Physics 216 Laboratory 12, Spring 2018
Interferometers

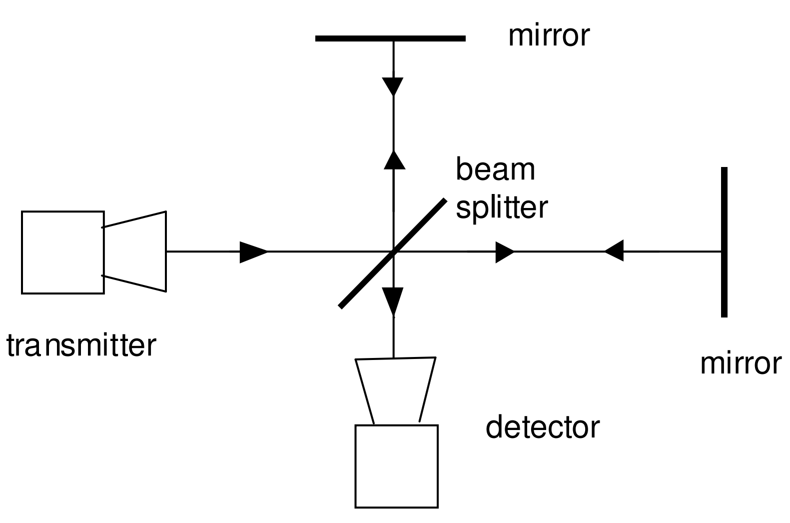
Introduction

Interferometers are devices that can be used to make various types of measurements, or produce patterns, based on the constructive and destructive interference of waves. One well-known type of interferometer is the Michelson interferometer (see Sec. 22.6 in Knight), famous for its use in the historically important Michelson-Morley experiment. This experiment showed (to the surprise of Michelson and Morley themselves) that the speed of light is the same in all directions in an inertial reference frame. In addition to its historic importance, the Michelson interferometer has many other uses, such as measuring very small distances and other properties (such as the index of refraction of air) with great precision. The other type of interferometer we will look at in this lab is Lloyd's mirror, which has applications in a variety of areas including nanopatterning. We will work with versions of these interferometers that use microwaves, since microwave wavelengths are large in comparison to visible light, making the interferometers easier to align and use.

Safety: The intensity of our microwave transmitters is well within accepted safety levels, but it is good practice to avoid unnecessary or close-range exposure (for example, don't stand in the microwave beam or look into the transmitter at close range when it's on). ***Pacemakers or other electronic medical devices may be affected by the microwave radiation. Please let me know if this is an issue.***

Investigation I: The Michelson Interferometer

Microwave radiation from the transmitter is divided into two beams by the partial reflector or "beam splitter" (for microwaves, a sheet of masonite makes a good beam splitter). The reflected beam travels to one "mirror" (a flat metal plate) and the transmitted beam travels to another mirror. These two beams then return to the beam splitter, and a portion of each travels to the detector, as shown. The distance between the beam splitter and one mirror is L_1, and the distance between the beam splitter and the other mirror is L_2.



Whether the beams add constructively or destructively (or something in between) when they recombine depends on the difference in the distance each beam travels from the point where they split to the point where they recombine: that is, the path-length difference. The first beam travels a distance $2L_1$ from the beam splitter to its mirror and back again ("there and back again" gives the factor of 2), and the second beam likewise travels $2L_2$ from the beam splitter to its mirror and back again, so the path-length difference is $2L_2-2L_1$.

If the two beams travel the same distance, the two waves arrive in phase and add constructively to produce a larger wave (which makes the signal in the detector a maximum). In fact, if the path-length difference is any integer multiple of the wavelength ($0, \lambda, 2\lambda, 3\lambda, \ldots$), the two waves arrive in phase and add constructively. But if the path-length difference is equal to $\lambda/2$, $3\lambda/2$, ... the two waves arrive out of phase and tend to cancel (destructive interference), which produces little or no signal in the detector. Stray radiation and the fact that the two beams may not have precisely the same amplitude means that the detector reading at the destructive interference position is usually not precisely zero.

In order to vary the path-length difference between the two waves, one mirror is kept fixed and the other one is moved (changing L_2). If we set the movable mirror at a position that gives constructive interference (a maximum), then moving the mirror a distance $\lambda/2$ brings us to the next maximum, since the path-length difference changes by $2(\lambda/2) = \lambda$. In other words, between successive maxima the mirror moves by $\lambda/2$. In this way, the wavelength of the radiation can be determined. (Or, if the wavelength is known well, it can be used to measure the distance the mirror moves.)

Set up the microwave apparatus, examining it as you do so. Consult the documentation for the microwave apparatus as needed to answer the following.

What do the T and R marks on the mounting stands represent?

Plug in the transmitter and turn on the receiver. Have them face each other and see what the effect is of rotating the receiver horn relative to the transmitter horn. For best sensitivity, how should the horns be oriented relative to each other?

Is the beam from the transmitter wide or narrow? How can you tell?

Adjust the Intensity dial on the receiver to see what effect it has. Move the transmitter and receiver closer to and then farther from each other and note what happens to the readings. What does the "10x" setting mean?

What does the Variable Sensitivity knob do?

