ECE422 Radio and Microwave Wireless Systems

Lab #3: Plane-Earth Reflection and Diffraction

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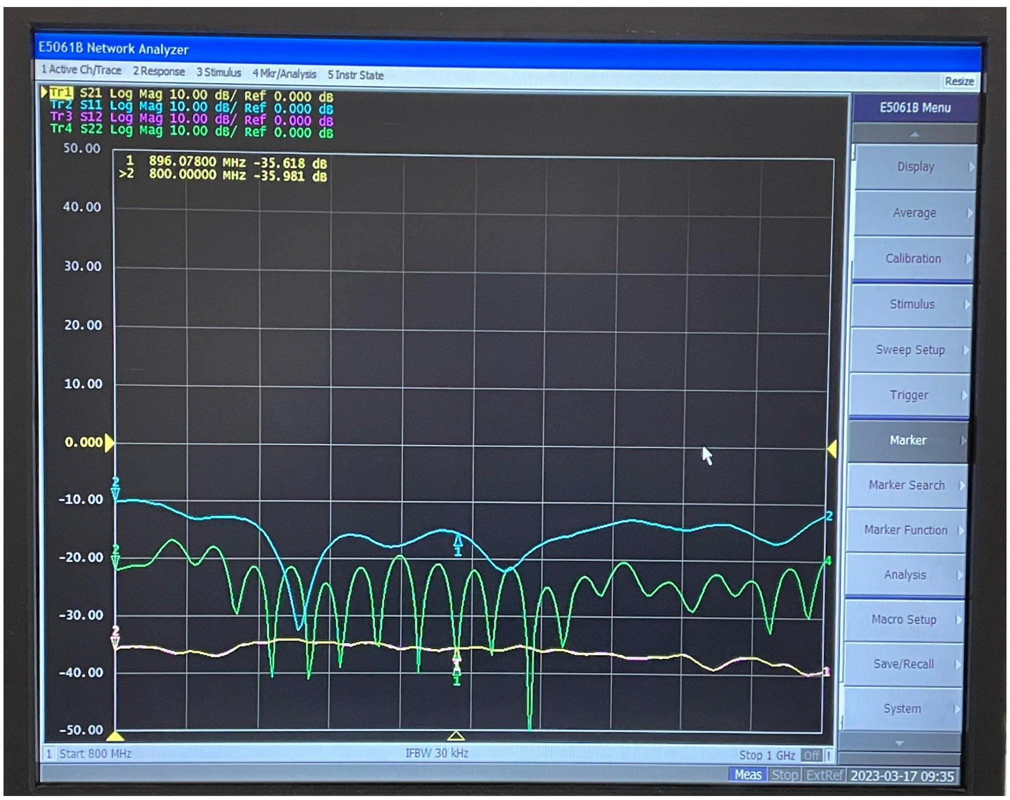
3. Multipath Measurements

2. Determine the far-field distance of each antenna and place them at a starting distance from each other corresponding to the sum of the far field distances of the two antennas.

Formula to determine the far-field distance >= $2D^2/\lambda$
Where D is the maximum linear dimension of the antenna, and λ is the wavelength of the EM waves.
The approximate far-field distance for each of the antennas was 3 meters.

6. Record the value of the magnitude read out by the network analyzer and the separation distance between the dipole arrays.

The S21 found from our VNA display using Marker 1 was -35.618 dB.



7. Note: Each square was 23 cm, and we moved in increments of each square.

8. Repeat steps 6 and 7 until you have reached the end of the room.

Distance from starting point [cm]	S21 [dB]
0	-35.618

23	-35.332
46	-37.728
69	-39.798
92	-37.402
115	-37.792
138	-39.173
161	-41.297
184	-41.001
207	-41.816
230	-41.072
253	-40.844
276	-40.458
299	-42.048
322	-43.148
345	-43.355

When processing your measurements, please answer the following questions.

