields the same TO angle registers the effective height of the array. **Fig. 14** and **Table 11** record the results of our work.

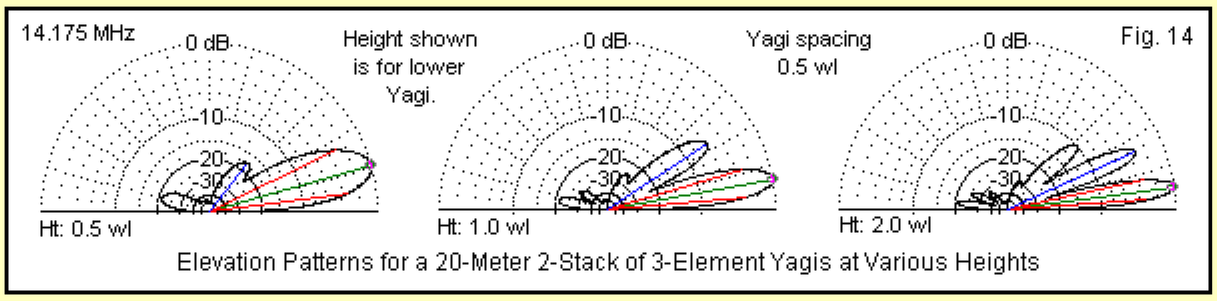


Fig. 14

Elevation Patterns for a 20-Meter 2-Stack of 3-Element Yagis at Various Heights

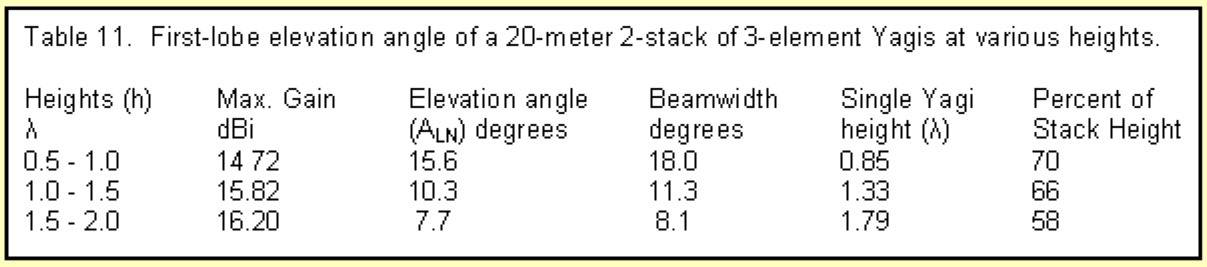


Table 11. First-lobe elevation angle of a 20-meter 2-stack of 3-element Yagis at various heights.

Heights (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees	Single Yagi height (λ)	Percent of Stack Height
0.5 - 1.0	14 72	15.6	18.0	0.85	70
1.0 - 1.5	15.82	10.3	11.3	1.33	66
1.5 - 2.0	16.20	7.7	8.1	1.79	58

The use of 1/2-wavelength spacing between Yagis changes the appearance of the elevation patterns relative to those for a single Yagi in **Fig. 4**. Half-wavelength spacing tends to suppress very high-angle radiation. Therefore, the highest lobes of the patterns in **Fig. 14** are "under-developed" relative to those in **Fig. 4**.

The most notable aspect of the tabular data is the height of the single Yagi that produces the same TO angle as the stack and its distance from the lowest to the highest beam in the stack. The closer that the stack is to the ground, the higher the effective height as measured by the TO angle. With stack heights of 1 and 1.5 wavelengths, the distance just about matches the rule of thumb.

A stack of 3 3-element Yagis: A 3-stack is a major structural undertaking for any amateur, but 3-stacks are quite common among avid DXers and contesters. **Fig. 15** outlines the 3-stack situation.

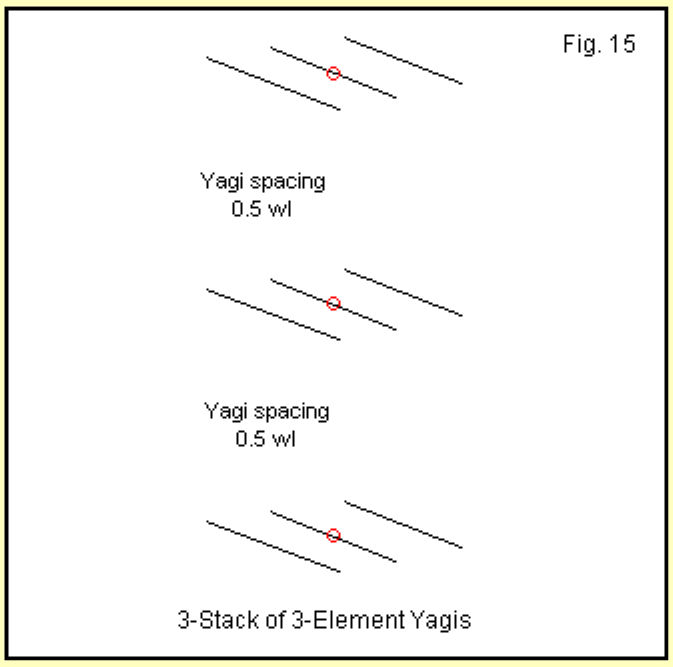


Fig. 15

3-Stack of 3-Element Yagis

I shall follow the same procedure for the 3-stack that I used for the 2-stack. The only difference in the tabular data is that the basic height column will list 3 values. The bottom heights will be 0.5, 1.0, and 1.5 wavelengths, with corresponding middle and top heights at 0.5-wavelength intervals. Once we know the stack TO angle, we can set a single 3-element Yagi at a height that produces the same TO angle and call that the effective height of the stack. **Fig. 16** and **Table 12** provide the patterns and the numerical data.

