Julia DiTomas
ECEN 5634
Lab 7 Report

Part I

Q1: To ensure far-field measurements, we must have $r > \frac{2d^2}{\lambda}$, where r is the distance between the antennas and d is the largest dimension. At 3 GHz, the wavelength is 0.1 m, and we are given that r = 3 m. This means that we must have $d < \sqrt{\frac{r\lambda}{2}} = 38.7\ cm$. In a square the largest dimension is the diagonal, which is the side length times $\sqrt{2}$. Thus, the largest square-shaped antenna that can be measured is 27.4 cm on each side and has an effective area of 0.075 m^2.

Q2: To calculate the required transmitted power, we use Friis formula solved for the transmitted power, which is $P_T = \frac{P_R}{G_T A_R} 4\pi r^2$. We assume that the noise floor of the receiver is at -60 dBm, and that the required SNR is 20 dB, which means that the received power must be -40 dBm or 0.0001 mW. We also convert the given gain of 11 dB to 12.589, and solve for P_T as

$$P_T = \frac{0.0001\ mW}{12.589 * 0.075\ m^2} 4\pi (3\ m)^2 = 0.12\ mW.$$

Q3: We measured 3 antennas in the anechoic chamber: an open waveguide, a horn antenna, and a vivaldi antenna. Figures 1 and 2 show sketches of each attached to the positioner.

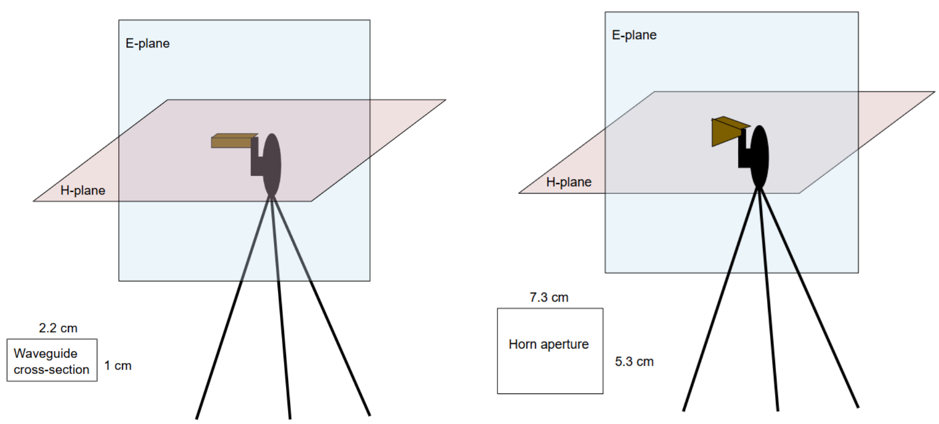

Figure 1: Sketch of waveguide antenna (left) and horn antenna (right) on positioner.

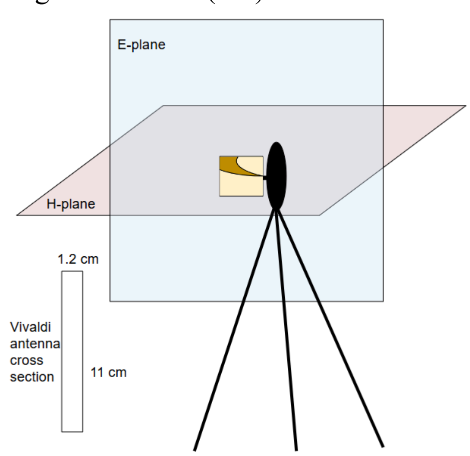

Figure 2: Sketch of vivaldi antenna on positioner.

Q4: The measurement required to plot the H-plane patterns is the elevation cut, which means that elevation is kept constant and azimuth is varied (set up as in the sketches and allowed to rotate horizontally). The measurement required to plot the E-plane patterns of all three antennas is the azimuth cut, which means that the azimuth is kept constant and the elevation varies. The azimuth cut is practically achieved in our case by pitching the antenna onto its side and scanning across horizontally as we do for the elevation cuts.

