Planning Antenna Systems For the Little Gun Station

Jim Brown K9YC Copyright 2015

One of the things I've always enjoyed about ham radio is planning and implementing HF antenna systems, both for my own station and for other hams. Our choices are usually limited by real estate, antenna supports that either exist or can be built, the feasibilty of putting antennas on those supports, the cost of various options, and what the neighbors (and the XYL) will tolerate. But that's only part of the equation. The other part is how well various options will meet our objectives. This article is about the second part.

With limited space for antennas and with limited supports, the choice often comes down to an all-band vertical or a horizontal dipole (perhaps in an inverted Vee configuration). And if a vertical, should it be ground-mounted or elevated -- perhaps on the roof of a house or garage? A few summers back, I was re-reading and eventually studying carefully a report by Ward Silver, N0AX, and Steve Morris, K7LXC, on comparative measurements they had done back in 2000 of eight multiband HF verticals that were representative of what was currently available. Most manufacturers were vague about mounting height, so all were set up at 18 inches over an extensive radial system.

The antennas fell into two distinct groups -- those in the first group were base-fed radiators that approximated an electrical quarter wave, with or without loading coils or traps, while those in the second group were some form of center-fed dipole, again with loading or various matching schemes to achieve multi-band operation. The first group required radials, some of which were integral to the antenna, while those in the second group were advertised as not needing radials.

In his report, Ward speculated that vertical dipoles might have been helped by the radial system, but skirted the issue of mounting height. All of which got me thinking -- what about mounting height? And what about radials for a half-wave antenna? I decided to undertake a serious study of these issues by modeling the two fundamental antenna types in NEC, comparing antennas that were ground-mounted over very good radial systems with the same antenna at mounting heights that the average ham might achieve, and I repeated each model for five different soil conditions representative of the wide range hams around the world are faced with. I presented the result of this work to the Pacificon Antenna Forum in October 2013 with the title, "If Can Put My Multi-band HF Vertical on my Roof, Should I?"

When evaluating any system, the first question to ask is, "What do I want to achieve?" In the case of an antenna system, the related questions are; 1) where are the stations I want to work? 2) at what vertical angles do signals to/from those stations most often propagate? 3) how much local noise is present at my QTH, where are the sources with respect to where I can put my antennas, their directivity, and what is the polarization of the noise? We'll study #1 and #2 first. For domestic contesting from the west coast, a horizontal antenna broadside to about 75 degrees is one good option, and 2-3 elements with that directivity would be even better. And because most of the stations we need to work are in the range of 2,000 - 2,500 miles, good performance at low angles is important.

A domestic contester on the east coast and midwest faces a very different set of challenges. Population density suggests the need for antennas that are less directional in both the horizontal and vertical plane. Given these realities, I chose to plot the vertical patterns of these antennas for the same soil conditions on the same graph, so that the relative differences are clearly shown. We can't change our soil (except by moving to a new QTH), but we can change the antennas we use and how we install them.

The first antenna modeled was an interesting design by N6BT -- it's an end-loaded center-fed dipole for 20M. The antenna is shown in Fig 1. Most multiband antennas based on center-fed dipoles are shorter than a half wave on 20M, so are loaded in some way to make them resonant. This loaded antenna is very approximately representative of how a typical multiband vertical dipole would behave on 20M.

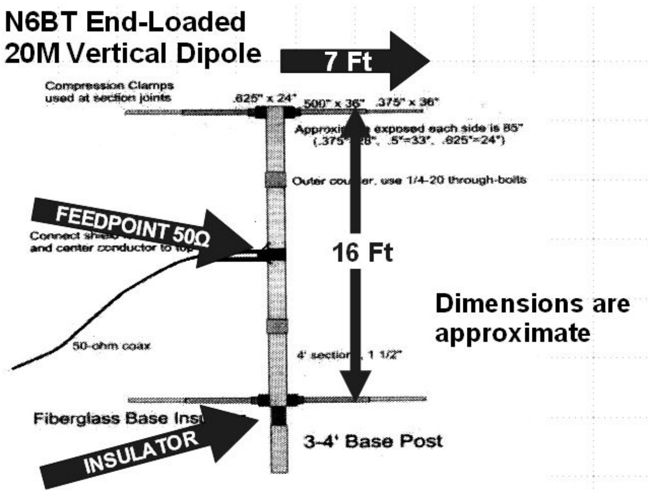

Fig 1

Fig 2 compares the vertical radiation of this antenna with its base at 3 ft over Average soil (the black curve), with the same antenna at 20 ft and 33 ft. The cursor is on the 33 Ft curve at 10˚ elevation. The bottom right readout of "3.14 dB Pr Trc" tells us that the antenna at 33 Ft is 3.14dB better at 10˚ elevation than the same antenna with its base 3 ft above ground. [Keep this read-out in mind as you study all the plots in this article.] Figs 4-7 show results of the same analysis for the very poor soil conditions typically present in cities, and the very good soil conditions of California's central valley and some Midwest US farm land.

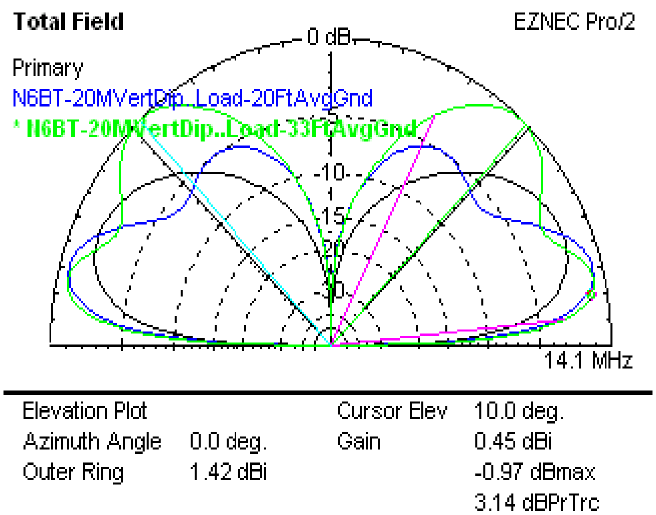

Fig 2 - Loaded 20M Dipole, 3 Ft, 20 Ft, 33 Ft Average Ground

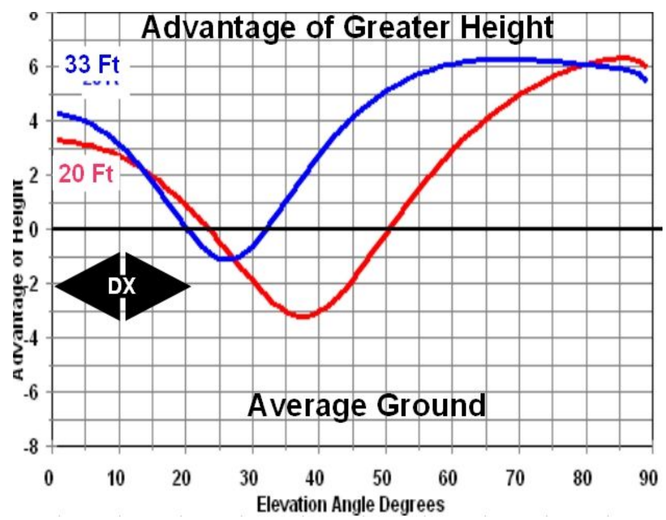

Fig 3 - Loaded 20M Dipole at 20 Ft, 33 Ft compared to same antenna at 3 ft

NEC only plots in polar form, which makes it difficult to see the differences between the results at very low angles where the curves appear to be almost on top of each other. I can see these differences in the NEC display by moving the cursor to various vertical angles, but they don't show up well in the plot. Moving the cursor shows the differences to be significant, but to show them here, I must export NEC's results in tabular form for each modeled condition to a Quattro Pro spreadsheet and re-plot them in linear form. Figs 3, 6, and 7 plot the ***difference*** between the antenna mounted at 20 ft and 33 ft with the antenna at ground level. In other words, they are subtracting the elevated curves from the ground-mounted curve and plotting the difference in dB. It takes a great deal of additional work to generate these plots, so, although they are useful, I didn't spend the many hours to develop them for the remaining analysis. But do keep these views of the data in mind as we study the conventional polar plots Virtually all of these modeled conditions follow the trends of this data set -- that is, the advantage of elevating verticals at 10 degrees is maintained all the way down to 1 degree, and in most cases, increases by a dB or so.

Also throughout most of this analysis, we'll use 10 degrees as a general indicator of the contesting and DX performance of an antenna.

