Measurement of Antenna Bore-Sight Gain

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***Abstract*— The absolute or free-field gain of a simple antenna can be approximated using standard antenna theory formulae or for a more accurate prediction, numerical methods may be employed to solve for antenna parameters including gain. Both of these methods will result in relatively reasonable estimates but in practice antenna gain is usually verified and documented via measurements and calibration. In this paper, a relatively simple and low-cost, yet effective means of determining the bore-sight free-field gain of a VHF/UHF antenna is proposed by using the Brewster angle relationship.**

I. Introduction

Testing and calibration of an antenna is performed to ensure that the antenna is functioning as designed and provide data such as calibration factors that are needed by RF/EMI test and measurement laboratories to determine critical parameters of Equipment Under Test (EUT). There are many methods, both near-field and far-field as discussed in [1], that are available to measure the absolute gain of a given antenna but acquisition and/or construction of such facilities are many times cost prohibitive and in many cases, such as for research and development activities, a rough order of magnitude measurement is all that is needed to assess the viability of a particular design. In addition, accurate antenna gain measurements in the VHF/UHF frequency range are in most cases non-trivial. In this paper a proposed test method is presented that uses the special properties of the Brewster angle to make an accurate measurement of the bore-sight gain of an antenna.

II. BackGround

The free space gain, G_t, of an antenna can be calculated using either (1) or (2) below.

$$G_t = \frac{4\pi R^2 P_d}{P_t} \tag{1}$$

$$G_t = \frac{\left(\frac{ER}{5.47}\right)^2}{P_t} \tag{2}$$

R = distance from transmit to receive antenna (m)
P_t = Power delivered to the transmit antenna (W)
P_d = Power Density measured at receiver (W/m^2)
E = RMS Electric field (V/m)

Although the above calculations are straightforward, accurately measuring the required parameters to perform the calculations can be quite challenging. A major contributor to error when trying to measure the power density or electric field is multipath. Whether constructive or destructive, multipath will adversely affect the measurements which will result in erroneous calculations for the free field gain of the antenna. Antenna measurement facilities use various methods to either mitigate the effects (e.g. anechoic facility) or fully understand the effects (e.g. precise ground plane construction and calibration) of multipath. This allows for very accurate measurements and in turn accurate determination of the gain. However, many times access to such facilities is limited by cost, schedule or both. The method presented in this paper has been shown to work in the VHF/UHF frequency range, does not require the use of anechoic material, diffraction fencing or other materials that have limited applicability in these frequency ranges and could be extended to work at higher frequencies. Figure 1 shows a simplified geometry of a typical antenna measurement setup.

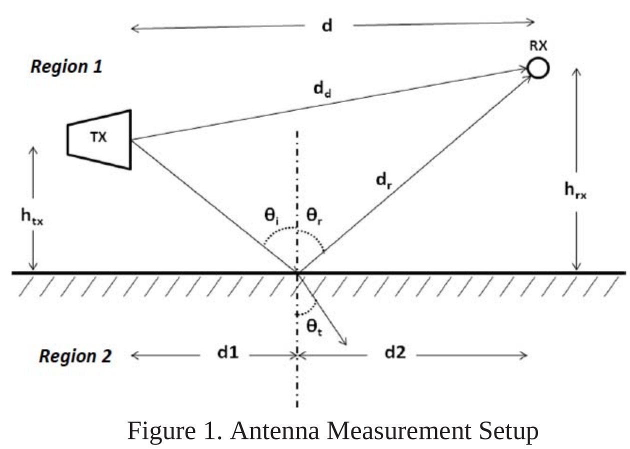

Figure 1. Antenna Measurement Setup

Examination of Figure 1 shows only two propagation paths are present from the transmitter to the receiver, the direct path, d_d, and the reflected path, d_r. This implies that no other reflecting objects such as buildings, walls, trees, etc. are near the measurement setup (d_d & d_r << than any other propagation path). To accurately measure the absolute gain of the transmitter, it is necessary to minimize the impact of d_r which depends largely on the reflection coefficient of the ground. For a vertically polarized plane wave the reflection coefficient, Γ_v, at the dielectric interface of nonmagnetic media can be written as in (3) [2].

$$\Gamma_v = \frac{\frac{1}{\sqrt{\varepsilon_t}}\cos(\theta_t) - \frac{1}{\sqrt{\varepsilon_i}}\cos(\theta_i)}{\frac{1}{\sqrt{\varepsilon_t}}\cos(\theta_t) + \frac{1}{\sqrt{\varepsilon_i}}\cos(\theta_i)} \tag{3}$$

