Near Field Drone Measurements of Broadcast Antennas

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Abstract – *In order to ensure that a broadcast antenna is operating as designed, installed correctly, and reaching the intended audience, a field verification study of its radiation characteristics should be performed. Before the recent development of drone measurements, user surveys, ground-based measurements or helicopter measurements were the only option for verification. Drone measurements are limited by FCC flight authorization, ground reflections and multipath. This paper will describe how these limitations can be overcome providing an accurate and cost-effective alternative to ground-based field strength studies.*

INTRODUCTION

There are many reasons for the need to verify the radiation characteristics of a broadcast antenna once on a tower. It is currently a reimbursable item for re-packed broadcasters so they can ensure their new antenna is radiating as predicted and oriented in the correct direction. Another scenario might involve the diagnosing of an older antenna that does not seem to be performing as it originally did. Whatever reason drives the need for field pattern verification, there is growing appeal to use drones to take the measurements, making the process quick and cost effective. The current drone measurement procedure is to fly an azimuth and elevation radiation pattern cut of the broadcast antenna in the far field. The radiating far field in the elevation plane is typically about one mile for a high-power UHF broadcast antenna. Drone flights at this distance from the tower require special FAA authorization. Signal strength measurements at this distance are subject to reflections and multipath. To overcome these drawbacks, a method to measure the antenna at a much closer distance is proposed.

GROUND BASED MEASUREMENTS

Pattern verification based on ground measurements is both time consuming and costly. Since the effect of terrain cannot be removed, the results can only be assumed since they are based on a statistical analysis of many measurements. The measurement method is specified in the "Field Strength Measurements" section 73.686 of the FCC rules. The rules are very specific, but in general, after measurement locations are selected, the field strength must be continuously recorded over a mobile run of 100' with the receive antenna at least 30' above the ground. The average field strength of the run will then be considered as the field strength at this location. Since a drone can collect data much more efficiently, it is apparent why drone measurements are an attractive alternative to ground-based measurements.

FAA RESTRICTIONS

The FAA (Federal Aviation Administration) has rules which place several restrictions on flying drones for commercial use. Currently there is a 400 feet altitude restriction on commercial drone flights unless the operator can fly the drone within a 400' radius around a structure and does not fly higher than 400' above the top of that structure. The FAA does have a means of obtaining certificates of waiver for these rules and certain others, which will require the right set of facts demonstrating that a flight can be conducted safely. Unfortunately, these waivers can take months or more to be processed and may never be granted due to other restrictions.

ANTENNA FAR FIELD

The far field of an antenna is basically defined by the region at which, for all practical purposes, the radiation pattern no longer changes with distance. This distance is defined by equation 1.

$$d = \frac{2D^2}{\lambda} \quad (1)$$

Where D is the aperture diameter of the antenna in the plane of measurement and λ is the wavelength. Radiation patterns made inside of the far field limit are not yet focused and tend to be spread out exhibiting much less gain than as defined in the far field. Since the development of near field chambers and compact test ranges in the 1970's and 1980's, the science of near field to far field transformation has been well understood. Amplitude and phase data are collected on a plane, cylinder, or sphere located in the antennas near field. The data is then transformed to the far field using Fourier techniques. The resulting data can then be viewed as conventional far field measurements. It must be noted, that to perform this calculation, both amplitude and phase data is required. If this is to be accomplished using a drone it would require a closed loop system between the drone and the broadcast antenna which is currently not considered.

FAR FIELD OF A BROADCAST ANTENNA

Top mount UHF pylon antennas are typically around 14” in diameter by approximately 50’ tall. At 600 MHz, this locates the far field at about 1.7’ in the azimuth plane and over 3000’ for the elevation plane.

Figure 1: UHF Top mounted pylon antenna

Obviously, using a drone to measure the azimuth pattern is not a problem since this can be done well within the 400’ shield of the tower. On the other hand, the elevation pattern’s far field is well outside the 400’ window and will require an FAA waiver. The measurements at that distance are also subject to reflections and multipath.