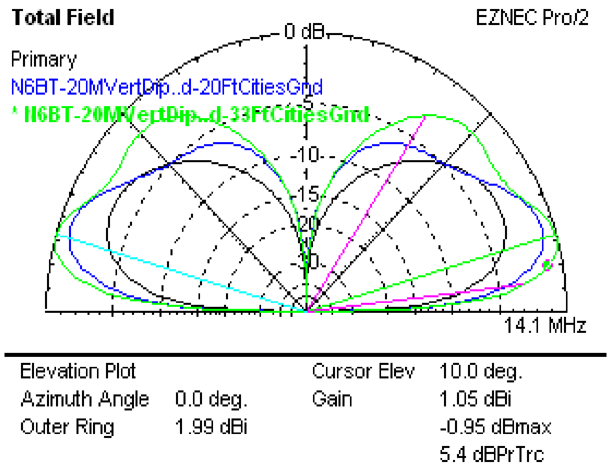

Fig 4 - Loaded 20M Dipole, 3 Ft, 20 Ft, 33 Ft
Very Poor Ground (Cities)

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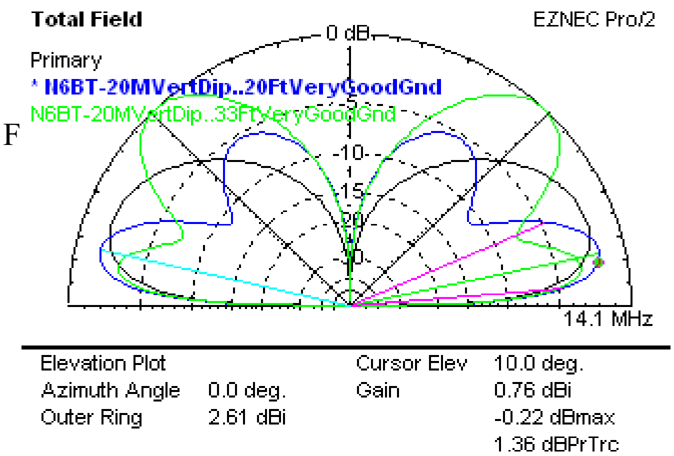


Fig 5 - Loaded 20M Dipole, 3 Ft, 20 Ft, 33 Ft
Very Good Ground

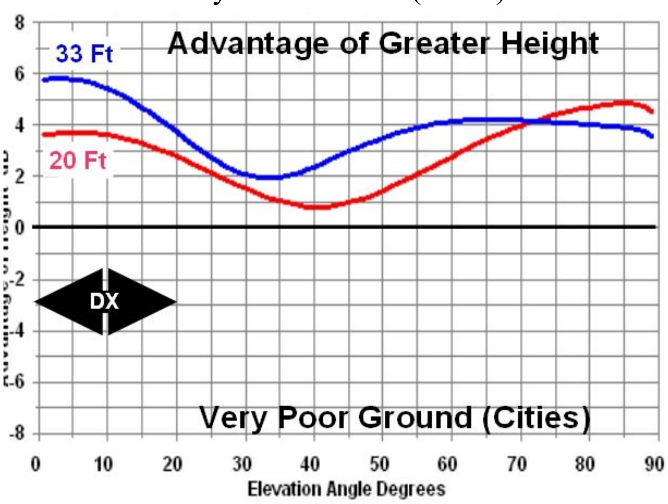


Fig 6 - Loaded 20M Dipole, at 20 Ft, 33 Ft
compared to same antenna at 3 ft

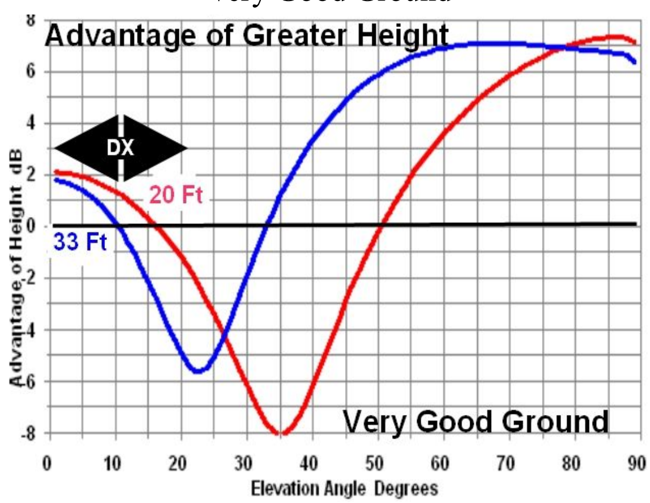


Fig 7 - Loaded 20M Dipole, 3 Ft, 20 Ft, 33 Ft
compared to same antenna at 3 ft

We learn several interesting things from these plots. First, for all soil conditions, the low angle performance of this loaded 20M vertical dipole is improved by increased mounting height, and the improvement is greatest for the poorest soil conditions. Indeed, for very poor soil, the higher antenna is the better performer at all wave angles! Second, the vertical pattern breaks down into two lobes, one at low angle and one at an intermediate higher angle. Both the strength of the lobes, and the depth of the dip between the lobes, are most pronounced for the best soil conditions. As I learned from further modeling, the same thing happens with virtually all vertical antennas.

Next, we'll look at a simple quarter-wave vertical under similar conditions. On the ground, it's modeled with 32 radials; at 20 and 33 ft, there are four radials. Both the vertical element and the elevated radials are 3/4-in aluminum. Figs 8, 9, and 10 show that this antenna responds as well to being elevated as does the shortened 20M dipole!

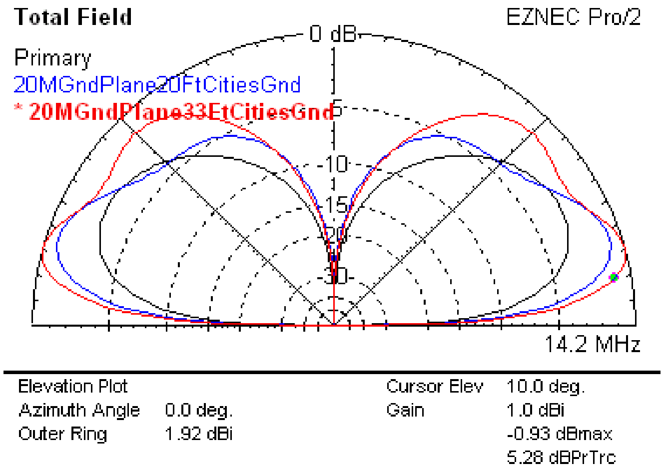


Fig 8 - 20M Ground Plane, 3 Ft, 20 Ft, 33 Ft
Very Poor Ground - Cities

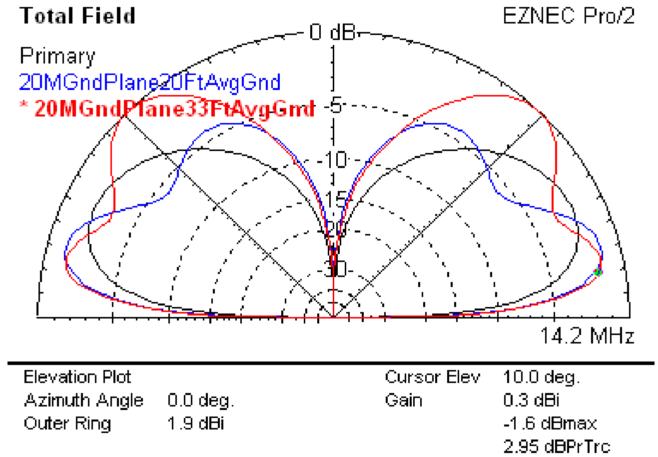


Fig 9 - 20M Ground Plane, 3 Ft, 20 Ft, 33 Ft
Average Ground

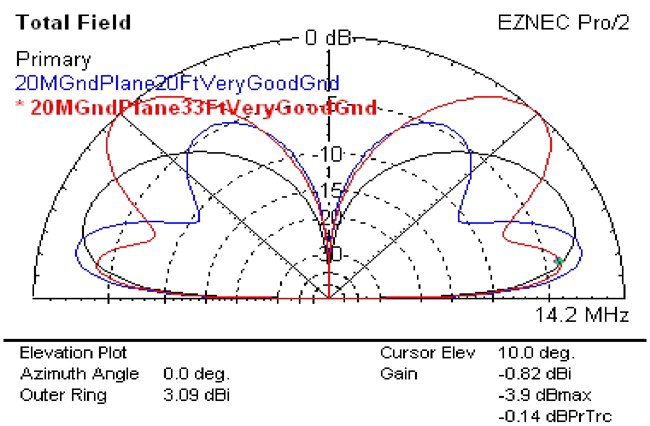


Fig 10 - 20M Ground Plane, 3 Ft, 20 Ft, 33 Ft
Very Good Ground

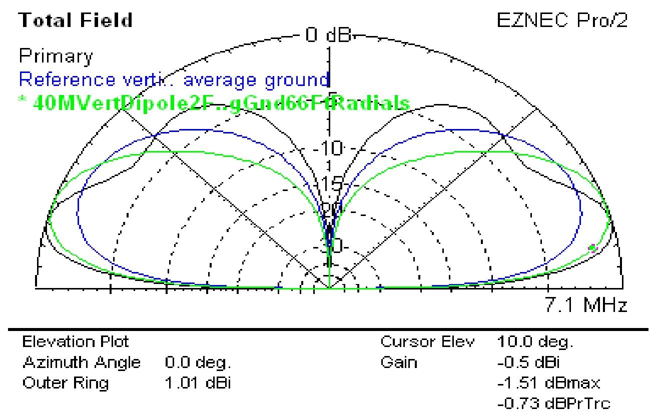


Fig 11 - Ground-mounted λ/4, λ/2, and 5λ/8 tall verticals over average ground

Fig 11 illustrates another important effect of making the vertical radiator longer as a fraction of a wavelength. The rounder, more uniform pattern is the λ/4 ground plane; the λ/2 pattern is smooth with no lobes, but is "flattened" so that energy is more concentrated at lower angles; and 5λ/8 vertical has slightly more low angle radiation, but develops both a high and low angle lobes with a mild null between them. As we will learn later, the differences in these patterns are essentially due to their current distribution. Raising the current maxima by a quarter wave increases low angle radiation by a few dB at the expense of a few dB less at higher angles. Adding another λ/8 improves both high and lower angles. Vertical radiator heights the range of 180 - 210 electrical degrees are quite popular with major AM broadcast stations.

