CAUTION: The output power of the microwave transmitter is well below standard safety levels. Nevertheless, do not look directly into the microwave horn at close range when the transmitter is on.

The arms of the goniometer slide through the holes in the base of the component holders, the magnetic strip on the bottom of the arms grips the base of the carriage. The microwave transmitter and receiver mount onto the arms in the same manner. It is usually advantageous to attach the transmitter to the fixed arm of the goniometer and the receiver to the rotating arm. This allows a fixed relationship to be maintained between the microwave beam and the components mounted on the fixed arm. The components maybe, reflectors, slits or polarizers.

Here is a holder attached to one of the arms.

What you Need to Know.

Here’s a quick survey of the equipment you will be using. You have a Gunn diode Transmitter and microwave receiver.

These can be mounted on the goniometer arms. One arm will rotate, it is best to attach the receiver to this arm.
**Transmitter:**

The Gunn diode transmitter provides 15mW of coherent, linearly polarized microwave output at a wavelength of $\lambda = 2.9$ cm. The unit consists of a diode in a 10.5 GHz resonant cavity, a microwave horn to direct output, and an 18 cm stand to help reduce table top reflections. The transmitter can be plugged directly into the wall outlet. You also have an LED power light and a rotational scale that allows easy measurement of angles.

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, narrow beam along the center axis of the horn.

**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 collects the microwave signal and channels it to a diode in a 10.5 GHz resonant cavity. The diode responds only to the component of the signal that is polarized along the diode axis, producing a dc voltage that varies with the magnitude of the microwave signal. You have signal amplification over a 5 decade range. There is a variable sensitivity knob that allows a full scale meter setting for any intensity. The receiver is battery powered and has an LED battery indicator for charge.

Unfortunately, the non linearity of the detector diode precludes better than an approximate proportionality between the signal intensity and the meter reading. For higher signal readings the meter reading tends to show a closer proportionality to the E-field than the intensity $|E|^2$ which should be considered when interpreting your data.

**Hints for Operation:**

1. To prolong the life of the meter always begin with a low sensitivity selection and increase sensitivity until you get a readable signal level. The available range is from 1-10,000.
2. Saturation of the receiver can occur at any sensitivity setting if the signal is too high for that setting. If the meter fails to respond to changes in signal intensity, change to a lower sensitivity setting. If the sensitivity is already at the lowest setting it may be necessary to move the transmitter and receiver farther apart or to attenuate the signal using a partial reflector.

**To Operate the Microwave Receiver:**

1. Turn the SENSITIVITY selection switch from OFF to 1, the lowest level. The battery indicator LED should light. If it does not replace the battery.
2. Point the microwave horn toward the incident microwave signal. Unless you are investigating polarization, align the rotational positions of the transmitter and receiver.
3. Adjust the VARIABLE SENSITIVITY knob to attain a meter reading of the desired level. If no deflection occurs, increase the amplification by turning the SENSITIVITY selection switch to a higher setting.

Microwave light is still electromagnetic radiation as is visible light. Microwave wavelengths are measured in cm, or $10^2$ m, whereas visible light wavelengths are measured in hundreds of nm., or $10^7$m. The same optics principles apply to both. The same equations apply for microwaves hence the title microwave optics. We could also set up a Michelson interferometer with microwave but we think 5 parts is enough!
This lab has 5 parts:

1. Reflection
2. Standing waves
3. Polarization
4. Single slit diffraction
5. Double slit interference.

INTRODUCTION:

Brief Introduction: Arrange the transmitter and receiver in a line as shown.

1. Make sure the rational scale on the back of each unit reads zero degrees. If not, loosen the hand screw and adjust the transmitter and receiver to the same polarity.

2. Plug in the transmitter and turn the sensitivity selection switch on the receiver from OFF to 1. Both LEDs should light up on transmitter and receiver.

3. Vary the distance between the transmitter and receiver and observe the meter reading. As the units are brought closer together there is a point where the meter reading stops increasing. At this point the receiver is saturated. Bringing the transmitter and receiver closer together will not give meaning results.

