Design and Analysis of a Parabolic Dish Antenna (700 MHz-900 MHz) for Automotive Antenna Measurement Facilities

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Abstract

The purpose of this project was to design a transmit antenna for an outdoor automotive antenna range covering the frequency range extending from 700 MHz to 900 MHz. The previous transmit antenna at Oakland University's outdoor automotive antenna range was a quad-ridge horn antenna that exhibited a half-power beam width of 60° causing antenna measurement errors due to reflections at low elevation angles. In this effort a parabolic dish antenna with a cross-dipole feed was designed to meet a half-power beamwidth of less than 30° over the frequency range from 700 MHz to 900 MHz. The design was first achieved utilizing a full-wave, three-dimensional electromagnetic field solver prior to the fabrication of the antenna. The resulting antenna exhibited a half-power beamwidth of 22° over the required frequency range. The final step of this research was to quantify the antenna measurement accuracy improvement of the parabolic dish antenna over the quad-ridge horn antenna. This was accomplished by using each antenna to measure the gain of a quarter-wave monopole antenna on a 1-meter diameter rolled edge ground plane. After analysis and comparison of the measured gains, it was determined that the parabolic dish antenna resulted in less measurement error in the desired frequency range.

Introduction

The largest difference between an indoor and outdoor antenna testing facility is the reflections from the ground. An indoor testing facility contains anechoic suppression to eliminate any signal that does not directly hit the antenna under test. An outdoor facility contains a metal turntable surrounded by a concrete apron and surrounding buildings to introduce a means for reflection at lower frequencies. Reflections cause a disturbance in the natural gain measurement of an antenna under test by either being added or subtracted from the direct signal depending on the phase of each signal. The phase is a function of frequency, distance traveled, and the material of the structure it was reflected upon. The reflected signal could add or subtract up to 5dB from the direct signal, proposing a high deviation and therefore, a large measurement error. One solution to minimizing reflections from the ground is to decrease the half-power beam width (HPBW) of the transmit antenna. By decreasing the HPBW, the area being illuminated by the transmit antenna will be lessened, effectively lowering the chance for a signal to come into contact with

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the ground or other structures and increasing the chance for a signal to contact the antenna under test directly.

The primary application for many outdoor antenna testing facilities is automotive. As antenna systems become more complex due to continuous development in wireless technology, the demand for automotive testing is increased. Therefore, the stress on more accurate measurements is also increased. By lowering the HPBW of the transmit antenna, the reflections will be reduced thereby lessening the measurement error. The current quad-ridge horn antenna being used as a transmitter at the Oakland University Outdoor Automotive Antenna Measurement Facility has too large of a HPBW and therefore presents unnecessary error.

In this paper, a parabolic dish antenna is designed to replace the extant quad-ridge horn antenna. The quad-ridge horn antenna consists of a HPBW of about 60° at 700 to 900 MHz [1]. The proposed solution is to develop a parabolic dish antenna with a HPBW of less than 30° in order to reduce reflections and minimize measurement error.

Antenna Design

The parabolic dish antenna consists of three components; a parabolic reflector, a printed antenna feed, and the cup that the feed resides in. The first parameter to be determined is the diameter of the parabolic reflector based on the desired HPBW. By calculating the solid angle formed by a conical beam pattern emitting from the parabolic dish using Eq. 1 [2] and choosing an illumination area to be a circle with radius of 2 meters at a distance of 9 meters, a HPBW of approximately 25.5° was found for a complete illumination using Eq. 2 [2].

$$\Omega = \frac{Area}{d^2} \tag{1}$$

$$HPBW = 2Cos^{-1}\left(1 - \frac{\Omega}{2\pi}\right) \tag{2}$$

Using Eq. 3 [2], the diameter of the parabolic dish at 800 MHz is estimated to be 104.14 cm.

$$HPBW = \frac{70\lambda}{D} \tag{3}$$

However, given supplier constraints, a parabolic dish with diameter 99.06 centimeters and dish depth of 17.78 centimeters was used for simulation and measurement.