MULTIPATH

Ground reflections and multipath affect the accuracy that can be obtained when measuring the elevation pattern with a drone from a distance. In general, the larger the distance the lower the reflection angle and the higher the measurement error. This is because the side lobe levels for both the broadcast antenna and the drone’s receive antenna, which is typically a directional Yagi, decrease with elevation angle. Refer to Figure 2. For all practical purposes, it be can assumed that there is no energy directed toward the ground in the very near field of two elevated high gain antennas.

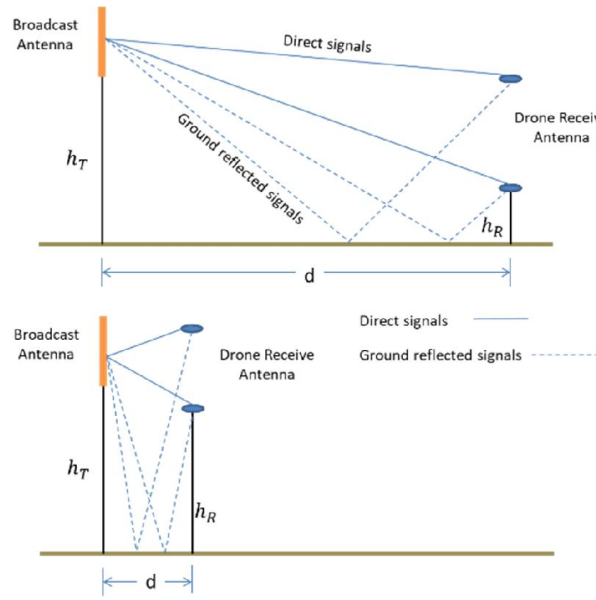

Figure 2: Ground reflections vs. distance from antenna

NEAR FIELD DRONE MEASUREMENTS

Since the FAA allows drone flights within 400’ of the tower, the goal is to transform the elevation pattern measurements at this distance into useful information about the far field. The data collected by the drone at 400’ is typically logged as received signal strength at a given latitude, longitude and altitude. Knowing the center of radiation and the height above mean sea level for each antenna, the raw data can be converted into distance and elevation angle coordinates. Either the Haversine formula or the Law of Spherical Cosines can be used to calculate the distance between two points on a sphere using latitude and longitude. At these close distances, the two methods are within .01” of each other.

$$a = sin^2\left(\frac{\Delta\emptyset}{2}\right) + cos\emptyset_1 cos\emptyset_2 sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (2)$$

$$c = 2 \cdot ATAN2\frac{\sqrt{a}}{\sqrt{a-1}} \quad (3)$$

$$d = R \cdot c \quad (4)$$

Or using the Law of Spherical Cosines:

$$d = acos(sin\emptyset_1 sin\emptyset_2 + cos\emptyset_1 cos\emptyset_2 cos\Delta\lambda) \cdot R \quad (5)$$

Where:

d = distance

φ = latitude

λ = longitude

R = Earth's radius (6,371 km)

Used for example is a typical slotted coaxial UHF pylon antenna. The drone measured elevation pattern at 400' compared to the factory measured far field elevation pattern is shown in Figure 3.

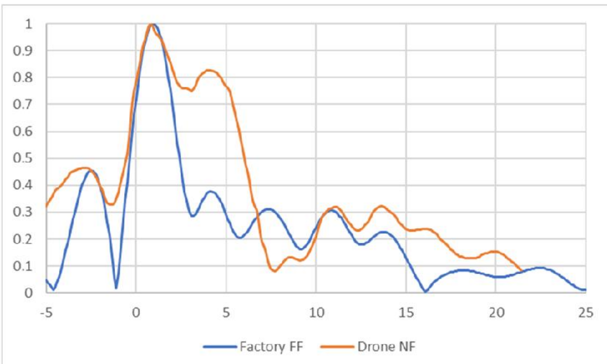

Figure 3: Factory measured far field pattern compared to drone field measurement at 400'.