From the above, it's quite reasonable to expect the effects of mounting height to be wavelength dependent, so we'll next study how a 40M ground plane at mounting heights of 33 and 45 ft compares to a ground-mounted vertical with 32 radials. Figs 12-15 show the result. Again, we see almost exactly the same effects as before, differing only by degree -- the benefits are greatest for the poorest ground types, less for very good ground, and greater heights with very good ground produces more pronounced lobes and nulls.

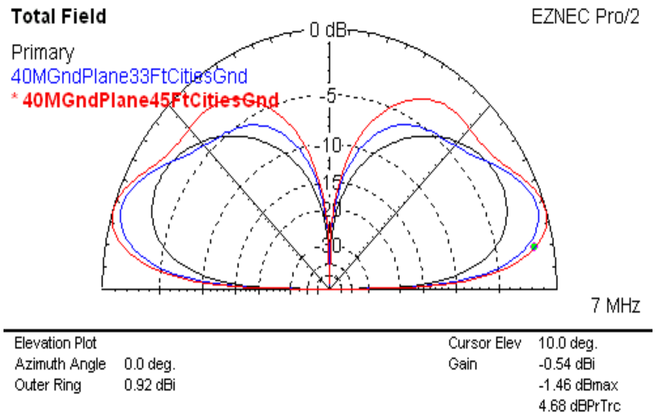


Fig 12 - 40M Ground Plane, 6 in, 33 Ft, 45 Ft
Very Poor (Cities) Ground

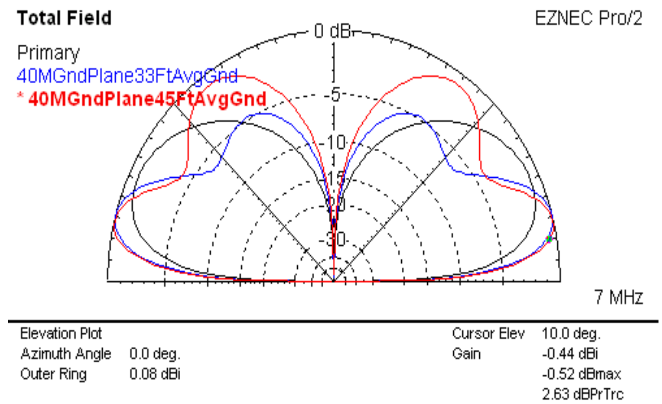


Fig 13 - 40M Ground Plane, 6 in, 33 Ft, 45 Ft
Average Ground

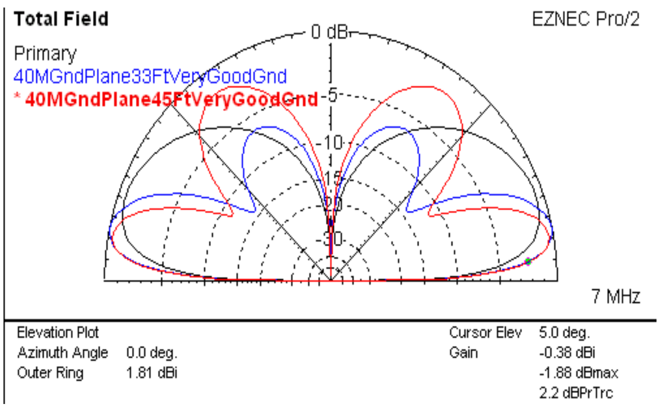


Fig 14 - 40M Ground Plane, 6 in, 33 Ft, 45 Ft
Very Good Ground

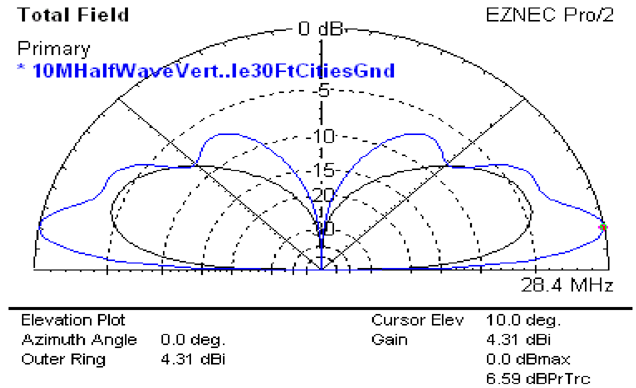


Fig 15 - 10M λ/2 Dipole at 6 in, 33 Ft
Very Poor (Cities) Ground

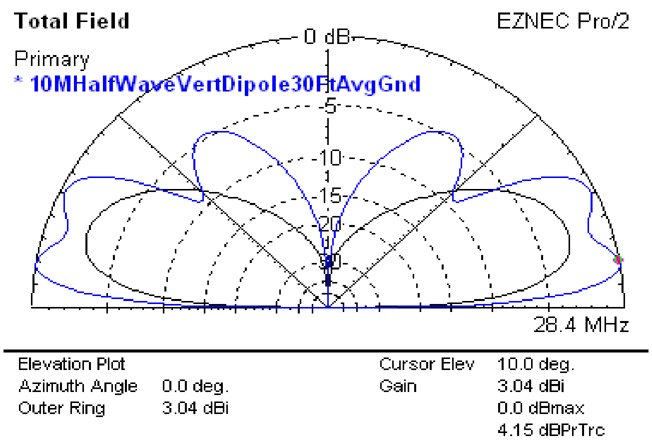


Fig 16 - 10M λ/2 Dipole at 6 in, 33 Ft
Average Ground

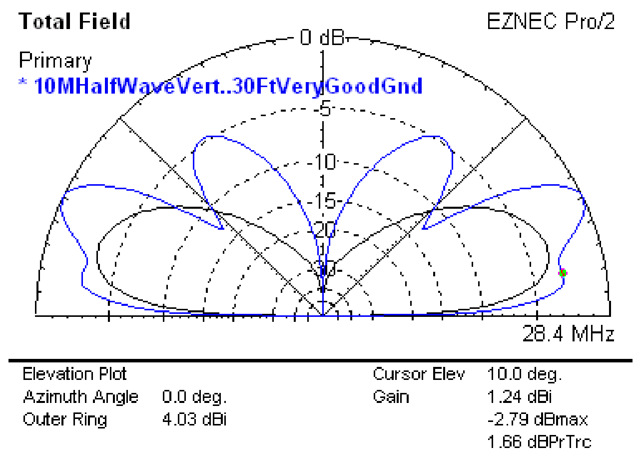


Fig 17 - 10M λ/2 Dipole at 6 in, 33 Ft
Very Good Ground

Our next antenna, a 10M vertical λ/2 dipole, is modeled with its base 6 inches above ground, and at 33 ft. Results are shown in Figs 15, 16, and 17. Here, elevating the antenna is a major improvement for all ground types, and for almost all vertical angles.

Next, I studied the issue of radials for a half-wave antenna. It's a commonly held belief that half wave antennas do not need radials, but a search of ARRL technical publications will find statements to the contrary (ON4UN book, for example). I modeled a half-wave centerfed 20M dipole built with 3/4-in diameter Al tubing, mounted 1 ft above ground, with and without 32 half-wavelength radials. Radials are laid on the ground and are connected only to each other in a star configuration. Results are shown in Figs 18-20. Increased radiation is greatest for the poorest soil and for higher vertical angles.