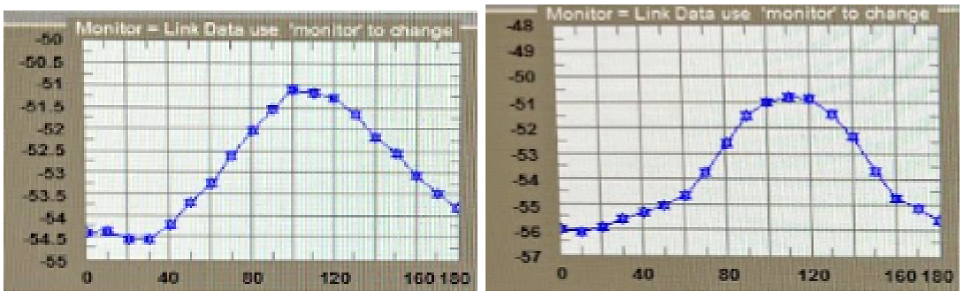

Figure 3: Waveguide antenna co-polarization E-plane (left) and H-plane (right).

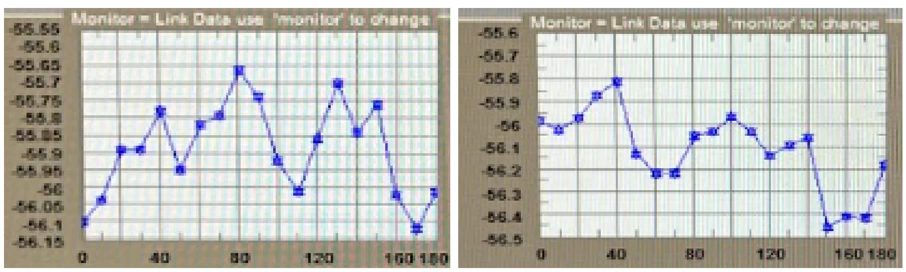

Figure 4: Waveguide antenna cross-polarization E-plane (left) and H-plane (right).

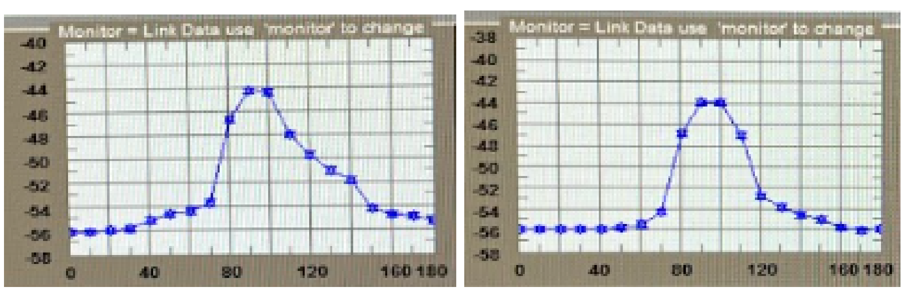

Figure 5: Horn antenna co-polarization E-plane (left) and H-plane (right).

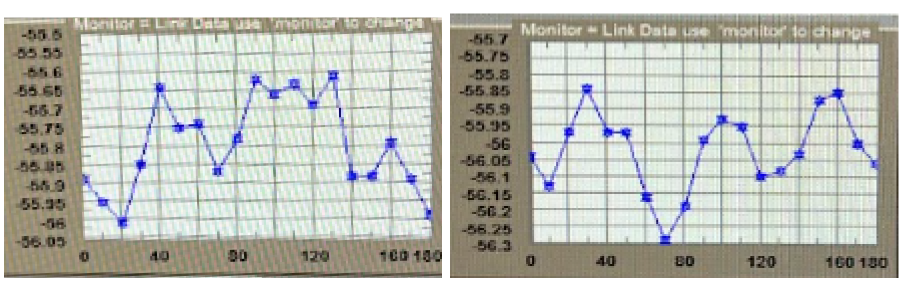

Figure 6: Horn antenna cross-polarization E-plane (left) and H-plane (right).

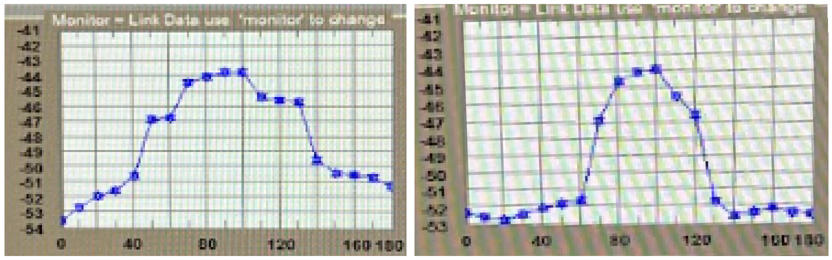

Figure 7: Vivaldi antenna co-polarization E-plane (left) and H-plane (right).