1.Compare the measured signal strength with the theoretical signal strength from plane-earth reflection. Bear in mind that the transmit power was not measured, so you should use the path loss from the first measurement (where the transmitter and receiver were closest) as the starting point (in dB) as a reference case and determine the EIRP from there assuming no plane-earth reflection for that case. (the lack of grazing angles for that case should make the free-space Friis' formula approximately valid). How does the data compare to the theoretical path loss as a function of distance compared to that predicted by plane-earth reflection theory?

Answer: We first calculate the path loss from the first measurement when the transmitting and receiving antennas were closest to each other. Since the frequency of our antennas were approximately equal to 900 Mhz, we will be using the same for our calculation. The free-space Friis formula will be used due to the lack of grazing angles.

$$PL[d0] = 20log\frac{4\pi d_0 f}{c}$$

where d0 is the distance between the transmitter and receiver at the first measurement, f is the frequency of the antennas, and c is the speed of light.

$PL[d0] = 20\ log(\frac{4\pi*0*900*10^6}{3*10^8}) = 20log(0) = \infty$

Since this is infinite, we shall assume that eirp at the transmitter is 0 dBW.

Next, we are concerned about the plane-earth reflection path loss, for which the formula is as follows:

$$PL[d] = 20log(d) + 20log(frequency) + 32.45 - 20log(h)$$

d is the distance between the antennas in km, the frequency is taken as 900 MHz, and h is the height of the antennas above the ground. This was measured to be 1.4 meters (or. The formula uses GHz, so our 900 Mhz is 0.9 Ghz. 32.45 is a constant that relates to the loss due the curvature of the Earth's surface.

Here is a sample calculation for 23 cm (or 0.00023km)

$PL[d] = 20log(0.00023) + 20log(0.9) + 32.45 - 20log(0.0014) = 15.85\ dB$

We have assumed that the starting point measurement was taken in free-space.

Distance from starting point [km]	**Measured S21 [dB]**	**Expected PL[d] [dB]**
0.00023	-35.332	15.848
0.00046	-37.728	21.867
0.00069	-39.798	25.389
0.00092	-37.402	27.888
0.00115	-37.792	29.826
0.00138	-39.173	31.410
0.00161	-41.297	32.749
0.00184	-41.001	33.909
0.00207	-41.816	34.932
0.00230	-41.072	35.847
0.00253	-40.844	36.675
0.00276	-40.458	37.430

0.00299	-42.048	38.126
0.00322	-43.148	38.769
0.00345	-43.355	39.369

As seen above, our measured signal strength, S21, generally decreases with increased distance between the antennas due to attenuation of the signal. This follows our expectation of an increased path loss with an increased distance.

2. You will likely not get an exact match between theory and measurements, especially with regard to null locations. Explain possible sources of error, and in particular, elaborate upon assumptions made in the plane-earth theory development that may have been violated in this experiment.

Answer: The following sources of errors may have resulted in the theoretical and measured values being mismatched:

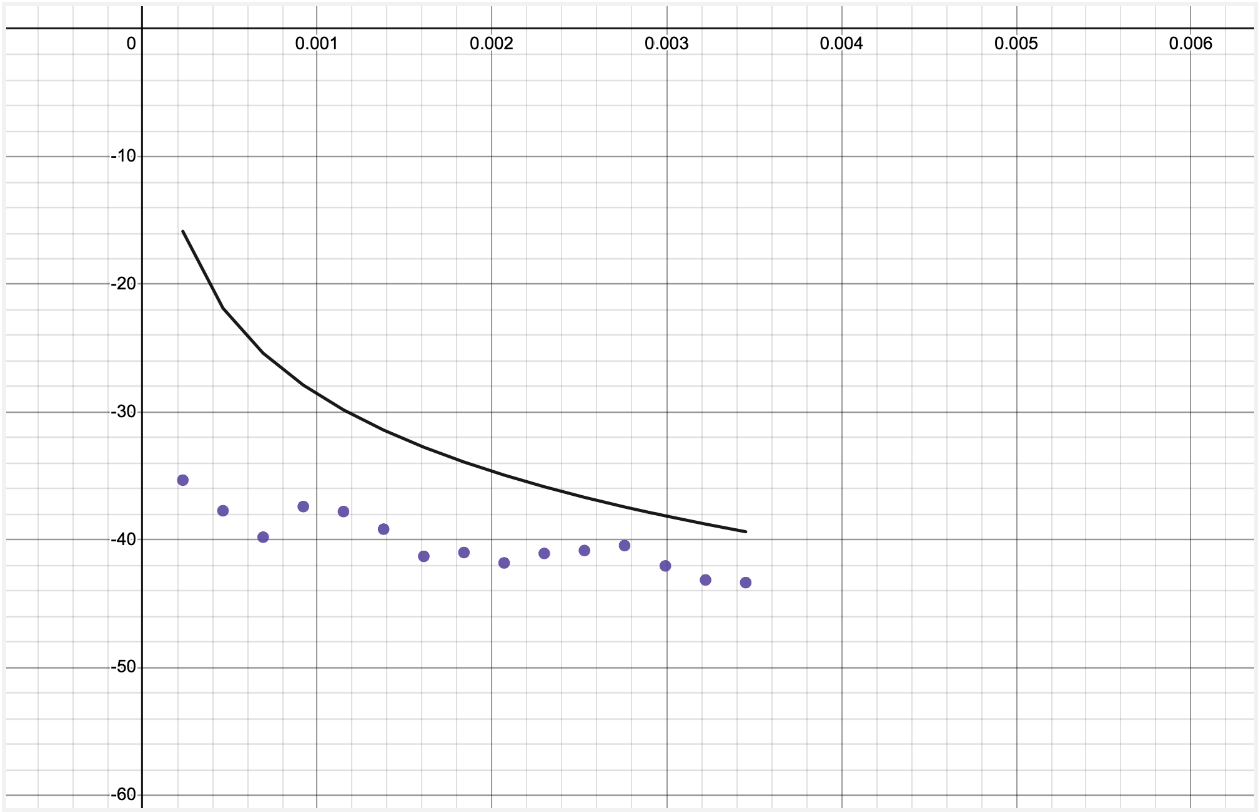
- Surround source interferences: RF devices including our phones, and other team's antennas can affect the signal strength of S21.
- Environmental factors: rain and other atmospheric conditions can affect how the RF signal is being reflected or absorbed, reducing the strength of the signal being measured.
- The plane-earth theory assumptions related to the Earth not having any significant terrain, which may not necessarily be true in the real world. We also assumed that the antennas were omnidirectional. This may not be true because all the antennas may not have the same gain/directivity.

3. We have seen for links in free space, that power falls off as $1/R^2$, whereas in plane-earth reflection, for large TX-RX separation distances, the power rolls off as $1/R^4$. In real multipath propagation scenarios, the power falls off as $1/R^n$, where n is a path loss coefficient between 2 and 4. Given this fact, try fitting your path loss data to the following formula for the path loss in dB:

$$PL\ [\text{dB}] = PL(d_0)\ [\text{dB}] + 10n\log_{10}\left(\frac{d}{d_0}\right) \tag{1}$$

In this formula, $PL(d_0)$ is the path loss measured at the starting position d_0, d is the actual distance between the transmitter and receiver, and n is the path loss coefficient. A computer program such as Microsoft Excel or MATLAB can assist with the curve fitting.

Answer:



When looking at our data, the line of best fit (in black) does not really match our data(in purple). This could be due to possible human/calculation errors. This could also be caused by interference (i.e one of us being in the way which could have altered the data points). It seems that in our data does not reflect the power rolling off as $1/R^4$.

4. Would you expect the fading to be better or worse if an antenna having more directivity was used? In particular, if the beamwidth is narrowed in the E-plane, what effect would this have on the reception of the plane-earth reflection and consequent fading process?