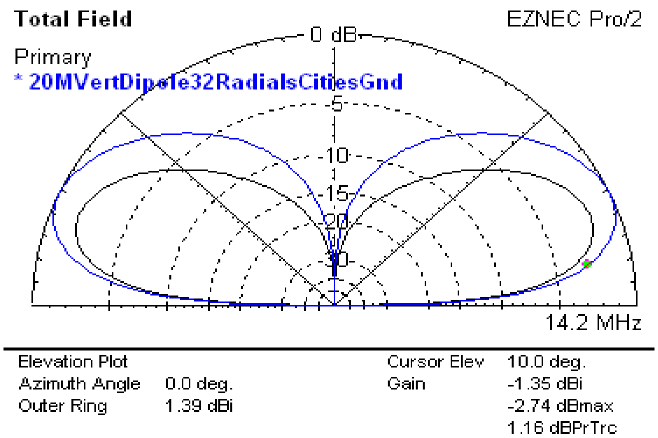


Fig 18 - Radials for a Half Wave Dipole
Very Poor Ground

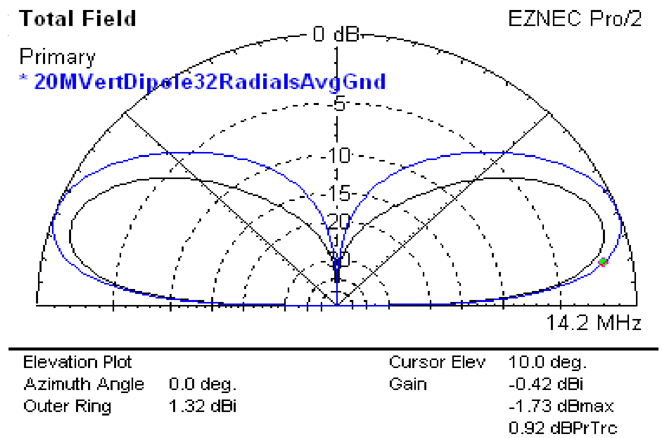


Fig 19 - Radials for a Half Wave Dipole
Average Ground

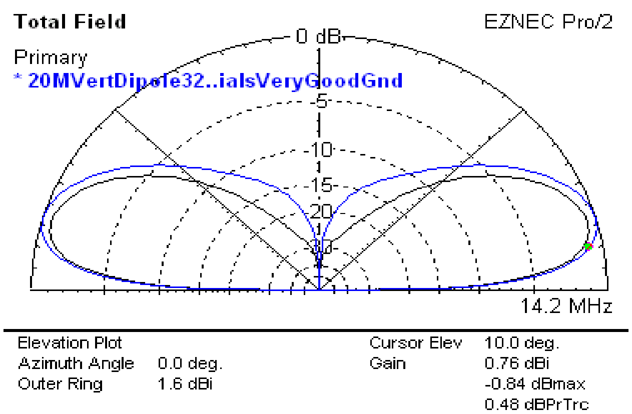


Fig 20 - Radials for a Half Wave Dipole
Very Good Ground

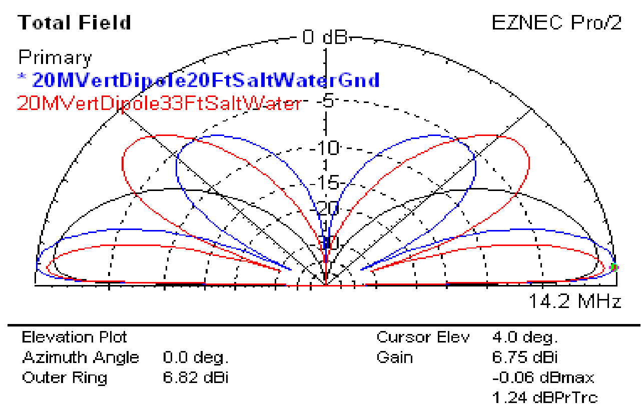


Fig 21 - 20M Vertical Dipole at 20 Ft and 33 Ft
Over Sea Water

We're now in a position to summarize the results of our study. 1) A vertical antenna mounted above ground in the range of λ/4 - λ will generally outperform the same antenna mounted in close proximity to the earth. 2) Improvement will be greatest for the poorest soil conditions. 3) Improvements will be greatest at low radiation angles. 4) At heights above about λ/4, lobes and nulls develop in the vertical pattern that are most pronounced with very good soil. 5) In general, there is little benefit to increased mounting height of antennas over sea water. The result of Fig 21 is typical -- while low angle radiation increases by a dB or so, lobing at high angles becomes more pronounced with increased mounting height.

The next question is, why do vertical antennas work this way? As I see it, there are three primary effects, the first two of which are included in the model. 1) Fields produced by vertical antennas, including their radials, induce currents in the lossy earth. These losses are greatest when the antenna is near the ground, and decrease the overall strength of the radiated signal. As the antenna is elevated, these losses are reduced, because the EM field, and the resulting current, are being returned to the antenna (the radials or the other half of the dipole) rather than to lossy earth. 2) The EM field radiated by the antenna hits the earth at some distance from the antenna, is reflected by the earth, and the two wavefronts, direct and reflected, add to produce the vertical pattern. At vertical angles where they are most nearly in phase, they add to increase the signal strength, and at vertical angles where they are close to 180 degrees out of phase they produce a null. Lobes are strongest, and nulls are deepest, when the direct and reflected waves are more nearly equal in amplitude at the 0 and 180 degree phase angles. 3) The horizontal and vertical pattern of any antenna is distorted by surrounding conductors -- often called "ground clutter," and additional losses may be introduced. This effect is difficult to model, and no attempt was made to do so, but it's safe to assume that it is reduced by elevating the antenna.

Elevating Verticals -- the Practical Side As noted earlier, multi-band HF verticals tend to fall into two generic types -- base-fed verticals that require radials, and center-fed verticals that do not. When ground-mounted, many radials are required, but length is not critical -- 32 λ/4 radials laying on the ground is generally within a dB or so of optimum. Radials serve to "shield" the fields produced by the antenna from the lossy earth, and they carry the antenna's return current. The return current divides approximately equally between the radials, and losses equal to I^2R are induced. The more radials, the lower the loss, because power is current squared. Also, the fewer the number of radials, the less likely the current will be equally distributed, which also increases the loss.

When radials are elevated, fewer radials are needed to equalize the current, and the increased height reduces coupling to the lossy earth. Four λ/4 radials are sufficient for verticals at least λ/8 above ground, and modeling suggests that two λ/4 radials per band are within a dB or so of optimum for multi-band verticals if those radials are distributed radially around the feedpoint. But that's still a lot of radials, so elevating a base-fed multiband vertical is a non-trivial effort.

Center-fed verticals are far easier to elevate because they do work without radials, and because elevating them reduces ground losses to the extent that radials have little effect. Some examples of center-fed multi-band verticals are the Gap Titan, Force 12 V3 and ZR3, HyGain AV620, AV640, and AV680, Cushcraft R6, R8, R9.

End-fed verticals can be mounted on towers with little effect on their performance as long as they have radials. End-fed verticals do not work well when mounted on towers without radials using the tower as a counterpoise -- the tower becomes part of the antenna and seriously degrades the vertical pattern.

Centerfed dipoles mounted on towers present a special problem. They must be insulated from the tower, but the feedline must come down the tower, and the capacitance between the feedline and the tower couples it to the tower. In addition, good practice for lightning protection of the feedline calls for the feedline to be bonded to the tower at top and bottom, which also couples the antenna to the tower. With this coupling, the antenna is vastly different from its original design, and its performance is likely to be poor.

Losses in Multiband Antennas My models are for fundamental antenna types, where losses are minimal. The various engineering techniques used to create a multiband antenna often add loss, whether due to the resistance of traps or increased current in matching sections. The radiation efficiency of any antenna is limited by the simple voltage division between the radiation resistance, R_R, (good resistance that accounts for radiated power) and series loss resistance (conductor resistance plus ground resistance). Radiation resistance increases with physical length as a fraction of a wavelength; R_R is about 37 Ω for a λ/4 antenna, but falls to about 7 ohms for a λ/8 radiator. We must keep these factors in mind when comparing one antenna to another, and these efficiency differences are essentially what the N0AX/K7LXC tests were measuring.

And there's yet another factor at play -- when an antenna is physically short as a fraction of a wavelength, the current must be increased (by means of a matching network) to maintain the same radiated power, and the increased current increases losses. This means that short antennas can benefit even more from being mounted higher because the coupling of the increased current to lossy earth is reduced. Figs 22 and 23 show the extreme case -- a 4 ft tall center-fed dipole on 20M at heights of six inches and at 30 ft. Most multiband antennas will be subject to this factor -- that is, they may benefit a bit more from being elevated than suggested by my models of near-ideal antennas.

Reduced Losses and Impedance Matching It's well known that many antenna designs "use" the ground loss component of the feedpoint impedance to bring that impedance closer to 50 ohms, so when losses are reduced by elevating the feedpoint, the SWR may rise a bit. Not to worry -- the small additional loss in the line due to mismatch is much less than the efficiency gained from elevating the antenna. Smart hams also know that the most important reason to use big coax is to reduce loss. This is especially important when running low power or with a compromised antenna system. Indeed, the only good reason for using small coax is to minimize visibility from neighbors (or an XYL) with an attitude!

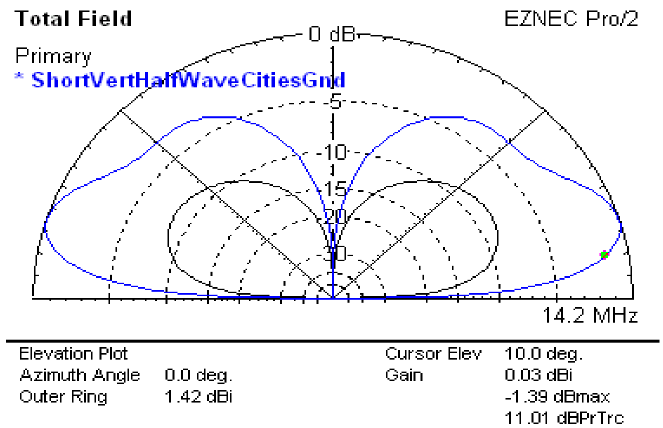


Fig 22 - Very Short 20M Dipole at 6-in, and 33 Ft, Very Poor Soil

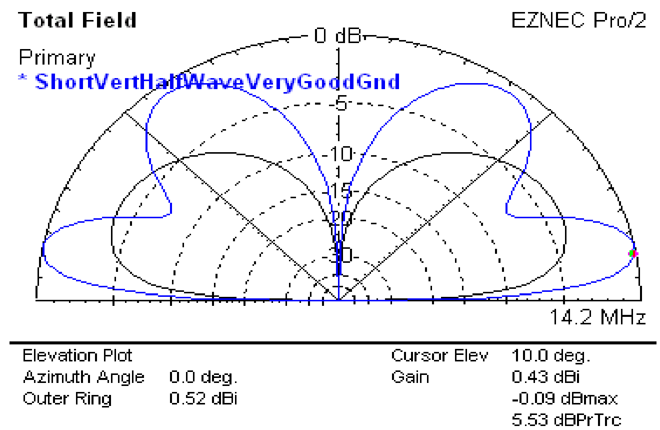


Fig 23 - Very Short 20M Dipole at 6-in, and 33 Ft, Very Good Soil

Comparing Verticals with Horizontal Dipoles

Now that we know a bit more about what can be done by elevating a vertical, the obvious question is, how do these verticals compare with a conventional horizontal half-wave dipole? We'll begin by studying the effect of ground quality on a horizontal dipole for 40M. Fig 24 shows that at low vertical angles the difference is negligible -- only 0.6 dB difference between the best and worst soil types, and an improvement of about 2 dB for the best soil at NVIS.

