Includes
Teacher's Notes
and
Typical
Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model WA-9314B

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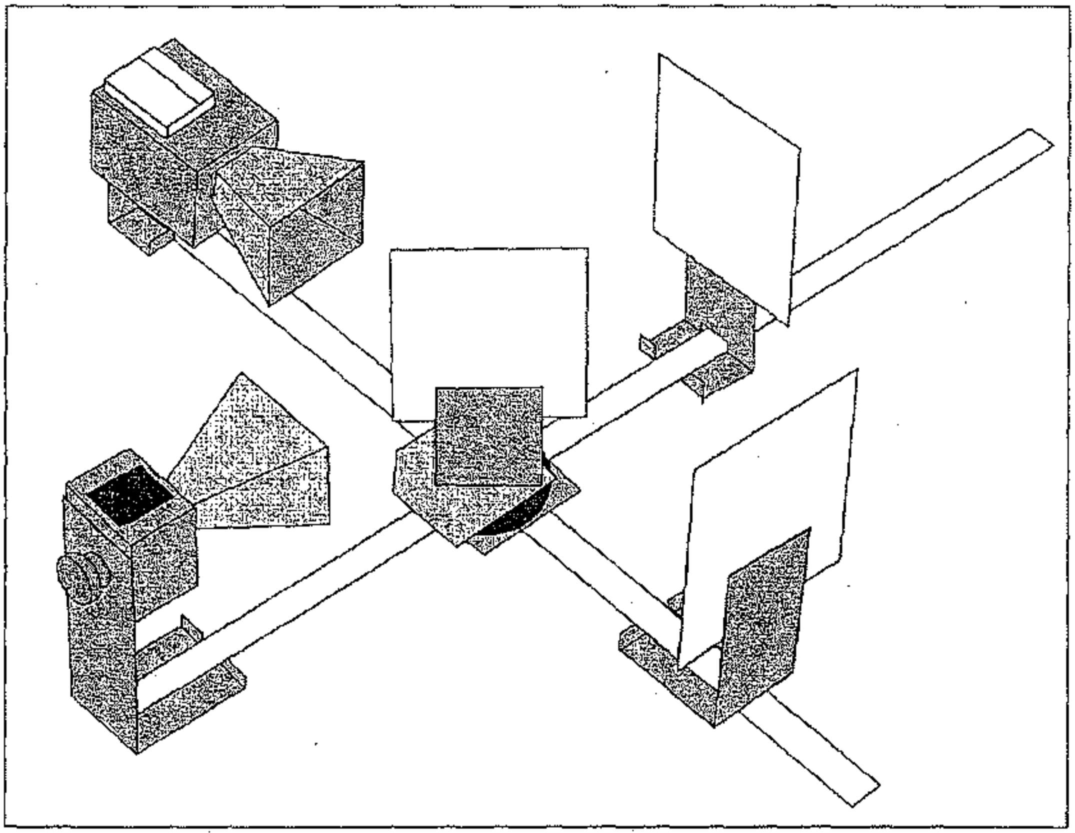
MICROWAVE OPTICS



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Introduction

There are many advantages to studying optical phenomena at microwave frequencies. Using a 2.85 centimeter microwave wavelength transforms the scale of the experiment. Microns become centimeters and variables obscured by the small scale of traditional optics experiments are easily seen and manipulated. The PASCO scientific Model WA-9314B Basic Microwave Optics System is designed to take full advantage of these educational benefits. The Basic Microwave Optics System comes with a 2.85 centimeter wavelength microwave transmitter and a receiver with variable amplification (from 1X to 30X). All the accessory equipment needed to investigate a variety of wave phenomena is also included.

This manual describes the operation and maintenance of the microwave equipment and also gives detailed instructions for many experiments. These experiments range from quantitative investigations of reflection and refraction to microwave models of the Michelson and Fabry-Perot interferometers. For those who have either the Complete Microwave Optics System (WA-9316) or the Microwave Accessory Package (WA-9315), the manual describes experiments for investigating Bragg diffraction and Brewster's angle.

