Beam Antenna Height versus DX Signal Arrival Angle

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It is probably universal for us to imagine the great DX we will be able to talk to with our first beam antenna. We imagine sighting along the boom of our antenna toward the horizon and can just feel the RF hurtling off to graze the horizon, our signals beaming off to distant places. We gradually become aware over time that reality has let us down. HF antennas just don't work that way.

The primary determining factor for an HF antenna's radiation pattern relative to the horizon is its height above ground. This is true for both horizontally and vertically polarized antennas, however, the effect of height above ground are qualitatively different and should be handled in separate discussions.

How high should an antenna be installed? This is important because higher costs more, in both effort and money, than lower, in most cases. The general rule we have all learned is "higher is better." Our checking accounts, though, tell us that "lower is better!"

Why would higher antennas be better than lower? Long distance (DX) communications on the HF ham bands depends upon the reflective/refractive characteristics of the Ionosphere. In general, the greater the communications distance, the lower the signals travel relative to the horizon. We therefore would like our DX antennas to transmit and receive in a way that will favor those lower departure and arrival angles.

	20 Meters	17 Meters	15 Meters	12 Meters	10 Meters
Europe	1-21	1-12	1-12	2-12	2-11
Far East	1-16	2-15	1-17	2-15	3-13
S. America	1-13	1-12	1-13	1-13	1-12
Oceana	2-10	2-10	2-10	2-10	2-10
S. Africa	3-12	2-11	2-12	1-12	2-11
S. Asia	2-14	1-12	2-14	3-14	4-11

Table 1: *Midwest signal arrival angles – degrees above the horizon*

The table above summarizes calculated signal arrival angles. Though these angles are ARRL computer estimates, they have shown a good correlation with real operating experience. Keep in mind, though, that signals typically do not arrive from one narrow angle, but from a range of angles. The angles shown above are where the computer simulations showed maximum signal strength. Antennas with higher angle radiation angles will often allow communications with these distant locations but will likely have lower signal levels to work with.

This article will concentrate on horizontal beam antennas. The specific antenna chosen for analysis is a common three element, three band, trap yagi. While it covers 20 meters, 15 meters, and 10 meters, only 20 meter operation is described. That is because all of the plots are for height in wavelengths. Gain, Front-to-Back Ratio, and effect of ground upon antenna pattern are essentially the same for the higher bands. In general, the information shown here can be used to estimate the performance of other kinds of beam antennas used in the 20 through 10 meter range. Some antennas will have higher or lower gain, some will have lower or higher front-to-back ratio. It should be fairly easy to extrapolate specific performance values from the graphics provided here.