Two characteristics of interest that should be noted with the 400' near field measurement are the beam tilt is already clearly established, but the gain is not. This is due to the full array not being focused yet in the elevation plane. The gain of the far field factory measured elevation pattern is 18.3 with respect to a half wave dipole and the beam tilt is 1.0 degrees. By integrating the drone measured elevation at 400', and estimating the area outside of the measurement range, a near field gain of 8.7 is calculated with a beam of .9 degrees. As can be seen, there is not much useful information that can be determined from the null structure of the elevation pattern at only 400' from the antenna without knowing what the pattern should look like at this distance.

DATA ANALYSIS

The near-field magnitude vs elevation angle can be predicted with knowledge of the antenna design. Comparison of this known value to a measured value is sufficient to prove certain performance characteristics of the antenna. ANSYS HFSS is a 3D electromagnetic (EM) simulation software tool for designing, simulating and evaluating high-frequency electronic products such as antennas, antenna arrays and RF or microwave components. Every slotted coaxial pylon antenna Dielectric designed for repack was done virtually using HFSS. With the use of this tool, the full broadcast antenna can be modeled, as designed, and tested. This requires the full knowledge of all the antenna features. For example, each layer of a slotted coaxial pylon antenna is unique, and the feed point is variable. Accurate modeling of the coupler sizes, slot lengths, fins or directors, vertical polarizing elements, harness feed location, etc. in the antenna is needed to correctly produce the radiated amplitude and phase at each layer.

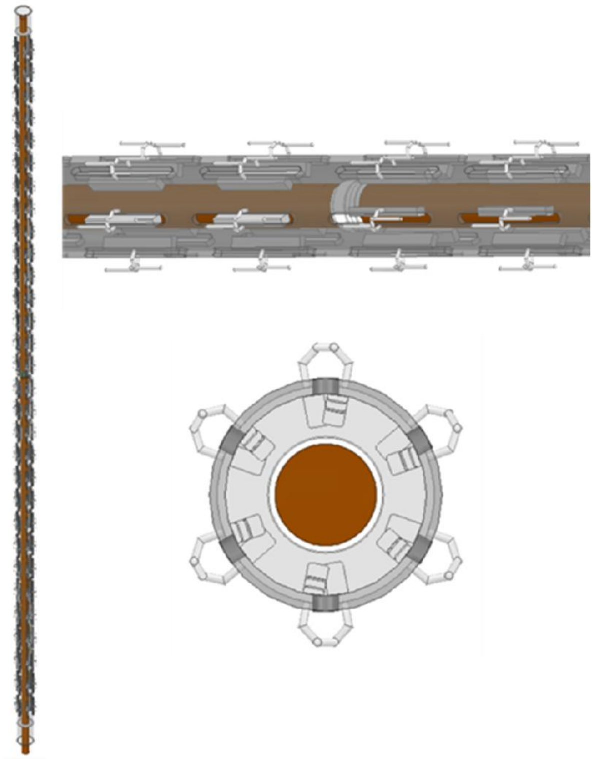

Figure 4: Modeling of the full antenna in HFSS.

Once modeled, the far field pattern can be calculated and compared to the final factory measurements for verification.

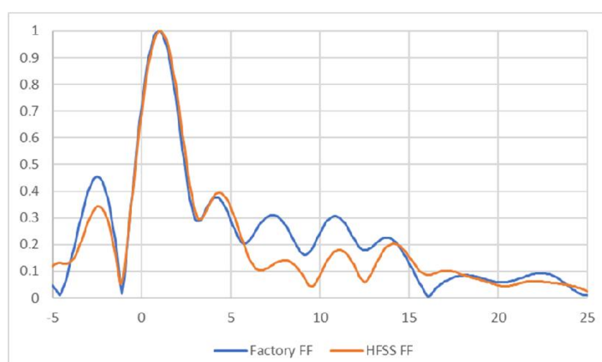

Figure 5: Factory measured far field pattern compared to far field HFSS prediction.

It can be concluded that the HFSS model is a good representation of the actual antenna since the factory measurement and the far field HFSS prediction show reasonable correlation. Since HFSS produces a full 3D electromagnetic solution, a radiation sphere can be placed around the antenna at 400’ to calculate the fields at this distance – Figure 6. The near field elevation pattern can then be calculated from the points on this sphere.

