Experiment 236: Microwave Optics B

Aims

To show that electro-magnetic radiation in the form of microwaves exhibits the same phenomena as light and to compare the observations made with predictions from optical wave theory.

References

1. Hecht 2nd. ed., “Optics”, Addison-Wesley
2. Pedrotti & Pedrotti, “Introduction to Optics”, Prentice-Hall

Experimental Set-up

Transmitter

The transmitter uses a Gunn diode oscillator to produce 15 mW of coherent, linearly polarised microwave radiation. The output is linearly polarised along the axis of the attached horn. The wavelength of the microwaves is about 3 cm. The transmitter is powered from a wall socket.

The output power of the microwave transmitter is well within safety levels. However, one should never look directly into the beam at close range

Receiver

Four ranges are available on the receiver unit, including a variable sensitivity dial. This can be used to offset an initial reading to a convenient value. However, in order to make comparative quantitative measurements, this offset must not be altered between readings. The receiver is powered from internal batteries. To conserve battery power, **do not leave the receiver unit on for long periods of time.**

Note the effective points of transmission and reception in the transmitter and receiver respectively, as shown in Figure 1.

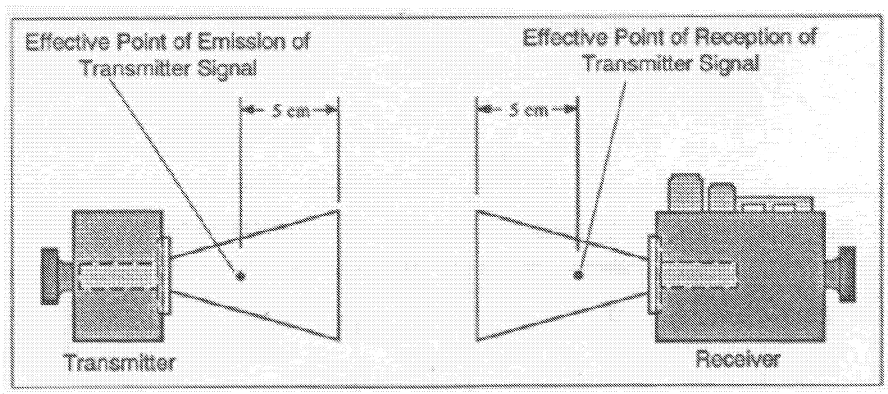

Figure 1: Effective transmission and reception points.

It will become apparent that microwaves are easily reflected off a variety of large scale surfaces. For this reason, it is important to note and minimise the effect of reflection of planar surfaces, including walls, the bench-top, the body and any nearby metallic objects.

Basic Operation

Before proceeding to more sophisticated experiments, you should become familiar with the basic transmitter and receiver system.

1. Place the transmitter and receiver on the *goniometer* (the hinged ruler) with the transmitter on the fixed arm, see Figure 2. Set the distance between the transmitter and receiver at 40cm. Turn on the transmitter and receiver, and set the receiver controls to show a near full scale deflection. Record the meter reading as the transmitter-receiver distance is increased. Make use of the various meter scales, and remember not to adjust the variable sensitivity dial between readings. Plot a graph of the meter reading against distance.

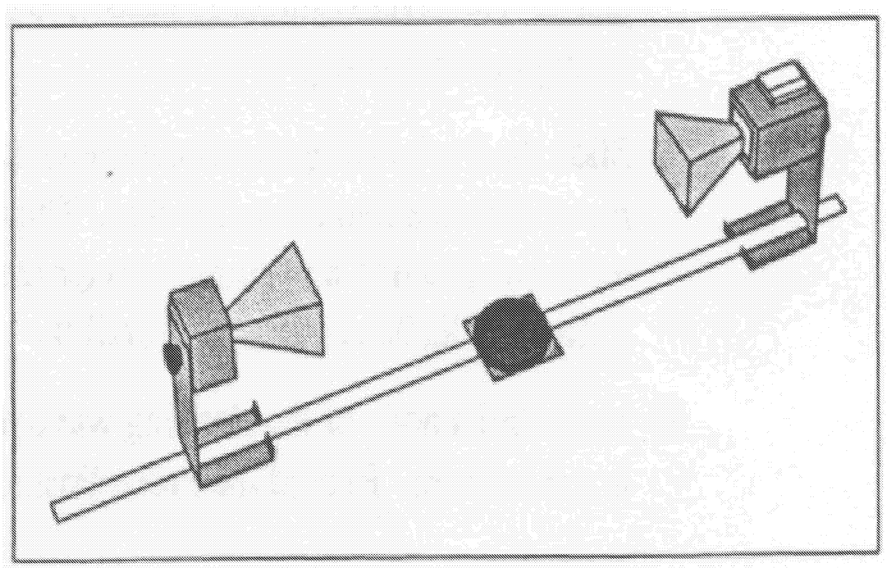

Figure 2: Transmitter and receiver units setup on the goniometer.