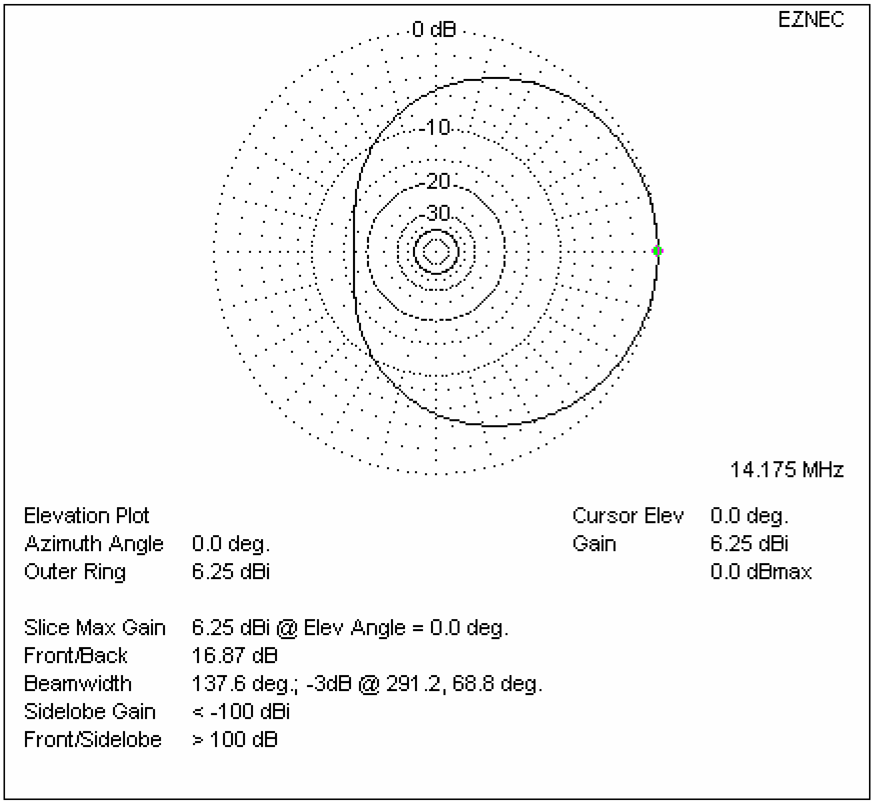

Figure 1: *Free space elevation pattern of 3 element trap yagi*

As a first step, let's look at what the calculated free space radiation pattern of our three band trap yagi. ***Figure 1*** shows a vertical slice of the antenna's overall pattern. The front of the antenna points to the right. At first glance, this may look to be a fairly shabby pattern. If you look a little more closely, it is actually not that bad. First we see 6.25 dBi gain or a little over 4 dB gain over a dipole. Next, the front-to-back ratio is about 17 dB. That would show up on our transceivers as around four to six S-units difference. (Typical S-Meter calibration is 3 to 5 dB per S Unit.)

Antennas like our example trap yagi typically exhibit quite wide variations in gain and front-to-back ratio across the bands that they cover. Manufacturers will naturally quote the best numbers achieved with an antenna, not typical numbers. I've tried to provide an estimate of average values for this analysis.

Additionally, this article deals with the 20 through 10 meter part of the HF spectrum. For the lower ham bands, 40 through 160 meters, few of us will have the opportunity to install antennas that are more than a small fraction of a wavelength above ground. After all, mounting a 40 meter antenna one half wavelength above the ground would place it at 69 feet. That is about as high as most of us will ever deploy an antenna. A 160 meter dipole at that height is only one-eighth wavelength above the ground. These antennas will work just fine but will definitely exhibit fairly high angles of radiation.