Equipment

Gunn Diode Transmitter

The Gunn Diode Microwave Transmitter provides 15 mW of coherent, linearly polarized microwave output at a wavelength of 2.85 cm. The unit consists of a Gunn diode in a 10.525 GHz resonant cavity, a microwave horn to direct the output, and an 18 cm stand to help reduce table top reflections. The Transmitter may be powered directly from a standard 115 or 220/240 VAC, 50/60 Hz outlet by using the provided power supply. Other features include an LED power-indicator light and a rotational scale that allows easy measurement of the angle of polarization.

The Gunn diode acts as a non-linear resistor that oscillates in the microwave band. 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.

To Operate the Microwave Transmitter

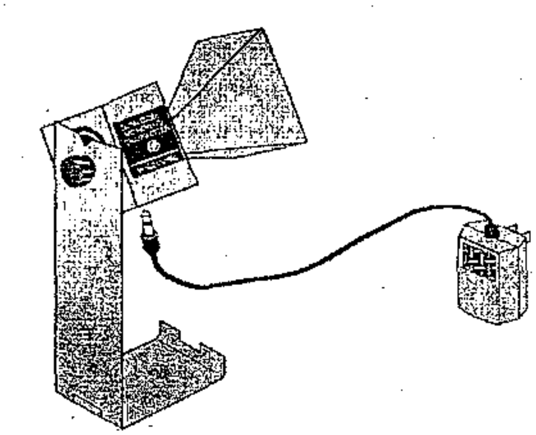
Simply plug the power supply into the jack on the Transmitter's bottom panel and plug the power supply into a standard 115 or 220/240 VAC, 50/60 Hz outlet. The LED will light indicating the unit is on.

> ➤ *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.*

Power Supply Specifications:

9 Volt DC, 500 mA;

Miniature Phone Jack Connector (the tip is positive)

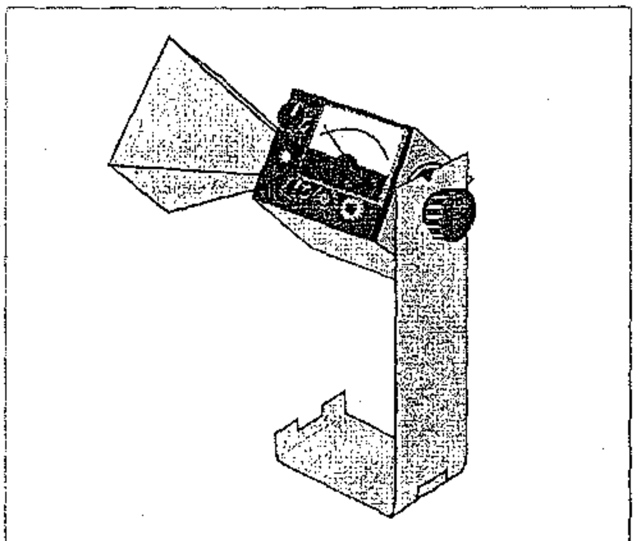


Microwave Transmitter with Power Supply

Microwave Receiver

The Microwave Receiver provides a meter reading that, for low amplitude signals, is approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal.

Special features of the Receiver include four amplification ranges—from one to thirty—with a variable sensitivity knob that allows fine tuning of the amplification in each range. For convenience in class demonstrations, banana plug connectors provide for an output signal via hookup to a projection meter (such as PASCO Model ES-9065 Projection Meter or SE-9617 DC Voltmeter). This output can also be used for close examination of the signal using an oscilloscope. The receiver is battery powered and has an LED battery indicator; if the LED lights when you turn on the Receiver, the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections, and a rotational scale allows convenient measurements of polarization angle.



Microwave Receiver

The female audio connector on the side of the Receiver is for an optional Microwave Detector Probe (PASCO Model WA-9319). The probe works the same as the Receiver except it has no horn or resonant cavity. The Probe is particularly convenient for examining wave patterns in which the horn could get in the way, such as the standing wave pattern described in Experiment 3 of this manual.

> ➤*NOTE: The detector diodes in the Receiver (and the Probe) are non-linear devices. This non-linearity will provide no problem in most experiments. It is important however, to realize that the meter reading is not directly proportional to either the electric field (E) or the intensity (I) of the incident microwave. Instead, it generally reflects some intermediate value.*

To Operate The Microwave Receiver:

> ➤*NOTE: Before using the Receiver, you will need to install the two 9-volt transistor batteries—they are included with the system. See the instructions in the Maintenance section at the end of this manual.*

① Turn the INTENSITY selection switch from OFF to 30X, the lowest amplification level. The battery indicator LED should light, indicating that the battery is okay. If it does not, replace the battery following the procedures in the Maintenance section of this manual.

