# Ionospherica

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**Figure 1—The Earth is not smooth, even in a region where the street level above sea level is nearly constant, like this region west of Ft. Lauderdale, FL.**

## Ground Reflections—The Rough and Spherical Earth.

The tool of choice for modeling antenna patterns over ground is numerical electromagnetic code (NEC), such as implemented in several popular software packages, including EZNEC and 4nec2 [1, 2] They each give excellent results as long as you are modeling your antenna in free space, or over a perfectly flat and perfectly smooth Earth.

In October 2015 Ionospherica we showed an evaluation of antenna patterns over a “medium” ground using NEC [3]. That study showed that the ground affects antennas and antenna patterns in two completely independent ways. First, for low antennas, the ground affects the feed-point impedance of the antenna through mutual impedance coupling with the ground *directly under the antenna*.

Second, the reflection from the ground distant from the antenna combines with the direct signal path from the antenna. This reflection occurs *far from the antenna* for useful elevation angles to generate ground-induced pattern lobes—two lobes per quadrant for every wavelength in height above the ground. In between those lobes were very deep ground-induced antenna pattern nulls.

However, the Earth is neither flat, nor smooth—and that has a dramatic effect on the details of the antenna patterns. The Earth is rough, as depicted in the aerial view in Figure 1.

So, how does that affect antenna patterns?

### What the NEC Models Calculate

The NEC software packages perform two functions. First, they consider the wire model of your antenna, and compute the currents in those wires by applying Maxwell’s equations. If you chose to include a ground, those antenna wire currents include the mutual impedance due to the ground directly below the antenna. So far, so good.

Second, NEC software computes electromagnetic (EM) fields using those antenna currents as sources. Again, if you included ground parameters then the software includes ground-reflection EM field components, as pictured in Figure 2. The specifics are not important, but getting the distant composite EM field *F* can be summarized as follows.

$$F(\theta) = Direct\ (\theta) + Reflected\ (\theta) \qquad (1)$$

where $\theta$ is the pattern elevation angle. The reflected path fields *Reflected* include ground reflection coefficients.

NEC and practically every other EM solver we are likely to encounter, uses reflection coefficients—typically Fresnel plane-wave specular coefficients—that are based on a flat and perfectly smooth Earth. Why? Because it is simple to do so! Or, more precisely, it can be incredibly difficult to model a rough environment, as in Figure 1, except statistically.

We showed the results of using some propagation models that relied on a statistical description of the environment in the April 2015 Ionospherica [4].

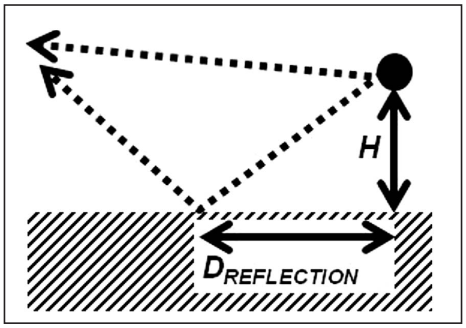

**Figure 2—The antenna pattern is a composite (vector addition) of fields traveling along a direct path and fields that are reflected from ground.**

### Statistical Models

Vast tracts of the radio propagation environment can be described statistically with just a few parameters, to arrive at simplified curves for propagation attenuation along urban and suburban radiowave paths. We didn’t get an exact answer, but rather a median signal value along with a standard deviation of the result, consistent with the detail (or lack of it) with which we described the environment.

It is possible to modify the *Reflected* term in Eq. (1) to approximately account for a rough and spherical, specifically,

$$\begin{aligned} F(\theta) = {} & Direct\ (\theta) \\ & + S(\theta) Reflected\ (\theta) \end{aligned} \qquad (2)$$

where $S(\theta)$ is a two part statistically-based modification to the reflection coefficient. One part is a frequency independent divergence factor derived for a spherical Earth [5]. The second part was derived originally to describe scattering from a rough sea [6]. The spherical divergence factor affects primarily the reflection at the very lowest elevation angles. It is purely a geometrical term involving the antenna height above ground and the radius of the Earth. It is independent of frequency. The roughness factor affects the higher elevation angles, and depends on frequency and on a roughness parameter $h_{rms}$.

