NewcomerNotes: The Effects of Ground on Radio Signals

By Robert Gulley AK3Q 5/18/14

Let me say right from the start: regardless of how cluttered or difficult a particular location is for sending or receiving signals, don't be overwhelmed by the challenges. Where there is a will there is a way.

-- When reading about antennas much of the discussion revolves around theoretical situations or "best case" scenarios which rarely exist in the real world.

-- Radio waves, like the dinosaurs of *Jurassic Park,* "will find a way."

-- While none of us have the perfect setup, many of us are on a continual quest to get the most out of our radios, and one way to do this is to understand how the terrain affects signals close in and farther out.

-- In past nets I have mentioned a bit about propagation, or how radio waves travel through the air and along the ground. Many radio signals bounce (or *refract*) off the atmosphere, while others travel along the ground.

-- Most signals are a combination of the two: there is a ground element and an atmospheric element to all radio signals, and this affects not only the distance a signal will travel, but also its quality.

-- When receiving a radio transmission the main things that determine what we hear are the frequency and the type of modulation of the signal.

-- AM radio waves during the day travel mostly along the ground because the skyward part of the signal fails to be refracted back to earth—this is why we usually only hear stations within a few hundred miles of our location.

-- The Earth is a relatively poor conductor of electricity overall, so signals dependent on ground travel alone don't go very far.

-- Think about a local 50K watt AM station for a moment and about how far one might expect that kind of signal to travel; my 100 watt station can span the globe, so why shouldn't 50,000 watts not make the trip several times over?

-- The answer lies in the placement of the signal in the radio spectrum and in the effects of atmosphere and ground upon that signal. Take the same power at a higher frequency, say the 20-meter band, and watch how far the signal goes!

-- FM signals travel through the atmosphere and along the ground, but are limited to line-of-sight for the most part (nighttime can open up some interesting possibilities for FM DX work, however, and turbulent weather can generate some skip conditions just as with 6- and 2-meter VHF signals).

-- FM signals are in the 100 MHz range which means the number of cycles is significantly higher than AM.

-- While there is some ground effect on an FM signal, by far the obstacles above the ground are more problematic to signals in this range.

-- Tall buildings, metal structures and even foliage can impact radio reception in the VHF portion of the spectrum

Signals in the shortwave band are less affected by local conditions and are thus used for international broadcasts, but bouncing between the atmosphere and the ground multiple times can take its toll on signal quality and readability.
-- Significant power helps, as many shortwave stations broadcast at 100-200K watts or more. The long distance does takes its toll on signal quality, however, as the received signal strength can fluctuate greatly and cause a signal to fade in and out.
-- While ground effect is more of an issue with transmitting than with reception, knowing which factors most impact a signal will help you understand why some signals come in better than others.
-- For example, if someone lives near a body of water, particularly saltwater, they will likely find signal reception is better nearer the shore as opposed to being further inland.
-- This is because salt water acts as a good reflector of radio signals (I'll talk about *angles of incidence* and *reflectivity* more in a moment).
-- While freshwater is something of a poor conductor of RF energy, the higher salinity of saltwater makes for what is in essence a "harder" surface on which radio waves may bounce.
-- Indeed stations which are relatively close in may be harder to hear around large bodies of water as the signals bounce over nearby receivers.

Conditions such as mountainous terrain may block some signals while helping others. Steel buildings and concrete roads all impact what one hears, sometimes in very strange ways.
-- *Diffraction* is the term most often used to describe how radio signals are bent, bounced, and otherwise redirected from their source to their final destination.
-- Trying to determine what factors impact radio signal reception is an inexact science at best, but when looked at from the transmission side of things, reception issues will make a lot more sense.
-- How a signal leaves its point of transmission and what impacts it along the way determines to a great extent how that signal will be received.

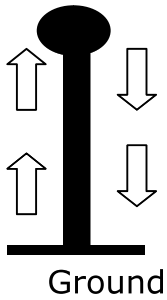
Near- Field Reactivity and Far-Field Radiation
Two common areas of study in the effects of ground on RF signals involve *near-field reactivity* and *far-field radiation*.
-- Near-field reactivity involves somewhat complex impedances as the physical surroundings of an antenna influence how much energy is allowed to radiate from the antenna.
-- The antenna can act like a capacitor or inductor depending on the interaction with ground.

-- Perhaps I should also mention here that when *ground* is discussed it does not refer to the actual surface of the ground where we walk, but rather a point somewhat below the surface of the earth.
-- This point changes depending on location and on the conductivity of the material making up the "ground" (such as liquid, rock, soil, etc.)
-- This interaction can greatly increase signal losses as well; this is why ground effect must be considered in any antenna setup.

-- *Far-field radiation* refers to the effect of ground on the radiation pattern of an antenna once the signal leaves the antenna.
-- Antenna orientation, elevation, terrain, wavelength, strength and modulation type all impact how well a signal is transmitted to a receiver.
-- There are even more factors than the ones mentioned here, but I want to keep things as simple as possible so that the details don't become overwhelming.
-- Antenna elevation, orientation, and the frequencies used are the biggest factors impacting how well a signal is transmitted.

