

Microwave Optics

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1 Introduction

Optical phenomena may be studied at microwave frequencies. Visible light has wavelengths of a few hundred nanometers, so most optical phenomena occur on very small scales. Using a three centimeter microwave wavelength transforms the scale of the experiment. Microns become centimeters and variables that are obscured by the small scale of traditional optics experiments are easily seen and manipulated.

The Gunn diode transmitter provides 15 mW of coherent, linearly polarized microwave output at a wavelength of 2.9 cm. The unit consists of a Gunn diode in a 10.5 GHz resonant cavity, a microwave horn to direct the output and an 18 cm stand to reduce table reflections. The output is linearly polarized along the axis of the diode and the attached horn radiates a strong beam of microwave radiation centered along the axis of the horn.

CAUTION: *The output power is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the transmitter is on. Under some circumstances, microwaves can interfere with electronic medical devices. If you use a pacemaker, or other electronic medical devices, check with your doctor to be certain that low power microwaves at a frequency of 10.5 GHz will not interfere with its operation.*

The microwave receiver provides a meter reading that is proportional to the intensity of the incident signal. A microwave horn, identical to that of the transmitter, collects the microwave signal and channels it to a diode in a 10.5 GHz resonant cavity. The microwave radiation from the transmitter is linearly polarized along the axis of the diode; that is, as the radiation propagates through space, its electric vector remains aligned with the axis of the diode. If the transmitter diode is aligned vertically the microwave radiation is also polarized vertically, as shown in Fig. 1 (left). If the detector diode were at an angle to the transmitter diode, as shown in Fig. 1 (right), it would only detect the component of the incident electric field that was aligned along that axis.

When two waves meet in space, they superimpose, so that the total electric field at any point is the sum of the electric fields of two waves at that point. If the two waves have the same frequency, and are travelling in the opposite directions, a standing wave is formed. The points where the fields of two waves cancel are called nodes; points where the oscillations are at maximum are called antinodes. The distance between two adjacent nodes (or antinodes) in the standing wave is exactly $1/2\lambda$ where λ is the wavelength of the radiation. Standing waves can be set up between the transmitter and receiver since the microwaves will reflect off the surfaces of the horns. The microwave horns are not perfect collectors of microwave radiation. Instead, they act as partial reflectors, so that the radiation from the transmitter is reflected back and forth between the two

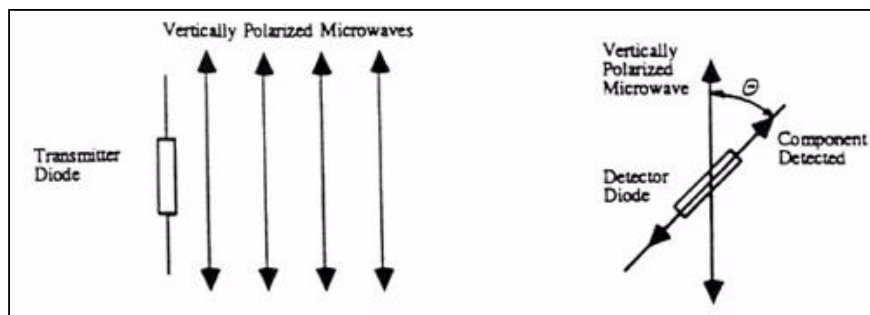


Figure 1: **Polarization.** The electric vector of polarized waves remains aligned with the diode (left). The receiver diode will only detect the component of the incident field that is aligned with it (right).

horns, diminishing in amplitude at each pass. If the distance between the transmitter and receiver diodes is equal to $n\lambda/2$, where n is an integer, then all the multiply-reflected waves entering the receiving horn will be in phase with the primary emitted wave. When this occurs, the meter reading will be a maximum. Therefore, the distance between two adjacent positions where a maximum will be seen is $\lambda/2$.

2 Equipment

microwave transmitter, microwave receiver, goniometer, rotating table, metal and plastic reflectors, polarizer

3 Procedure

In this experiment you will study reflection and polarization of microwaves, and measure the wavelength by generating a standing wave.

3.1 Reflection

1. Arrange the equipment as shown in Fig. 2, with the transmitter on the fixed end of the goniometer. Adjust the polarization angles of both the transmitter and the receiver to the same orientation by turning the receiver until it shows a maximum reading.
2. The angle between the incident wave from the transmitter and the line normal to the reflector is the angle of incidence (see Fig. 2). Adjust the rotating holder so that the angle of incidence equals 45 degrees. Turn the receiver intensity selection switch to 30X. The intensity selection settings (30X, 10X, 3X and 1X) are the values by which you must multiply the meter reading to normalize your measurements. That is, 30X means that you must multiply the meter reading by 30 to get the same value you would get if you measured the same signal with the intensity selection set to 1X. Of course, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements. Without moving the transmitter or

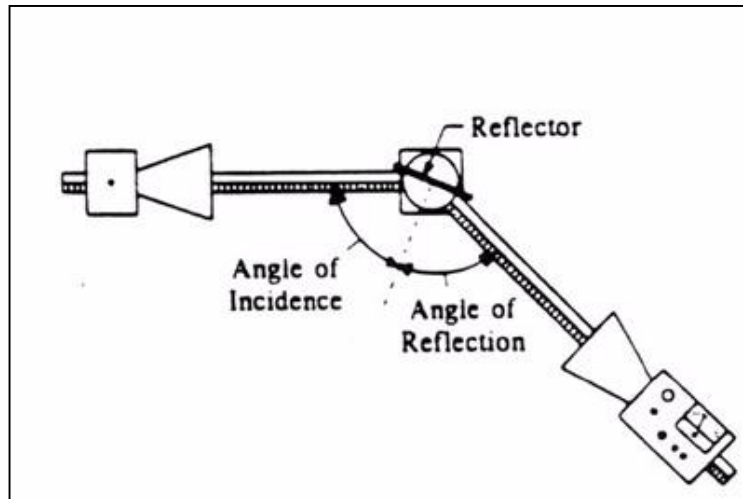


Figure 2: **Reflection of microwaves.** Angles of incidence and reflection are measured relative to a line normal to the plane of the reflector.