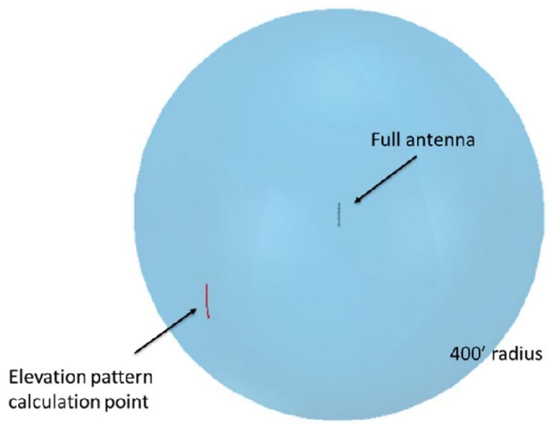

Figure 6: Radiation sphere placed around the full antenna to calculate the fields at 400’.

An overlay of the near field HFSS calculated pattern and the near field drone measurement is shown in Figure 7.

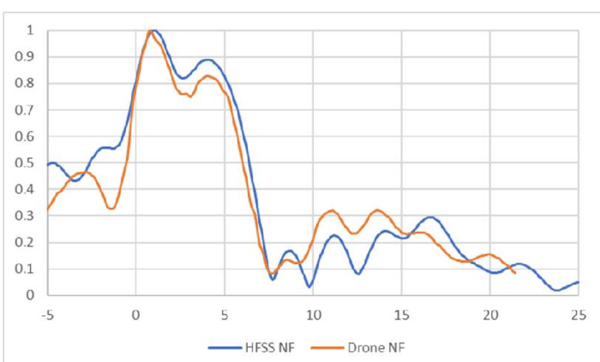

Figure 7: HFSS calculated elevation pattern at 400’ radius vs drone measurement at 400’.

Since there is very good correlation between the drone near field measurement and the HFSS simulation prediction, both at 400’ from the antenna, it can be concluded that the antenna’s far field elevation pattern is operating normally as designed.

AZIMUTH PATTERN DRONE MEASUREMENT

As stated earlier, measurement of the azimuth pattern inside the 400’ tower shield will always be in the far field and should correlate directly with the designed shape. Figure 8 is an example of a elliptically polarized side mounted UHF pylon antenna modeled in HFSS for a drone measurement comparison. Note that the tower is also completely modeled since it will distort the free space pattern and needs to be incorporated for the drone measurement comparison.

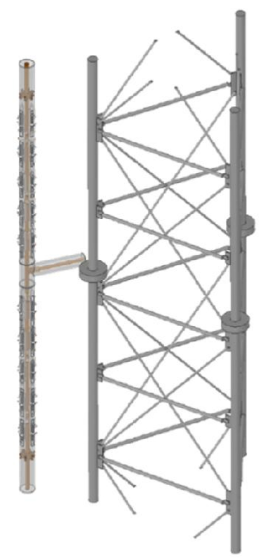

Figure 8: Side mounted UHF pylon antenna modeled in HFSS. Note the tower is included for accurate drone measurement comparison.

There is a very good correlation between the HFSS prediction and the drone measurement as is shown in Figure 9.

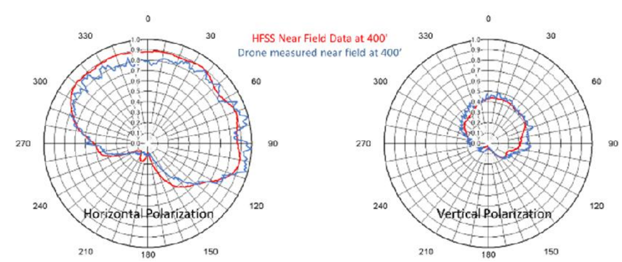

Figure 9: HFSS calculated azimuth pattern compared to drone measurement at 400’.

CONCLUSIONS

It has been shown that a near field drone measurement taken within the FAA shield of the tower will yield useful information for both azimuth and elevation pattern verification. The data can be compared to the predicted near field elevation pattern to draw conclusions about the validity of the far field pattern.