

Lab Exercise 8: Antenna Measurements

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Objective

To characterize the antennas used in the microwave transmission system and explore the concept of polarization.

General concepts to be covered:

- Antenna patterns
- Beamwidth
- Gain
- Polarization
- Range dependence on received power

8-1 PRE-LAB ASSIGNMENT

8-1.1 **Read** Section 7-3, 9-2, 9-5, 9-6, 9-7, 9-8 of the text.

8-1.2 **To be entered into your lab notebook prior to coming to lab:**

Summarize the experimental procedure (1 paragraph per section) of:

- (a) Section 8-4.1: Range Dependence
- (b) Section 8-4.2: Polarization
- (c) Section 8-4.3: Antenna Patterns

8-2 INTRODUCTION

In today's technological society, wireless communication has become an increasingly important part of daily life. We have come to depend on our pagers, cellular phones, satellite dishes, radios, etc., usually without understanding how they work. The one element common to all of these wireless systems, whether they transmit or receive, is the antenna. The antenna is responsible for coupling the RF energy from the transmission-line feed (guided) to free space (unguided), and vice versa. Antennas are characterized using several parameters, such as geometry, gain, beamwidth, sidelobe level, frequency of operation, polarization, etc.

There are several parameters that are used to describe the performance of antennas. Examples include the gain, beamwidth, sidelobe level, and efficiency. Another parameter that is used to describe the polarization purity of an antenna is the cross-polarization ratio. The cross-polarization ratio describes how much of the transmitted power (at the maximum of the main-lobe) is transmitted in the orthogonal direction. For example, if the antenna is vertically polarized and you measure a horizontally polarized component that is 30 dB weaker than the vertically polarized component, the antenna is said to have a cross-polarization ratio of -30 dB.

As you have learned in class, the electric and magnetic fields are vector quantities. This means that they not only have magnitudes, but they also have directions associated with them. This is unlike the scalar quantity voltage, which was used in the previous transmission line experiments to quantify how waves traverse down a transmission line.

On a transmission line, the waves are guided by the transmission line structure, so the waves can be described by using scalar quantities, and noting whether the waves are moving toward or away from the load (or generator). In the system you will be using in this lab, the waves exist in air (free space) and hence are unguided. It is no longer sufficient to describe the waves produced by your source as a scalar quantity since now direction is important.

Since the electric field has a direction associated with it, the portion of the incident wave that a receiver intercepts is dependent on the orientation of the polarization direction of the receiver with respect to the direction of the electric field of the incident wave. If the receiver and the incident wave are aligned, the receiver will intercept the maximum possible portion of the incident wave. If the two directions are orthogonal to one another, the receiver will completely miss the incident wave.

In this lab, you will be using an X-band (8-12 GHz) microwave transmission system operating at 10.5 GHz to explore the nature of wave polarization and the performance of different sized horn antennas.

8-2.1 Transmitter And Receiver

The transmitter is shown in Fig. 8-1, and consists of an antenna attached to antenna mount. The receiver and the transmitter are identical except for how they are mounted. The polarization of the transmitter or receiver is determined by the orientation of the antenna. A protractor has been attached to the antenna mount behind the antenna to determine the polarization angle. The angle reading from the protractor minus 90° is the polarization angle for the transmitter. For example, a reading of 90° on the protractor corresponds to a polarization angle of 0° , and a reading of 180° on the protractor corresponds to a polarization angle of 90° .

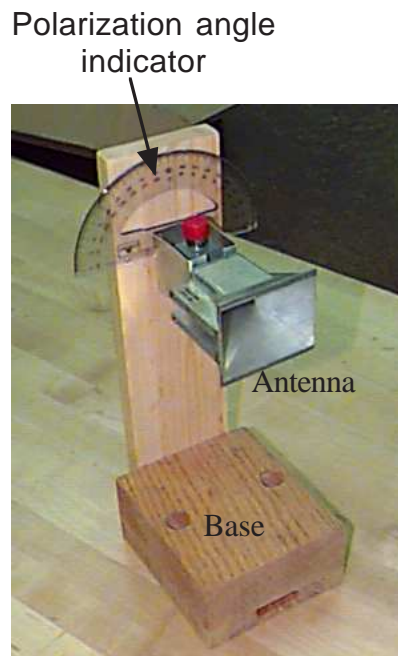


Figure 8-1: Transmitter/Receiver assembly.

