Ionospherica

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

Propagation Laws— When is it "Free Space?"

Ionospherica (i·on′ə·sfir·ə·kə) – *noun, radiowave propagation by means of ionized atmospheric layers.*

Radio signals do not travel from point to point. Instead, they spread and expand according to the geometry of the environment, and they diffract and scatter, much like scattered light illuminating the sky from a Sun set just below the horizon (Figure 1). The "Radiowave Propagation Laws," follow the laws of physics, and ultimately define the communications distance possible, subject to the physical environment. We'll illustrate some propagation laws with VHF examples, then turn our attention to HF propagation.

Figure 1—Sky illumination by the setting Sun resembles signal illumination from a distant HF station via the ionosphere. Source: *Copyright 2015 Chris Dean, KD7CNJ, used with permission.*

I operate a 5 W VHF handheld transceiver. With it I can talk to hams orbiting 400 km above Earth in the International Space Station (ISS). Why can't I talk directly to another handheld radio 10 km (6 miles) across town? Is the path affected by the ionosphere? How does all of this apply to apply to HF?

The VHF Path

Let's look closely at a pair of handheld radios. The transmitting power is 5 W or +37 dBm (decibels relative to a milliwatt), and the receiver sensitivity is 0.16 uV (–123 dBm for 12 dB SINAD). The difference between the transmitter level and the receiver sensitivity is 37 + 123 = 160 dB. That's how much link margin we can "burn up" in the path, including the antennas. For now we'll assume that the antennas at both ends of the link have –7 dBi gain, so 146 dB is the path link margin including the antennas. How far will 146 dB take you at VHF? It depends on the path-specific propagation law.

The Free Space Propagation Law

The path distance to ISS can vary from 400 km (249 miles) straight up, to about 2,293 km (1425 miles) on the horizon. We operate on a line-of-sight path, so the radiated waves expand spherically, meaning the radiated power density diminishes as the square of the distance. The receiving antenna gathers 6 dB less power every time that the distance doubles—this the free-space propagation law. Said mathematically, free space path attenuation P_{FS} is this:

$$P_{FS} = 32.4 + 20\log(F_{MHz}\, D_{km}) \qquad (1)$$

Plug in F_{MHz} = 146, and D_{km} = 2,293 and we get a path attenuation of 143 dB, or 3 dB stronger signal than we need! Of course, the antenna polarizations must be aligned, and we've ignored ground reflections, which can affect the signal near the horizon. But you get the basic idea —in the absence of interference, you can reach ISS with a 5 W handheld transceiver! There is also an ionospheric effect— Faraday rotation of the polarization—but we compensate for that by reorienting our antenna [1]. The Free Space Propagation Law holds for most HF paths, but we'll get to that later.

Urban/Suburban Propagation

Why, then, can't I talk across town to another handheld transceiver? The radiated waves still expand spherically in the manner of free space propagation, but there are additional factors when both transceiver antennas are low, below the building roof lines. For one thing, the waves illuminate the local buildings and streets, like the setting Sun, and waves travel by multiple paths. When they reach the building roof lines, or building corners, they diffract (this adds diffraction losses), then propagate further by multiple paths. Multiple paths mean that one path will be the shortest, followed by many signal copies that arrive delayed in time. Those time-delayed copies of the signal interfere with one another and with the first-path signal, causing multipath fading, just like ripples of the surface of a swimming pool after a splash. The time-delayed multiple copies also steal energy from the first arriving signal copy [2]. We can show that fading gives rise to an additional attenuation of another 0.5 to 2 exponent in the distance attenuation behavior. It's no longer inverse square law, but inverse 2.5 to 4th power! The diffraction losses and losses along the roof tops of the suburban path add around 62 dB of loss at a distance of 2.7 km (1.6 miles) between handheld transceivers for a total of 146 dB! [3] That's where repeaters show their stuff.