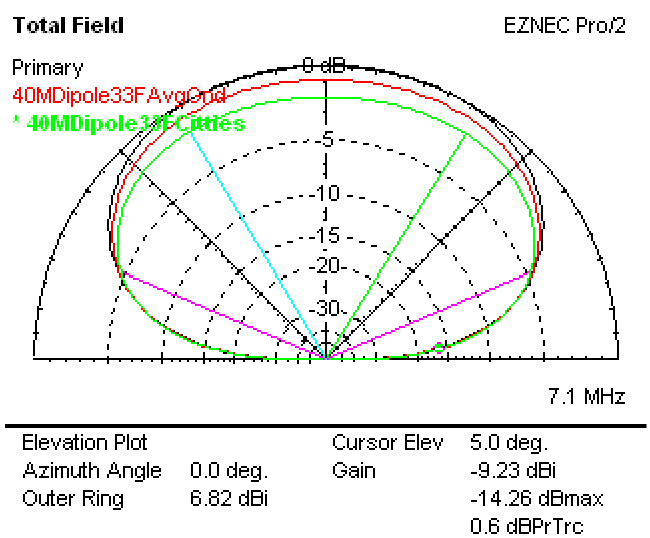


Fig 24 - The Effect of Ground on a 40M Dipole at 33 Ft

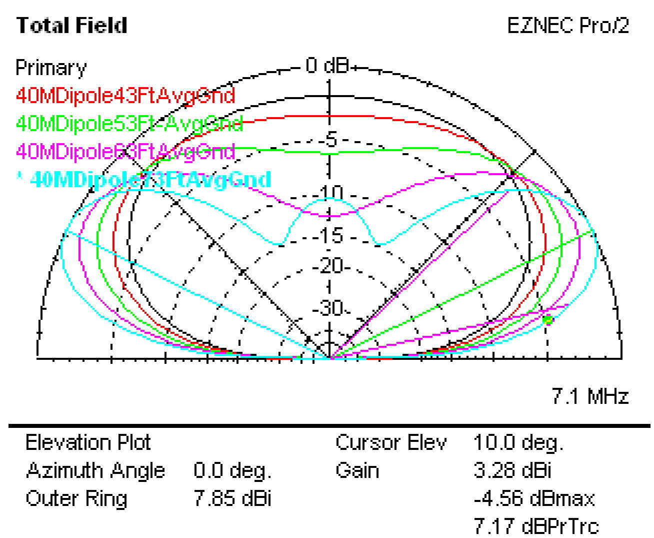


Fig 25- The Effect of Height on a 40M Dipole over Average Ground

Height of Horizontal Antennas The most important characteristic of a horizontal antenna is its height above ground. Fig 25 compares the vertical pattern of a 40M dipole at heights of 33 Ft, 43 Ft, 53 Ft, 63 Ft, and 73 Ft. As the antenna is raised, high angle radiation is suppressed and low angle radiation is enhanced. For most contesting, a higher dipole is a much better performer! Fig 25 can be scaled by wavelength -- that is, to predict behavior of a 20M dipole, divide heights by 2, for 80M, multiply by 2.

Now we're ready to compare verticals and dipoles at mounting heights that are practical for many hams, even on small lots. Figs 26-28 compare a horizontal 40M dipole at 33 Ft with a simple 40M ground plane at 6 inches and at 33 Ft. For all three soil types, the vertical at 33 ft outperforms the horizontal dipole at low angles, at the sacrifice of high angle radiation, ***in the main lobe of the dipole***! Off the ends of the dipole the advantage of the vertical at low angles is even greater.

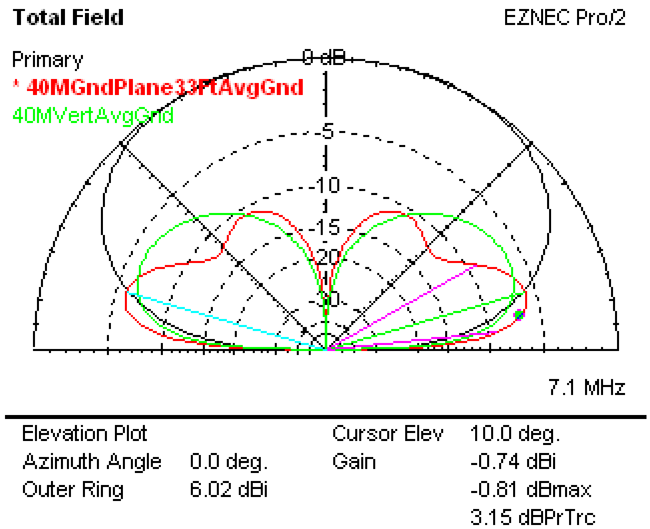


Fig 26 - 40M Horizontal Dipole at 33 Ft, Average Ground, as Compared to λ/4 Vertical at 33 Ft and 6 inches

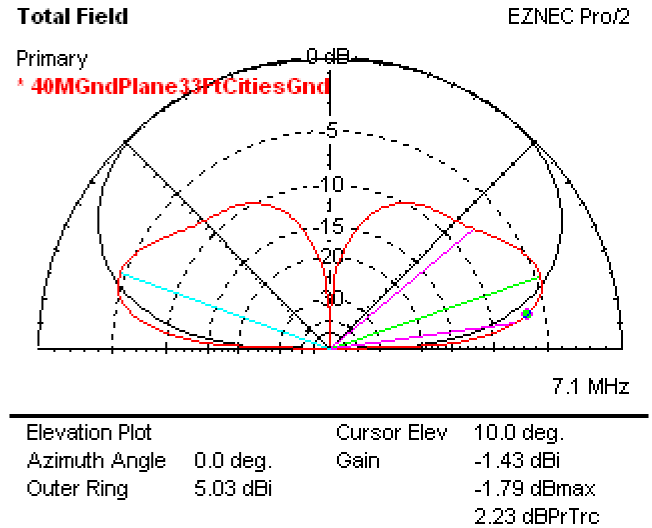


Fig 27 - 40M Horizontal Dipole at 33 Ft, Very Poor (Cities) Ground, as Compared to λ/4 Vertical at 33 Ft

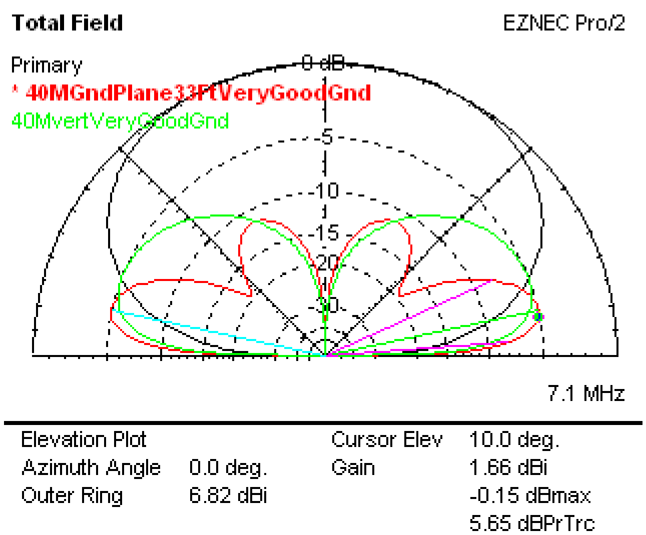


Fig 28 - 40M Horizontal Dipole at 33 Ft Compared to λ/4 Vertical at 33 Ft and 6 inches, Very Good Ground,

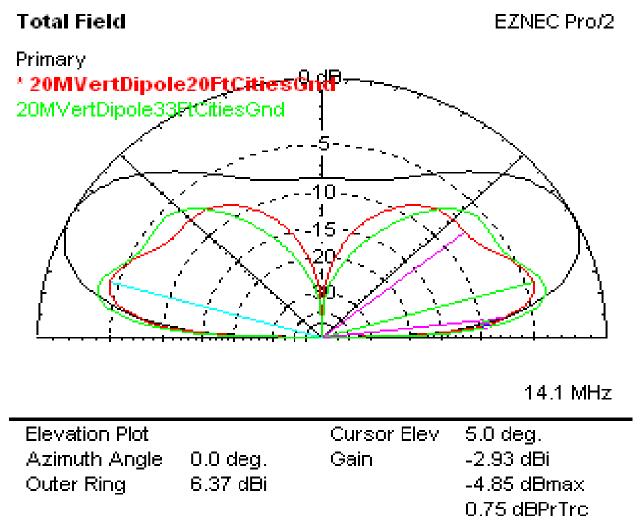


Fig 29 - 20M Horizontal Dipole at 33 Ft, Compared to λ/2 Vertical Dipole at 20 Ft and 33 Ft, Very Poor (Cities) Ground

Figs 29-31 compare a 20M horizontal dipole at 33 ft to vertical dipoles with their base at 20 ft and 33 ft for three soil types. The verticals have a slight advantage at low angles, up to about 10 degrees, depending on soil type. Again, this is broadside to the horizontal dipole -- off axis of that, the vertical has a greater advantage. Note also that the high angle radiation of the vertical dipole doesn't fall off as much as for the 40M antenna. Again, remember that these models are for near ideal antennas -- the efficiency of practical multiband antennas reduces their performance by a dB or two.

