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Antenna Measurements — the Antenna Range

One of the things you can do at UHF and microwave frequencies that is difficult at other frequencies is to experiment with antennas and actually measure the results. A modest antenna range can be set up in a backyard or park and yield reasonably accurate antenna gain measurements. At lower frequencies, most antenna measurements are limited to VSWR because of size and space constraints.

Since the 1960s (see photo), good antenna measurements at various VHF conferences, Microwave Update and other gatherings have resulted in significant improvements in antenna design and availability. Conversely, some poor designs and products have faded into oblivion — perhaps you have wondered why no one uses the xxx antenna anymore. These antenna measuring sessions continue today, with one scheduled at Microwave Update 2012 (**www.microwaveupdate.org**).

I don't think I can describe antenna measurements adequately in two pages, so this topic will be broken into two parts: the antenna range in this column, and the measurement equipment and techniques in the next Microwavelengths.

Antenna Range

Accurate measurement of antenna gain requires measurement in the far field, as it would be for a signal far away. If the signal source is too close, the wavefront from the source will not appear as a plane wave, but will be curved, resulting in a phase error that reduces the gain. The Rayleigh distance is the distance at which this phase error becomes small, less than $\lambda/16$, so that the error in measured gain is less than 1 dB. This distance is usually considered the beginning of the far field.

Rayleigh distance = $2D^2/\lambda$

where

D = the diameter of the dish aperture and
λ = the wavelength

For a modest sized 2 foot dish at 10 GHz, the Rayleigh distance is about 85 feet, so we would need an antenna range at least this long for gain measurement. The length increases as the square of the diameter, so a 4 foot dish would need 340 feet. For other antennas, the aperture, or capture area, is not as obvious as a dish, but the largest dimension is a rough estimate — for a Yagi antenna, the boom length might be a good approximation for the aperture diameter. A range longer than the Rayleigh distance will have a flatter phasefront and reduce gain error. A range set up for the largest antenna to be measured will work fine and give even more accurate results for smaller ones.

Antenna measuring session on the West Coast in the 1960s. Can you identify these hams? [W6PO photo]

In most practical environments, stray reflections will be present and result in unwanted signals arriving at the test antenna to produce errors in measurement. If a long enough path with no reflecting surfaces can be located, then we have a free-space antenna range. A good approximation is an elevated range with height much greater than the signal path so ground reflection is minimized. This might be possible with two tall towers or the roofs of two tall buildings, as shown in Figure 1, but most of us must work on the ground and manage the reflections.

The slant antenna range elevates the one end of the range high enough so that the ground reflection angle is well away from the main beam of a high-gain antenna, as shown in Figure 2. Typically, the range is at an angle of 45 degrees, so that the required height equals the horizontal distance at the Rayleigh distance divided by the square root of 2 (1.414). This can be fairly high, but is sometimes practical — at Microwave Update 2010, the signal source was located on top of the conference hotel.

In most locations, only a ground-reflection range is possible. In this case, instead of trying to eliminate the reflection, we realize that the ground reflection is predictable and choose a geometry that controls the ground reflection. (Of course, the range should be clear of other reflecting objects for a good distance in all directions.) The path length of the ground-reflected signal to the receiving antenna increases with antenna height, while the direct path length is constant. As a result, at some heights the reflected signal is in phase and adds to signal strength, while at others it is out of phase and subtracts. Figure 3 is a sketch of a ground-reflection range showing how the receive amplitude varies with test height due to ground reflection. We choose the lowest in-phase height for maximum signal strength.

The height of the desired maximum is controlled by the height of the source (transmitting) antenna:

Source height:

$$H_{Source} = \frac{\lambda}{4} \bullet \frac{Rangelength}{H_{Test}}$$

In practice, the ground is not perfectly flat and uniformly reflecting, so the source height may need some adjustment.

The final constraint is the height of the test (receiving) antenna, which should be at least four times its aperture diameter above the ground, and the source height is calculated and adjusted to place the maximum received signal at this height.