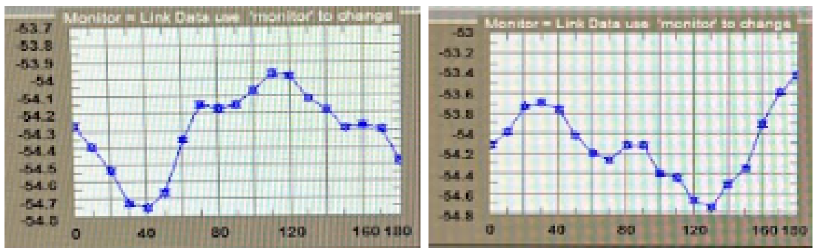

Figure 8: Vivaldi antenna cross-polarization E-plane (left) and H-plane (right).

Q5: Based on our measurements, we then found the 3 dB beamwidths of each antenna in both the E-plane and H-plane, by taking the difference between the angles at which the co-polarized patterns crossed 3 dB below their maximum values.

Antenna	E-plane 3 dB beamwidth (°)	H-plane 3 dB beamwidth (°)
Waveguide	155	76
Horn	30	30
Vivaldi	73	52

Table 1: 3 dB beamwidths measured using anechoic chamber for each antenna.

Q6: We then calculated the directivity of each antenna using Equation 7.17, $D = \frac{32000}{\theta_E \theta_H}$, and by using the effective area and assuming efficiency of 1, which is represented by the equation $D = \frac{4\pi A_{eff}}{\lambda^2}$. The effective areas are assumed to be the same as the geometric areas, which are drawn in Figures 1 and 2. The frequency is 9 GHz, so the wavelength is 3.33 cm.

Antenna	Directivity (using Eq. 7.17)	Effective area (cm^2)	Directivity (using A_{eff})
Waveguide	2.72	2.2	2.49
Horn	35.56	38.7	43.77
Vivaldi	8.43	13.2	14.93

Table 2: Approximate directivity and directivity calculated with effective area for each antenna.

Q6: We measured the cross-polarized patterns by rotating the transmitting antenna 90° with respect to the AUT. Our measurements are shown in Figures 4, 6, and 8 for the waveguide, horn, and vivaldi antennas respectively. We then calculated the cross-polarization ratio for each pattern.

Antenna	E-plane cross-polarization ratio (dB)	H-plane cross-polarization ratio (dB)
Waveguide	5	5.5
Horn	11.6	11.9
Vivaldi	10	10.4

Table 3: Cross-polarization ratio for each pattern measured.

Completing this portion of the lab did make E-plane and H-plane much more intuitive, as we were able to watch the physical motion of the positioner required to navigate across a given plane. It also helped me visualize co-polarization and cross-polarization, as I saw that this had to do with the relative orientations of the two antennas (whether they were aligned the same way for maximum received power or orthogonal to measure the power leaked into the other polarization). We found that the horn antenna had the highest gain of the three antennas we tested, and that the waveguide's gain was 33 dB lower while the vivaldi antenna's gain was 27 dB lower (again assuming efficiency of 1). For the waveguide antenna, the approximate directivity and area-based directivity were nearly the same, but for the other two antennas, the latter was 8 dB higher. We did still find that the horn antenna had the largest directivity, then the vivaldi, and then the waveguide, which was the same ordering of the effective areas.

Part II

Q8/9: In this part, we measured the reflection of each antenna using the VNA. For the waveguide, we found that the design frequency is 7.45 GHz, where its $|S_{11}|$ is -24.8 dB, and the bandwidth is 0.3 GHz (this is the 10 dB bandwidth). For the vivaldi antenna, the design frequency is 5.76 GHz where the magnitude of the reflection coefficient is -34.9 dB, and the bandwidth is 6.4 GHz. For the horn antenna, the design frequency is 11.35 GHz and $|S_{11}|$ at this frequency is -32.5 dB. The bandwidth of the horn antenna is 6 GHz (the range below -10 dB extends all the way to the maximum measured frequency). The horn and vivaldi antennas are more broadband because they are tapered. The vivaldi antenna has the lowest design frequency because it is the largest physically.