The wavelength or frequency dependency of roughness should be no surprise. The roughness portrayed in Figure 1 involves fixed heights of buildings and foliage, whereas EM wavelengths vary with frequency. Said another way, a cluster of 12 m tall (40 ft) buildings is just a fraction of a wavelength at 1.8 MHz. So the cluster may appear relatively "smooth" at that frequency. In the 2 m band however, those buildings are tens of wavelengths tall. The cluster appears very "rough" in the 2 m band. That frequency dependency of the roughness parameter is evident in Figure 3

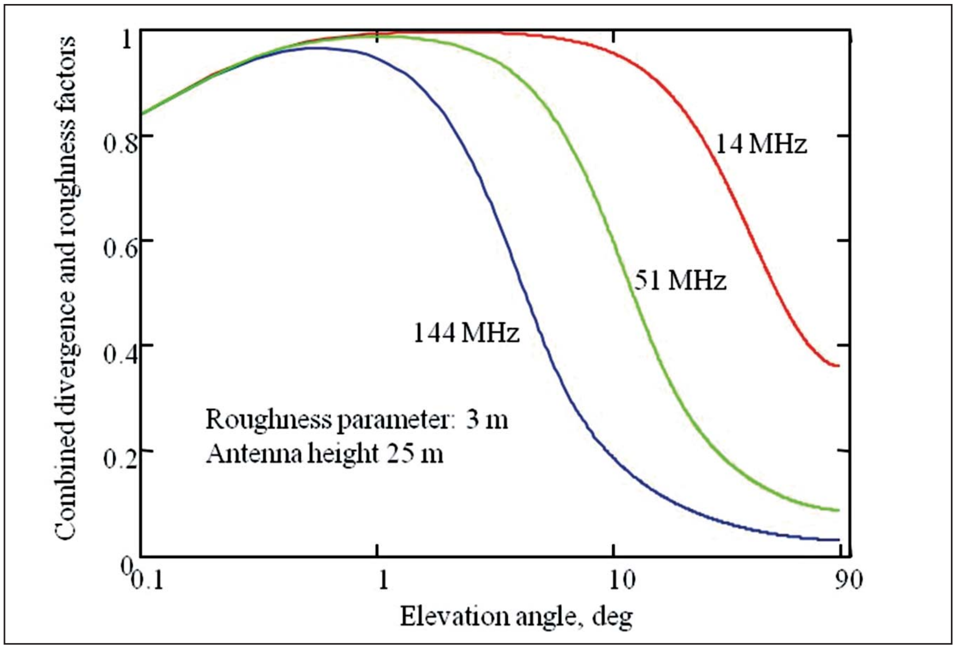

**Figure 3—*S(θ)* for a suburban area similar to Figure 1. The dip for angles below one degree is due to the frequency independent spherical earth divergence factor; the frequency dependent behavior above one degree accounts for Earth roughness.**

## Accounting for a Rough Spherical Earth

Parameter $h_{rms}$ was derived to represent the standard deviation of ocean waves, or about 0.25 times the wave crest to peak height. In applying this to buildings and foliage, $h_{rms}=3$ would represent the standard deviation of buildings and foliage with a median height of 12 m.

Figure 3 shows the combined spherical divergence and roughness factor computed for an environment of 12 m tall buildings. $S(\theta)$ reduces the ground reflection contribution, making ground reflection nulls and pattern lobe peaks less pronounced.

## Effect on Antenna Patterns

Antenna patterns computed by NEC have excessively deep ground-induced nulls, as do the analytical pattern for a smooth flat Earth, as seen in Figure 4. Analytically including a roughness parameter appropriate to a suburban environment reduces the reflection coefficient amplitude, and consequently reduces the ground induced pattern nulls.