Test height: $H_{Test} = 4 \bullet D$

For example, our 2 foot dish should be measured at least 8 feet above the ground. For maximum 10 GHz signal at this height with a range length equal to the Rayleigh distance, the source antenna height would be about 3 inches.

The source antenna should have a radiation pattern with a beam narrow enough to reduce sidelobes that might result in stray reflections, but broad enough that the test antenna is reasonably uniformly illuminated. An aperture diameter for the source antenna of about ⅓ of the test antenna aperture is a ballpark number, not critical.

Polarization

For a ground reflection range, horizontal polarization is preferred because reflections are consistent and predictable. Ground reflection of vertical polarization suffers from amplitude variation and phase reversal at low incidence angles, so results are unpredictable over imperfect surfaces. Circular polarization is best measured using a fixed linearly polarized source with horizontal polarization, rotating the CP antenna to measure circularity.

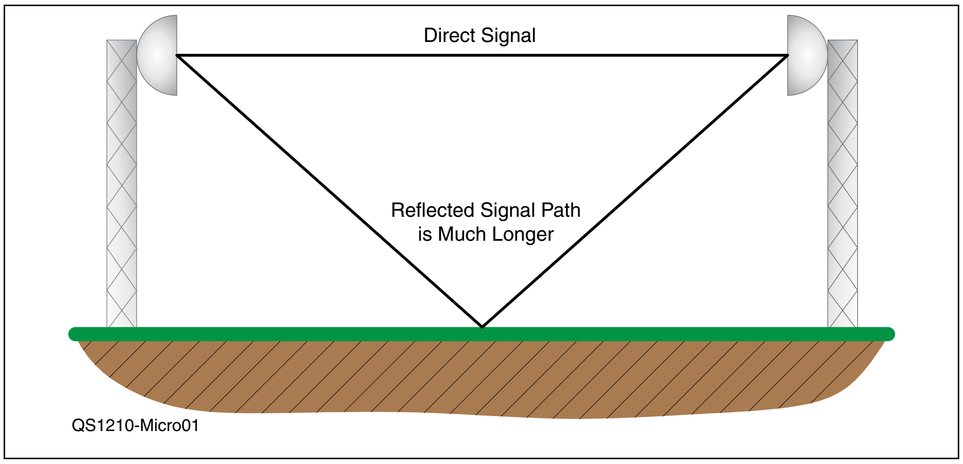

Figure 1 — Elevated antenna range requires high structures and clear path.

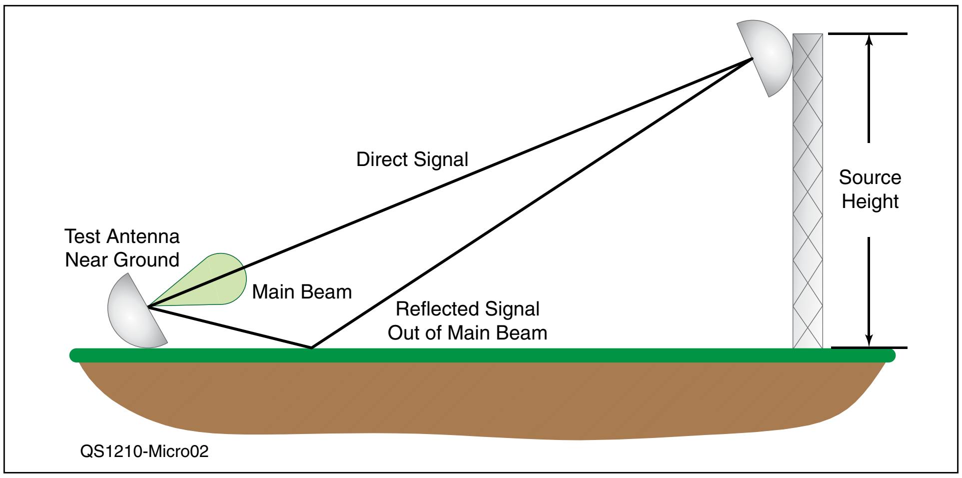

Figure 2 — Slant antenna range needs one high structure.