4. Vary the sensitivity by turning the VARIABLE SENSITIVITY knob. Does varying this setting effect the distance at which the amplifier saturates? Move the receiver and transmitter further apart and check for saturation at higher SENSITIVITY settings. Note that readings taken near saturation will not be accurate.

We continue with Experiment 1….
Experiment 1: Reflection.

You need a metal reflector and a rotating component holder in addition to the transmitter, receiver and goniometer.

![Diagram of equipment setup]

Make sure the rotational scales at the back of each instrument are set to zero. Arrange the equipment as shown in the left diagram. Plug in the transmitter, turn on the receiver and set a low sensitivity. Make sure the receiver is not saturated at the separation distance you have chosen.

Half width angle measurement:

With the reflector still NOT attached, move the movable arm off axis at which the meter drop to ½ of the maximum value. The difference between these two angles is the angular half width of the signal.

Realign the goniometer to zero degrees, like the left diagram. Now attach the reflector (metal plate) like in the right diagram.

Rotate the arm 40 degrees off axis… now rotate the component (plate ) holder to get the maximum possible signal reading. At what angle does this occur?

Measure several angles on incidence and reflection as shown in the diagram, use 10 degree increments for the angle. You may need to increase the sensitivity for small angles.

What relationship holds between angle of incidence and angle of reflection?

For each angle you try measure the half width angle. Does the half width of the signal vary with angle of reflection?
**Experiment 2: Standing Waves**

The microwave horn of the receiver is not a perfect collector of microwave signals. In fact a substantial proportion of the incident wave is reflected back toward the source. The superposition of the incident and reflected waves creates a standing wave pattern. In this experiment we investigate this standing wave and use it to measure the wavelength of the microwaves.

1. Arrange the equipment as shown. Remove the reflector for now. Make sure the transmitter and receiver are far enough apart that the receiver is not saturated. Turn on the transmitter and receiver and adjust to low sensitivity. Then adjust the sensitivity knob to obtain a full scale reading.

2. Re-attach the reflector to the holder. Slide the component holder along the arm and observe the fluctuations in the meter reading. When the reading goes to its lowest value we call this position a “node” when the reading is a maximum this position is an “anti-node”. Determine the positions of the nodes and anti-nodes.

3. Record the meter readings with the partial reflector at a node and at an anti-node. Try several different positions for each. Compare these values with that obtained with the reflector removed from the path of the beam.

4. Measure the distance between adjacent nodes of the standing wave pattern. This is measured most accurately by measuring the distance between several nodes and dividing by the number of nodes. What is the wave length of the microwaves? See the diagram below… it might help you decide. You know the freq is 10.5 GHz, what do you expect the velocity of these microwaves in air to be?

**Standing waves:**

Think are you measuring E-field or intensity $|E|^2$, does it matter here?
Experiment 3: Polarization.

Remember we have standing waves and there are nodes, bare this in mind when taking measurements for this experiment. Make sure the receiver is at a anti-node position, or a maximum signal point.

Set up the arrangement shown below.

1. Arrange the transmitter and receiver approximately 35 cm apart as shown. Check that this does not saturate the receiver.

2. **Remove the polarizers** (metal sheets with slits in them) and adjust the receiver controls for a meter reading of about 0.8. Slide the receiver a few centimeters along the arm to be sure it is located at a maximum.

3. Loosen the hand screws on the back of the receiver and rotate the receiver by about 5 degrees. Record the meter reading. Continue rotating the receiver in small increments. Plot the meter reading as a function of the angle of the receiver.

4. Reset the angle of rotation of the receiver to zero. **Attach a polarizer to one of the component holders** (which should already be in place). Set the slits to be horizontal. Slide the component holder slowly along the arm and observe the fluctuations in the meter reading. The effect of the polarizer depends on the position with respect to the standing wave pattern between the horns.

5. With the slits of the polarizer aligned horizontally, position the component holder for maximum meter deflection. Compare the meter reading with that obtained without the polarizer in place. Rotate the polarizer 45 degrees and observe the output. How does this compare with the measurements made in step 3? (with no polarizer present.) You could also try this with the polarizer position set to a node just to see what the difference is.

