Ionospherica

Kazimierz "Kai" Siwiak—KE4PT ke4pt@amsat.org

Pitching and Catching Radio Waves - The Last Bounce

In the previous Ionospherica (Spring 2013) we learned that the Earth-Sun system is the source of our DXing delight - the ionosphere. The last 300 kilometers of the Earth-Sun distance governs all the magic we call ionospheric propagation. We can exhibit some control over ionospheric radio wave propagation in just the last few tens of meters by choosing how we orient our antennas. In this episode we consider the last bounce of the path between the ionosphere and our station antenna.

Radio wave photons "pitched" from the ionosphere are "caught" at our station antenna, see Figure 1. Those packets of HF energy arrive by two paths. One path is direct, but the second path involves a bounce from earth. This earth-reflected wave fights and interferes with the direct wave at the our receiving antenna. We observe a vertical standing wave pattern over home plate right where we place our antenna to snag the RF energy! The story is all about geometry, and the detailed spherical Earth geometry equations are in [1]. Our pitcher's mound is the typical 100 km height of the ionosphere, and our catcher represents the height of our station antenna.

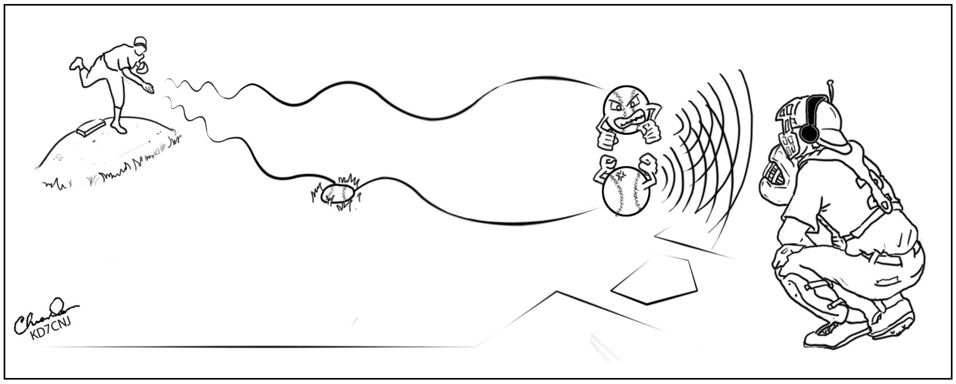

Figure 1—The ionospheric pitcher hurls radio wave photons that take both direct and earth-reflected path to the catcher's receiving antenna. © 2013 Chris Dean, KD7CNJ, used with permission.

Arrival Angle and Takeoff Angle

An "aluminum cloud" of antennas placed on a high tower can snag a lot of DX. So, questions arise. Why does height matter? Is there an optimum height? What exactly is "takeoff angle", and how does it relate to a good DX antenna system? We gain a lot of insight by turning the problem around from transmitting to receiving. "Arrival angle" is the receiving analog to the transmitting "takeoff angle", and is a DX parameter rather than an antenna characteristic, see [2]. Remember, the Theorem of Reciprocity guarantees that transmit and receive antenna system performance is identical so we are justified in looking at the antenna from the perspective of receiving performance.

The field-strength of a radio wave arriving from the ionosphere at our receiving location varies with height. So the proper height for an antenna must be where the field strength is at a maximum, or at the very least, is not in a null. Proper antenna height matters! Figure 2 shows the field strength variation (dB relative to a free space path) versus height for signals pitched from a 100 km height along a 10 degree arrival angle. The three curves illustrate reflection from a medium earth ($\varepsilon = 12$) ground (solid), from fresh water (dashed), and from sea water (dotted). See [3] for details concerning reflection coefficient. Figure 2 shows the vertical polarization and horizontal polarization field strength versus height. In general, both polarizations are present no matter what was transmitted by the DX station, but that is a tale for a future episode. We pick off the polarization we want by choosing a suitable antenna.