Question 1: Using your data, can you determine if the meter reading is proportional to the *intensity* or the *electric field* of the microwaves?

2. Set the transmitter-receiver distance to about 80cm. Slowly decrease the distance between the transmitter and receiver.

   Question 2: Does the meter reading increase smoothly? Describe and explain what you observe.

3. Set the transmitter and receiver at about 80cm apart. Hold a metal reflector parallel to the beam axis and perpendicular to the table-top. Slowly move the reflector towards the beam axis, keeping the reflector plane parallel to the beam axis. Describe and explain the meter reading.

4. Place the transmitter such that the end of the output horn is directly over the degree plate. Set the transmitter-receiver distance to about 50cm. Offset the receiver from the beam axis by various angles. Record the meter reading at each angle, maintaining the same receiver-transmitter distance. Plot your results. From your plot, find the angle where the meter reading drops to $1/e$ of the on-axis maximum.

5. Using a metal reflector, a rotating component holder, and the goniometer, verify that the law of reflection holds for microwaves, see Figure 3. Compare the relative reflectivities of the metal and wood reflectors. Is all the incident energy reflected? Is any energy absorbed?

Refraction

In this experiment, you will investigate the refraction of microwaves, and estimate the refractive index of styrene, n_s.

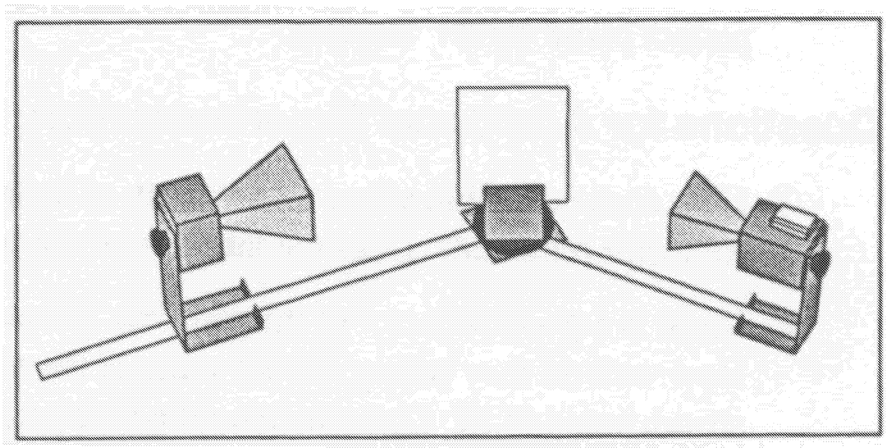

Figure 3: Setup to verify the principle of reflection.

6. Arrange the transmitter and receiver on the goniometer directly facing each other at a distance of about 60 cm. Place the rotating table on the goniometer degree plate. Place the foam prism on the rotating table. See Figure 4. Set the receiver controls to give a near full scale reading. Rotate the empty prism mold.

   Question 3: Does the orientation of the empty prism affect the meter reading?

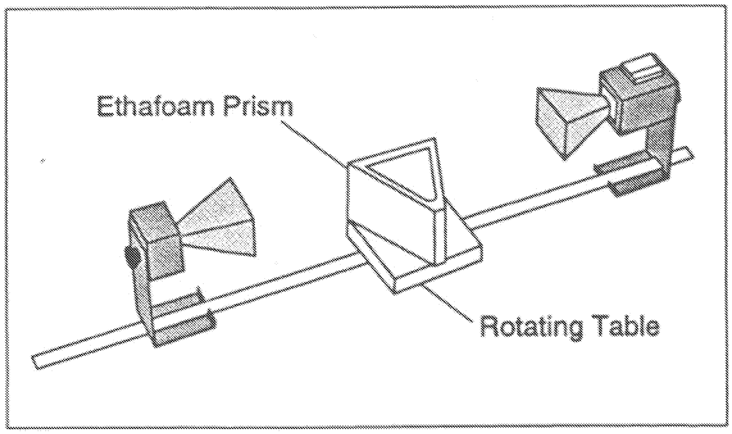

Figure 4: Refractive index of styrene.

