



N0AX

HANDS-ON RADIO

Experiment #82 — Antenna Height

Ask an experienced ham about antenna height and the answer will often begin, “It depends...” On what? Doesn’t an antenna work better higher above ground? Well, it depends! There is such a thing as “too high,” believe it or not, and we’ll do a quick modeling experiment this month to illustrate why.

Antenna Modeling

In the “good old days” antenna design involved a lot of “cut and try” consisting of cutting the wire or tubing, assembling the antenna and hoisting it into position. Those with access to a test range could actually measure the antenna’s pattern. But most amateurs could only evaluate the antenna by patiently conducting comparisons and trying to draw conclusions despite the changing conditions. Today, the personal computer has given amateurs access to sophisticated modeling programs that take a lot of the cutting and trying out of the process — if you were careful in applying the modeling tool.

We’re going to make use of one of the most popular modeling programs, *EZNEC* by W7EL, to observe the effects of antenna height above ground.¹ If you already own *EZNEC*, skip ahead to the next section. If not, download the free demo copy of *EZNEC 5.0* from the program’s Web site. It’s a full featured version of the program, including the help information, but limited in the precision with which it can analyze an antenna. The demo version will suffice for this experiment. If you develop a taste for modeling larger or more complex antennas, you can buy a package with additional capabilities from the same Web site. The ARRL also offers an online antenna modeling course.²

The Backyard Dipole

EZNEC comes with a number of prepared antenna models. If you run the program and click the OPEN button (or select FILE, then OPEN), you’ll see a list of available model files. The one we’re going to work with is

¹Several versions of *EZNEC* antenna modeling software are available from developer Roy Lewallen, W7EL, at www.ez nec.com.

²ARRL online course EC-004, “Antenna Modeling”; www.arrl.org/cce/courses.html#EC-004.

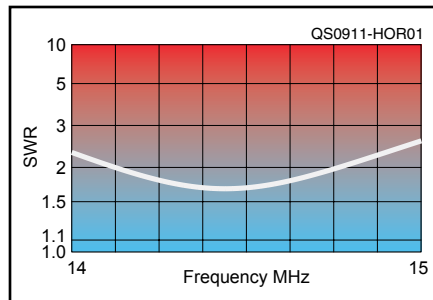


Figure 1 — The SWR curve for the backyard dipole at a height of 30 feet over *EZNEC*’s Real Ground. The resonant frequency of 14.46 MHz indicates the dipole is too short.

called BYDIPOLE (*backyard dipole*). It’s an electrical half wave ($\lambda/2$) long, center fed dipole, cut for the 20 meter band. Open this file, review the antenna structure and the program’s configuration. By clicking the right-arrow (>) next to WIRES, you can see that the dipole is made from 33.43 feet of #12 AWG bare wire, fed in the middle and suspended at a height of 30 feet. Click VIEW ANT to see the antenna and keep this window open as you make changes as a check.

Click the SWR button and plot SWR from 14 to 15 MHz in steps of 0.02 MHz. By moving the cursor along the curve, you can find the frequency of resonance at which the feed point reactance is zero — 14.46 MHz — out of the band! According to the well-known formula for dipole length, l (in feet) = $468/f$ (in MHz), the length checks out as 33.43 feet. What happened? The constant 468 in the length formula is an approximation based on a dipole that is higher above ground in terms of its wavelength. Multiplying 33.43×14.46 shows that 484 would be

more appropriate. Recalculating the wire length as $484 / 14 = 34.57$ feet results in resonance at 14 MHz. Find the length for which resonance occurs at 14.175 MHz, the center of the band. (34.14 feet) What is the feed point impedance at resonance? (87 Ω)

There’s Always an Angle

Go back to the main *EZNEC* screen, click > next to GROUND TYPE, select FREE SPACE and run the SWR curve again. You’ll have to extend the SWR curve below 14 MHz because the resonant frequency drops to 13.8 MHz at which the feed point impedance is 72 Ω . The absence of ground reflection causes the resonant frequency to be lower. The reflection creates an *image* antenna as far below the surface as the real antenna is above ground. This is the same model for the vertical ground-plane antenna, except that the dipole is horizontal and above ground.

The image antenna has two primary effects. The first, as you have observed, is to change the resonant frequency and feed point impedance from the free space values. The second is to create a two element phased array with one element being the real antenna and the image forming the second element. The combination of the fields from both result in the radiation pattern of the antenna.