the reflector rotate the movable arm of the goniometer until the meter reading is a maximum. The angle between the axis of the receiver and a line normal to the plane of the reflector is called the angle of reflection. Measure and record the angle of reflection for each of the angles of incidence shown in the data sheet. (At some angles the receiver will detect not only the reflected wave but also the wave coming directly from the transmitter giving misleading results. Determine the angles for which this is true.)

3. Replace the metal reflector with the partial reflector made of plastic and repeat the measurements.

3.2 Polarization

1. In this part of the experiment you will investigate how a polarizer can be used to alter the polarization of microwave radiation. Place the detector opposite to the transmitter. Loosen the hand screw on the back of the receiver and rotate the receiver in increments of 10 degrees until you reach 180 degrees. At each position record the meter reading. Record your measurements in the data sheet.
2. Set up the equipment as shown in Fig. 3, and reset the angle of rotation of the receiver for vertical polarization. With the slits of the polarizer aligned horizontally, find the orientation of the receiver for which the meter will show the minimum deflection.
3. Repeat this measurement with the slits aligned at about 22.5, 45, 67.5 and 90 degrees with respect to the horizontal.

3.3 Standing waves

In this part of the experiment you will measure the wavelength of microwaves generated by the transmitter.

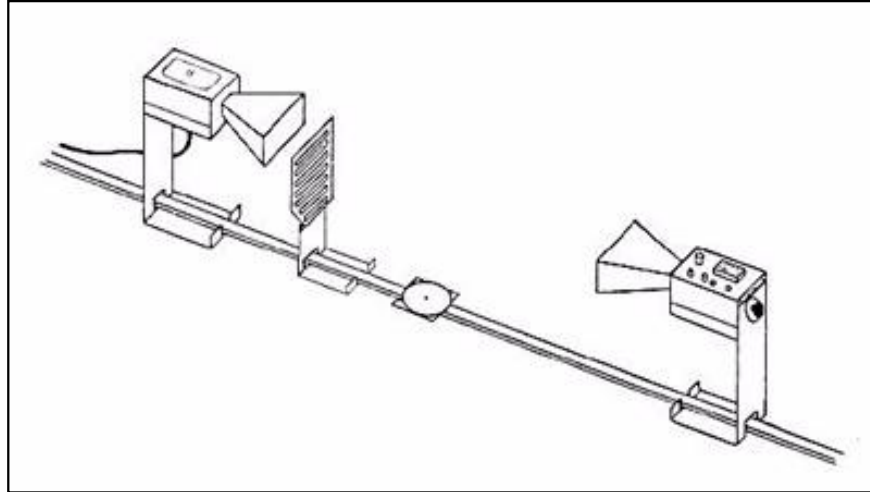


Figure 3: **Polarization measurements.** A polarizer is placed between the transmitter and the receiver.

1. Set up the transmitter and the receiver on the goniometer as close together as possible and adjust the receiver controls to get a full scale meter reading (Use the 1X scale). Slowly move the receiver away from the transmitter. You should notice that beam intensity decreases with the increasing distance. You might need to adjust the intensity selection settings; be sure to make a note if you do. You should also be able to notice fluctuations in the meter reading. These fluctuations are due to radiation reflected from the receiver.
2. Slide the receiver one or two centimeters along the goniometer arm to obtain a maximum meter reading. Record the initial position of the receiver on the metric scale of the goniometer. While watching the meter, slide the receiver away from the transmitter, until the receiver has passed through at least 10 positions at which you see a minimum meter reading, and return to a position where the reading is a maximum. Record the new position of the receiver. Use the data to calculate the wavelength of the microwave radiation. Repeat the procedure and recalculate the wavelength.

4 Report

Make sure your report includes the following:

1. What relationship holds between the angle of incidence and the angle of reflection? Does this relationship hold for all angles of incidence?
2. In determining the angle of reflection, you measured the angle at which a maximum meter reading was found. Can you explain why some of the wave was reflected into different angles? How does it affect your answer to question 1?
3. How does reflection affect the intensity of microwave? Is all the energy of the wave that strikes the reflector reflected? What has happened to the missing energy?

4. Graph the data from the polarization measurements. If the meter reading, M , were proportional to the component of the electric field, E , along its axis, then the meter reading would be given by the relationship $M = M_0 \cos \theta$, where M_0 is the maximum reading of the meter. If the intensity of a wave is proportional to the square of the electric field (e.g.; $I = kE^2$), then the meter reading would be given by $M = M_0 \cos^2 \theta$. Plot both functions ($\cos \theta$ and $\cos^2 \theta$) on the same graph as your experimental data and discuss the relationship between the meter reading and the polarization and magnitude of the incident microwave. **ATTENTION:** If you decide to use Excel remember that its trig functions work only in radians and angles measured in degrees must be converted first to radians.
5. Explain how the polarizer affects the incident microwave.
6. Use your estimate of the wavelength and the formula

$$v = \lambda\nu \tag{1}$$

to calculate the velocity of microwave propagation in air. ν is the frequency of the microwave radiation used in the experiment, 10.5 GHz. Estimate the error of your speed of light measurement. Compare calculated speed of light with the textbook value and discuss possible sources of error.