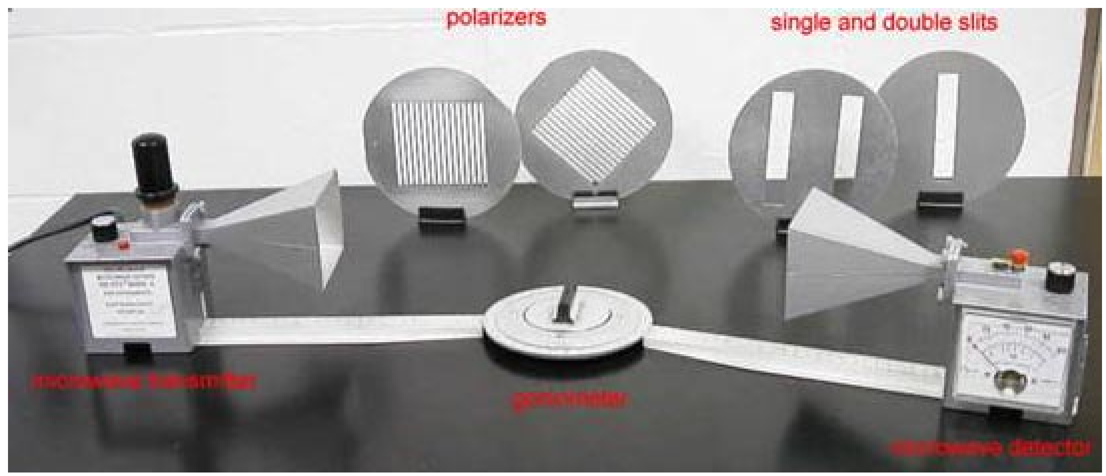
Physics 313: Laboratory 1 – Experiments with Microwaves

Introduction: Microwaves offer an opportunity to study optical phenomena on length scales of centimeters rather than hundreds of nanometers. This makes it very easy to investigate wave phenomena at a qualitative level. After completing the experiments, you should be able to answer the following questions:

- What are the characteristics (angular distribution and polarization state) of the microwave beam produced by the repeller?
- How do polarizers work?
- What are standing wave patterns and how can you produce them?
- What is the wavelength and speed of the microwave radiation?
- What do diffraction patterns look like? How do they arise?

The following equipment is required to collect the data:



Microwave source	Metal slit arrangements	Simulation software	Computer
Microwave detector	Metal polarizers	Goniometer (angle measurer)	Ruler, tape measure

The basic equipment for the experiments in this lab consists of a microwave source or transmitter, which generates about 10 mW of vertically polarized electromagnetic radiation with a frequency around 10 GHz, and a simple diode detector/receiver. Both transmitter and receiver have a small microwave horn to give them some directionality. Operation of the equipment is simple. After plugging in, the source requires about 20 seconds to warm up. It has just one control, labeled "repeller". Adjust this control so that a maximum reading is achieved on a detector facing the source. The detector itself has a sensitivity control, labeled "gain" which can be adjusted to avoid an overload condition on the readout. Note: do not work on the metal optics table to avoid reflections.

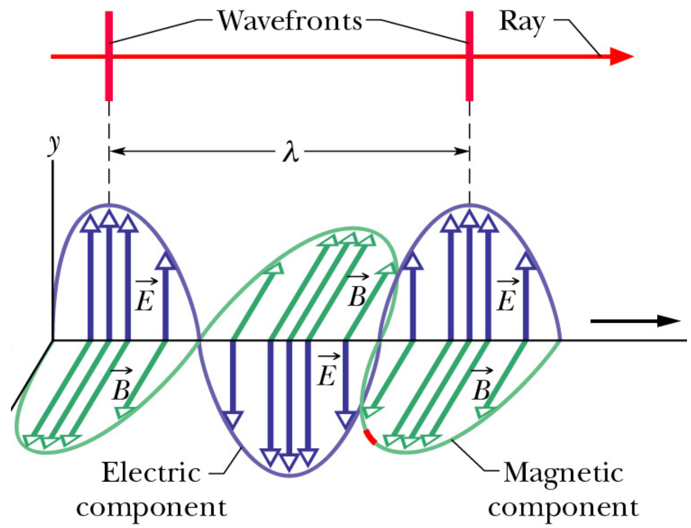


Figure 1: Vertically polarized electromagnetic plane wave.

Experiment 1: Microwave beam characterization

The microwave beam generated by the source is fairly broad both in horizontal and vertical direction. The detector also responds to electromagnetic fields with only limited directionality. <u>Determine the angular resolution of the transmitter/detector combination, using the goniometer. Plot the detector reading as a function of angle between the transmitter and detector.</u>

The transmitter produces vertically polarized microwaves. The detector is only sensitive to electric fields parallel to the diode in the detector. <u>Verify that when you rotate the detector by 90°, while facing the source, the detector reading falls to zero.</u>

Experiment 2: Polarizers

There are many devices that can be used to affect or determine the polarization state of an electromagnetic wave. In a very common situation, realized in the visual wavelengths by Polaroid material, electrical current is free to flow in one direction but not in the perpendicular one. If the electric field is polarized in the direction in which a current can flow, there is a strong interaction between the field and the "polarizer". Energy is transferred from the field to the grid due to Joule heating of the moving electrons in the metal. The accelerated electrons will radiate in a manner which will tend to cancel the incident wave.