Figures 2A through 2G show the elevation radiation pattern of the dipole at six electrical heights; from $1/8$ through 2λ . Table 1 shows several measurements for each height. First, the dipole length is shown for resonance at 14.175 MHz along with the $l \times f$ constant. The next column shows feed point impedance and SWR at resonance. Finally, maximum gain with respect to an isotropic radiator in free space (dBi) is shown along with the vertical angle at which it occurs. Our simple backyard

Table 1 — Variation in Dipole Performance with Height

Height in Wavelengths at 14.175 MHz (feet)	Resonant Length in Feet ($l \times f$)	Feed-point Impedance in Ω (SWR)	Max Gain (dBi) at Angle (Degrees)
$1/8$ (8.8)	33.0 (467.8)	31.5 (1.59)	7.4 @ 90
$1/4$ (17.4)	32.9 (466.4)	81.7 (1.63)	5.6 @ 62
$1/2$ (34.7)	34.1 (483.4)	69.6 (1.39)	7.4 @ 28
$3/4$ (52.0)	33.4 (473.4)	73.4 (1.47)	7.3 @ 18
1 (69.4)	33.9 (480.5)	71.9 (1.44)	7.7 @ 14
$1\frac{1}{2}$ (104.1)	33.8 (479.1)	72.0 (1.44)	7.8 @ 9
2 (138.8)	33.8 (479.1)	72.3 (1.45)	7.9 @ 7

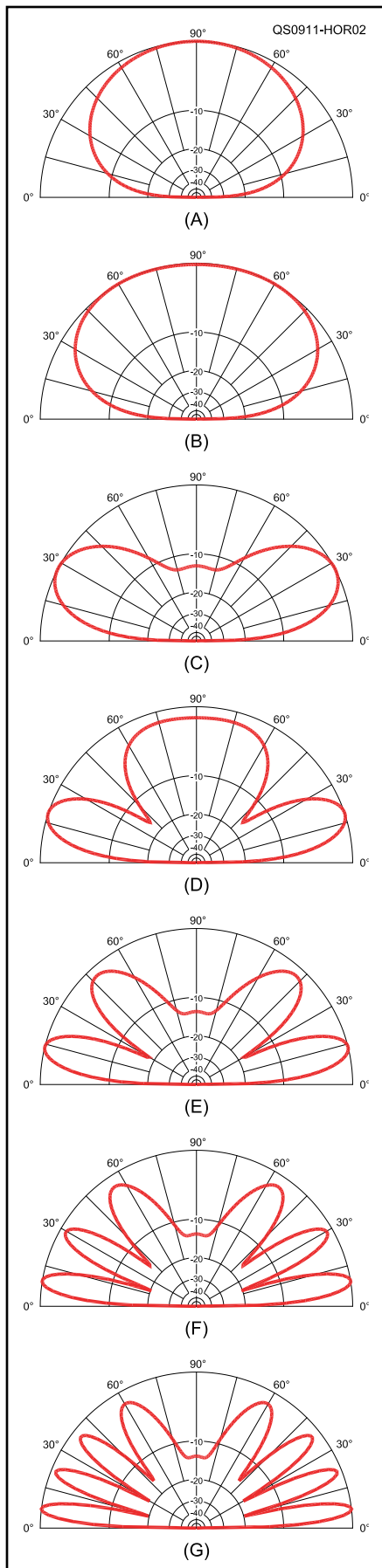


Figure 2 — Six radiation patterns for the dipole at different heights: (A) $\frac{1}{8} \lambda$, (B) $\frac{1}{4} \lambda$, (C) $\frac{1}{2} \lambda$, (D) $\frac{3}{4} \lambda$, (E) 1λ , (F) $1\frac{1}{2} \lambda$, (G) 2λ .

Antenna Modeling: Boon or Bane?

As anyone who has ever used a computer simulation program knows, pitfalls abound. In fact, while creating Figure 2, the author misentered some parameters, leading to some serious head-scratching about the dipole's surprising behavior! Nevertheless, no one seems to be clamoring for the days before modeling software.