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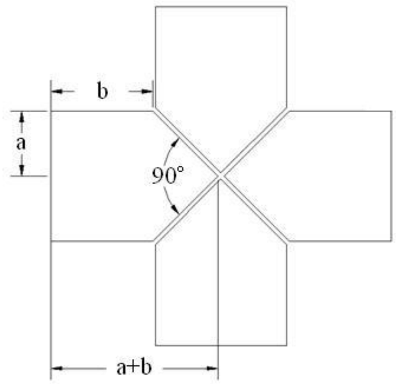

Figure 1. Cross Dipole Antenna

The printed antenna feed is chosen to be a cross-dipole as shown in Figure 1 in order to introduce two separate orthogonal polarizations to allow for measurements of both the electric field and magnetic field without having to adjust the test setup. The cross-dipole was simulated in FEKO [3] to determine the size in order to center the return loss to 800 MHz. The parameters a and b were set to 11.43 and 25.4 millimeters, respectively, as a starting point. Simulations were run varying the scaling factor of the entire cross-dipole to determine the size which corresponds to the target center frequency. The simulated return losses for various scaling factors is shown in Figure 2.

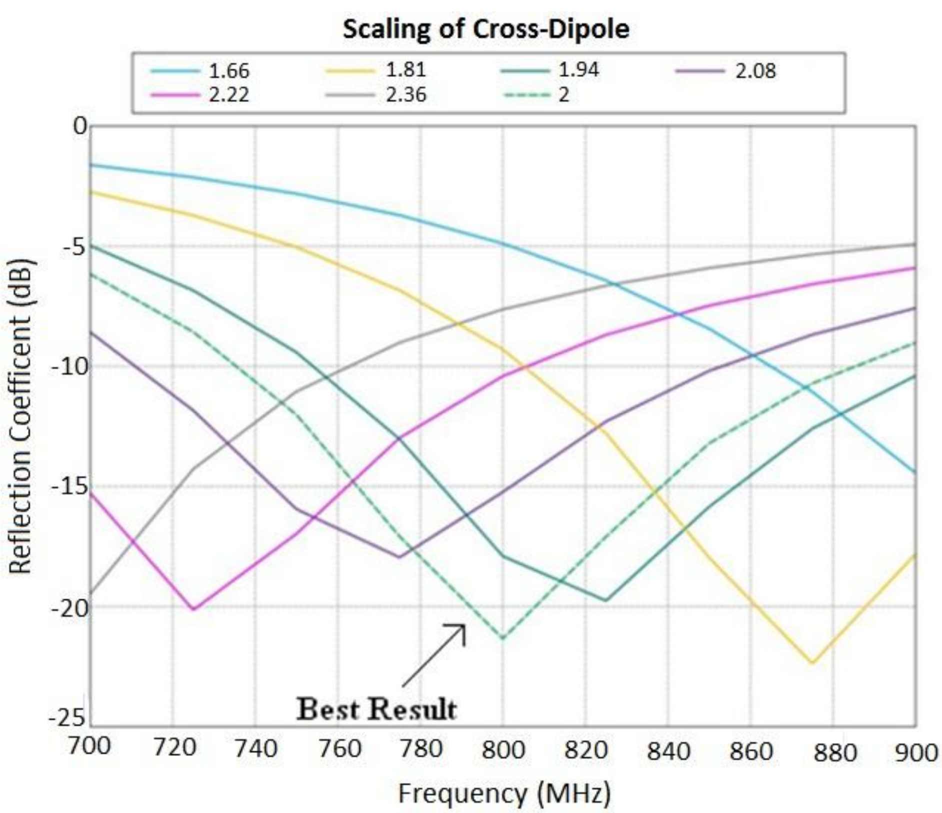

Figure 2. Simulated Return Loss for Scaling of a Cross Dipole

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The resulting scaling factor was found to be 2, which provides final dimensions of a and b to be 22.86 and 50.8 millimeters, respectively. Using the parabolic reflector and cross-dipole dimensions found, the parabolic dish antenna was constructed with a cup big enough to house the cross-dipole as shown in Figure 3.