> ➤*NOTE: The INTENSITY selection settings (30X, 10X, 3X, 1X) are the values you must multiply the meter reading by to normalize your measurements. 30X, for example, means that you must multiply the meter reading by 30 to get the same value you would measure for 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.*

② Point the microwave horn toward the incident microwave signal. Unless polarization effects are under investigation, adjust the polarization angles of the Transmitter and Receiver to the same orientation (e.g., both horns vertically, or both horns horizontally).

③ Adjust the VARIABLE SENSITIVITY knob to attain a meter reading near midscale. If no deflection of the meter occurs, increase the amplification by turning the INTENSITY selection switch clockwise. Remember, always multiply your meter reading by the appropriate INTENSITY selection (30X, 10X, 3X, or 1X) if you want to make a quantitative comparison of measurements taken at different INTENSITY settings.

Experiment 1: Introduction to the System

EQUIPMENT NEEDED:

- Transmitter
- Receiver
- Goniometer
- Reflector (1)

Purpose

This experiment gives a systematic introduction to the Microwave Optics System. This may prove helpful in learning to use the equipment effectively and in understanding the significance of measurements made with this equipment. It is however not a prerequisite to the following experiments.

Procedure

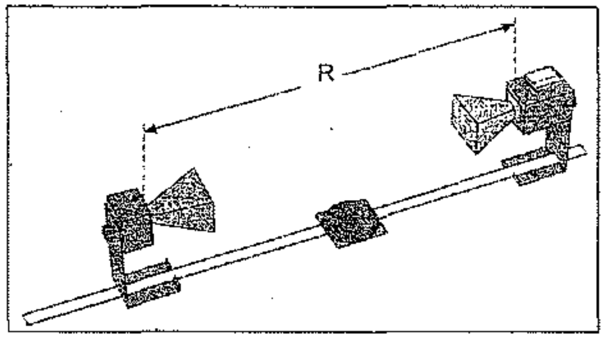


Figure 1.1 Equipment Setup

① Arrange the Transmitter and Receiver on the Goniometer as shown in Figure 1.1 with the Transmitter attached to the fixed arm. Be sure to adjust both Transmitter and Receiver to the same polarity—the horns should have the same orientation, as shown.

② Plug in the Transmitter and turn the INTENSITY selection switch on the Receiver from OFF to 10X. (The LEDs should light up on both units.)

③ Adjust the Transmitter and Receiver so the distance between the source diode in the Transmitter and the detector diode in the Receiver (the distance labeled R in Figure 1.1) is 40 cm (see Figure 1.2 for location of points of transmission and reception). The diodes are at the locations marked "T" and "R" on the bases. Adjust the INTENSITY and VARIABLE SENSITIVITY dials on the Receiver so that the meter reads 1.0 (full scale).

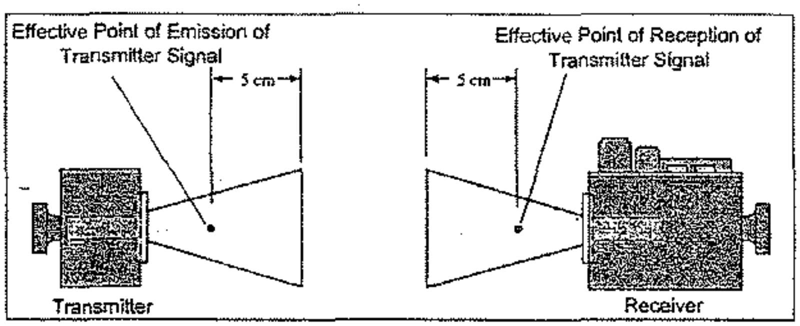


Figure 1.2 Equipment Setup

④ Set the distance R to each of the values shown in Table 1.1. For each value of R, record the meter reading. (Do not adjust the Receiver controls between measurements.) After making the measurements, perform the calculations shown in the table.