Height Above Ground
An antenna's height above ground will greatly impact how that ground interacts with a transmitted signal.
-- If an antenna is too low to the ground much of the signal is absorbed or *dissipated* into the ground. Too high above ground and the positive effects of ground reflection can be lost.
-- Each antenna design has its own rule of thumb concerning elevation and this should be used as a starting point for testing the antenna.
-- Every situation is different, even when ground conditions seem fairly uniform. Soil composition, dielectric constant (it's ability to conduct electricity), and physical shape all combine to impact the effectiveness of a signal.

Just as matching the transmission line is important to reducing signal losses, so is measuring and accounting for impedance losses due to ground.
-- Some RF energy being created at the antenna radiates downward and will be reflected right back up into the antenna causing an interaction with signal current, helping or hurting the overall signal strength (see illustration).
-- If the reflected current is in phase with the radiating current, the signal is stronger as a result. If the reflected current is out of phase with the radiating current, the signal strength is diminished.



Near-Field Reactance can boost signal strength or weaken it depending on whether or not the reflected signal is in phase with the radiating current.

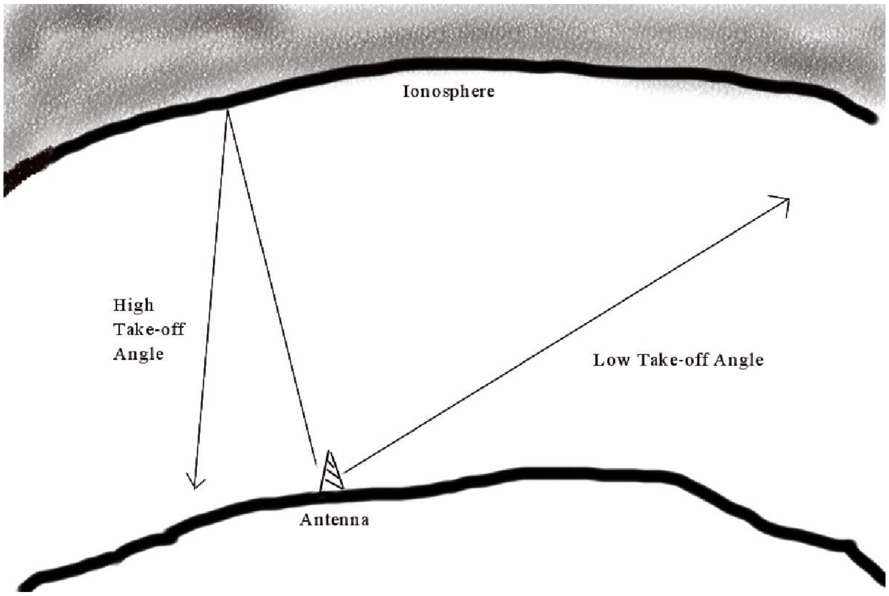
Changing the height of the antenna will change the current, so if possible, try different heights and compare the results both in terms of the VSWR readings and of the real-world reception/transmission capabilities of the antenna.
-- You may also find your readings differ when the height remains constant but you change locations for the antenna.
-- This is particularly true when working in areas where the terrain is uneven or there is a mix of ground materials such as concrete, metal or grass.
-- Keep in mind with any RF radiation there are two fields being generated: a magnetic field and an electronic field, with each being at 90° to one another.
-- Both of these fields can be reflected, or disrupted by the effects of ground.
-- While there are many resources available on the net to study the theoretical effects of near-field reactivity, you can't beat experimentation in the real world for getting a handle on what impacts your signal.

Reflections and Far Field Radiation
Allow me to make some generalizations with regard to signal reflection in an effort to make the concept manageable.
-- The subject of signal reflection and ground effect on radio waves in general can get bogged down in technicalities very quickly and one can get lost in the details.
-- When thinking about signal reflections think about skipping a rock over water.
-- Typically you want a flat stone to get the best distance, and you want to hit the water at an angle that will provide just the right balance between distance and number of skips.
-- Throw the stone at too steep of an angle and it, ahem, sinks like a rock.
-- Throw the stone at too shallow of an angle and the stone only skips once or twice.
-- Thrown at just the right angle, say around 30°, the stone will bounce a number of times to the delight of all who watch it skip along the water's surface. A similar thing happens with radio waves.

Radio waves bounce or reflect off of the ground in ways similar to the way light reflects off a mirror.
-- Roughly speaking if a radio wave strikes the ground at a 60° angle it will reflect at a 60° angle.
-- This is known as the *Brewster Angle*, named for Sir David Brewster, a Scottish physicist. Unlike light bouncing off a mirror, however, when radio waves bounce off the ground there is a certain amount of absorption and thus weakening of the signal.
-- This effect is less noticeable when the angle of incidence is greater.
-- In other words, less than 45° more of the signal is absorbed by ground; greater than 45° more of the signal is reflected for a greater radiation pattern (note: I am using 45° more as a median value rather than as an actual suggested value).