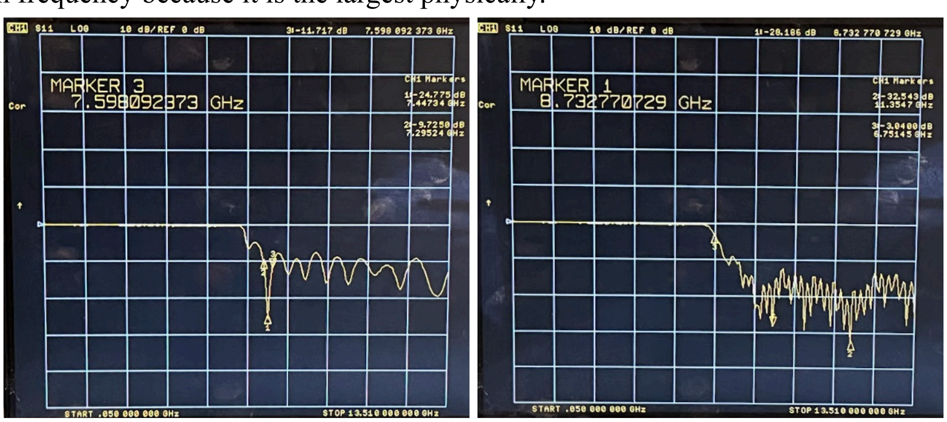

Figure 9: Measured $|S_{11}|$ of waveguide (left) and horn antenna (right).

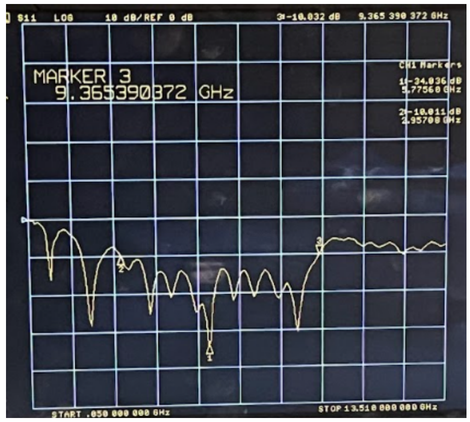

Figure 10: Measured $|S_{11}|$ of vivaldi antenna.

Part III

Q10: We use the Friis formula written in dB form and in terms of gains to calculate the identical gains of the horn antennas. We placed the antennas 93 cm apart, transmitted 10 dBm of power at 10 GHz, and received -12.75 dBm. We calculated the gain of each antenna as 14.53 dB.

$$P_R = P_T + G_R + G_T + 20log(\frac{\lambda}{4\pi r})$$

$$P_R - P_T - 20log(\frac{\lambda}{4\pi r}) = 2G$$

$$-12.75 - 10 - 20log(\frac{3}{4\pi * 93}) = 2G$$

$$G = 14.53$$

Q11: We measured the received power over the distance, and found that our results do obey the trend of the Friis transmission formula (the power is inversely proportional to the distance squared). We found that the received power is a little more than what we calculate by assuming P_{tr}=P_r at 0 distance and that the gains are those we found in the last problem. We calculated the required far-field distance to be 55 cm in this case, but we found that the trend did not change dramatically between near and far field.