Useful Equations

Friis transmission formula:
$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \quad (\text{W})$$

Gain of a horn antenna:
$$G \approx 0.7 \frac{4\pi A_p}{\lambda^2}$$

3 dB beamwidth of a horn antenna:
$$\beta = k \frac{\lambda}{\ell} \quad (\text{rad})$$

Far-field:
$$R \geq \frac{2d^2}{\lambda} \quad (\text{m})$$

8-3 EQUIPMENT

Item	Part #
Antenna mounts (2)	—
Detector	—
Measuring tape	—
Multimeter	HP 973A
Polarizer	—
SMA to BNC cable	—
Receive antenna	—
Transmit antenna	—
Tripod	—

8-4 EXPERIMENT

8-4.1 Range Dependence

In this experiment, you will explore how the received power level is related to the separation distance between the antennas.

Setup

This experiment uses the multimeter, transmitter, receiver, detector, SMA to BNC cable, BNC to banana plug adaptor, and tripod.

Setup the system as shown in Fig. 8-2:

- Place the receiver on the edge of the workbench facing out. Use the two C-clamps to hold the receiver in place. Place the transmitter on the tripod.
- Adjust the height of the tripod so the transmitter and receiver are at the same height.
- Place the tripod with the transmitter attached 1 meter in front of the receiver.
- Make sure the transmitter is level on the tripod.
- Adjust the location of the tripod so the transmitter and receiver are pointing directly at each other.
- Attach the input of the detector to the receiver. Attach the SMA to BNC cable to the output of the detector. Using the BNC to Banana plug adaptor, connect the output of the detector to the multimeter. Configure the multimeter to measure mV DC.
- Plug the transmitter into the transmitter regulator box. **Make sure that the switch on top of the transmitter regulator box is in the off position before plugging in the transmitter.**

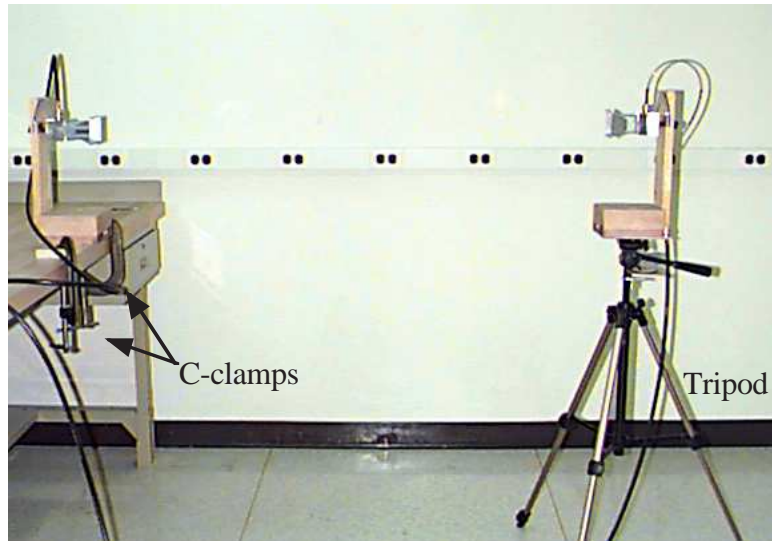


Figure 8-2: Setup for the range dependence measurements.