Expected DX Station Arrival Angles

The arrival angle (or takeoff angle) is a characteristic of the geometry between the ionospheric height and the distance separating our location from the DX station. Since we don't know the angle of arrival, we will want to find the best height solution over a range of arrival angles. Dean Straw, N6BV, has provided updated statistical elevation-angle files for use with the HFTA application contained on the *ARRL Antenna Book CD* in [4]. Using the combined arrival angle statistics between several USA regions and all other regions of the world, we can show that 90% of the arrival angles are smaller than 16 degrees. So we will confine our interest to arrival angles between 3 and 16 degrees. This is the range of "takeoff angles" that the antenna must accommodate. As seen in Dean Straw's arrival angle files, the lower arrival angles become much less important as frequency is decreased.

Height Gain

The field strength variation depends on wavelength as well as on the wave polarization. When the direct and earth reflected waves meet, their constructive and destructive interference form a vertical standing wave. The curves in Figure 2 were calculated for a 10 degree arrival angle.

For horizontal polarization the gain initially increases with height to the first peak near 1.5 wavelengths. The vertical standing wave scales with the arrival angle. A 16 degree arrival angle compresses the curves so that the first peak appears near one wavelength height. A 5 degree arrival angle expands the curve so that the peak appears three wavelengths high. For horizontal polarization, the curves have a very similar behavior over the range of reflection parameters from medium ground to sea water. Placing horizontally polarized antennas between 1 and 1.5 wavelengths above ground, emerges as one definition of the optimum antenna height. We are not taking into account terrain variations here. That detail is handled by Dean Straw's HFTA terrain analysis application.

For vertical polarization, one optimum height is at ground or sea level, as depict-

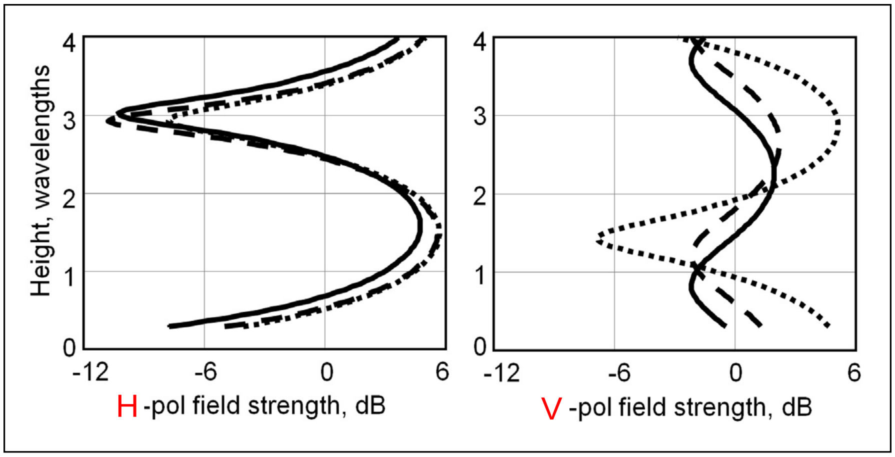

Figure 2—The vertically polarized (V-pol) and horizontally polarized (H-pol) field strengths vary differently and depend on whether the reflection is from medium earth ground (solid), fresh water (dashed) or sea water (dotted).

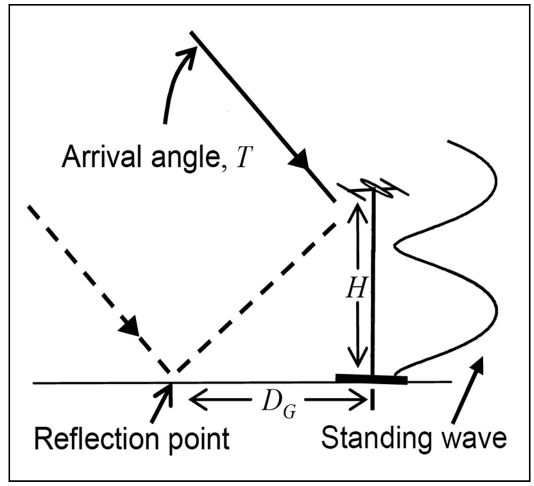

Figure 3—The reflection point is distant from the antenna tower.