What About a Small Beam? To estimate its performance, add 4 dB to the advantage of a horizontal antenna for a small beam without traps at the same height (only 2-3 dB if there are traps). And remember that its directivity can reduce noise and QRM, so it may help us hear the weak ones. For a simple 2-element vertical array, add 3 dB over the performance of a single vertical.

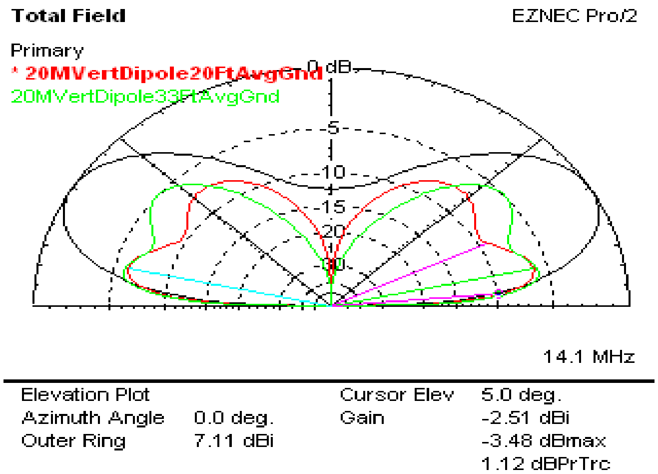


Fig 30 - 20M Horizontal Dipole at 33 Ft,
λ/2 Vertical Dipole at 20 Ft and 33 Ft
Average Ground

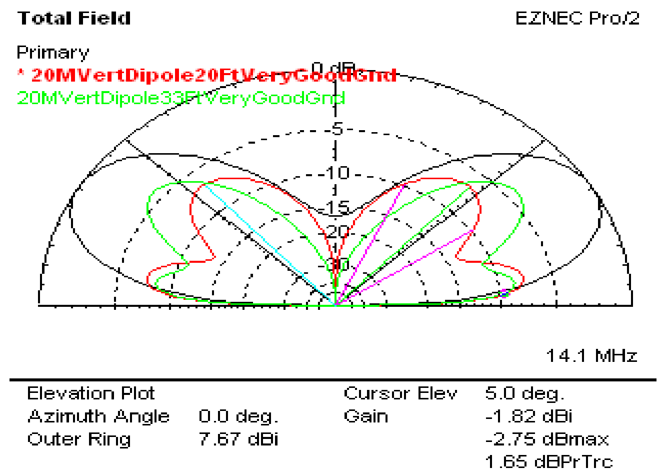


Fig 31 - 20M Horizontal Dipole at 33 Ft,
λ/2 Vertical Dipole at 20 Ft and 33 Ft.
Very Good Ground

Figure of Merit for Height of Horizontal Dipoles

A careful study of Fig 25 suggests that another view of the data might be worthwhile. Fig 32 expands the data set of Fig 25 to 110 Ft. Fig 33 provides another very useful view of the same data. I took data points from each antenna height curve for vertical elevations of 5˚, 10˚, 15˚, and 20˚, entered them in a Quattro Pro spreadsheet, and plotted it to produce Fig 33. The slopes of these curves, which are essentially parallel to each other below about 80 ft, allows us to define a "figure of merit" for the height of a horizontal 40M antenna for low radiation angles.

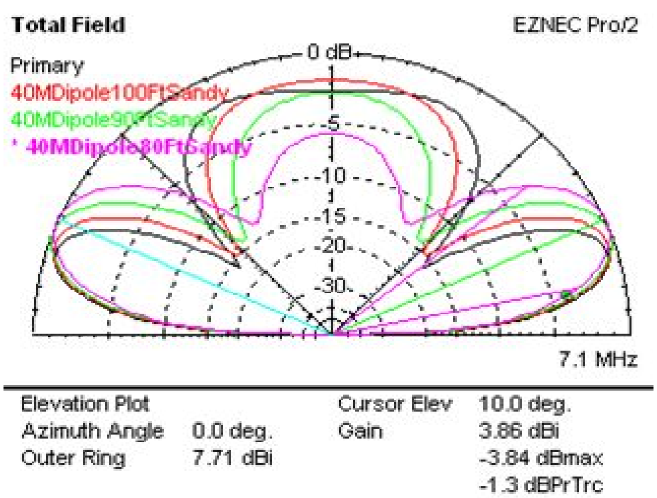


Fig 32 - 40M Horizontal Dipole at 80 Ft, 90 Ft,
100 Ft, 110 Ft, Sandy Ground

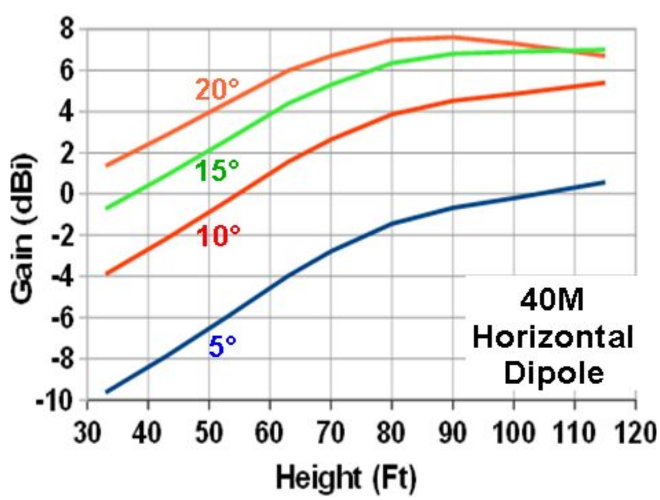


Fig 33 - Another Look At The Same Data

What is Height Worth On 40M? Fig 33 clearly shows that, for all angles below about 25 degrees, 10 ft of added height is worth about 1.9 dB on 40M between 20 ft and 70 ft. The advantage of additional height is much less above 70 ft (λ/2). Raising a 40M dipole from 33 ft (λ/4) to 67 ft (λ/2) is worth about 6 dB at vertical angles below about 20 degrees; going up to 120 ft (.433λ) is good for another 3 dB for radiation angles below about 15 degrees.

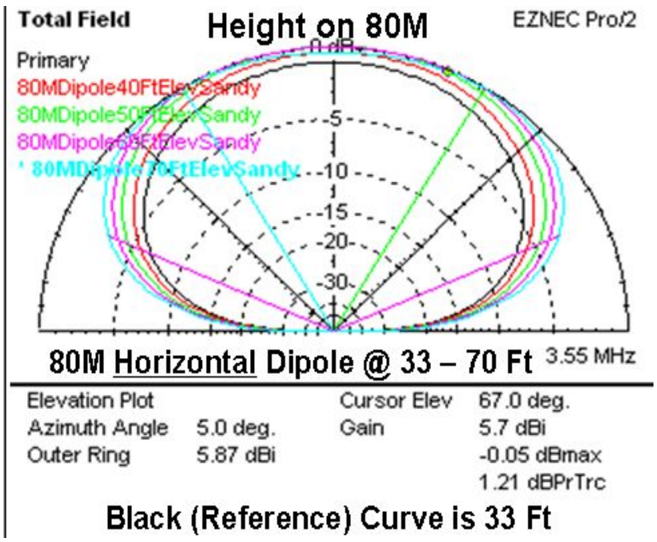


Fig 34 - 80M Horizontal Dipole at 33 Ft, 40 Ft, 50 Ft, 60 Ft, 70 Ft Sandy Ground

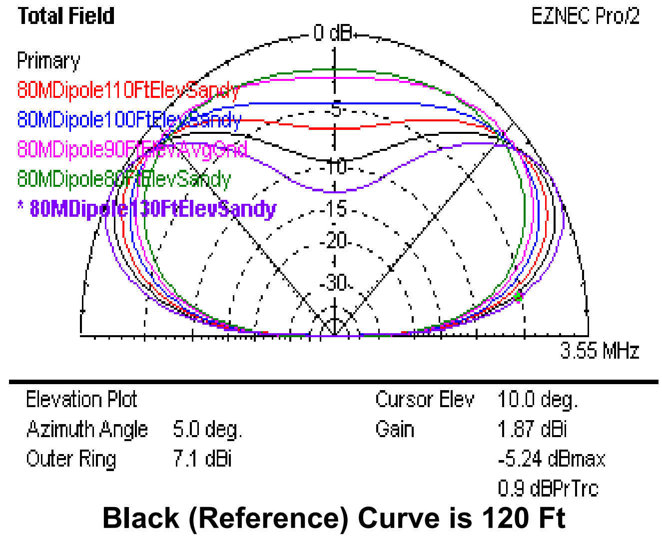


Fig 35 – 80M Horizontal Dipole at 80 Ft, 90 Ft, 100 Ft, 110 Ft, 120 Ft, 130 Ft, Sandy Soil

What is Height Worth on 80M? Figs 34-36 show the corresponding results for 80M. Below a height of about 133 ft (λ/2), every 10 ft of mounting height increases signal strength by about 0.9 dB at elevation angles below at least 30˚. A dipole at 133 ft (λ/2) is nearly 6 dB louder at low angles than one at 67 ft (λ/4), and the 67 ft high dipole is 3 dB louder than it would be at 33 ft (λ/8).

