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FACULTY OF APPLIED SCIENCE AND ENGINEERING
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ECE422H1S: RADIO AND MICROWAVE WIRELESS SYSTEMS

EXPERIMENT 3: PLANE-EARTH REFLECTION AND DIFFRACTION

1 Introduction

In the lectures, you have learnt about two major large-scale radio wave propagation effects: plane-earth reflection (or multipath reflection) and diffraction. The purpose of this lab is to help you understand how these phenomena effect a wireless system. In two separate experiments, you will characterize each effect and compare to the theoretical expectations derived in class.

You will need the following pieces of equipment to complete this experiment:

- Agilent network analyzer
- SMA calibration kit (short, open, load, through)
- 8 planar half-wavelength dipole antennas
- Two 4-way Wilkinson power dividers (5-port board with oval-shaped trace on it)
- 2 mounting tripods and associated hardware
- 2 long SMA cables
- 10 UFL cables and SMA-to-UFL adaptors
- UFL removal key
- Two 1 metre rulers and masking tape
- Measuring tape
- Large metal sheet
- Cart
- Computer running MATLAB or Microsoft Excel, for recording data

As this lab uses a significant amount of space, it will only be possible to run two experiments in parallel along the two sides of GB450. Teams should set up a schedule in which two groups at a time complete the measurements for both parts of the lab at different times, allocating perhaps 20 minutes for each pair of groups to gather their data. The data collection should not be lengthy once the antennas have been set up.

2 Experimental Setup for Both Experiments

Before beginning the experiments, calibrate the network analyzer from 800 MHz to 1 GHz according to the instructions attached at the end of this document. Attach the long SMA cables to the network analyzer so that its electrical response is calibrated out of the measurement.

After calibrating the network analyzers, determine the frequency at which the dipoles are operating by measuring the input reflection coefficient of one of the dipoles, and setting the marker to report measurements at this frequency.

In this experiment, the transmitter and receiver will each use a 4-element dipole array in a broadside configuration, with half-wavelength spacing between elements, as the transmit and receive antenna, respectively. This configuration was used and investigated in Lab 2. This is to increase the transmitted EIRP and received signal strength so that more dynamic range in the measurements is possible than if dipoles were used alone. As you will recall, the beam is formed in the H-plane, which will allow use to minimize the effect of reflections from objects outside the main beams of the antennas. This is desirable, because we are trying to focus on the effect of a specific object in these experiments: the earth (floor) in the case of plane-earth reflection, and the knife-edge obstacle in the case of diffraction. We don't want reflections off of desks, chairs, etc. interfering with our measurements.

Set up the 4-element array in the same manner as you did for Lab 2, mounting each array on the supporting tripod when finished. Consult the documentation for that lab if necessary. Once both the transmit and receive arrays have been constructed, connect them to the two ports on the network analyzer.

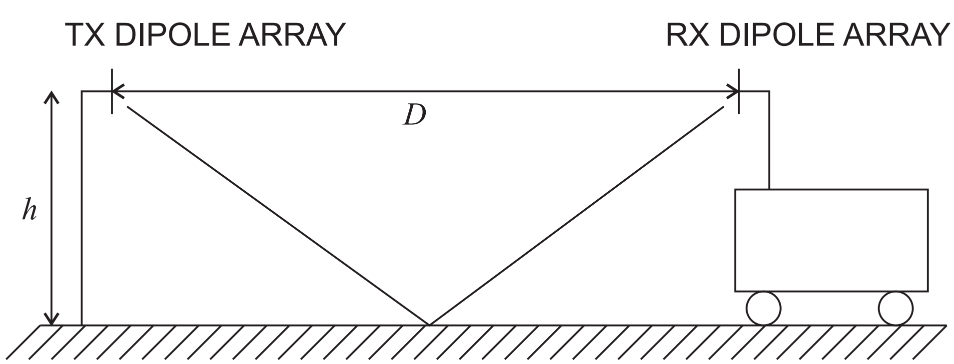

Figure 1: Plane-earth reflection experiment setup

3 Multipath Measurements

To investigate multipath effects, you will measure the transmission between the transmit and receive antennas as a function of the distance between the two antennas.

1. Place the transmit antenna on the bench at the end of the lab, and the receiver on the cart. Set up the arrays so that they are aimed at each other, and co-polarized.
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.
3. Press [MEAS] and select S21.
4. Press [FORMAT] and select Log Mag.
5. Press [MARKER] and set the marker to the centre of your frequency band.
6. Record the value of the magnitude read out by the network analyzer and the separation distance between the dipole arrays.
7. Move the cart away from the dipole array by 30 cm.
8. Repeat steps 6 and 7 until you have reached the end of the room.