6. Set the transmitter and receiver rotation at zero, (vertical polarization.) Attach polarizers to both component holders with the slits aligned horizontally. Adjust the position of the component holders for a maximum meter reading. Now turn the polarizer nearest the receiver so its slits are vertical. Does any signal get through to the receiver? Rotate the receiver through 360 degrees to check all polarization angles. Can you adjust the polarization angle of the other polarizer so that the signal passes through to the receiver? How about if you adjust the receiver polarization as well?
**Experiment 4: Single Slit Diffraction.**

This microwave system will not allow observation of higher order maxima in the single slit pattern. This is because the narrow beam of the microwave transmitter will not provide sufficient illumination over a wide enough slit. However, it is a useful prelude to 2 slit interference coming next.

Set up the arrangement below:

1. Use the slit extender arm and both reflectors to construct a vertical slit of approximately 4 cm width. Align the slit as symmetrically as possible.

2. Set the rotation scale on the back of both transmitter and receiver to 90 degrees, for horizontal polarization. Adjust the receiver controls to give a full scale reading at the lowest possible sensitivity setting.

3. Rotate the receiver arm slowly about its axis. Observe the meter readings. At several different angles of the arm, move the receiver a few centimeters back and forth along the arm and observe the meter readings.

4. Reset the arm so that the receiver faces the transmitter. Slide the receiver along the arm (no more than a cm in each direction) to obtain a maximum reading. Record this value. Now rotate the arm in increments of a few degrees.

5. At each setting, slide the receiver along the arm just enough to ensure that the reading is a relative maximum. Plot these meter readings as a function of the angle of the goniometer arm.

6. Use the wide slit spacer to re-adjust the slit width to 7 cm. Move the transmitter about 20 cm further away from the slit to provide a more uniform illumination of the slit. Repeat the measurements of step 3.

Measure the $\frac{1}{2}$ widths of the graphs plotted in parts 4 and 5. This is the change in angle corresponding to a drop of $\frac{1}{2}$ the intensity in the meter reading. How does the $\frac{1}{2}$ width relate to the slit width? How closely does this experiment follow the theory?

\[ I = I_0 \left( \frac{\sin x}{x} \right)^2 \]

where \[ x = \left( k \frac{a \sin \theta}{\lambda} \right) / 2 = \left( \pi \frac{a \sin \theta}{\lambda} \right) / k \quad \text{and} \quad k = 2\pi / \lambda. \]

Here \( I_0 \) is the maximum signal strength, \( \lambda \) is the wavelength, \( a \) is the slit width and \( \theta \) is the angle at which the signal was detected.

The standard Fraunhoffer formula for a single slit depends on several assumptions. What are they and do they apply in this experiment? *(Relative widths, lengths and distances are involved.)*
Experiment 5. Double Slit Interference.

Set up the arrangement below:

1. Use the slit extender arm, 2 reflectors and the narrow slit spacer to construct a double slit. The slits should be about 1.5 cm wide, make the arrangement as symmetrical as possible. The separation of slits should be about 3cm.

2. Adjust the transmitter and receiver for horizontal polarization (90 degree on back scale). Adjust the receiver controls to get a full scale reading at the lowest possible amplification.

3. Rotate the goniometer arm through 90 degrees in increments of 5 degrees or less. At each position, slide the receiver back and forth a cm or two to ensure the deflection is at a maximum. Plot the meter readings as a function of the angle of the receiver arm. Zero angle is the straight through position shown above.

4. Change the distance between the slits by using the wide slit spacer instead of the narrow one. Adjust the transmitter position to the starting position shown in the figure. Repeat the measurements of steps 2 and 3.

Calculate the angles at which you could expect maxima and minima in a standard 2 slit interference pattern. Use the wavelength measured in Experiment 2. How does this compare to the experimental values? Can you explain any discrepancies? What assumptions are made in the usual Fraunhofer theory and are these assumptions met here?

Explain the relative drop in intensity for higher order maxima.
How could you minimize the relative drop and would this introduce any further difficulties?

For maxima \( d \sin \theta = m \lambda \), the intensity goes like \( I = I_0 \cos^2 y \) where \( y = (kd \sin \theta)/2 = (\pi d \sin \theta)/\lambda \).

The \( I_0 \) has the single slit diffraction intensity in it also!

THE END