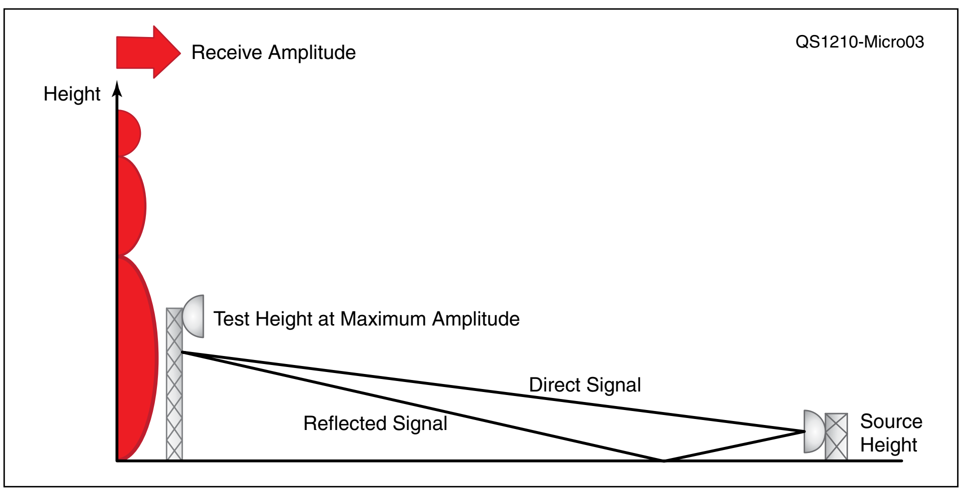

Figure 3 — Ground-reflection antenna range for management of reflections.

Path Loss

How much power is necessary for an antenna range? We can easily estimate the path loss using the Friis equation:

$$\text{Path Loss} = 10 \bullet \log\left(\frac{4\pi \bullet Rangelength}{\lambda}\right)^2 - Gain_{Transmit} - Gain_{Receive}$$

The first term is the loss between two isotropic antennas — the total path loss includes the gain of the transmitting and receiving antennas. The loss over our 85 foot range is about 80 dB at 10 GHz, but a good 2 foot dish might have 33 dBi gain. If the source antenna is a modest horn with 17 dBi gain, then the received signal would only be about 30 dB weaker than the transmitted signal. However, we also need some margin for cable loss, and a standard gain horn might have only 20 dBi gain. So planning for 50 or 60 dB of path loss would be reasonable, for this example. Longer ranges do not have much greater loss, since doubling the distance only increases loss by 6 dB, according to the inverse square law.

Frequency Scaling

Suppose you have a great idea for a 6 meter antenna, but the dimensions for an antenna range would require a football field? Or you have an idea for a 24 GHz antenna, but only have test equipment at 1296 MHz? A scale model of the antenna made for the test frequency will work identically, as long as *all* dimensions are scaled by the wavelength ratio. So a 6 meter antenna design could be evaluated at 432 MHz, or a 24 GHz design evaluated at 2304 MHz.

More Reading

This column is a brief discussion of antenna ranges. For an in-depth treatment, the *IEEE Standard Test Procedures for Antennas* (IEEE Std 149) is recommended. One that is more accessible for ARRL members by Dick Turrin, W2IMU, is available on the *QST* archives: "Antenna Performance Measurements," *QST*, Nov 1974, pp 35-41.

Accuracy and Compromises

Most amateur antenna ranges aren't perfect — we make some compromises and don't meet all the guidelines above. As a result, the measurements aren't truly accurate, but they are good relative numbers — comparisons of comparable size antennas are pretty good. So when we compare an unknown antenna to a known good one, or one with a known gain, we can get reasonable results. And we can learn how well an actual antenna works — something that computer simulations can only promise.