7. Carefully fill the foam prism with styrene pellets. Use the tray provided to avoid spilling the pellets. Place the prism on the rotating table such that one of the non hypotenuse faces is normal to the incident beam.

8. Rotate the receiver goniometer arm until a maximum signal is found. Record the angle moved from the beam axis. Reset the receiver to the beam axis and repeat several times. Find the average value for the angle of refraction. Call this angle θ_{r}.

   Question 4: Show that

   $$n_{\mathrm{s}} = \frac{n_{\mathrm{air}} \sin\theta_{\mathrm{a}}}{\sin\theta_{\mathrm{p}}}$$

   where $\theta_{\mathrm{a}} = \theta_{\mathrm{r}} + \theta_{\mathrm{p}}$, and θ_{p} is the smallest internal prism angle.

9. Measure (with a protractor or through trigonometry) the prism angle, θ_{p}. Find the refractive index of styrene, n_{s}. Return the styrene pellets to the container.

Polarisation

In this part of the experiment, the polarisation properties of the microwave beam will be investigated. The microwave beam is linearly polarised along the transmitter diode axis, see Figure 5. Similarly, the receiver diode only detects the component of the incident microwave field that is parallel to its axis.

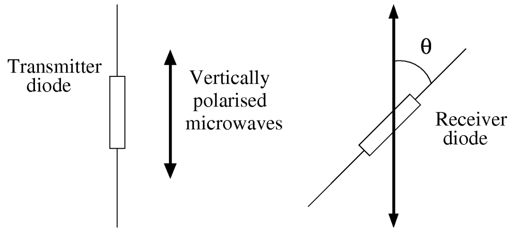

Figure 5: Detecting polarized radiation.

Question 5: If the meter reading was directly proportional to the electric field along the receiver diode axis, show that the meter reading will be $M = M_0 \cos\theta$ where θ is the angle between the receiver and transmitter diodes and M_0 is the meter reading when $\theta = 0$.

Question 6: Show that if the receiver meter reading was directly proportional to the *intensity* of the incident beam, then $M = M_0 \cos^2\theta$.

10. Arrange the transmitter and receiver units to be directly facing each other at a distance of about 60cm. Ensure that the horn on each unit has the same orientation, e.g. both horizontal or vertical. Loosen the hand-screw at the back of the transmitter unit and rotate the unit in increments of 10 degrees. Record the receiver meter reading. Plot the meter reading against polarisation angle.

    Question 7: Does the meter measure the electric field or intensity of the incident microwaves? Justify your answer. How does your result compare with those from Procedure 1?

11. Set the transmitter and receiver units for horizontal polarisation. Place the *polariser* midway between transmitter and receiver, and at about 10 degrees to normal incidence

    Question 8: How can you determine that the transmitter is set to give horizontal polarisation using the polariser?

    Set the receiver controls for a half full scale reading. Record the meter reading when the polariser is oriented at 0, 22.5, 45, 67.5 and 90 degrees with respect to the horizontal. Tabulate your results and comment.

12. Remove the polariser. Turn the transmitter 90 degrees to give vertical polarisation. Record the meter reading with the polariser slits horizontal, vertical and at 45 degrees. Explain the results.

Brewster's Angle

In this experiment, Brewster's angle for microwaves will be determined.

13. Set up the goniometer with the receiver unit on the rotating arm. Place the rotating table on the degree plate. Place the polyethylene panel on the rotating table. See Figure 6. Set the angle of incidence to 20 degrees and observe at the same angle (i.e. 140 degrees from the straight through position). Ensure that both the transmitter and receiver units are set for horizontal polarisation. Set the receiver controls for a half full scale reading. Record the meter reading. Carefully rotate both the receiver and transmitter units for vertical polarisation. Record the meter reading.