Far-field radiation is greatly affected by terrain and by the *angle of radiation*, also known as the *take-off* angle.
-- Most signals received by an antenna have taken several if not many more hops to get to where they are going, and this is where ground in the far-field has significant impact.
-- The goal for distant signals is to send out a transmission that starts low and rises on a low angle for greatest distance, like driving a golf ball.

Take-Off Angles
Take-off angles refer to the angle at which a radio signal leaves the antenna.
-- A high take-off angle means that the signal angles up to the sky more sharply than a low take-off angle (see illustration).



While some RF energy is absorbed into the ground regardless of the take-off angle, DX operators shoot for low take-off angles which allow for the greatest travel distance for their signals.
-- (Note: when local coverage is desired vertical or *NVIS* antennas are often used specifically for their short-range, high take-off angles. Emergency systems almost always use vertical antennas to provide the best coverage of a local area.)
-- As might be imagined, larger waves travel greater distances, so lower frequency transmissions are affected by ground conditions further out from the transmitting antenna than frequencies in the VHF range of the RF spectrum.

Take-off angles and reflections are determined in part by the type of antenna being used and in part by the antenna's height above ground.
-- Again speaking in generalizations, horizontal antennas produce *horizontally polarized* signals, while vertical antennas produce *vertically polarized* signals.
-- Horizontally polarized antennas rely less on ground effect than do vertical antennas unless they happen to be fairly close to the ground.
-- Horizontal antennas up to 20- or 40-meters offer a good balance of reach, low loss and reasonable take-off angles assuming one has the space for them.

Vertical antennas usually offer better take-off angles in the higher bands simply because much above 40 meters it becomes hard to place horizontal antennas at the appropriate elevation for a good take-off angle.

-- An 80-meter antenna would need to be at least 120+ feet off the ground, while a 160-meter antenna would need to be 260+ feet in the air to approach the proper angle!
-- This is why vertical antennas are a popular choice when space is a consideration.

Vertical antennas rely on a mirror image usually created by a system of radials which double the electrical height of the antenna.
-- This has advantages and disadvantages. While vertical antennas usually offer a lower take-off angle on the higher bands, the ground effect becomes far more uncertain due to the greater wavelength distance involved.
-- Unless the signal travels over a long expanse of flat land equal to its wavelength, predicting the ground effect on the radiation pattern becomes almost impossible to any degree of accuracy.
-- There are just too many variables to take into account. This is where one must rely on an "educated guess" and go from there.
-- While the ground effect may not be able to be changed, other factors such as antenna direction, orientation and near-field reactance are able to be controlled and tweaked for best performance.

RF Absorption and Dielectric Constants
Just how much RF energy gets absorbed by the ground and how much is reflected is partly a function of what type of surface the signal is traveling over.
-- Much like electronic capacitors which use dielectric materials to control the flow of electricity, soil has dielectric properties which can be measured.
-- These properties can then be used to estimate the conductivity of a given region's soil. The greater the dielectric constant, the higher the conductivity.
-- Maps are available online or in the *ARRL Antenna Book* which give a numeric representation of various parts of the United States.
-- The range of listings go from "poor conductivity" (represented numerically as 1.8 or less) to "excellent conductivity" (numerically 30—closest to saltwater) depending on various characteristics of the soil.

I have only scratched the surface of the effects of ground on radio signals, but hopefully you now have some heightened appreciation for how ground can impact your signal reception and transmission.
-- If this is a topic you wish to pursue further there are a number of on-line and printed resources available which use some rather complex mathematical formulas to come up with more precise ground effect characteristics for antennas and RF absorption figures.
-- Google "ground effect on antennas" or "soil conductivity" for more information, or check out some of the antenna and terrain modeling software available just for this purpose.

When experimenting with a new antenna try several different heights and locations before settling in on the placement which seems best.
-- Check the VSWR at each location as well as the receive/transmit strength. Be aware of what is around the antenna, above and below.
-- Short range signals will be affected by houses, trees, and varying terrain.
-- Long-range signals will not be as affected by local obstacles assuming there is enough clearing for the signals to take off properly, but the height above ground can be a real issue for any antenna.
-- Strive to have at least ½ wavelength height for all of your antennas whenever possible.

Finding A Compromise

Keep in mind what I said at the outset: theory is fine, but there is no substitute for trying out real-world scenarios based on your own local conditions.
-- Understanding how ground can affect your signals is an important step in getting a handle on how antennas work.
-- Experiment by manipulating those areas over which you have some control, and don't worry about the rest.
-- Chances are the factors you cannot control won't affect you nearly as much as the ones you can, so have at it and have fun along the way!