PHYS2090 OPTICAL PHYSICS

Laboratory – Microwaves

Reference

Hecht, *Optics*, (Addison-Wesley)

1. Introduction

Interference and diffraction are commonly observed in the optical regime. As wave-particle duality highlights, these phenomena can also occur in other systems, e.g. with neutrons, atoms, and electrons. However, observing fine detail in all of these systems is difficult, due to the small length scales. In this laboratory we explore interference and diffraction using microwaves, with the benefit of the wavelength of the source (and hence the apertures) being several centimeters instead of fractions of a micron.

CAUTION: The output power of the Microwave Transmitter is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the Transmitter is on.

2. Microwave Propagation and Detection

This section gives a systematic introduction to the microwave optics system. It is designed to be helpful in learning to use the equipment effectively and in understanding the significance of measurements made with this equipment.

Note that reflections from nearby objects, including the table top, can affect the results of your microwave experiments. To reduce the effects of extraneous reflections, keep your experiment table clear of all objects, especially metal objects, other than those components that are required for the current experiment.

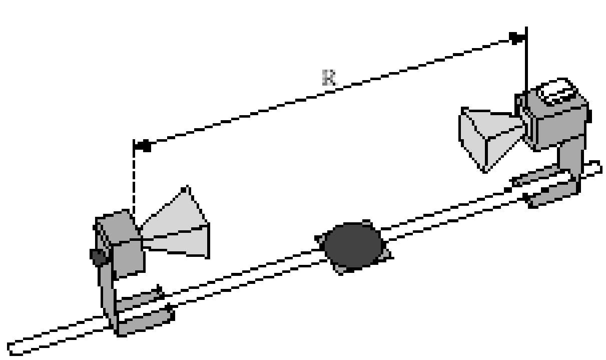

Figure 1. Basic arrangement

(a) Arrange the transmitter and receiver on the goniometer (the base which allows angle measurement), with the transmitter on the fixed arm as shown in figure 1. Be sure the transmitter and receiver are adjusted to the same polarity – the horns should have the same orientation. Plug in the transmitter and set the intensity switch on the receiver to 30X. Set the separation between the transmitter and receiver so that the distance between the source diode and the detector diode, R, is 40 cm. Adjust the settings on the receiver so that the meter reads full scale. Make a range of measurements of the meter reading, M, for values of R up to 1 m. Do not adjust the receiver controls between measurements. After making the measurements, tabulate values for MR and MR^2. The electric field of an electromagnetic wave is inversely proportional to the distance from the source of the wave (i.e., $E \approx 1/R$) while the intensity of an electromagnetic wave is inversely proportional to the square of the distance from the source of the wave (i.e., $I \approx 1/R^2$). Use your data to determine if the meter reading of the receiver is directly proportional to the electric field of the wave or the intensity.

(b) Loosen the hand screw on the back of the receiver and rotate the receiver about a horizontal axis. This varies the polarity of maximum detection. (Use the slotted plate to determine the polarisation.) Observe the meter readings through a full 360° rotation of the horn. Explain what you observe.

(c) Position the transmitter so the output surface of the horn is directly over the degree plate of the goniometer arm. With the receiver directly facing the transmitter and as far back on the goniometer arm as possible, adjust the receiver controls for a full scale reading. Then move the rotatable arm of the goniometer. Make measurements from 0° to 90° (measured from the 180° point on the degree scale), and record the meter reading at each setting. To what extent can the output of the transmitter be considered a spherical wave? A plane wave?

3. Double Slit Interference

In the double-slit experiment, an incoming wave is broken into two waves which superpose in the space beyond the apertures. Here there are points in space where maxima are formed and others where minima are formed. With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection.

For two thin slits separated by a distance d, show that the minima will be found at angles such that

$$d \sin\theta = n\lambda \qquad (1)$$

where θ is the angle of detection, λ is the wavelength of the incident radiation, and n is any integer. Before beginning this experiment, consult a textbook and be sure you understand the nature of the double-slit interference pattern.

Use two reflectors and the narrow slit spacer to construct a double slit with a slit width of about 1.5 cm as shown in figure 2. Be precise with the alignment of the slit and make the arrangement as symmetrical as possible. Place the slits between the transmitter and receiver (set for vertical polarisation) and adjust the receiver controls to give a full scale reading at the lowest possible amplification. Rotate the rotatable goniometer arm (on which the receiver is mounted) slowly about its axis. Observe the meter readings. Reset the goniometer arm so the receiver directly faces the transmitter. Adjust the receiver controls to obtain a meter reading of 1.0. Now set the angle θ to values between 0° and 85° in 5° steps. At each setting record the meter reading. In places where the meter reading changes significantly between angle settings, you may find it useful to investigate the signal level at intermediate angles.