If you see significant "fading" in your measurements, try to zero in on those fades by making small adjustments to the cart's position and recording the exact location of the fades.

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 compare to that predicted by plane-earth reflection theory?
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 have may been violated in this experiment.
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 of as $1/R^4$. In real multipath propagation scenarios, the power falls of 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:

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

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.

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?

4 Diffraction Measurements

In this part of the lab you will investigate diffraction around an obstacle, in this case, a fairly large metal sheet. With the transmitter and receiver placed a fixed distance apart, the sheet will be moved and the height of the antennas above the ground manipulated to produce various diffraction scenarios.

1. Using the same setup of antennas as the multipath experiment, place the transmitter and receiver a fixed distance apart (e.g., 3 metres) and align the antennas for minimum path loss. Make sure the antennas are at the same height with respect to each other.
2. Record the distance between the two antennas.
3. Press [MEAS] and select S21.
4. Press [FORMAT] and select Log Mag.
5. Press [MARKER] and set the marker to the centre of your frequency band.
6. Record the value of the magnitude read out by the network analyzer.
7. Place the metal screen between the transmitter and receiver. Measure the height of the screen, particularly the distance between the line-of-sight path and the top of the screen (the parameter h we have studied in class), and record the path loss between the transmitter and receiver.
8. Repeat the measurements for various values of h, taking at least 10 points that illustrate various levels of shadowing. You can change h by changing the heights of the antennas using the tripods (over a small range), and also by raising and lowering the screen (obviously, diffraction is introduced at the bottom of the screen, but we will ignore that in calculations).

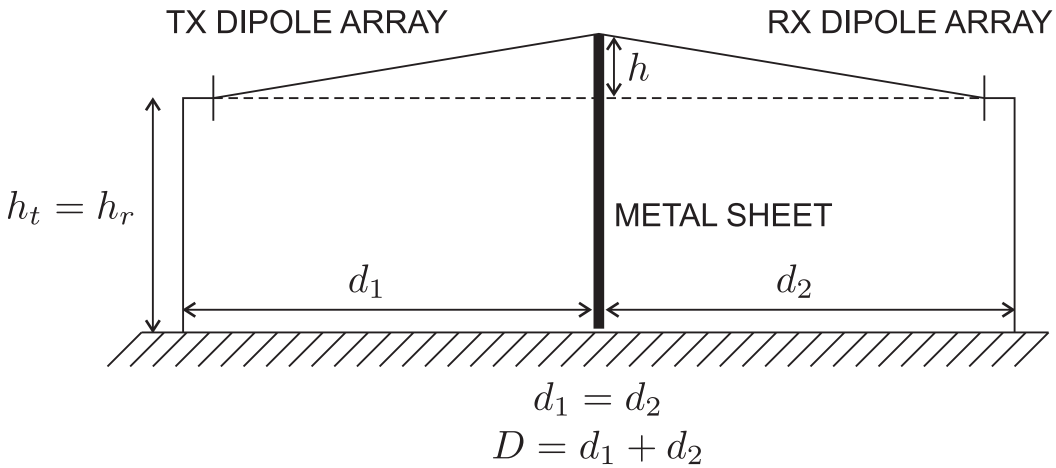

Figure 2: Diffraction loss experiment setup

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

5 Network Analyzer Calibration

This section describes the procedure of how to calibrate the network analyzer. Square brackets [] denote a hard button on the front panel of the network analyzer and round brackets () denote a soft button on the screen of the network analyzer.

1. Press [Preset] $\rightarrow$ (OK). Setting the instrument to a default state.
2. Press [Start], enter 800 MHz. Press [Stop], enter 1 GHz. Setting the frequency range of interest for the measurement.
3. Press [Cal] $\rightarrow$ (2-Port Cal) $\rightarrow$ (Reflection).
4. Connect the appropriate Short/Open/Broadband Load calibration standards to Port 1 and 2 and press corresponding soft buttons on the screen..
5. Press (Return).
6. Press (Transmission). Connect the Short/Open/Broadband Load calibration standards to Port 1 and 2 and press corresponding soft buttons on screen.
7. Connect a Through standard.
8. Press (Port 1-2 Thru) to measure the standard.
9. Press (Return)
10. Press (Done) to enable the calibration.
11. Check the calibration by making sure the calibration is selected to be ON. Connect the Through calibration standard to make sure the reflection s_{11} is less than -40 dB and the transmission s_{21} is near 0 dB.