Propagation to Repeater Systems

In a repeater system one end of the link is always high up on the repeater tower antenna. Everyone talks to the repeater, and everyone listens to the repeater. The propagation law is somewhere between our free-space ISS path, and that brutal street to street level suburban path. More specifically, one end of the path is high on the repeater system tower, way above the suburban buildings, but the other end might still be at street level, and includes scattering and diffraction losses to the nearest roof edge.

Consider a repeater antenna on a tower of height 61 m (200 ft), and with a

+6 dBi antenna (13 dB more than the handheld radio antenna), so that the link margin is 159 dB. The suburban propagation model then predicts a coverage radius of 47 km (29 miles) centered on the repeater tower. Figure 2 shows a comparison of the VHF propagation laws for the three scenarios: free-space to a space craft on the horizon at 2239 km (1425 miles), portable to a tower high above roof-top level at 47 km (29 miles), and portable to portable radio at street level at a distance of 2.7 km (1.6 miles). Notice that 1425 miles on 5 W is pretty decent QRP DX, especially at VHF!

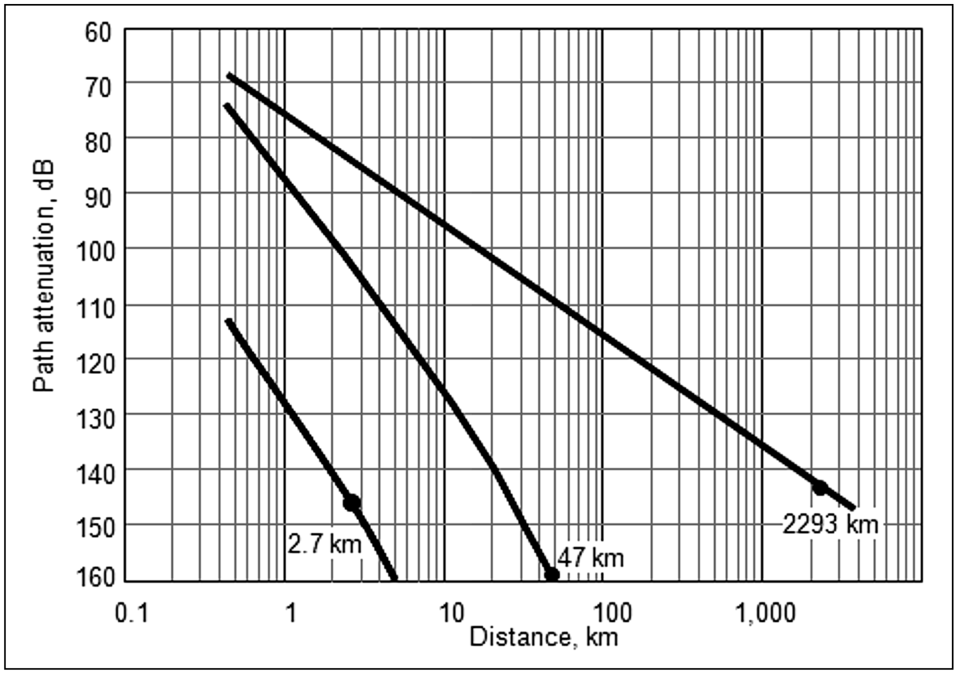

Figure 2—Propagation laws for a 5 W VHF handheld transceiver: (top) by free-space law a spacecraft; (middle) by suburban law to a repeater tower; and (bottom) to another handheld transceiver at street. The dots indicate maximum range.

HF Propagation

Figure 3 shows the ground illuminated by an omnidirectional transmitting antenna located in Florida. Local coverage extends just tens of kilometers around the transmitter, then a skip zone extends to the first reflection zone at D. I calculated the prediction map using VOACAP software using the graphical interface (HamCAP) written by Alex Shovkoplyas, VE3NEA.

I chose Hawaii as the receiving endpoint. The ionosphere is lit up by the transmitter in concentric circles as the spherically expanding wave reflects from the ionosphere back to the ground. The Sun (star symbol), roughly midway between the two endpoints, activates the ionosphere over the day portion of the Earth, but also lingers in the night portion of the globe, as seen here over central and southern Africa.