It's important to pay attention to the limitations of any program, usually discussed in the users manuals. Results too good to be true, very different than expected, or that change dramatically with small changes in the design often indicate a problem. Because of modeling programs, antenna design has blossomed in Amateur Radio, one of the most active areas of experimentation and discovery. Skeptics need not fear that the computer will completely displace construction and on the air tests. As W7IUV once said, "I don't think anyone has made an *EZNEC* contact yet!"

dipole is a fairly complex antenna!

You can see why using the formula $468/f$ can lead to a lot of extra antenna trimming — the variation from 466.4 at $\frac{1}{4} \lambda$ high to 483.4 at $\frac{1}{2} \lambda$ high results in a difference of 1.2 feet! The most rapid change takes place between heights of $\frac{1}{4}$ and $\frac{1}{2} \lambda$ — about where most hams install a 20 meter dipole. Impedance also varies from 31.5 to 81.7 Ω . As the antenna is raised beyond 1λ , resonant length and feed point impedance stabilize near their free-space values.

The radiation pattern, however, does not stabilize — quite the opposite! Starting from a low height and radiating mostly straight up, the pattern flattens out until at $\frac{1}{2} \lambda$ it is radiating mostly at low vertical angles because the signal reflected from the ground cancels the direct radiation in the vertical direction. This would be a good DX antenna, but poor for short skip and regional coverage.

As the antenna is raised to $\frac{3}{4} \lambda$, the reflected energy no longer cancels, creating a large vertical lobe. Even though the main lobe has essentially the same gain and is at a lower angle (18°) than at $\frac{1}{2} \lambda$, short-skip high-angle signals would be stronger, creating interference to low angle DX signals. The pattern continues to break up into more and more lobes as the antenna is raised. Even though the maximum gain and vertical angle are very similar above $\frac{1}{2} \lambda$, the on air performance of these antennas, especially on a crowded band, would be very different!

Gaining Gain

If you are struggling to hear and be heard through the pileups on 20 meters and are won-

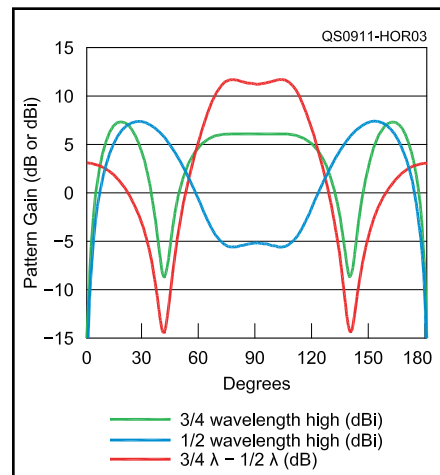


Figure 3 — The difference in gain (red) between the dipole at $\frac{3}{4} \lambda$ high (green) and $\frac{1}{2} \lambda$ (red). The higher dipole has more gain at low angles, but also at high angles.

dering if your dipole would do any better if raised from its present 35 feet to about 50 feet, take a look at Figure 3. The red line shows the difference in gain between the dipole at $\frac{3}{4} \lambda$ (50 ft) and $\frac{1}{2} \lambda$ (35 ft). If the red line is above 0, the higher dipole has more gain.

The higher antenna does have a bit more gain below 22° — a maximum of 3 dB near the horizon. However, in the large range of vertical angles between 22 and 56° , the lower dipole is stronger. And what of the angles above 56° ? If you are having trouble with interference from nearby and regional stations, the higher dipole would be a poor choice because it will hear those stations 10 to 12 dB better than the low antenna. Higher is not always better — you would have to raise the dipole to 1λ or higher before it begins rejecting high angle signals.

Recommended Reading

The best antenna reference for hams is *The ARRL Antenna Book*.³ For those who want an easier to digest introduction to the subject, the ARRL also offers *Basic Antennas*.⁴ There are a number of other excellent books that focus on specific types of antennas or offer collections of designs. Hams love reading about antennas — almost as much as using them!

³R. D. Straw, Editor, *The ARRL Antenna Book*, 21st Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9876. Telephone 860-594-0355, or toll-free in the US 888-277-5289; www.arrl.org/shop; pubsales@arrl.org.

⁴J. Hallas, W1ZR, *Basic Antennas — Understanding Practical Antennas and Designs*, available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9994. Telephone 860-594-0355, or toll-free in the US 888-277-5289; www.arrl.org/shop; pubsales@arrl.org. 