Answer: We would expect an improved fading. More of the transmitted power would now be directed in one direction, thus increasing the amount of power the receiver antennas gets.

The beamwidth is inversely related to the antenna's gain. A narrowed beam width would imply an increased antenna gain in that direction, thus increasing the reception of the plane-earth reflection. The reception would also be impacted by increased directivity, which is now more sensitive to surrounding obstacles.

4. Diffraction Measurements

Height [cm] (Starting from 0 cm from the *base* of the tripod)	S21 [dB]
0	-37.89
2	-41.87
4	-39.53
6	-37.24
8	-36.32
10	-37.97
12	-38.41
14	-36.32
16	-38.47
18	-36.87
20	-34.88

When processing your measurements, please answer the following questions….

1.Compare the theoretical path loss to the actual path loss you actually obtained (similar to the plane-earth experiment). Comment on differences and possible reasons for discrepancies.

Answer: The theoretical path loss was calculated using the same approximation of 900 Mhz for the frequency of the antennas (approximately 0.33 m = wavelength = λ), a fixed separation of 1m between the antennas, and a changing height h (h of both the antennas were equal for each instance).

$$Path\ Loss\ [dB]\ =\ 20log(\frac{4\pi d}{\lambda})\ +\ 20log(h)$$

Where d is the fixed separation of 1m between the antennas.

Here is a sample calculation for 2 cm

$$Path\ Loss\ [dB]\ =\ 20log(\frac{4\pi}{0.33})\ +\ 20log(0.02)\ =\ -\ 2.365\ dB$$

Height [cm] (Starting from 0 cm from the *base** of the tripod)	Measured S21 [dB]	Actual Path Loss [dB]
2	-41.87	-2.365
4	-39.53	3.655
6	-37.24	7.177
8	-36.32	9.676
10	-37.97	11.614
12	-38.41	13.198
14	-36.32	14.537
16	-38.47	15.696
18	-36.87	16.719
20	-34.88	17.635

base* - this does not imply from the ground. This is the vertically extendable tripod's base.

As seen above, our measured signal strength, S21, generally decreases when increasing heights on the transmitting and receiving antennas. This follows our expectation of an increased path loss with an increasing height.

2. The finite width of the screen is obviously a problem when comparing to theoretical calculations which assume an infinitely wide screen. Explain how using an array as we have done relaxes this constraint.

Answer: Using an array helps us obtain a more accurate signal:

- A single antenna will only cover the area in front of it, but an array helps cover a wider area, therefore allowing more of the signal to be detected.
- Helps avoid the issue of multi-path propagation (2 or more paths to reach the receiver antenna) by combining them into one signal.
- Overall flexibility in terms of directing at a desired angle, for example.
- There will be more narrow directivity in the array, which creates a more directive radiation pattern which more accurately maps to an infinitely wide screen.
- It helps lessen the differences between experimental data and theoretical calculations.

3. Explain if, based on your measurements, that the rule of thumb that "diffraction can be neglected provided the first Fresnel Zone is not blocked", was valid based on your measurements.

Answer: The first Fresnel zone can be calculated using the following equation:

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{(d_1 + d_2)}}$$

n = 1, lambda = wavelength, d1 = d2 = 1m

$r_1 = \sqrt{\frac{0.33m * 1}{2}} = 0.40m$

This means that if there happens to be an obstacle within this fresnel zone radius of 0.4m, it causes diffraction, and we would need to take the same into account when measuring the received power by the receiving antenna. Our S21 values measured were negative, hence we can conclude that the measured signal is ‘weak’ when in proximity to the obstacle. Also, the path losses calculated were quite high. Hence, diffraction was not a dominant factor affecting our measured signal, and as a result, the rule of thumb is valid.

4. Explain why we can ignore the effects of plane-earth reflection effects in most diffraction scenarios.

Answer: In most situations the effect of plane-earth reflection can be ignored as the reflection effects are minimal compared to diffraction effects. The environment also causes a sort of offset when looking at plane-earth reflection effects.