⑤ Set R to some value between 70 and 90 cm. While watching the meter, slowly decrease the distance between the Transmitter and Receiver. Does the meter deflection increase steadily as the distance decreases?

Table 1.1

R (cm)	Meter Reading (M)	M X R (cm)	M X R^2 (cm^2)
40	1.0	40	1600
50			
60			
70			
80			
90			
100			

⑥ Set R to between 50 and 90 cm. Move a Reflector, its plane parallel to the axis of the microwave beam, toward and away from the beam axis, as shown in Figure 1.3. Observe the meter readings. Can you explain your observations in steps 5 and 6? Don't worry if you can't; you will have a chance to investigate these phenomena more closely in Experiments 3 and 8, later in this manual. For now just be aware of the following:

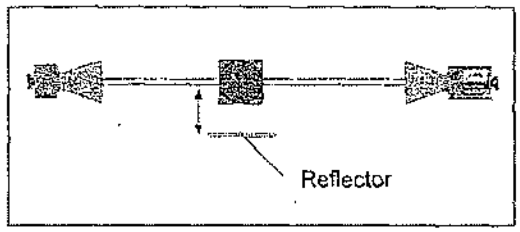


Figure 1.3 Reflections

> ➤ IMPORTANT: 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 required for the current experiment.

⑦ Loosen the hand screw on the back of the Receiver and rotate the Receiver as shown in Figure 1.4. This varies the polarity of maximum detection. (Look into the receiver horn and notice the alignment of the detector diode.) Observe the meter readings through a full 360 degree rotation of the horn. A small mirror may be helpful to view the meter reading as the receiver is turned. At what polarity does the Receiver detect no signal?

Try rotating the Transmitter horn as well. When finished, reset the Transmitter and Receiver so their polarities match (e.g., both horns are horizontal or both horns are vertical).

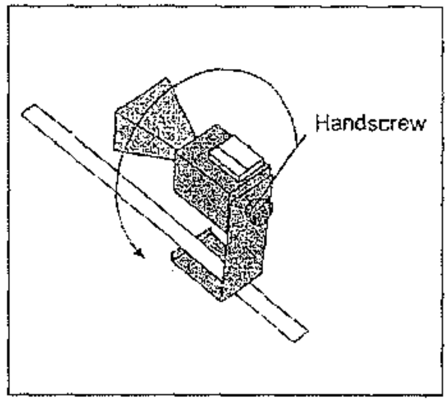


Figure 1.4 Polarization

⑧ Position the Transmitter so the output surface of the horn is centered directly over the center of the Degree Plate of the Goniometer arm (see Figure 1.5). With the Receiver directly facing the Transmitter and as far back on the Goniometer arm as possible, adjust the Receiver controls for a meter reading of 1.0. Then rotate the rotatable arm of the Goniometer as shown in the figure. Set the angle of rotation (measured relative to the 180-degree point on the degree scale) to each of the values shown in Table 1.2, and record the meter reading at each setting.

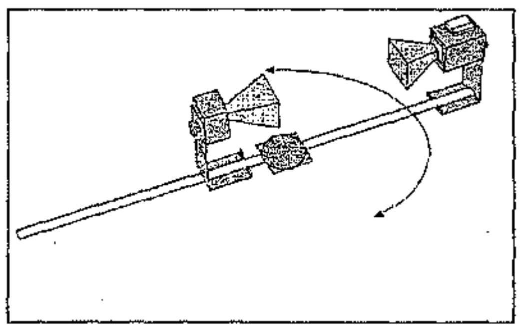


Figure 1.5 Signal Distribution

Table 1.2

Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading
0°		70°		140°	
10°		80°		150°	
20°		90°		160°	
30°		100°		170°	
40°		110°		180°	
50°		120°			
60°		130°			

Questions

① The electric field of an electromagnetic wave is inversely proportional to the distance from the wave source
(i.e., $\mathbf{E} = 1/\mathbf{R}$). Use your data from step 4 of the experiment to determine if the meter reading of the Receiver is directly proportional to the electric field of the wave.

② The intensity of an electromagnetic wave is inversely proportional to the square of the distance from the wave source (i.e., $\mathbf{I} = 1/\mathbf{R}^2$). Use your data from step 4 of the experiment to determine if the meter reading of the Receiver is directly proportional to the intensity of the wave.