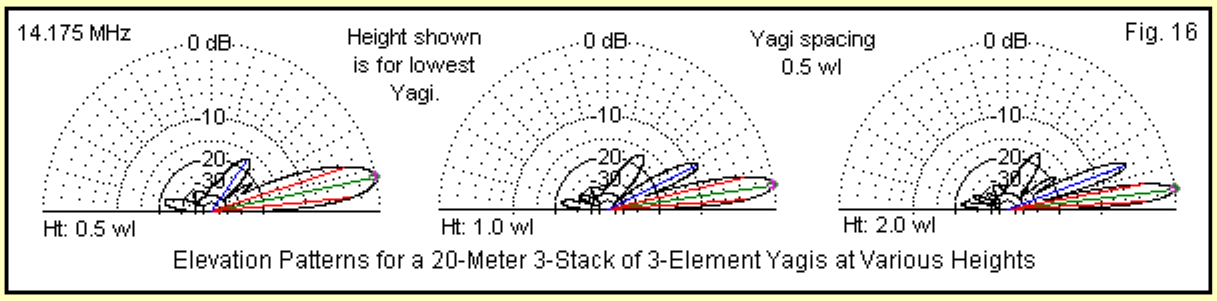


Fig. 16

Elevation Patterns for a 20-Meter 3-Stack of 3-Element Yagis at Various Heights

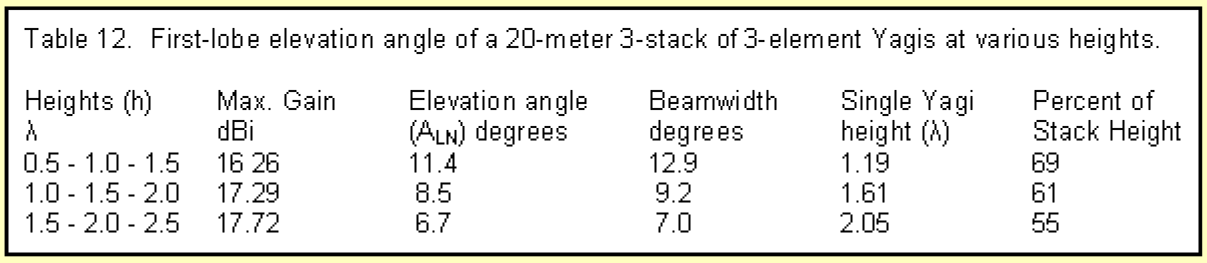


Table 12. First-lobe elevation angle of a 20-meter 3-stack of 3-element Yagis at various heights.

Heights (h) λ	Max. Gain dBi	Elevation angle (A_{LN}) degrees	Beamwidth degrees	Single Yagi height (λ)	Percent of Stack Height
0.5 - 1.0 - 1.5	16 26	11.4	12.9	1.19	69
1.0 - 1.5 - 2.0	17.29	8.5	9.2	1.61	61
1.5 - 2.0 - 2.5	17.72	6.7	7.0	2.05	55

The 3-stack patterns show relatively greater suppression of higher-angle lobes than for a single Yagi or for a 2-stack. The most significant data in the table (with respect to this exercise) is the range of effective stack heights. The range runs from 69% of the distance from the lowest to the highest antenna in the stack for the lowest array down to 55% for the highest set of 3 Yagis. The distances are slightly lower than for the 2-stack when measured as a percentage of the distance from stack bottom to top, but still close enough to the rule of thumb to make it a useful quick estimate.

Conclusion

We have looked at the basics of antenna height and its relationship to the elevation angle of the lowest lobe--the one that we tend to presume is doing most of the work in long-distance amateur communications in the HF range. Because antennas having horizontal polarization but a vertical physical dimension present complex situations, we examined a number of typical antennas in this very general class. The lower that we place an inverted-V, the closer it comes to meeting the rule of thumb, but as we raise the V, the more its TO angle corresponds to the angle for a linear dipole. Quads and Yagi stacks respond in a different manner. The effective height of these types of arrays is always above the mid-point between the lowest and the highest points in the array. While the rule of thumb is inadequate to precisely characterize the effective height of these types of antennas, it is rarely much off the mark to say that the effective height is about 2/3 the way from array bottom to array top. If you have a special interest in any one of the antenna types in our little survey, the tabular data will provide a more accurate means of estimating the effective height for the antennas that you encounter.

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