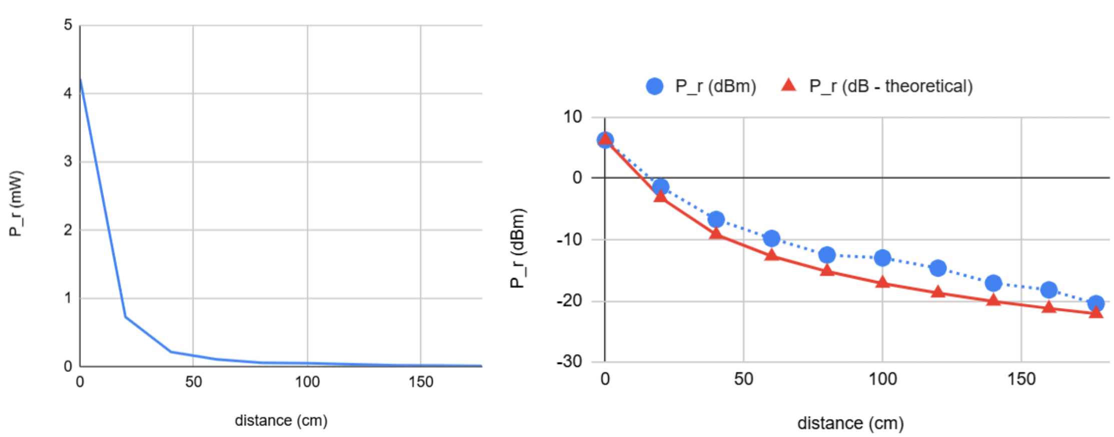

Figure 11: Received power in milliwatts over distance (left) and received power in dBm over distance along with theoretical received power calculated by the Friis formula (right).

Q11: We placed the antennas 1 m apart and measured the received power as we rotated the receiving antenna in increments of 10°.

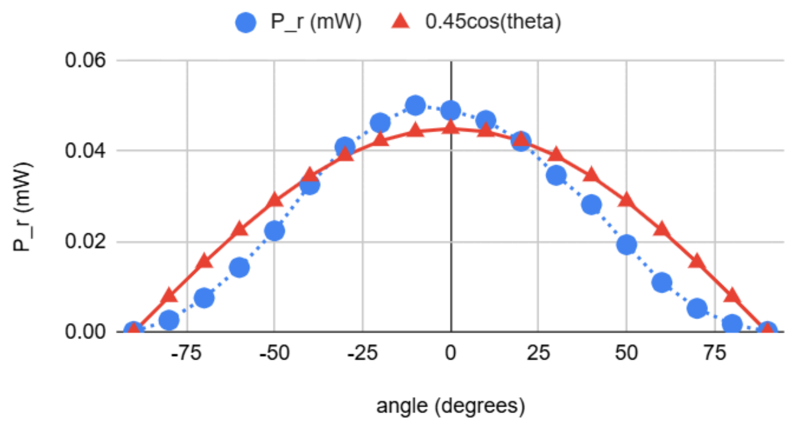

Figure 12: Received power versus angle of polarization rotation and sinusoidal approximation.

Q13: We then measured the 3 dB and 10 dB beamwidths in the E-plane and H-plane, by moving the receiving antenna vertically and horizontally until we were at 3 dB or 10 dB below the maximum power. We found that the E-plane had 3 dB beamwidth of 25.7° and 10 dB beamwidth of 46.2°. We found that the H-plane had 3 dB beamwidth of 19.6° and 10 dB beamwidth of 43.4°. In **Q5**, we found both 3 dB beamwidths were 30°. This is close to our measurement for the E-plane, but a good amount higher than that for the H-plane (most likely due to human error).

P_r (dBm)	vertical offset (cm)	distance (cm)	angle (°)	beamwidth (°)
-13	0	100	0	0
-16	22.25	100	12.85591259	25.71182517
-23	39.25	100	23.11014641	46.22029281

Table 4: E-plane (vertical) beamwidth measurements and calculations.

P_r (dBm)	horizontal offset (cm)	distance (cm)	angle (°)	beamwidth (°)
-13	0	100	0	0
-16	17	100	9.787819057	19.57563811
-23	37	100	21.71561728	43.43123457

Table 5: H-plane (horizontal) beamwidth measurements and calculations.

Part IV

Q14: We first compared the received power when pointing the antennas directly at one another and when using the reflector. We found that using the reflector increased the received power from -22 dBm to -19 dBm, which means that we received twice as much power. It is possible that we could have received slightly more if we had placed the feed antenna at the exact focal point.

Q15: Adjusting the upwards angle of the feed horn decreased the received signal strength because it altered the direction of the beam. If we had moved the receiving antenna up or down, then it may have been beneficial to rotate the feed antenna to redirect the beam, but since we were already pointing at it from the reflector, this change only made it worse.

Q16: Other possible enhancements to increase the gain of the horn antenna include increasing the area of the horn, using a larger reflector to “capture” and reflect more power towards the receiver, and using a further focal point to illuminate more of the reflector’s surface (assuming we have excess reflector area to use and will not fall off the edges).