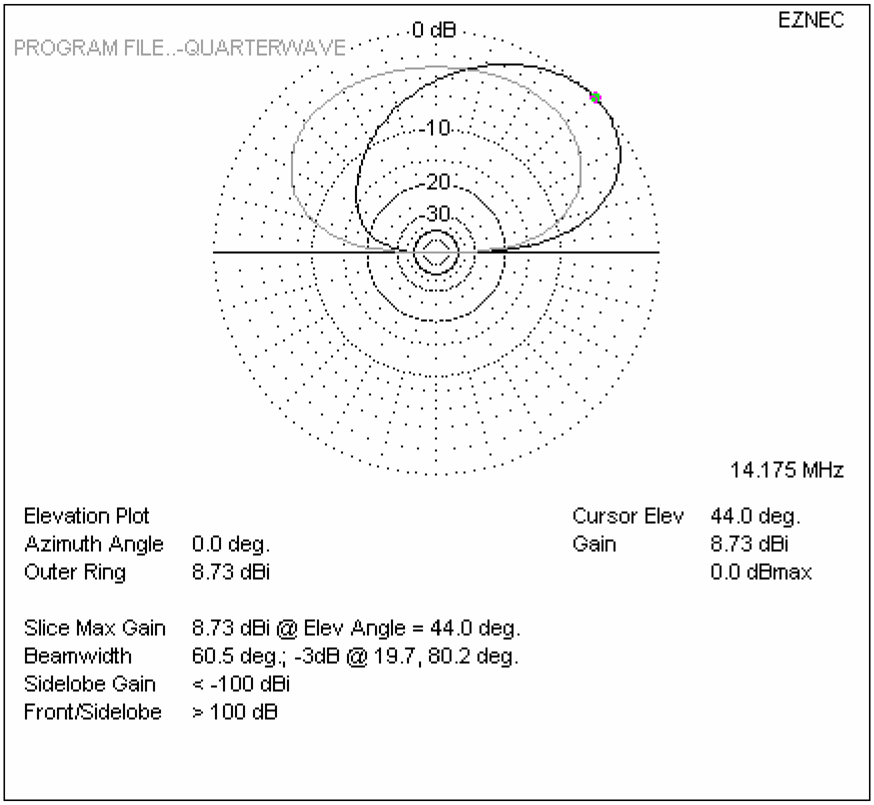

Figure 2: *3 element trap yagi at 1/4 wavelength*

Now, let's look at what placing our yagi above dirt will do to the radiation pattern shown in ***Figure 1***. ***Figure 2*** shows the yagi installed at one quarter wavelength high. For reference, you will also see a lighter shaded pattern of a half wavelength dipole installed at the same location. Notice that the vertical radiation pattern for our yagi peaks at 44.0 degrees while the dipole's peak is at 90 degrees. Also, note that signals off the back of the antenna are down 10 to 20 dB from those off the front. This may not be the pattern we would associate with a big-gun DX antenna but is does provide some operational advantages over a simple dipole. AND – This is only 17 feet off the ground for 20 meters, 8.5 feet for 10 meters.

What's going on here? A couple things are happening. The electrostatic and magnetic fields around the yagi elements are creating an RF current flow in the ground under the antenna, causing the ground to become part of the antenna system. Also, RF radiation from the antenna strikes the ground, both under and away from the antenna, causing signal reflection. RF radiation reflected back to the antenna will be partially reabsorbed, causing additional shifting of the RF currents in the antenna elements. The combination of these effects produces the overall modification of the free space yagi radiation pattern to what we see above.

An important point to keep in mind is that the dirt under the antenna is not a perfect conductor. If has its own non-perfect conductivity and dielectric constant. That causes the reflected signal to be phase shifted somewhat from what would be seen with a perfect conductor. In fact, the phase shift even varies with the angle the RF signal strikes the dirt. This is a complex subject but, fortunately, we don't have to worry about that as the antenna analysis program used here automatically takes that into account.

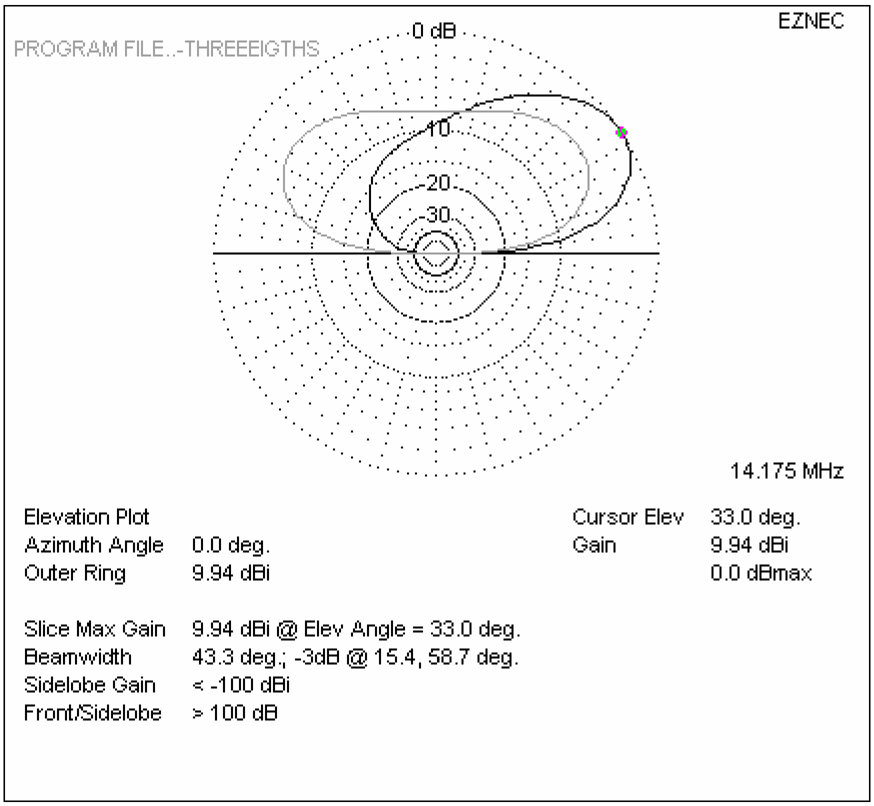

Figure 3: *3 element trap yagi at 3/8 wavelength*

OK, let's start raising our antenna and see what happens. ***Figure 3*** above shows the radiation pattern for the yagi installed at three eighths wavelength above the ground. As predicted the pattern peak has dropped from 44 degrees to 33 degrees which would probably produce a noticeable improvement in DX signal levels.