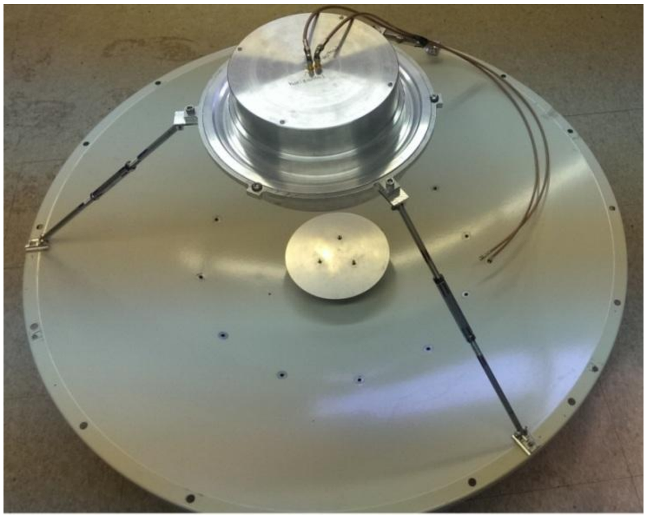

Figure 3. Constructed Parabolic Dish Antenna

Results and Discussions

In this section, the HPBW of the parabolic dish and quad-ridge horn were measured and compared. The measurements were taken at the Oakland University Outdoor Automotive Antenna Measurement Facility with the antenna under test oriented towards the zenith (0°). Data were taken for elevation angles of 0° - 90° (theta) in steps of 2° and for azimuth angles of 0° - 358° (phi) in steps of 2° for frequencies 700 to 900 MHz in steps of 25 MHz. The HPBW of the measured frequencies are shown in Figure 4.

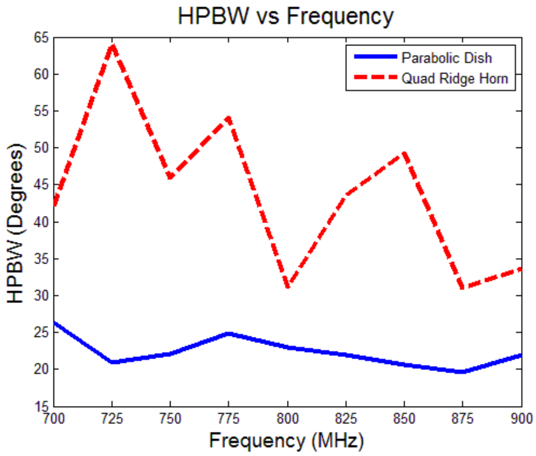

Figure 4. Half Power Beam Width of Parabolic Dish and Quad-Ridge Horn

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The measured HPBW of the parabolic dish and the quad-ridge horn varied between 20°-26° and 31°-64°, respectively over the frequency range extending from 700 MHz to 900 MHz.

In order to verify that the smaller HPBW results in less measurement error, a quarter-wave monopole, tuned to 775 MHz, was measured on a 1 meter rolled edge ground plane using each antenna as the transmitter. The return loss for the monopole can be seen in Figure 5.

Figure 5. Return Loss for the Quarter–Wave Monopole

The quarter-wave monopole was measured at four different heights; 99.06, 129.54, 162.56, and 190.5 centimeters. The linear average gain measurements for 775 MHz are shown in Figure 6.

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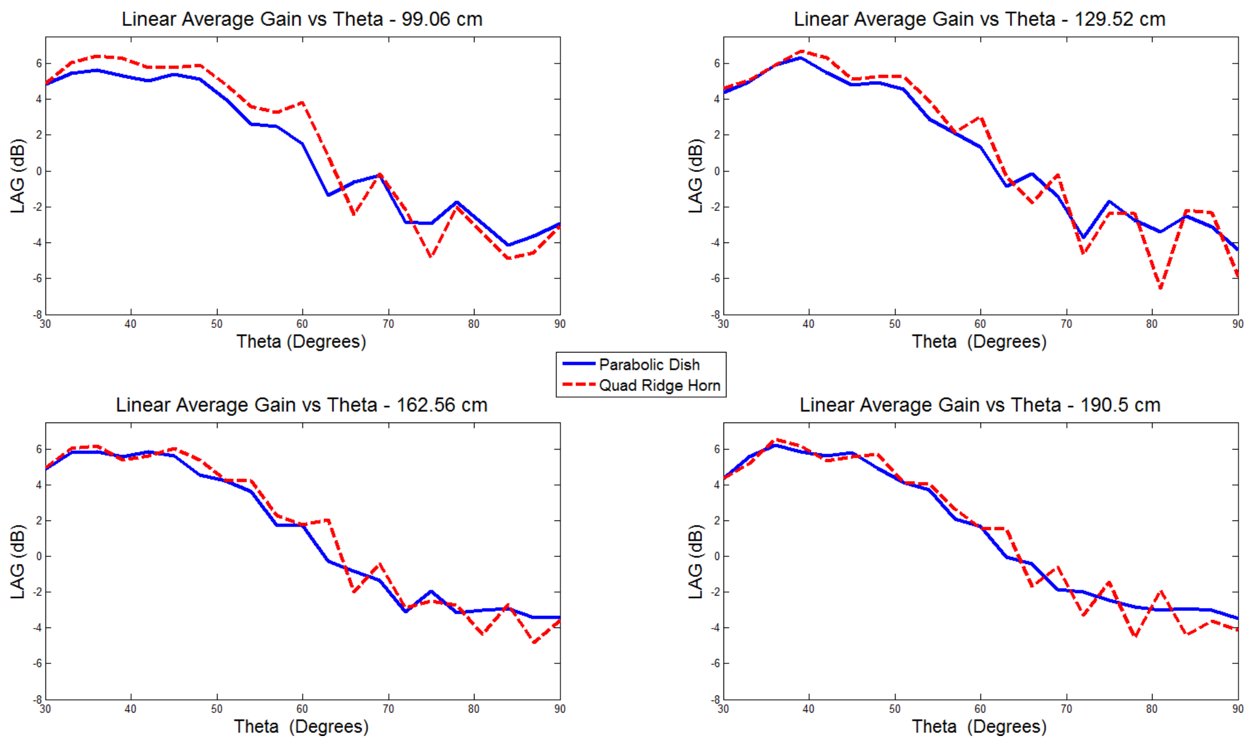