There are several HF propagation predictors that use the VOACAP software developed by NTIA/ITS for the Voice of America. There is even one available online www.voacap.com/prediction.html.4

I find HF propagation prediction tools indispensible for my QRP DXing.

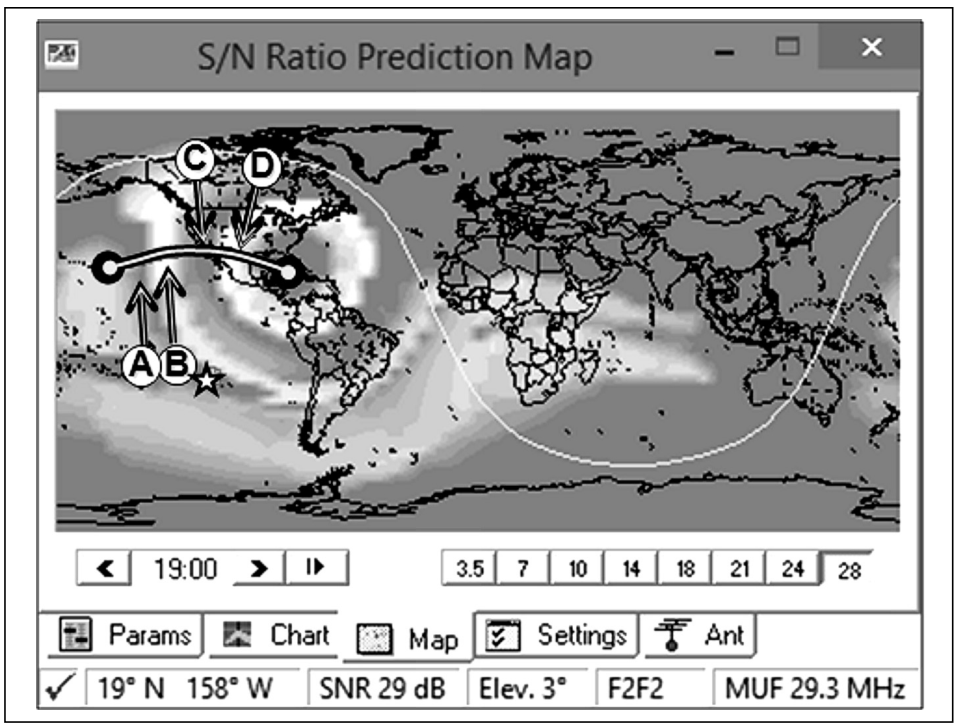

Figure 3—HF propagation prediction at 28 MHz between a transmitter in Florida and receiver in Hawaii. The signal on the ground peaks at D, B, and Hawaii, but skips over C and A. The Sun (star) is roughly midway between the two end points. *[Source: HamCAP software by VE3NEA]*.

References

1. K. Siwiak, "Hams Test Antennas Aboard Space Shuttle Columbia," *QST*, Oct 1993, pp. 53-55.

2. K. Siwiak, H. Bertoni, and S. Yano, "Relation between multipath and wave propagation attenuation," *Electronic Letters*, Vol. 39, No. 1, Jan 9, 2003, pp. 142-143.

3. L.R. Maciel, H. L. Bertoni, H. H. Xia, "Unified approach to prediction of propagation over buildings for all ranges of base station antenna height," *IEEE Transactions on Vehicular Technology*, Vol. VT-42, No. 1, pp. 41-45, Feb 1993.

4. VOACAP on-line courtesy of J. Perkiömäki,OH6BG, J. Watson, HZ1JW, and J. Juopperi, OH8GLV.

Kazimierz (Kai) Siwiak, KE4PT, is an avid DXer who packs a DX Go-Bag station on his travels. His technical writings appear in many publications. ●●