Things don't start really perking up for DX operation until we reach about a half wavelength above the ground. ***Figure 4*** shows the vertical pattern at that height. Notice that this height finally gets rid of the high angle radiation that does nothing for us at 20 meters and above.

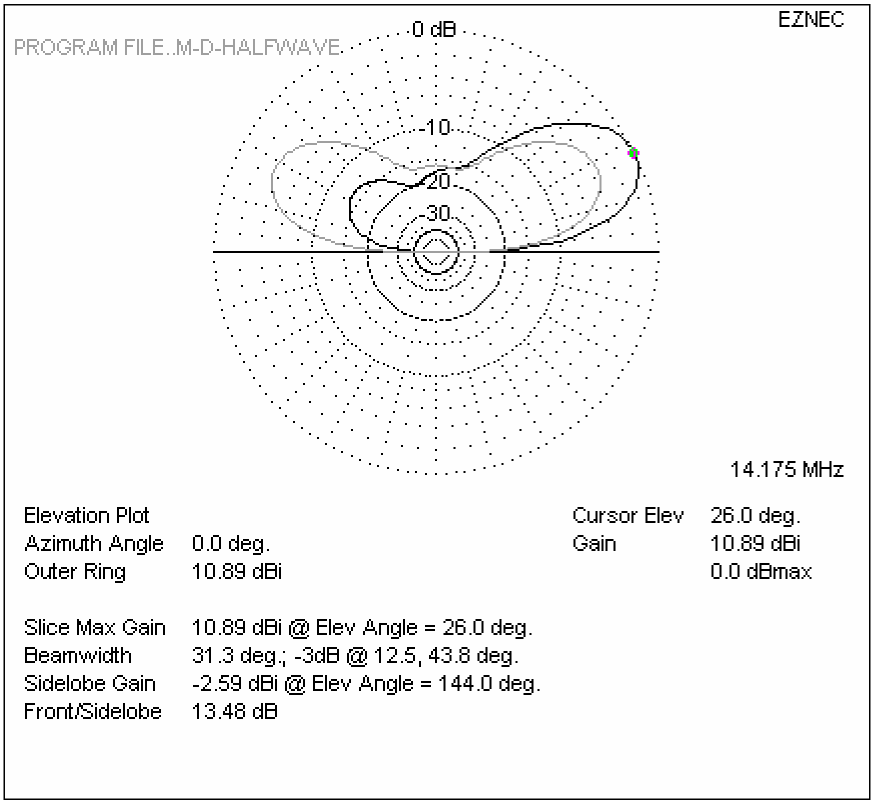

Figure 4: *3 element trap yagi at 1/2 wavelength*

Don't get too excited about the overhead null in ***Figure 4***. That null occurs only at a half wavelength above ground and multiples there of. ***Figure 5*** and ***Figure 6*** show that the overhead null goes away at other heights. Notice that even with the return of the high angle radiation in these patterns, the gains are slightly higher and the radiation peaks have dropped, now to 22 and 18 degrees. Some transmitter power is lost shooting off into space but most is still heading towards the DX stations.

Optimum general purpose DXing height turns out to be in the 1 wavelength to 1 ½ wavelengths height range. As you can see in ***Figure 7*** and ***Figure 8***, the main beam angles of between 9 and 14 degrees are nicely within the main DX signal arrival angle range.

As the antenna is raised above 1 ½ wavelengths above the ground, the main beam angle continues to drop but you will notice more of the power is split off to higher angle lobes. It isn't until about 3 wavelengths height that the angle of one of the higher angle lobes drops into the DX range. In some cases, the angle of the main lobe with antennas at 2 wavelengths and higher may be too low for some paths to the DX station. Many installations with towers in the 150 to 200 foot range will have antennas installed at the top and at half height. That allows the operator to choose an antenna with a radiation angle that most closely matches that of the current Ionospheric path.