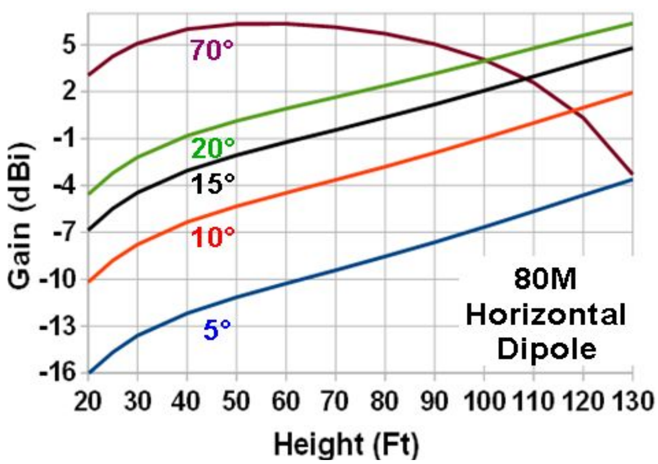


Fig 36 –Data From Fig 34, Fig 35 Re-plotted

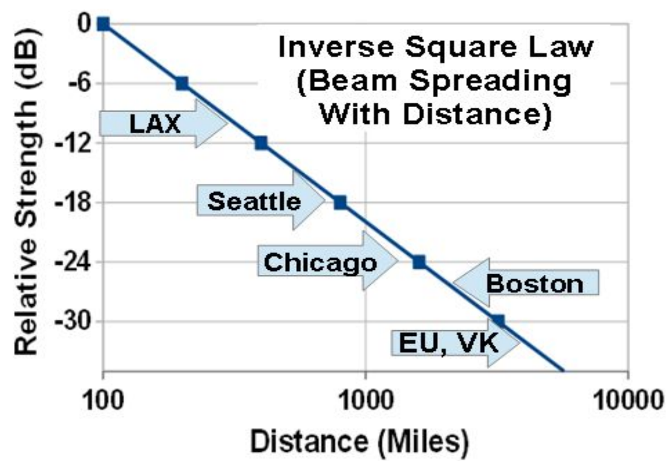


Fig 37 – Reduced Signal Loss to Closer Stations

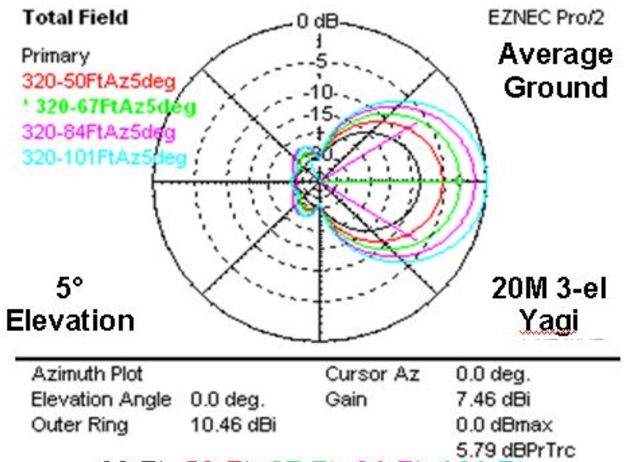
Debunking The NVIS Myth Fig 36 clearly shows that you don't need a ground-hugging dipole for NVIS (high-angle paths to work nearby stations). Indeed, the optimum height for NVIS is 0.22λ (60 ft on 80M), and an antenna at 0.33λ (90 ft on 80), is only 1 dB less than optimum. And, as we've already learned, the higher antenna is 2.5 dB louder at the lower angles needed to work distant stations. Even when the antenna is raised to 120 ft, high angle radiation is only 3 dB below maximum, while the 120 ft antenna is 3 dB louder at low angles than the 90 ft antenna! On 40M, 30 ft is near optimum for NVIS, 45 ft is only 1 dB down, and 60 ft is only 3 dB below optimum. Table 1 summarizes the result by band.

Table 1 -- NVIS Performance @ Height

Band	Max	-1dB	-3 dB
160M	120 ft	180 ft	240 ft
80M	60 ft	90 ft	120 ft
40M	30 ft	45 ft	60 ft

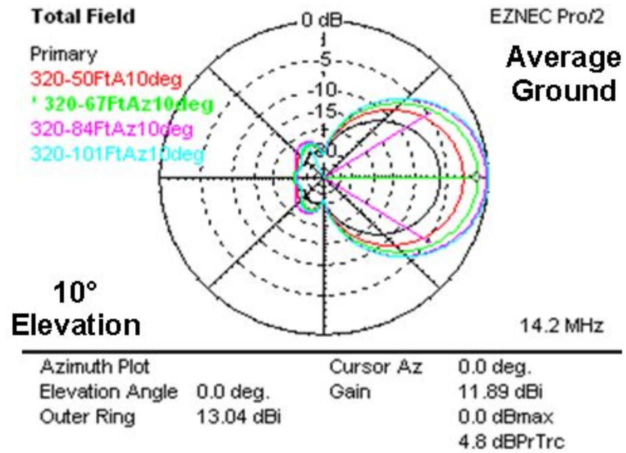
Inverse Square Law Fig 37 shows relative path loss vs distance. Stations we're likely to work by NVIS are in the range of a few hundred miles or less; Fig 37 shows that stations around LAX are 8 dB closer than those in Seattle or Phoenix, and 14 dB closer than those around Chicago. For contesting and DX chasing, we want maximum gain to those distant locations, because inverse square law helps us work the closer ones; the design choices I'll make with horizontal antennas for 40M and 80M will be to get them as high as possible, compromising NVIS performance for maximum DX performance.

Height Of Horizontal 20M Antennas Figs 38-41 show the effect of mounting height on a typical 3-el 20M Yagi. This particular design is taken from the ARRL Antenna Book.



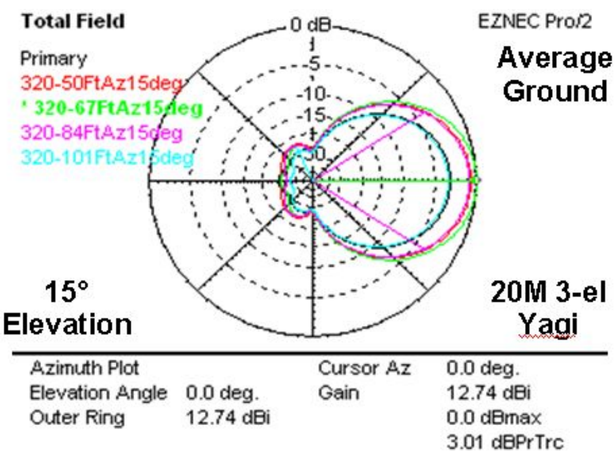
33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft

Fig 38 – 20M Yagi vs Mounting Height



33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft

Fig 39 – 20M Yagi vs Mounting Height



33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft

Fig 40 –20M Yagi vs Mounting Height

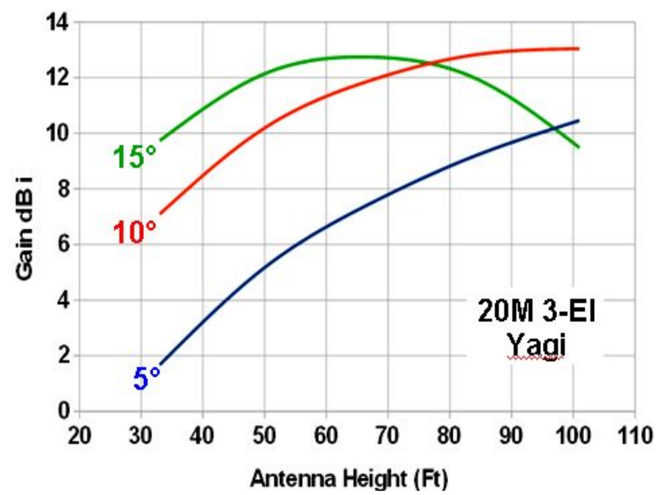


Fig 41 – Data From Figs 38-40 Re-plotted

The Value of Height on 20M Fig 41 shows that for a 20M Yagi at low angles, every 5 ft of mounting height below about 70 ft is good for about 0.9 dB; we get 6 dB by going from 33 ft to 67 ft. At 5 degrees, we get 2 dB by going from 67 ft to 100 ft. Another way of looking at it is that the three sections of Rohn 25 that it takes to go from 30 ft to 60 ft is worth 5.5 dB.

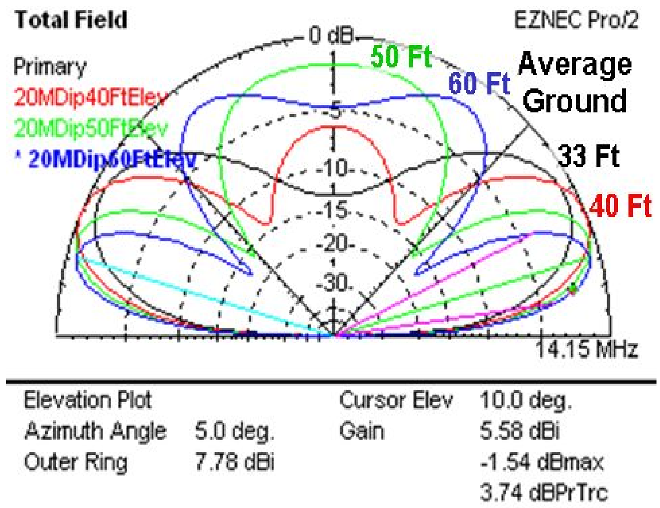


Fig 42 –20M Yagi vs Mounting Height

Lobing of High Horizontal Antennas Fig 42 shows how the vertical pattern of a 20M dipole varies with mounting height. Lobing begins as the antenna is raised above about λ/2 (33 ft on 20M). Lobes appear first at higher vertical angles; nulls move down as the antenna is raised, and a second null develops at a higher angle. Thus, as we raise the antenna we can optimize it for low angles, but degrade performance at higher angles. Propagation to any given station varies with time; at one time, the path may be at a high vertical angle; an hour later it may be at a low angle. Note that while this data is plotted for a dipole, any horizontally polarized antenna will exhibit the same effects.