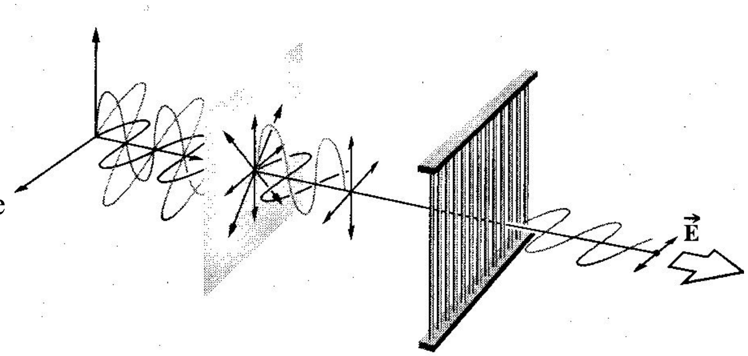


Figure 2: A wire-grid polarizer. The grid eliminates the vertical component (I.e., the one parallel to the wires) of the E-field and passes the horizontal component.

If currents potentially induced by the E-field are not free to flow, no interaction is possible and the electromagnetic wave passes through as if the polarizer is not present.

At the frequency that we are using here, one can achieve this directionality in electrical conductivity by just cutting slots in a piece of aluminum sheet metal. <u>Investigate the effects of placing a polarizer in between the transmitter and detector for various orientations of the polarizer and detector. Also, investigate the effects of a second polarizer.</u>

Experiment 3: Standing waves and wavelength determination

Stable 1D standing waves form when low amplitude waves interfere which are traveling in both directions and which have fixed phase relationships. One physical system which can produce standing waves is a perturbed string. If the distance between string ends is equal to $n\lambda/2$ (n an integer and λ the wavelength), multiply reflected waves will be in phase and standing waves will form. Investigate the formation of standing waves using the "standing waves" applet available by opening the file applets\HRM\index.htm. What frequencies produce standing waves? Is this consistent with the condition given above?

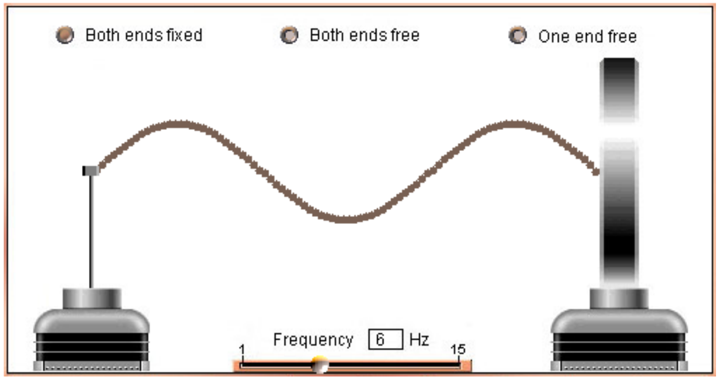


Figure 3: Standing waves applet.

The microwave horns of the transmitter and detector do not perfectly adsorb incoming waves, but will partially reflect them. If the distance between reflecting surfaces is equal to $n\lambda/2$, the detector reading will show a maximum. By determining positions of subsequent maxima it is possible to obtain the wavelength of the microwaves. Instead of using just the transmitter and receiver, you can put a polarizer at 45° in between them. This provides better reflections and much more pronounced maxima and minima. What wavelength do you measure for the microwaves? If their frequency is 10 GHz, what speed for electromagnetic waves does that imply?

Experiment 4: Diffraction

When a plane electromagnetic wave "illuminates" an aperture in a sheet of metal, the aperture becomes a smaller "source" of electromagnetic radiation. When the dimensions of the aperture are of the order of the wavelength, points in the aperture are at different distances to the detector, and radiation from those points will in general have different phases. Thus for some angular positions the interference of the waves coming from different parts of the aperture will be constructive, for others there will be destructive interference. The result is a diffraction pattern.

Investigate diffraction patterns with the "2D Electrodynamics (TE)" applet in the applets\Falstad directory, or go to the website at www.falstad.com. Open directions.html for information on the applet. You can add or subtract conducting surfaces with the mouse. <u>Qualitatively, what do you get when you have a tiny aperture and thus a line source? What happens as you open up the aperture? Does this pattern make sense in terms of interference?</u>

<u>Next, observe and record microwave diffraction patterns for various arrangements of apertures. Are these consistent with the simulations?</u>

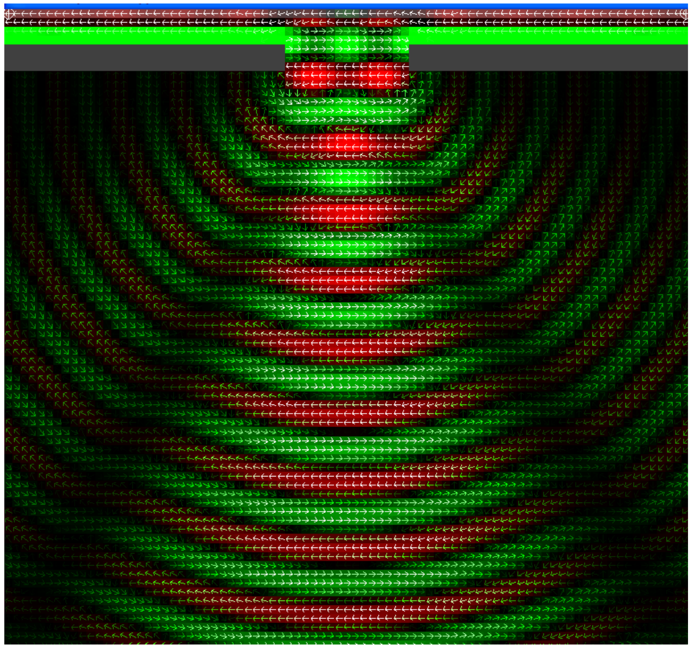


Figure 4: 2D Electrodynamics (TE) applet using the single slit setup.