ed in Figure 2. Although you should elevate vertical antennas above local obstructions and local roof lines, increasing height any further may initially reduce the received field strength. The sea-reflected vertically polarized wave has an optimum at sea level that can add as much as 5 dB height gain to the actual antenna gain. This is why vertically polarized antennas on the beach are so effective. Ground mounted vertical antennas over earth ground exhibit negative height gains of –1 to –5 dB depending on the signal arrival angle. The gains shown in Figure 2 are in addition to any directive gain provided by the antenna system.

Where's the Reflection Point

The reflection from earth that causes the vertical standing wave does not occur under the elevated antenna. Let's rephrase that. The ground directly under the antenna (catcher) has no effect on the constructive and destructive wave behavior that results in height gain. There may be mutual coupling to the ground which may affect the antenna impedance, but that is a completely different matter. The location of the reflection point is shown in Figure 3. For arrival angle T in degrees and antenna height H in meters, the distance D_G in meters along the ground to the reflection point is $D_G = 55\ H/T$. Thus an antenna on a 30 m tall tower receiving a wave from 3 degree arrival angle observes a reflection from earth that is 550 m (1,800 ft) from the base of the tower. Ground parameters that are 550 m from the antenna determine which of the curves in Figure 2 are relevant. What's directly under the antenna doesn't matter!

Finding an Optimum Antenna Height

Some multiband Yagi beams can cover the 40 m to 10 m bands in a single structure. Raising and lowering such an antenna to the optimum height per wavelength is not desirable, so knowing an overall optimum height could be very useful. We can calculate a family of curves, like in Figure 2, for any band or any combination of frequency bands. One effective strategy is to choose the best height for the highest frequency band of interest. That sacrifices some of the performance for the lowest arrival angles at the lower frequency bands, but does so more gently than the destructive interference loss for higher arrival angles if a higher antenna were chosen. For frequency bands between 7 and 30 MHz, 1.5 wavelengths at 30 MHz is reasonable if higher frequencies are deemed more important, and 1.5 wavelengths at 14 MHz may be used if the lower frequencies are more important.

Summary and Conclusions

You can increase your low power fun by understanding how radio waves reach your antenna. By adopting a "receive mode" view we see that wave interference from a direct path and an earth reflected path causes a vertical standing wave at the antenna location. The details depend on the radio wave angle of arrival, the polarization, on whether the reflection point is ground or sea water, as well as on terrain (not considered here). Optimum antenna heights are largely governed by the highest frequency deemed important and by the range of expected arrival angles. Antennas that are placed too high can suffer from significant wave destructive interference at the higher arrival angles. Optimum height for horizontally polarized antennas is 1.5-1.6 wavelengths for any one band, or a compromised height can be found for a multiband antenna operating over several bands by using the optimum height for the highest frequency. Keeping in mind that this analysis was limited to rough but not locally mountainous earth and not a dense urban region, HF antenna heights in the range of 15 to 30 m (50 to 100 ft) emerge as reasonable compromise choices for horizontally polarized multiband antennas operating from a fixed height. Vertically polarized antennas are best kept near ground or sea level, but above local obstructions.

References:

1. K. Siwiak, KE4PT, "An Optimum Height for an Elevated HF Antenna", *QEX*, May 2011, pp 32-38.

2. K. Siwiak, KE4PT, "Is There an Optimum Height for an HF Antenna?", *QST*, Jun 2011, pp 33-36.

3. K. Siwiak and Y. Bahreini, *Radiowave Propagation and Antennas for Personal Communications*, Third Edition, Artech House, Norwood MA: 2007, Chapter 6.

4. *ARRL Antenna Book* tab at www.arrl.org/product-notes, "updated statistical elevation-angle files"..

●●