How Does This Relate To Terrain Effects? (HFTA) All of the analysis shown in this report is on the basis of extensive modeling done in NEC, which assumes antennas are in "flatland" – that is, terrain has no effect on propagation. For some of us, this represents the real world, but for many of us it does not. Corresponding models for non-flat terrain should be done using HFTA, simply by setting antennas at various heights and studying the result. In general, the principles outlined here will simply be "superimposed" on the effects of terrain as predicted by the NEC model. That is, increasing the height of a horizontal antenna will tend to concentrate its radiation at a lower angle, which will then interact with the terrain as HFTA predicts.

N6BV's very useful High Frequency Terrain Analysis (HFTA) software is on the CD that comes with the ARRL Antenna Book. HFTA uses terrain data obtained from government sites on the internet, processes it to generate radial data for every five degrees of azimuth, then computes the effect of that terrain for an antenna at specified mounting heights. HFTA comes with statistical data for each HF band for the vertical arrival angles from one part of the world to another, the user then calls up that data and HFTA superimposes it on the modeled data.

My QTH is at 2,000 ft; with nearby ridges in the range of 2,550 ft to the NE and about 2,200 ft to the east and NW. Extensive HFTA modeling showed that a tower height in the range of 120 ft was near ideal for the HF bands – to improve on it, I'd need to raise the Yagi to about 300 ft. I stopped at 120 ft.

A Practical Design Question: Joe Ham is considering a 2-el Yagi for 40M, which he can put on a 70 ft tower. As an alternative, Joe can hang a pair of horizontal dipoles at right angles to each other in tall redwoods at 120 ft. Which of these two antenna systems would perform best, and by how much?

Performance Difference: From Fig 33, a horizontal antenna would be 2 dB louder at 120 ft at low angles than at 70 ft. If the gain of the 40 Yagi Joe is considering is 3.5 dBd, and we mount it at 70 ft, it will be 1.5 dB louder than the dipoles at 120 ft.

Cost Difference: If you have the trees, two dipoles at 120 ft will cost about $1,400 for climbers, $600 for antennas (wire, hardware, coax, rope, pulleys), total $2,000. An Optibeam Moxon on a 70 ft tower (antenna, hardware, coax, rotator, labor) will cost $5,000 - $7,500, depending on whether you do your own climbing and whether you can buy hardware used. Bottom line – the 1.5 dB advantage of that Yagi on transmit costs $2,500 – $5,000 more than the dipoles. And, of course, the Yagi may hear better by virtue of its directivity. The reader is encouraged to do his own cost estimates for practical installations.

Summarizing What We Have Learned

Ground Quality refers to the nature of the earth around your QTH. It has nothing to do with an electrical connection to the soil. Rocky, sandy soils are very poor grounds; moist, loamy soils are good grounds. If you live in the mountains or in highly developed area like a city, your ground is poor to very poor. If you live in a fertile valley, your ground is pretty good. The ground under our antennas burns transmitter power before it can be radiated; good radial systems minimize that loss. The ground at a distance from our antennas (hundreds of yards) reflects the energy radiated by our antennas, which combines with direct radiation from the antenna to form the vertical pattern.

Horizontal antennas are not affected by ground quality, because the strength of the first reflection does not depend upon ground quality. .

Vertical antennas are strongly dependent upon ground quality – the better the quality of the ground, the better they will work because that first reflection is stronger.

Horizontal antennas are strongly affected by height – higher is better.

Vertical antennas work better if elevated above ground. Roof level of a one-story or two-story home is a good mounting height for HF verticals.

Vertical Antennas on Towers interact with the tower to distort the vertical pattern of the antenna unless they are effectively isolated from the tower. If not very well isolated, the resulting vertical pattern can be pretty nasty. Isolation is provided by radials and by common mode chokes. See Appendix One of k9yc.com/RFI-Ham.pdf

End-fed verticals (verticals that require radials) can work well on towers ONLY if they have effective radial systems for each band on which they will operate. Two resonant radials per band is a minimum. If it's a mono-band antenna, you'll need four. The feedline also requires an effective common mode choke at the feedpoint. The Butternut, Hustler BTV-series, and HyGain AVQ-series are examples.

Verticals that are, in essence, center-fed dipoles must be insulated from a tower, and the feedline must have a common mode choke that is physically located at the point where the antenna is mounted to the tower. The Cushcraft R-series and MA6-series, the HyGain AV-series, Gap Titan, and Force 12 verticals are examples.

Vertical Antenna Interactions All antennas interact with surrounding conductors to some extent, but vertical antennas tend to have strong interactions with other vertical conductors that can strongly affect their polar pattern.

Ground and Antennas A connection to earth does not make an antenna work better – the earth is a big resistor, so any current flowing into the ground burns transmitter power. We use radials on vertical antennas to shield the earth from the antenna, so that current and fields from antenna return to the low resistance radials rather than the high resistance earth.

Earth Connections are important – we need them for lightning protection. But they do not make antennas work better, and they do not reduce noise or RFI. What does reduce noise and RFI is to bond together all of the equipment in our shacks, and the earth connections in our homes. Bonding is also critical for lightning safety.

Bonding simply means a mechanically robust, low impedance connection between grounded objects. The impedance must be low at all frequencies, not just DC. Inductance dominates the impedance above power frequencies, so bonding conductors must be very short to be effective.

Getting Practical -- Where *Can* I Put Antennas?

Now that we have a good idea about how various antennas perform, we're back to where we began. We can start looking at the possibilities that our real estate (and the attitudes of XYL and neighbors) permit. Can I sweeten up my XYL so that she'll accept the antenna I really want? Perhaps she'd like a new sewing machine? What do we have for skyhooks? Can we launch a rope into a tree to support one end of a dipole? Will a building support one end of an antenna? Can we safely mount a multiband vertical on the roof of our home or garage? Can we route a feedline from the proposed location to the shack? How close would the proposed antenna be to noise sources? To our neighbor's living room entertainment system? What are the best orientations for horizontal dipoles based on where the QSOs are? Do I need much high angle radiation?

References:

"HF Vertical Performance- Test Methods and Results," H. Ward Silver (N0AX) and Steve Morris, K7LXC, Champion Radio Products, 2000

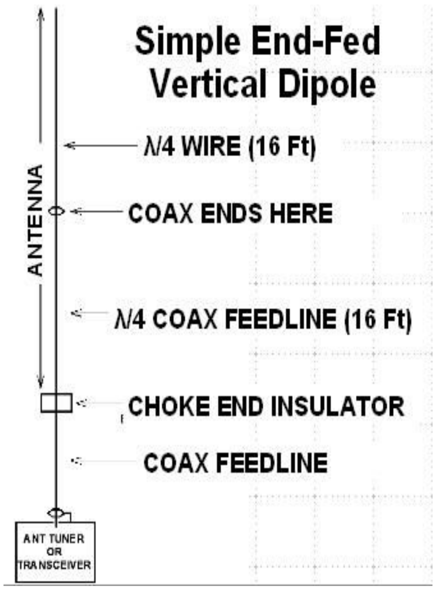
Collected tutorials by Rudy Severns, N6LF. http://www.antennasbyn6lf.com/

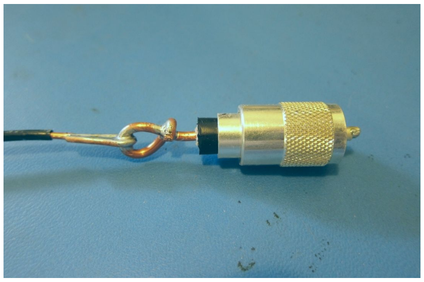
ARRL Antenna Book

Low Band DXing, by ON4UN (for 160M, 80M, and 40M), published by ARRL

Experimental Confirmation of Modeling

All of the work presented here is the result of modeling --none of these antennas have been rigged and measured on a testing range, and doing so is far outside the capabilities of all but the wealthiest hams. There was, however, one real world experiment with varying the height of a half-wave vertical dipole for 20M. My neighbor, Glen Brown, W6GJB, built and rigged the dipole from a pulley roughly 75 ft above ground and about 15 ft from one of his redwoods. The dipole is based on my design, which I came up with after seeing something similar that N6LF had published. Rudy used a simple "coil of coax" to act as the end insulator; I refined the design to make it independed of feedline length by using a high impedance common mode choke wound on a #31 ferrite core. This small choke is enough for 100W. Two in series are required for high power. Our tests were done at 3W wth Glen's KX3 as the transmitter and my K3 as the calibrated voltmeter. We're 5 miles apart, the terrain is quite irregular, and soil quality is very poor. The antenna models at 75 ohms, and was fed with RG59.





Signal strength measurements were made with the dipole center at ground level and the feedline laying on the ground to form a quarter-wave vertical with a single radial; then with the choke 6-inches above ground level, forming a half-wave dipole with its base 6-inches ground level; then with the dipole raised in 10 ft increments to a maximum height of 40 ft above ground. My RX antenna was a 20M vertical with two radials laying on the ground. Results are shown below.

Height of Choke	**Received Signal Strength**
Center insulator on ground	- 4 dB
6 inches (Zero Reference)	0 dB
10 Ft	0.5 dB
20 Ft	3.2 dB
30 Ft	6.5 dB
40 Ft	9.5 dB