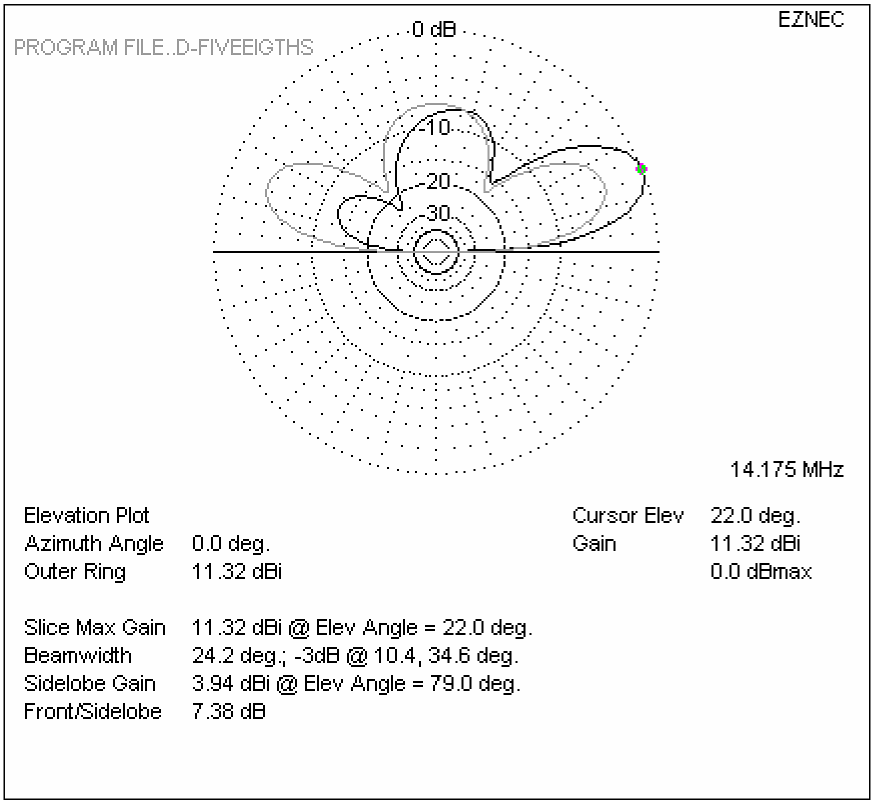

Figure 5: *3 element trap yagi at 5/8 wavelength*

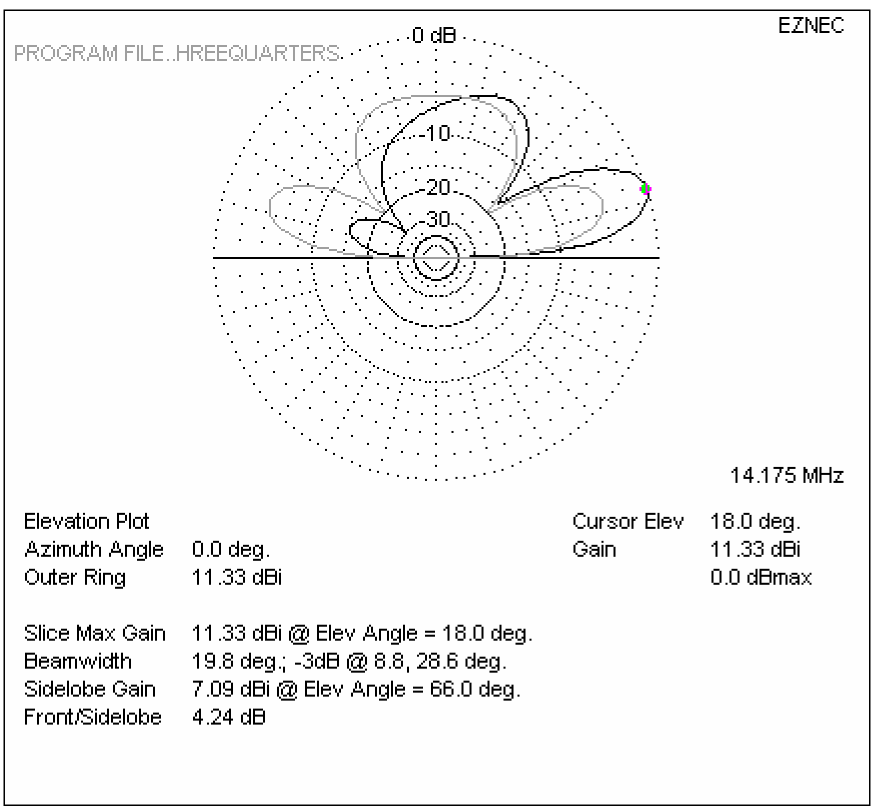

Figure 6: *3 element trap yagi at 3/4 wavelength*

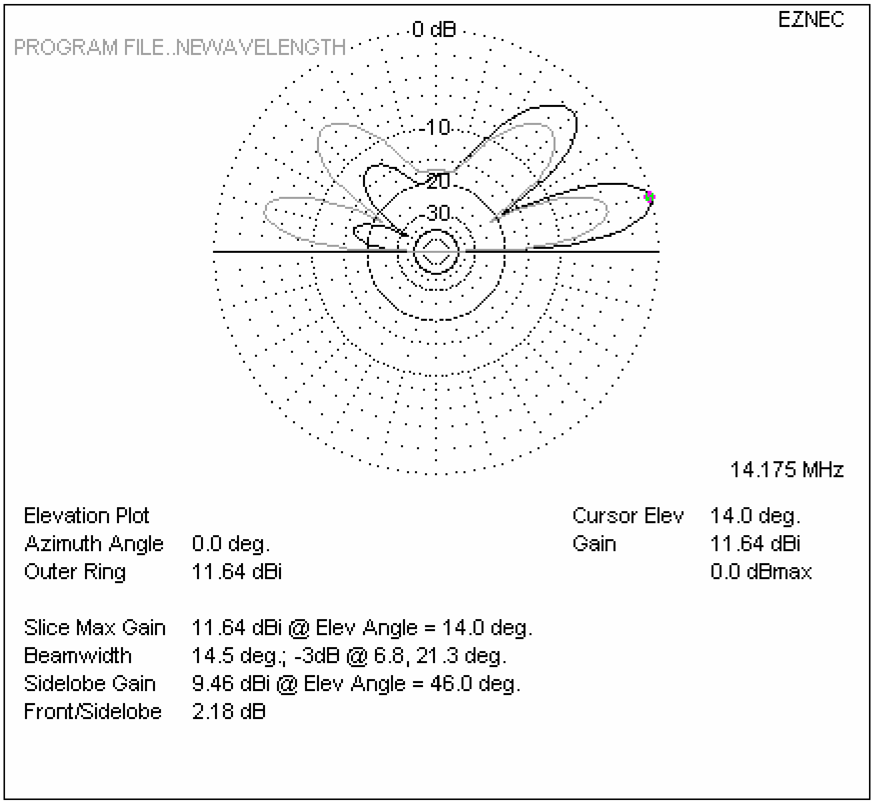

Figure 7: *3 element trap yagi at 1 wavelength*

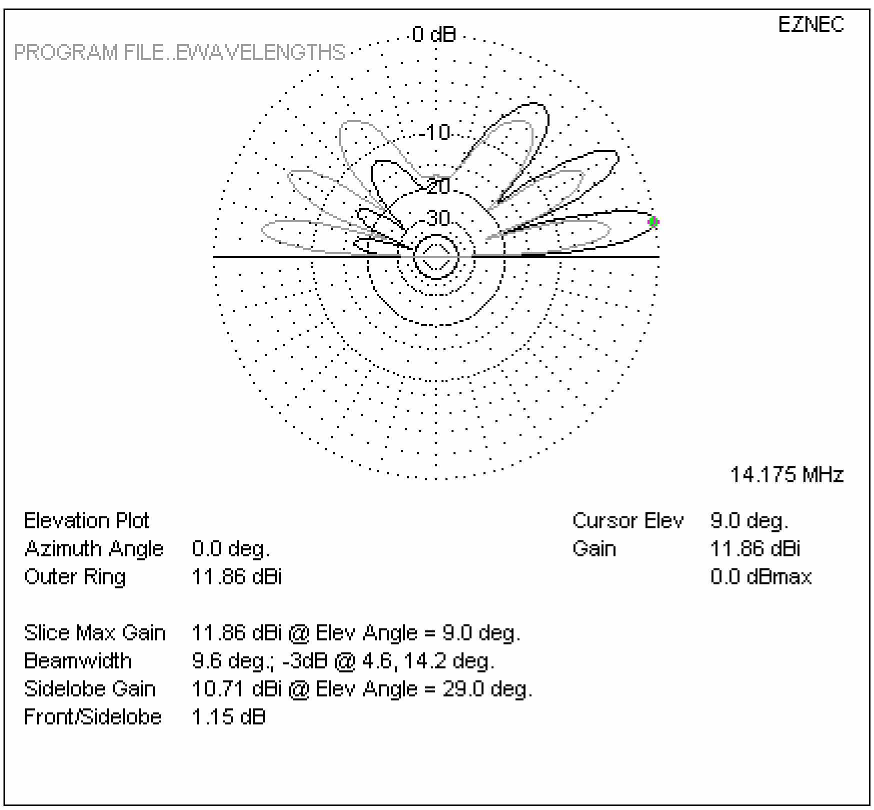

Figure 8: *3 element trap yagi at 1 1/2 wavelength*

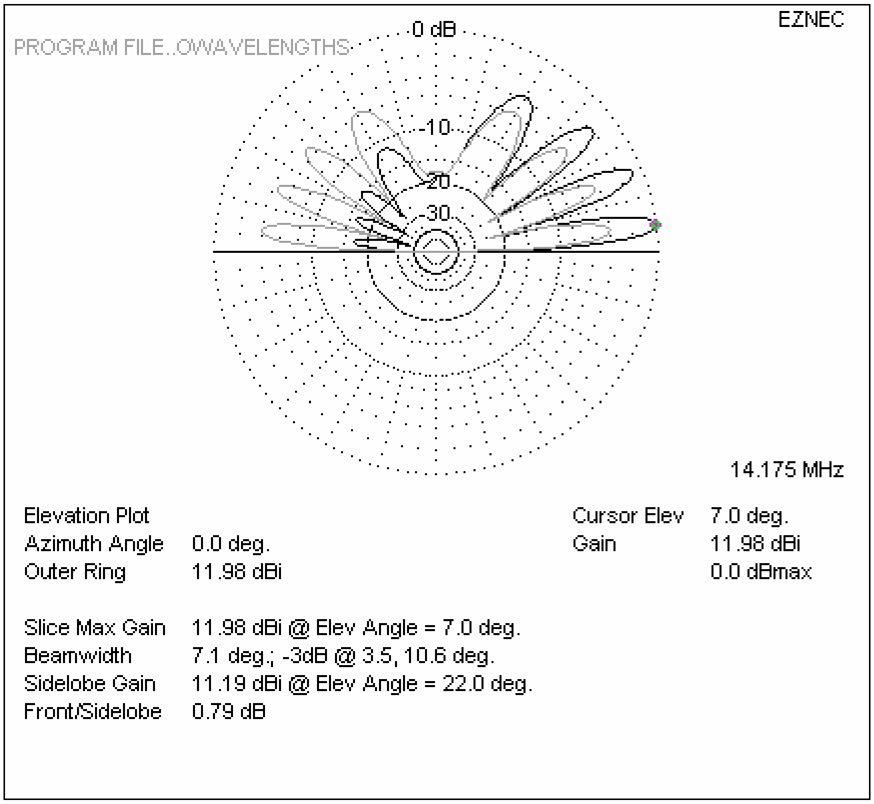

Figure 9: *3 element trap yagi at 2 wavelengths*

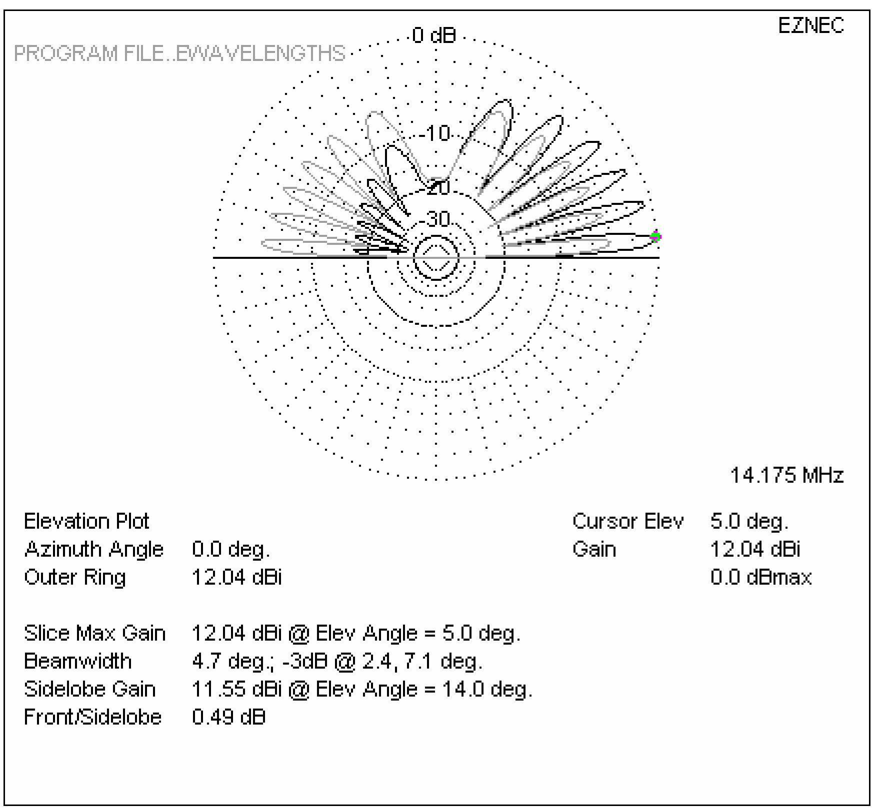

Figure 10: *3 element trap yagi at 3 wavelengths*