Figure 6. Linear Average Gain Measurements of the Quarter-Wave Monopole at 775MHz

A fifth-order polynomial curve fit line, found by Eq. 4 [4], was placed in conjunction with the measured results using MATLAB [4] in order to visualize the gain deviation at each elevation angle.

$$p(x) = p_1x^n + p_2x^{n-1} + \cdots + p_nx + p_{n+1} \tag{4}$$

Figure 7 was created to show the numerical values of the discrepancies. It is evident that there is more error with the quad-ridge horn than the parabolic dish when measuring the quarter-wave monopole especially at angles closer to the horizon (90°). When measuring at the low cellular frequency band on a vehicle, the most important elevation angles are 60°-90° because it emulates a cell tower's position. At these angles, the parabolic dish performs with a much smaller deviation. It can also be seen that the deviation magnitudes are much lower for the antenna under test when measured at a greater height.

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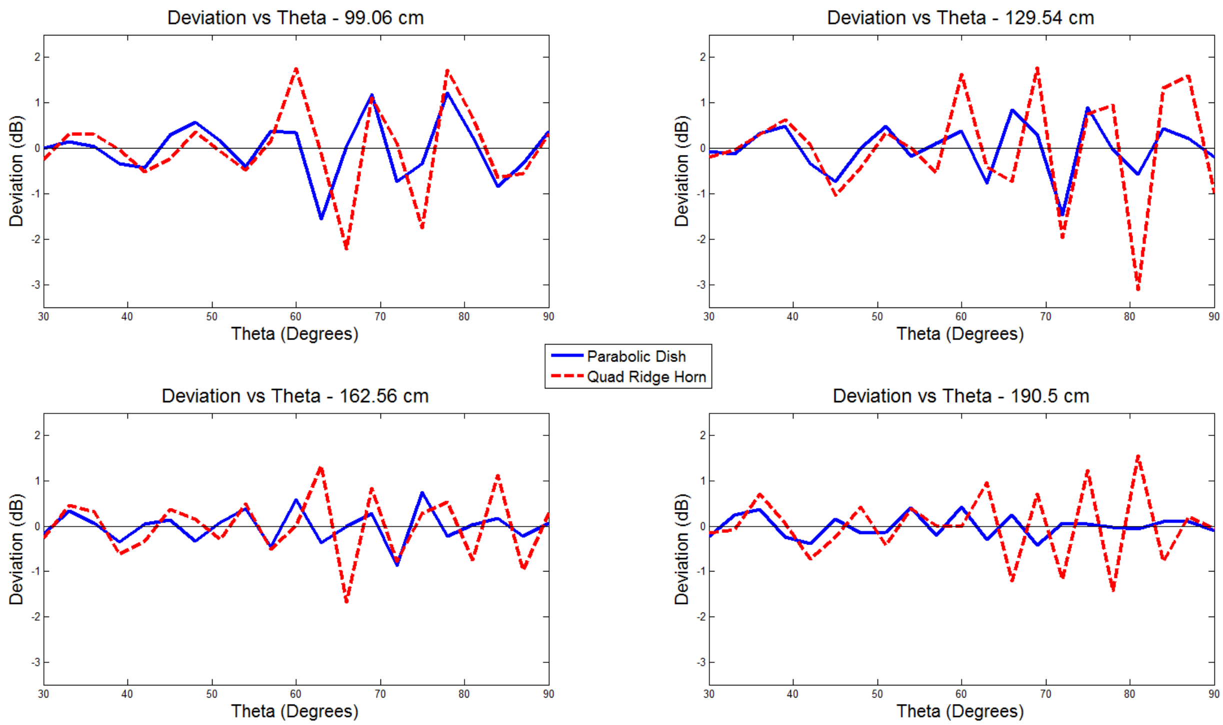