③ Considering your results in step 7, to what extent can the Transmitter output be considered a spherical wave? - A plane wave?

Experiment 3: Standing Waves - Measuring Wavelengths

> ➤ NOTE: This experiment is best performed using the PASCO Microwave Detector Probe (Model ME-9319), as described in Method A below. However, for those without a probe, Method B may be used, although in this Method λ can not be measured directly from the standing wave pattern.

EQUIPMENT NEEDED:

- Transmitter
- Receiver
- Component Holder (2)
- Goniometer
- Reflector (1)
- Microwave Detector Probe (ME-9319)

Introduction

When two electromagnetic waves meet in space, they superpose. Therefore, the total electric field at any point is the sum of the electric fields created by both waves at that point. If the two waves travel at the same frequency but in opposite direction they form a standing wave. Nodes appear where the fields of the two waves cancel and antinodes where the superposed field oscillates between a maximum and a minimum. The distance between nodes in the standing wave pattern is just 1/2 the wavelength (λ) of the two waves.

Procedure

Method A

In this experiment, you will reflect the wave from the Transmitter back upon itself, creating a standing wave pattern. By measuring the distance between nodes in the pattern and multiplying by two, you can determine the wavelength of the microwave radiation.

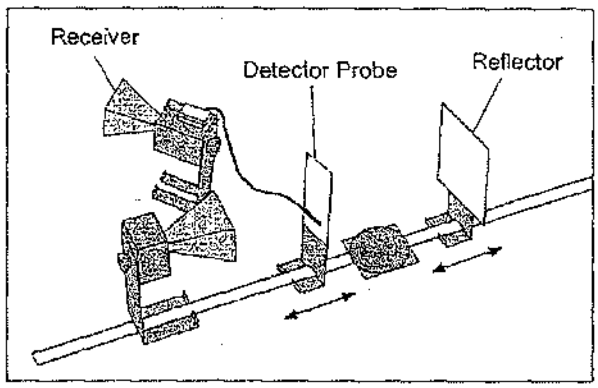


Figure 3.1 Equipment Setup

① Arrange the equipment as shown in Figure 3.1.

② Plug the Detector Probe into the side connector on the Receiver. Face the Receiver horn directly away from the Transmitter so that none of the microwave signal enters the horn. Adjust the Receiver controls as needed to get a strong meter reading.

③ Slide the Probe along the Goniometer arm (no more than a centimeter or two) until the meter shows a maximum reading. Then slide the Reflector (again, no more than a centimeter or two) to find a maximum meter reading. Continue making slight adjustments to the Probe and Reflector positions until the meter reading is as high as possible.

④ Now find a node of the standing wave pattern by adjusting the Probe until the meter reading is a minimum. Record the Probe Position along the metric scale on the Goniometer arm.

Initial Probe Position = ______________________.

⑤ While watching the meter, slide the Probe along the Goniometer arm until the Probe has passed through at least 10 antinodes and returned to a node. Record the new position of the Probe and the number of antinodes that were traversed.

Antinodes Traversed= ______________________.

Final Probe Position = ______________________.

⑥ Use your data to calculate λ, the wavelength of the microwave radiation.

λ = ______________________.

⑦ Repeat your measurements and recalculate λ.

Initial Probe Position = ______________________.

Antinodes Traversed = ______________________.

Final Probe Position = ______________________.

λ = ______________________.

Questions

① Use the relationship velocity = $\lambda\nu$ to calculate the frequency of the microwave signal (assuming velocity of propagation in air is **$3x10^8$ m/sec**).

(ν = the expected frequency of the microwave radiation - 10.525 GHz).

Method B

① Set up the equipment as shown in Figure 3.2. Adjust the Receiver controls to get a full-scale meter reading with the Transmitter and Receiver as close together as possible. Slowly move the Receiver along the Goniometer arm, away from the Transmitter. How does this motion effect the meter reading?

The microwave horns are not perfect collectors of microwave radiation. Instead, they act as partial reflectors, so that the radiation from the Transmitter reflects back and forth between the Transmitter and Reflector horns, diminishing in amplitude at each pass. However, if the distance between the Transmitter and Receiver diodes is equal to **$n\lambda/2$**, (where **n** is an integer and λ is the wavelength of the radiation) then all the multiply-reflected waves entering the Receiver horn will be in phase with the primary transmitted wave. When this occurs, the meter reading will be a maximum. (The distance between adjacent positions in order to see a maximum is therefore $\lambda/2$.)