ε_t = Relative permittivity of the ground, Region 2
ε_i = Relative permittivity of free space, Region 1

By setting the two terms of the numerator equal, it can be seen that a case exists where there is no reflection, $\Gamma_v = 0$, from the ground meaning only the direct or free space electric field component reaches the receiver. The incident angle, θ_i, at which this unique condition exists is known as the Brewster angle and in most practical cases only exists for a vertically polarized Electric Field [2]. By assuming a lossless, nonmagnetic media, the Brewster angle, θ_B, can be written as in (4).

$$\theta_B = sin^{-1}\sqrt{\frac{\varepsilon_t}{\varepsilon_i + \varepsilon_t}} \tag{4}$$

III. Measurements and Gain Calculation

To test this approach, a set of measurements was performed at an Outdoor Area Test Site (OATS). The purpose of the measurements was to measure the electric field generated by the Antenna under Test (AUT) and then calculate the maximum or bore-sight free space gain of the antenna using the Brewster angle relationship. Measurements were taken using an electric field probe but other methods such as a receiving antenna and spectrum analyzer could also be used to measure the electric field. The transmit antenna / AUT was a quadruple ridged horn with an aperture size of 1.524 m^2 and measurements were taken over the 100 – 400 MHz range. Measurements were taken at a distance of 10 meters from the front edge of the antenna since this would be considered far-field over the entire measurement frequency range. The OATS consisted of an asphalt test pad with no obstructions within 200+ meters. The asphalt pad over which the measurements were taken had a low conductivity, was nonmagnetic and therefore the reflection coefficients were assumed to be purely real with a relative permittivity, ε_t, of 6 [3]. Given this setup, the Brewster angle, θ_B calculated from (4), is 67.8˚.

With the height of the transmit antenna, h_{tx}, set to 1.854 meters and the distance, d, set to 10 meters, the height of the receiver, h_{rx}, that produces the Brewster angle is calculated to be 2.23 meters. TABLE I below shows the free space gain that was calculated using the measured data and (5).

$$G_t = \frac{\left[\frac{(E)(R)^2}{5.47}\right]}{P_t} \tag{5}$$

P_t = Power delivered to the transmit antenna (W)
G_t = Numeric power gain of transmit antenna
R = distance from transmitter to receiver (m)
E = RMS Electric field (Volts/meter)

TABLE I. CALCULATED GAIN OF THE ANTENNA

Frequency (MHz)	Gain (Numeric)	Gain (dBi)
100	1.76	2.5
150	4.33	6.4
200	5.08	7.1
250	3.99	6.0
300	7.21	8.6
350	8.93	9.5
400	8.63	9.4

Figure 2 shows a comparison of the electric field from an empirically derived horn antenna model that uses the calculated gains in Table I as an input and the measured antenna data from the OATS. The data is plotted at a single frequency, 400 MHz, and at varying heights above the ground. The measured data is depicted by points while the model data is shown as a solid line.

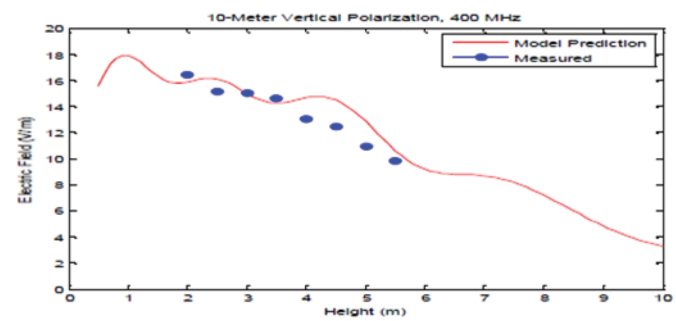

Figure 2. Predicted Versus Measured Antenna Data

IV. Conclusion

A relatively simple means of predicting the bore-sight gain of a directional antenna has been presented. As can be seen from Figure 2, the measured and predicted data based on the Brewster Angle gain approximation presented agree quite well. The presentation will consist of a much more extensive data set that will cover the other frequencies tested at the 10 meter distance as well data comparisons for a distance of 3 meters to further reinforce the validity of this method. In addition a small amount of time will be devoted to explaining the empirical model.

References

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