Procedure

1. Set the transmitter and the receiver to a polarization angle of 0° .
2. Adjust the position of the transmitter to give a maximum reading on the multimeter (make sure that the transmitter and receiver are separated by 1 m). Record the detector voltage.
3. Repeat for distances of 1.25, 1.5, 1.75, and 2 m.

Measured Data

Copy the following chart into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding to the analysis section.

R (m)	Reading (mV)
1.0	
1.25	
1.50	
1.75	
2.0	

Analysis

1. Convert the measured detector voltages to received powers in mW^* .
2. Normalize the data to the maximum value.
3. Plot your data as a function of range (R). Start the graph at $R=1$ m.
4. On the *same* graph, plot the functions $1/R$, $1/R^2$, and $1/R^3$.

*See Appendix B for measured detector voltage to received power conversions.

Questions

1. Which function ($1/R$, $1/R^2$, $1/R^3$) best fits the trend in the recorded data? Is this what is predicted by theory?

8-4.2 Polarization

In this experiment, you will investigate the polarization properties of electromagnetic waves and antennas using a microwave transmission system.

The two horn antennas that you are using in this experiment are linearly polarized, which means that they only intercept the electric field that is oriented along a specific direction (a line). In class, you have seen that electric fields can exist in any direction. What happens if the direction of the electric field and the polarization direction of the antenna do not coincide? Since the portion of the incident field that is intercepted is dependent on $\cos(\theta)$, where θ is the angle between the direction of the electric field and the polarization direction of the antenna, the power intercepted by the antenna will decrease, and may go to zero if the two directions are orthogonal. To show this relationship, you will measure the polarization pattern of the transmitter and receiver antennas.

In general, you want to have the antenna polarization direction and the direction of the electric field aligned so that the maximum amount of power is intercepted by the antenna. There are certain cases where you want to limit the amount of power received. One such example is sunglasses. The light from the sun that is incident on your eyes is randomly polarized. This means that the direction of the electric field changes as a function of time. On a bright, clear day, it is sometimes hard to see because too much power is being received by your eyes, either directly from the sun or from reflections. How can you reduce the amount of light that is incident on your eyes? One way to accomplish this is to block your eye with an opaque object, but you would not be able to see anything. Instead, we could use a polarizer (see below) to block one polarization from reaching your eyes. Although the polarization of the light reaching your eye is random, you can model the light as being polarized in a certain direction 50% of the time, and in the orthogonal direction the rest of the time. By using a polarizer, you can block out one of these components, reducing the intensity of the light reaching your eye by 50%.

Polarizers are devices that change the polarization of a wave. The most common polarizers are made from an array of wires (or grooves in a metal) that are parallel to each other with a spacing between wires (grooves) that is much shorter than a wavelength.

Polarizers allow waves that are polarized in the orthogonal direction to the wires (grooves) to pass through. If the wave is not oriented along the direction orthogonal to the wires (grooves), only the component of the incidence wave that lies in the orthogonal direction is permitted to pass through. One common example of polarizers is a good pair of sunglasses.

The polarizer used in this lab is an aluminum plate that has grooves milled into it (see Fig. 8-3). It is mounted to the polarizer stand using a single metal screw in the center, allowing the polarizer to rotate about its center. There are three marks on the front of the polarizer corresponding to 0° , 45° , and 90° . The 0° degree position of the polarizer is when the grooves are horizontal.

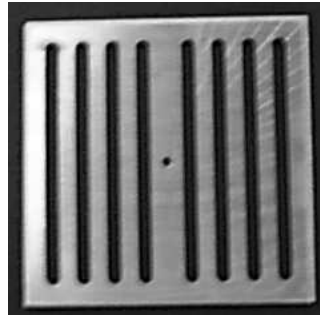


Figure 8-3: Polarizer used in this experiment.

Setup

This experiment uses the multimeter, transmitter, receiver, and polarizer.

Using the same configuration as in the previous experiment, separate the transmitter and receiver by a distance of 1 m.