So, how high should your antenna be? In many ways, the correct answer depends upon how much money you can justify for a ham antenna system. 30 feet is too low to have your main beam down in the desirable DX propagation elevation angles, but some of your signal is in that range. Many very successful DXers have antennas at that height.

A height that is a good compromise between performance and cost is 50 feet. This height places your main lobe down into upper part of the main 20 meter band DX range. This angle is also still high enough for stateside rag chewing. This height also places the antenna at 1 ½ wavelengths on 10 meters.

High performance DX antennas are usually found in the 70 to 200 foot height range. Their low angle main beams may help make the owner the first station heard when a path opens and the last station heard as it closes, but may be at a disadvantage for stateside operation from the Midwest.

Table 2 below lists the height in feet above the ground for various heights in wavelengths for the different upper HF bands. Use this table to estimate which of the graphic patterns shown above best match your existing or planned antenna.

Height Wavelengths	20 Meters	17 Meters	15 Meters	12 Meters	10 Meters
¼	17 ft	14 ft	12 ft	10 ft	9 ft
3/8	26 ft	20 ft	17 ft	15 ft	13 ft
½	35 ft	27 ft	23 ft	20 ft	17 ft
5/8	43 ft	34 ft	29 ft	25 ft	22 ft
¾	52 ft	41 ft	35 ft	30 ft	26 ft
1	69 ft	54 ft	46 ft	39 ft	34 ft
1 ½	104 ft	81 ft	69 ft	59 ft	52 ft
2	139 ft	109 ft	93 ft	79 ft	69 ft
3	208 ft	163 ft	139 ft	118 ft	104 ft

Table 2: *Height in wavelengths for versus height in feet*

The bottom line is there is no "best" antenna height. Every height is a compromise of one sort or another. The right height is the one that works for you. The idea should be to maximize your fun. Whatever height achieves that is the proper choice for you.