② Slide the Receiver one or two centimeters along the Goniometer arm to obtain a maximum meter reading. Record the Receiver position along the metric scale of the Goniometer arm.

Initial Position of Receiver =

______________________.

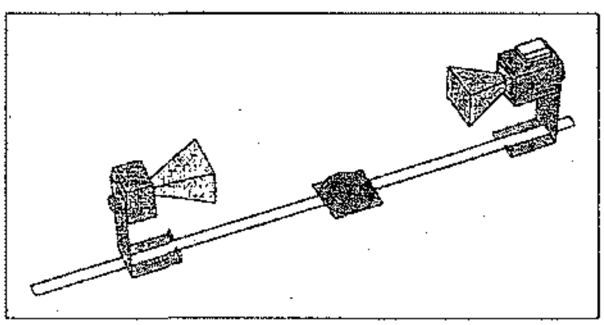


Figure 3.2 Equipment Setup

③ While watching the meter, slide the Receiver away from the Transmitter. Do not stop until the Receiver passed through at least 10 positions at which you see a minimum meter reading and it returned to a position where the reading is a maximum. Record the new position of the Receiver and the number of minima that were traversed.

Minima Traversed= ______________________.

Final Receiver Position = ______________________.

④ Use the data you have collected to calculate the wavelength of the microwave radiation.

λ = ______________________.

⑤ Repeat your measurements and recalculate λ.

Initial Position of Receiver = ______________________.

Minima Traversed = ______________________.

Final Receiver Position = ______________________.

λ = ______________________.

Questions

① Use the relationship velocity = $\lambda\nu$ to calculate the frequency of the microwave signal (assuming velocity of propagation in air is 3×10^8 **m/sec**).

(ν = the expected frequency of the microwave radiation -10.525 GHz).

Experiment 5: Polarization

EQUIPMENT NEEDED:

- -Transmitter
- -Goniometer
- -Polarizer (1).
- -Receiver
- -Component Holder (1)

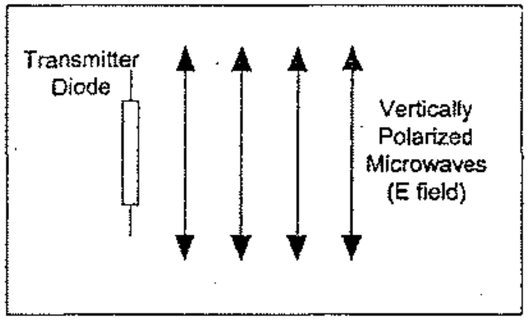


Figure 5.1 Vertical Polarization

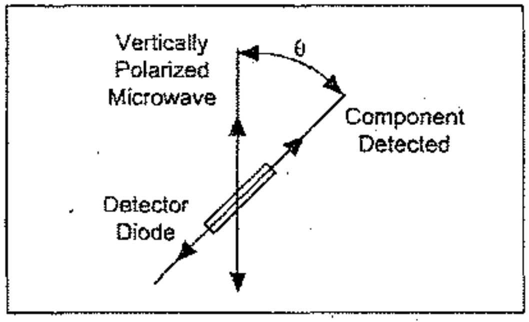


Figure 5.2 Detecting Polarized Radiation

Introduction

The microwave radiation from the Transmitter is **linearly polarized** along the Transmitter diode axis (i.e., as the radiation propagates through space, its electric field remains aligned with the axis of the diode). If the Transmitter diode were aligned vertically, the electric field of the transmitted wave would be vertically polarized, as shown in Figure 5.1. If the detector diode were at an angle θ to the Transmitter diode, as shown in Figure 5.2, it would only detect the component of the incident electric field that was aligned along its axis. In this experiment you will investigate the phenomenon of polarization and discover how a polarizer can be used to alter the polarization of microwave radiation.

Procedure

① Arrange the equipment as shown in Figure 5.3 and adjust the Receiver controls for nearly full-scale meter deflection.