Procedure

1. Set the transmitter and receiver to a polarization angle of 0° . This corresponds to the transmitted electric field being polarized in the vertical (parallel) direction.
2. Adjust the azimuthal position of the transmitter to give a maximum reading on the multimeter.

Receiver Polarization Pattern

3. Rotate the receiver from a polarization angle of 0° (vertical or parallel polarization) to a polarization angle of 90° (horizontal or perpendicular polarization) in increments of 10° . At each position, record the detector voltage.

Transmitter Polarization Pattern

4. Return the receiver to a polarization angle of 0° .
5. Rotate the transmitter from a polarization angle of 0° to a polarization angle of 90° in increments of 10° . At each position, record the detector voltage.

Polarizer

6. Attach the polarizer to the receiver.
7. Rotate the polarizer to 0° . Record the detector voltage.
8. Rotate the polarizer to 90° . Record the detector voltage.
9. Rotate the polarizer to 45° and record the marker value.
10. Change the transmitter polarization to 0° and the receiver polarization to 90° . Record the detector voltage for polarizer angles of 0° , 90° , and 45° .

Measured Data

Copy the following chart into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding to the analysis section.

Receiver and Transmitter Polarization Patterns

θ_{pol}	Rv V_d	Tx V_d
0		
10		
20		
30		
40		
50		
60		
70		
80		
90		

Polarizer

Rv \angle	Tx \angle	Pol \angle	V_d
0°	90°	0°	
0°	90°	90°	
0°	90°	45°	
90°	0°	0°	
90°	0°	90°	
90°	0°	45°	

Tx: Transmitter
 Rv: Receiver
 Pol: Polarizer
 V_d : Detector voltage

Analysis

Receiver And Transmitter Polarization Pattern

1. Convert the measured detector voltages to received powers in dBm.
2. Normalize the receiver and transmitter polarization pattern data by the value at 0° (both the transmitter and receiver at polarization angles of 0°).
3. Plot the normalized polarization pattern for the receiver and transmitter. On the *same* graph, plot the functions $\cos(\theta)$ and $\cos^2(\theta)$.

Polarizer

3. For each of the polarizer-antenna interaction measurements, draw the vector representing the transmitted wave, polarizer direction, and the receiver. Using these vectors, determine what percentage of the transmitted electric field passes through the polarizer. Also indicate what percentage of the transmitted electric field is intercepted by the receiver. Compare with the measured results. What conclusions can you draw?

Questions

1. Using the graphs made for the transmitter and the receiver, how does the magnitude of the received signal vary with the difference in the polarization angle of the transmitter and the receiver (i.e. as $\cos(\theta)$ or $\cos^2(\theta)$)? Based on this, are you measuring the electric field or power? How do you know?
2. Assuming that the antennas and the cables are identical, how does the function of the antenna (as a transmitter or a receiver) affect the polarization dependence of the system? (Hint: how would you expect the polarization patterns of the transmitter and the receiver to change if you physically reversed their functions in the system?)
3. When you placed the transmitter and receiver so their polarization angles differed by 90° , what effect did the polarizer have when it was oriented with the transmitter, the receiver, and at a 45° angle?

8-4.3 Antenna Patterns

In this experiment, you will measure the antenna pattern as a function of azimuth angle for two horn antennas of different size.

Setup

This experiment uses the multimeter, transmitter, receiver, detector, small and large antennas, and tripod.

Setup the experiment:

- Using the same setup as in the previous experiment, place the transmitter 1 m away from the receiver.
- Remove the polarizer from the receiver.
- Adjust the angular position of the transmitter and receiver for the maximum signal on the multimeter.

Note: In this experiment, you will be using two different horn antennas.

Color Code	P_t (dBm)
Black	10.5
Orange	7.5
Red	11.5
Yellow	10.5
Black & Red	10.5
Orange & Red	9.5

Table 8-1: Transmitted power, P_t , for each of the transmitter modules by color code.