√ Checkpoint 1

Now set up the Michelson interferometer as in the diagram. Place one of the mirrors at about the middle of its track (this will be the moveable mirror) and the other mirror about 40 cm from the beam splitter. The beam splitter should be set at about 45°. Adjust the location of the movable mirror to obtain a maximum reading on the detector meter. (If the needle goes off scale, or goes below half scale, change scales.) Also play with the angles of the mirrors and the beam splitter to get a strong maximum. Then move the second mirror slowly away from the beam splitter until the meter reading is a minimum. Rotate the beam splitter slightly to see whether you can reduce the meter reading still further. Move the receiver back and forth and notice the response of the meter as you pass through maxima and minima.

When you're satisfied with the setup, start at a maximum and then move the second mirror slowly away from the beam splitter, determining with as much precision as possible the positions of the mirror at which maxima occur. Make a table below and record at least 10 mirror positions for maxima, x_1, x_2, x_3, ..., x_{10}, along with the meter reading (including which meter scale is being used) for each maximum.

Data analysis
Since the position differences between successive maxima should be equal to λ/2, you might be tempted to simply average all of the differences in order to determine the best value for λ/2, that is, to calculate $\frac{(x_{10}-x_9)+(x_9-x_8)+\cdots+(x_2-x_1)}{9}$.

This turns out to be a poor way to process all that data you took, though, because the above expression reduces to $(x_{10}-x_1)/9$—which means you're throwing away all but your first and last values! Can you think of a way to average your data that doesn't throw most of it away? Discuss your ideas with your instructor.

√ **Checkpoint 2**

Carry out your proposed analysis to find a mean value for the transmitter wavelength and its uncertainty (remember that standard deviation of the mean is the best estimate of uncertainty when you're taking a mean).

An even better analysis procedure is to graph the points $(1,x_1)$, $(2,x_2)$, $(3,x_3)$, ..., $(10,x_{10})$. A graph allows you to check that the underlying theory is actually a good description of what's going on, and helps you spot any possible systematic errors.

What is the relationship between the slope and the wavelength for this graph?

Does the y-intercept have any physical significance? If so what?

Graph your data and determine the slope and the uncertainty in the slope. Use these results to find the wavelength of the microwave radiation and determine the uncertainty in its value. Compare your experimental estimate of the wavelength to the expected value based on the manufacturer's claims.

√ **Checkpoint 3**

Investigation II: Lloyd's mirror
In this type of interferometer, the transmitter produces a wave the spreads out so that part of it goes directly to the receiver, and part of it reaches the receiver after reflecting from a mirror. With our microwave setup, this looks like the diagram below, where the transmitter is to the left, the receiver to the right, and the mirror placed off to the side.

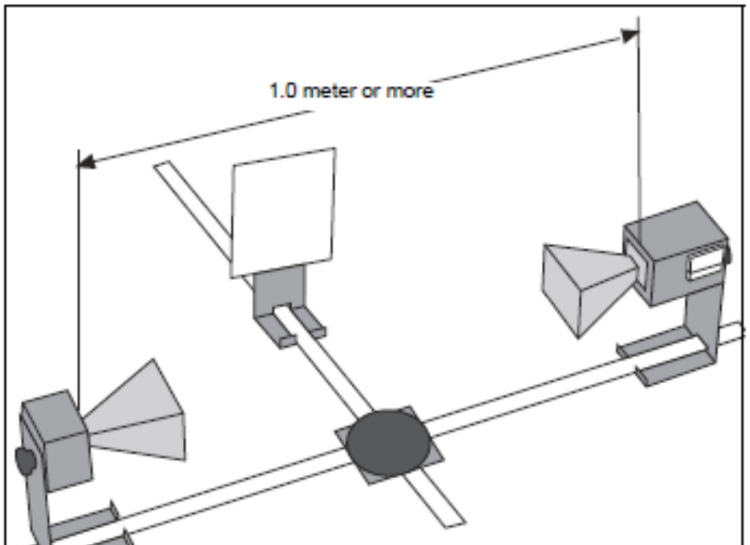


Figure 7.2: Equipment Setup

In the schematic diagram below, we see that waves that travel straight from the transmitter to the receiver (A to C) interfere with waves that travel from the transmitter to the mirror and then reflect to the transceiver (A to B to C).

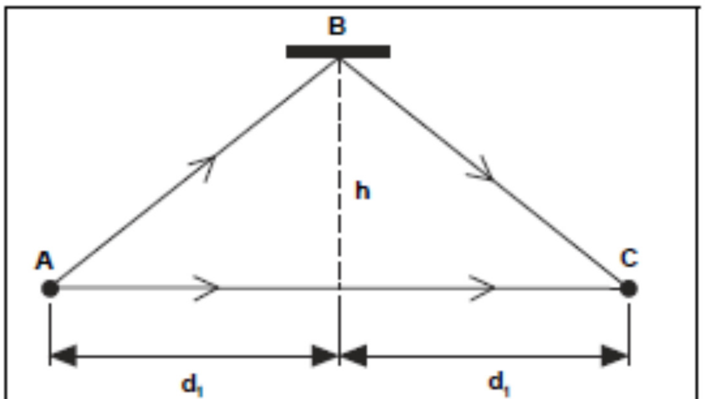


Figure 7.1: Lloyd's Mirror

Write an expression for the path-length difference between the two beams in terms of the distances d_1 and h.

Set up the Lloyd's mirror. Slide the mirror back and forth to find maxima and minima. (Note: your body can reflect microwaves, too, so you'll want to keep it out of the way!)

Record measurements for one position that gives a maximum, and calculate the path-length difference for that position using your expression above.

Move the mirror to the next position that gives a maximum, and again calculate the path-length difference.

Calculate the difference between these two path-length differences. What does this represent? Does this make sense?

√ Checkpoint 4