② Loosen the hand screw on the back of the Receiver and rotate the Receiver in increments of ten degrees. At each rotational position, record the meter reading in Table 5.1.

③ What happens to the meter readings if you continue to rotate the Receiver beyond 180-degrees?

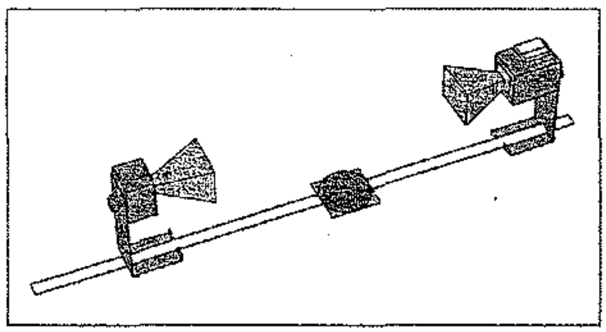


Figure 5.3 Equipment Setup

Table 5.1

Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading
0°		70°		140°	
10°		80°		150°	
20°		90°		160°	
30°		100°		170°	
40°		110°		180°	
50°		120°			
60°		130°			

④ Set up the equipment as shown in Figure 5.4. Reset the Receivers angle to 0-degrees (the horns should be oriented as shown with the longer side horizontal).

⑤ Record the meter reading when the Polarizer is aligned at 0, 22.5, 45, 67.5 and 90-degrees with respect to the horizontal.

⑥ Remove the Polarizer slits. Rotate the Receiver so the axis of its horn is at right angles to that of the Transmitter. Record the meter reading. Then replace the Polarizer slits and record the meter readings with the Polarizer slits horizontal, vertical, and at 45-degrees.

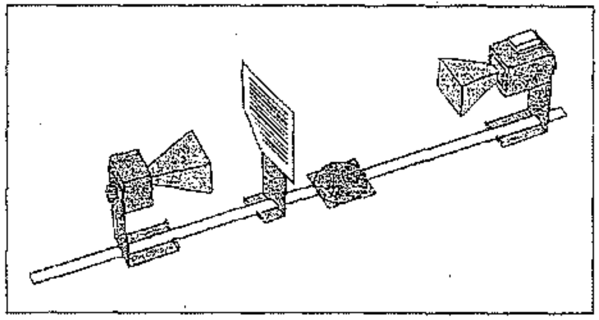


Figure 5.4 Equipment Setup

Angle of Polarizer	Meter Reading
0° (Horiz.)	
22.5°	
45°	
67.5°	
90° (Vert.)	

Angle of Slits	Meter Reading
Horizontal	
Vertical	
45°	

Questions

① If the Receiver meter reading (M) were directly proportional to the electric field component (E) along its axis, the meter would read the relationship $M = M_o\cos\theta$ (where θ is the angle between the detector and Transmitter diodes and Mo is the meter reading when $\theta = 0$). (See Figure 5.2). Graph your data from step 2 of the experiment. On the same graph, plot the relationship $M_o \cos\theta$. Compare the two graphs.

② The intensity of a linearly polarized electromagnetic wave is directly proportional to the square of the electric field (e.g., $I = kE^2$). If the Receiver's meter reading was directly proportional to the incident microwave's intensity, the meter would read the relationship $M = M_o\cos^2\theta$. Plot this relationship on your graph from question 1. Based on your graphs, discuss the relationship between the meter reading of the Receiver and the polarization and magnitude of the incident microwave.

③ Based on your data from step 5, how does the Polarizer affect the incident microwave?

④ Can you explain the results of step 6 of the experiment. How can the insertion of an additional polarizer increase the signal level at the detector? (HINT: Construct a diagram like that shown in Figure 5.2 showing (1) the wave from the Transmitter; (2) the wave after it passes through the Polarizer; and (3) the component detected at the detector diode.)

Experiment 6: Double-Slit Interference

EQUIPMENT NEEDED:

- Transmitter, Receiver
- Component Holder
- Slit Extender Arm
- Wide Slit Spacer
- Goniometer, Rotating
- Metal Reflectors (2)
- Narrow Slit Spacer

Introduction

In Experiment 3, you saw how two waves moving in opposite directions can superpose to create a standing wave pattern. A somewhat similar phenomenon occurs when an electromagnetic wave passes through a two-slit aperture. The wave diffracts into two waves which superpose in the space beyond the apertures. Similar to the standing wave pattern, there are points in space where maxima are formed and others where minima are formed.