Procedure

1. Determine the transmitted power using Table 8-1. Each of the transmitting modules is marked with a color code on one of the sides. Record the transmitted power P_t .

Large Horn Antenna

1. Temporarily switch off the transmitter regulator box. With no transmitted signal, measure the dimensions of the small and large horn antennas.
2. Switch the transmitter regulator box back on.
3. Place the transmitter at an azimuth angle of 0° (90° on the protractor). In this configuration, the two antennas should be pointed directly at each other. Rotate the receiver to a polarization angle of 0° and the transmitter to a polarization angle of 90° . The received signal with the two antennas cross-polarized should theoretically be zero. Any signal received by the detector is due to ambient noise and represents the *noise floor* of the measuring system. Record the detector voltage.
4. Return the transmitter to a 0° polarization angle.
5. Rotate the transmitter to an azimuth angle of -90° (0° on the protractor). Record the detector voltage. **Be sure to move away from the transmitter and receiver before recording the measurement.**
6. Rotate the transmitter from an azimuth angle of -90° to an azimuth angle of 90° (180° on the protractor) in 10° steps, recording the detector voltage at each angle.

Small Horn Antenna

1. Replace the large horn antenna on the transmitter with the small horn antenna (ask the lab instructor to change the antennas).
2. Repeat step 3 through step 6 for the small horn antenna.

Measured Data

Copy the following chart into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding to the analysis section.

P_t _____ dBm

Antenna Dimensions

Dimensions*	Small antenna	Large antenna
Length		
Height		

* at 0° polarization angle

Noise Floor

Antenna	V_d
Large horn	
Small horn	

Antenna Pattern Measurements

\angle	Large Antenna V_d	Small Antenna V_d
-90		
-80		
-70		
-60		
-50		
-40		
-30		
-20		
-10		
0		
10		
20		
30		
40		
50		
60		
70		
80		
90		

Analysis

1. Compute the far-field distance for the small and large horn antennas. (The frequency of operation is 10.5 GHz). Is the far-field criterion satisfied?
2. Compute the theoretical gain, half power beamwidth and first side-lobe level (see Fig. 9-23 in the text) for both the small and large horn antennas. (Assume $k \approx 1$).
3. For the small horn antenna, using the distance between the antennas and the detector voltage reading at 0° (azimuth angle) from the co-polarized pattern, compute the gain of the small horn antenna using the Friis transmission formula[†]. Assume that the two antennas are identical.

[†]Be sure to convert all measured detector voltages to received powers before computing the gain.

4. For the large horn antenna, using the distance between the antennas, the gain of the small horn antenna (computed above), and the detector voltage reading at 0° (azimuth angle) from the co-polarized pattern, compute the gain of the large horn antenna using the Friis transmission formula.
5. Normalize the pattern data for the small antenna by the maximum value.
6. Plot the normalized pattern for the small horn antenna. When you make your graph, correct the angle so the maximum occurs at 0° .
7. Normalize the pattern data for the large antenna by the maximum value.
8. On the same graph, plot the normalized pattern for the large horn antenna. When you make your graph, correct the angle so the maximum occurs at 0° .
9. From your graph, determine the half power beamwidth (β_{3dB}) and first sidelobe level for both antennas. Comment on your results.

Questions

1. How do the measured values compare to the theoretical values?
2. Explain the pattern shape at the ends (around $\pm 90^\circ$). Are these values real or is something else happening here? (Hint: compare the detector voltages to the detector voltage measured with no signal present.)
3. Why did we use the smaller antenna for the receiver for both pattern measurements? What would have happened if we had used a third larger antenna for the receiver when making the pattern measurements?

8-5 LAB WRITE-UP

For each section of the lab, include the following items in your write-up:

- (a) Overview of the procedure and analysis.
- (b) Measured data.
- (c) Calculations (show your work!).
- (d) Any tables and printouts.
- (e) Comparisons and comments on results.
- (f) A summary paragraph describing what you learned from this lab.