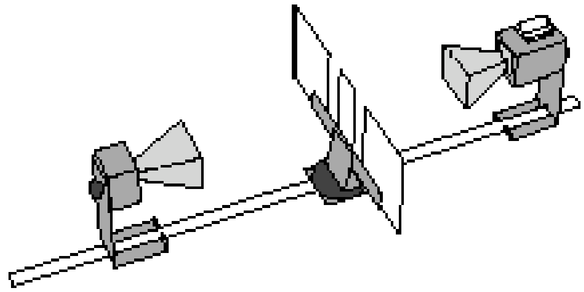

Figure 2. Double slit experiment

Keep the slit widths the same, but change the distance between the slits by using the wide slit spacer instead of the narrow slit spacer. Move the transmitter farther back so that the slits are evenly illuminated. Repeat the measurements above.

Use your data to determine the wavelength of the source for each slit separation. What assumptions are made in the derivation of equation (1) and to what extent are they met in this experiment?

4. Single Slit Diffraction

When a wave passes though an aperture whose dimensions are near that of the wavelength of the wave, a diffraction pattern is found. If the aperture is a single slit, the intensity of the diffracted wave will vary depending on the angle of detection.

Show that minima will be found at angles such that

$$a\sin\theta = n\lambda \qquad (2)$$

where a is the slit width, θ is the angle of detection, λ is the wavelength of the incident radiation, and n is any integer.

Use the slit extender arm and both reflectors to construct the vertical slit. Set the slit width to 7.0 cm and align the slit as symmetrically as possible. Set the rotational scale on the back of both the transmitter and receiver for vertical polarization (0^o). Adjust the receiver controls to give a full scale reading at the lowest possible intensity setting. Rotate the goniometer arm (on which the receiver is mounted) slowly about its axis. Observer the meter readings. Reset the goniometer arm so the receiver directly faces the transmitter. Adjust the receiver controls to obtain a full scale reading. Now set the angle of the goniometer arm to values between 0˚ and 85˚ in 5˚ increments. At each setting record the meter reading in the table. You may need to increase the intensity setting to clearly see all the maxima and minima. If so, be sure you multiply all your data by the appropriate value (i.e., 30, 10, 5, or 1) so your results are truly proportional to the signal intensity. In places where the meter reading changes significantly between angle settings, you may find it useful to investigate the signal level at intermediate angles.

Change the slit width to 13.0 cm. Move the Transmitter further from the slit to provide a more uniform illumination of the slit. Repeat the measurements above.

From your data, plot a graph of meter reading versus angle. Identify the angles at which minima and maxima occur. Are the angles in agreement with those you would expect in a Fraunhofer single-slit diffraction pattern? The standard Fraunhofer formula for single-slit diffraction depends on several assumptions. What are these assumptions and to what extent are they met in this experiment?

5. Lloyd's Mirror

In the double slit section, you have seen how a single electromagnetic wave can be broken up into two waves and, when the two components are brought back together, an interference pattern is formed. Lloyd's Mirror is another example of this phenomena. Just as with the other interference patterns you have seen, the interference pattern provides a convenient method for measuring the wavelength of the radiation.

In the Lloyd's mirror experiment, an electromagnetic wave from a point source is detected on a screen. There are two pathways to reach the screen: the direct path, and by a reflection from a mirror placed with its reflective surface parallel to the axis of the system. A maximum signal will be detected when the two waves reach the detector in phase. There will also be minima where the two beams arrive out of phase.

Arrange the transmitter, receiver and mirror on the goniometer as shown in figure 3. For best results, the transmitter and receiver should be as far apart as possible – approximately 1 m gives good results. Be sure the receiver and transmitter diodes are equidistant from the centre of the goniometer degree plate and that the horns are directly facing each other. (The diodes are approximately 12 cm behind the output surface of the microwave horns.) Also be sure that the surface of the

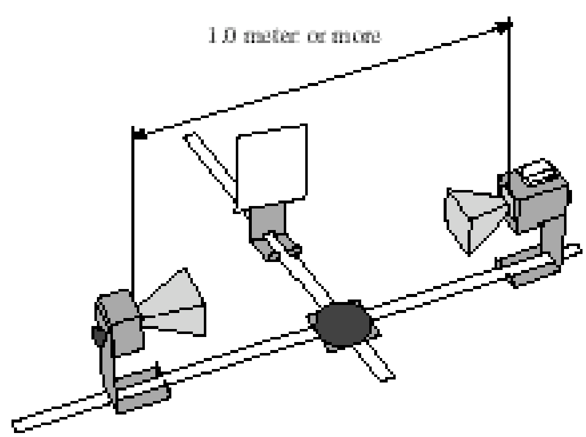

Figure 3. Lloyd's mirror

reflector is parallel to the axis of the transmitter and receiver horns.

While watching the meter on the receiver, slowly slide the reflector away from the degree plate. Notice how the meter reading passes through a series of minima and maxima.

Find the reflector position closest to the degree plate which produces a maximum meter reading. Measure and record h_1, the distance between the centre of the degree plate and the surface of the reflector.

Slowly slide the reflector away from the degree plate until the meter reading passes through a minimum and returns to a new maximum. Measure and record h_2, the new distance between the centre of the degree plate and the surface of the reflector.

Measure d_1 the distance between the centre of the degree scale and the transmitter diode. Use your collected data to calculate λ, the wavelength of the microwave radiation.

Change the distance between the transmitter and receiver and repeat your measurements and analysis.

Compare your results for the wavelength with the earlier measurements.