14. Increase the angle of incidence in regular steps up to about 75 degrees. For each angle of incidence, observe at the same angle and record the meter reading for the reflected beam for both horizontal and vertical polarisations. You may need to change the receiver sensitivity. Remember, do not alter the variable sensitivity dial. Plot a graph of the meter reading against incident angle for both vertical and horizontal polarisations. You should be able to identify Brewster's angle (where a horizontally

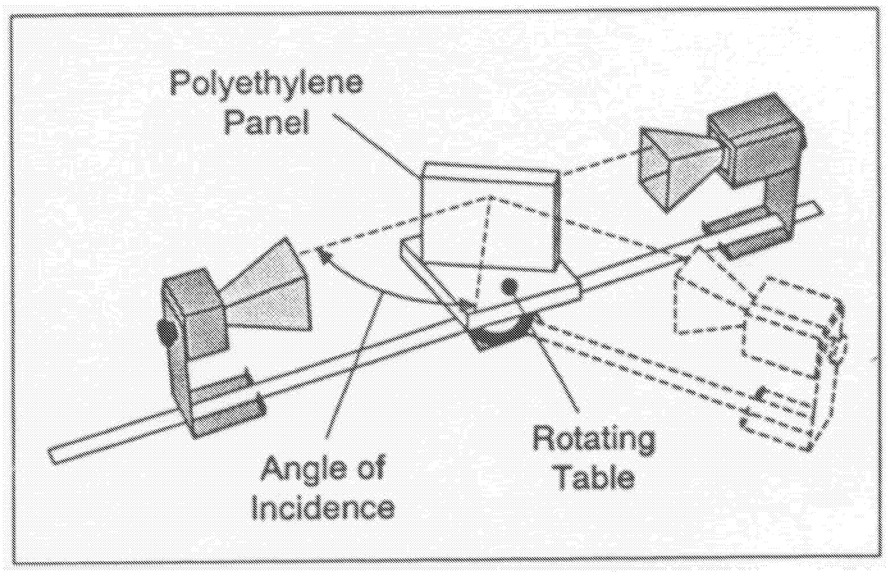

Figure 6: Set-up for the measurement of Brewster's angle

polarised wave does not reflect). Make further readings for angles around this value. Plot your whole data set. Comment on your result.

Question 9: It is possible to identify a minimum at about 43.6 degrees. What is the cause of this minimum?

Total and Frustrated Total Internal Reflection

The goals of this experiment are: (i) To find the refractive index of wax to microwaves, (ii) observe total internal reflection and (iii) frustrated internal reflection. This experiment calls for the use of wax prisms. Handle the wax prisms gently, as the wax is brittle and will shatter if dropped.

15. Use one of the wax prisms to demonstrate total internal reflection. Describe in detail how you demonstrated the phenomenon of total internal reflection, see Figure 7.

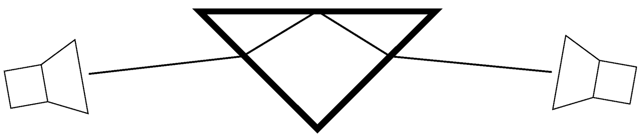

Figure 7: Total internal reflection of microwaves through the wax prism.

16. Dismantle the apparatus used above. Take the transmitter and receiver units off their metal stands. Arrange the transmitter, receiver and a prism on the table top such that total internal reflection is occurring. Place the transmitter about 20 cm away from the prism. Check that total internal reflection is occurring by bringing the receiver right up against the hypotenuse face of the prism. With the second prism, place the receiver hard up against one of the (equal length) faces. Move the receiver and the second prism as one slowly towards the first prism, as in Figure 8. Keep the hypotenuse faces of the prisms parallel. Monitor the meter reading. Continue until the hypotenuse faces nearly contact. What happens? Explain your observations.

17. Arrange the prisms such that the meter reading with the meter in position A is roughly equal with that as in position B, see Figure 8.

Question 10: How can a similar arrangement of prisms be used in optics?

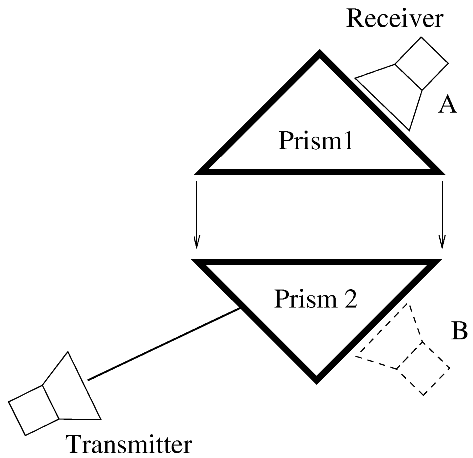

Figure 8: Frustrated total internal reflection.

List of Equipment

1. Gunn Diode Transmitter and Receiver units
2. Goniometer
3. 1 component holders
4. 1 metal reflectors (15 cm)
5. 1 partial (wood) reflectors
6. Metal Polariser
7. Rotating foam table
8. Foam prism and quantity of styrene pellets
9. 1 polyethylene blocks
10. 2 wax prisms

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