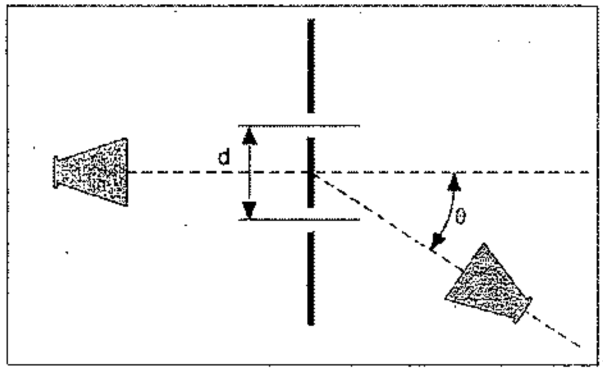


Figure 6.1 Double-Slit Interference

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**, maxima will be found at angles such that **d** $\sin\theta = n\lambda$. (Where θ = the angle of detection, λ = the wavelength of the incident radiation, and **n** is any integer) (See Figure 6.1). Refer to a textbook for more information about the nature of the double-slit diffraction pattern.

Procedure

① Arrange the equipment as shown in Figure 6.2. Use the Slit Extender Arm, two Reflectors, and the Narrow Slit Spacer to construct the double slit. (We recommend a slit width of about 1.5 cm.) Be precise with the alignment of the slit and make the setup as symmetrical as possible.

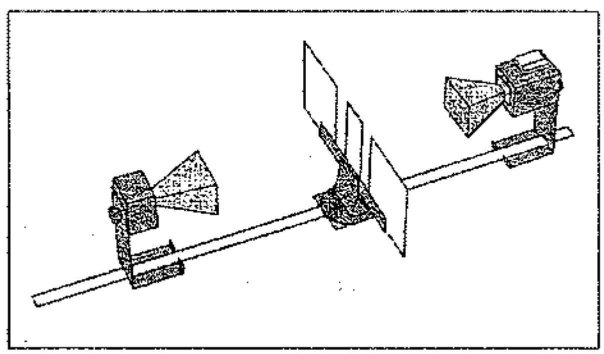


Figure 6.2 Equipment Setup

② Adjust the Transmitter and Receiver for vertical polarization (0°) and adjust the Receiver controls to give a full-scale reading at the lowest possible amplification.

③ Rotate the rotatable Goniometer arm (on which the Receiver rests) slowly about its axis. Observe the meter readings.

④ 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 each of the values shown in Table 6.1. At each setting record the meter reading in the table. (In places where the meter reading changes significantly between angle settings, you may find it useful to investigate the signal level at intermediate angles.)

⑤ 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. Because the Wide Slit Space is 50% wider than the Narrow Slit Spacer (90mm vs 60mm) move the Transmitter back 50% so that the microwave radiation at the slits will have the same relative intensity. Repeat the measurements. (You may want to try other slit spacings as well.)

Table 6.1

Angle	Meter Reading	Angle	Meter Reading
0°		45°	
5°		50°	
10°		55°	
15°		60°	
20°		65°	
25°		70°	
30°		75°	
35°		80°	
40°		85°	

Questions

① From your data, plot a graph of meter reading versus θ. Identify the angles at which the maxima and minima of the interference pattern occur.

② Calculate the angles at which you would expect the maxima and minima to occur in a standard two-slit diffraction pattern—maxima occur wherever $\mathbf{d \sin\theta = n\lambda}$, minima occur wherever $\mathbf{d \sin\theta = n\lambda/2}$. (Check your textbook for the derivation of these equations, and use the wavelength measured in experiment 3.) How does this compare with the locations of your observed maxima and minima? Can you explain any discrepancies? (What assumptions are made in the derivations of the formulas and to what extent are they met in this experiment?)

③ Can you explain the relative drop in intensity for higher order maxima? Consider the single-slit diffraction pattern created by each slit. How do these single slit patterns affect the overall interference pattern?

➤ NOTE:

① Wavelength at 10.525 GHz = 2.85 cm.

② The experimenter's body position may affect the results.