## References

1. EZNEC antenna modeling software, Roy Lewallen, W7EL, www.eznec.com.

2. 4nec2 modeling software by Ari Voors, www.qsl.net/4nec2.

3. K. Siwiak, KE4PT, "Ionospherica, Ground Influence—It's not a property of the antenna," *QRP Quarterly*, Vol 56 No. 4, Oct 2015.

4. K. Siwiak, KE4PT, "Ionospherica, Propagation Laws—When is it Free Space?," *QRP Quarterly*, Vol 56 No. 2, Apr 2015.

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

6. M. Skolnik, Ed., *Radar Handbook*, McGraw-Hill, 1990. See Eq. (2.46), Chapter 2. ●●

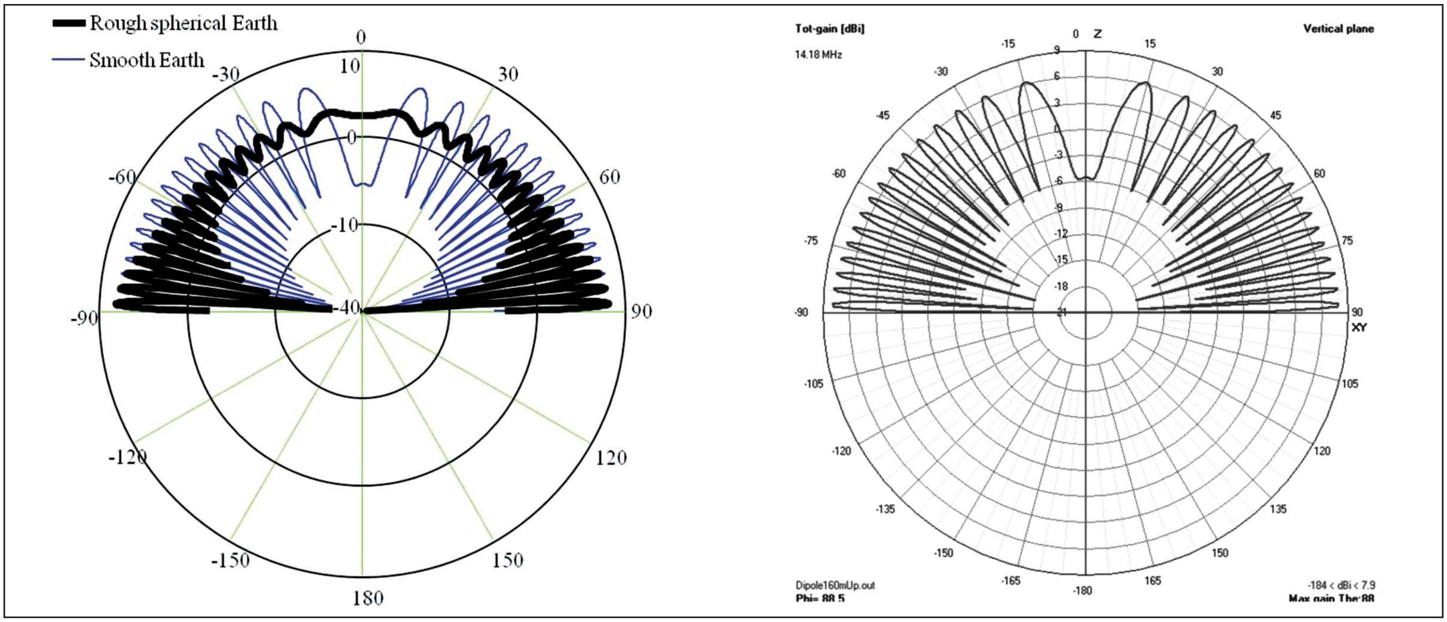

**Figure 4—The right side pattern shows a NEC calculation of a dipole 8 wavelengths above the Earth. The left patterns are analytical results for a smooth Earth (thin line) that matches the NEC calculation, and for a rough Earth (thick line).**