Figure 7. Deviation of Linear Average Gain for Parabolic Dish and Quad-Ridge Horn

Taking the average of the deviations from the preceding plot, it becomes more evident that the parabolic dish performs with much less error than the quad-ridge horn. As shown in Figure 8, the average deviation for the parabolic dish is about 0.35 dB less than the average deviation for the quad-ridge horn.

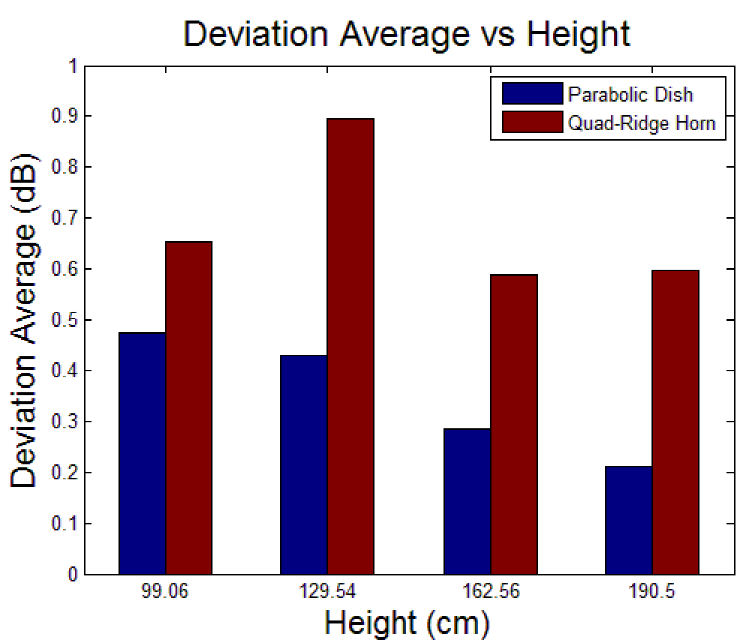

Figure 8. Average Deviation of Parabolic Dish and Quad-Ridge Horn Measurements

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Simulations were run of the quarter-wave monopole on a rolled edge ground plane in free space in HFSS [5]. The linear average gain of the measured monopole was subtracted from the peak gain for the simulated monopole at the corresponding angle. The differences are presented in Table 1. Comparing the two antennas at three frequencies of interest it can be seen that the quad-ridge horn had a larger variation from the simulated data.

Table 1. Comparison of Simulated and Measured Gain of the Quarter-Wave Monopole

		750 MHz			775 MHz			800 MHz		
		Peak Angle = 51°			Peak Angle = 48°			Peak Angle = 51°		
		PD	QRH	Simulation	PD	QRH	Simulation	PD	QRH	Simulation
Monopole Height	99.06 cm	1.9	1.22	3.61	5.13	5.92	5.35	4.49	5.69	4.46
	129.54 cm	2.63	2.56	3.61	4.92	5.26	5.35	4.59	5.82	4.46
	162.56 cm	2.97	2.38	3.61	4.575	5.37	5.35	4.21	4.99	4.46
	190.5 cm	3.02	2.35	3.61	4.9	5.69	5.35	4.54	5.68	4.46

Conclusion

An antenna with a smaller HPBW shows less measurement error than an antenna with a larger HPBW. As shown, a parabolic dish antenna can produce a HPBW of 20°- 26° compared to the quad-ridge horn antenna which has a HPBW of 31°- 64° in the 700 to 900 MHz range. When comparing measurements of a quarter-wave monopole centered at 775 MHz, the parabolic dish antenna shows less measurement errors than the quad-ridge horn antenna. The measurement deviation is much larger for angles closer to the horizon and for antennas closer to the ground. For automotive antenna measurements, the height of most vehicles requires a transmit antenna with a narrow HPBW for greater measurement accuracy.

Acknowledgements

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