EXPERIMENT 4
Microwave Michelson Interferometer

1. Microwaves

Microwaves are a form of electromagnetic radiation with wavelengths in the range from 1 cm to 1 m. This wavelength is long enough (frequency is low enough) that an electronic device can be built which will produce the radiation in quantity. At the lowest powers, a few milliwatts, such devices may be either Gunn diodes or klystrons, and at higher powers, hundreds of watts or more, a magnetron is used. The wavelength of microwaves is sufficiently short that diffraction and interference are small enough to allow the radiated energy to be focused or directed into a parallel (collimated) beam. Accordingly, there are many practical uses for microwaves, including signal transmission, heating hot chocolate, detecting thunderstorms, and measuring the speed of baseballs. This experiment explores a few of their simplest optical characteristics.

2. Klystron

In the klystron, electrons are emitted from a hot filament cathode (the negative electrode in the tube) by thermionic emission. These electrons are accelerated toward a hollow anode (the positive electrode) by an external electric field. After the electrons pass through the anode, they are reflected back toward the anode by another negative reflector electrode. The velocity of electrons within the klystron is modulated by their interaction, and an oscillation develops that depends on the reflector voltage and the dimensions of a cavity that is part of the tube. An adjustment of the reflector
voltage is used to tune the tube to resonant oscillation at a typical oscillation frequency $>1 \ \text{GHz}$, $10^6 \ \text{Hz}$, producing radio waves with a wavelength of a few cm. This energy is coupled out of the tube into a waveguide, and then to an antenna. In the device we use, the antenna is a simple horn that matches the waveguide to free space, and directs the radiated energy into a beam.

3. Detector

The frequency of microwave radiation is too high to be detected directly easily, since a typical laboratory oscilloscope would work only up to $\approx 100 \ \text{Mhz}$. The energy of the photons is too small to be detected with your eye, photography, or a photoelectric device. To “see” the microwaves in this experiment, you will use a diode that will rectify the oscillation and produce a current. This DC signal is approximately proportional to the energy incident on the diode, and it is detected by a simple meter in the instrument in the optics lab. The meter has a variable attenuator to adjust its sensitivity for different circumstances.

4. Let the experiments begin ...

A. Startup

Turn on the klystron power supply. Both the klystron and the detector have a similar appearance - the klystron is the one with the power cord! Rotate the on-off switch about 1/3 turn, and wait 30 s or so for the tube to warm up. Point the klystron horn toward the detector horn and separate the two by about 20 cm. Adjust the on-off knob on the klystron while you watch the detector meter. You should
see the power indication increase and decrease as you rotate the knob. The adjustment is very sensitive, but you will find a setting that will produce a maximum signal. Once this setting is found, you should leave it alone for the duration of the experiment. It will probably be necessary to also adjust the attenuator on the detector, but this is not a critical adjustment and you may change it later as the experiment progresses.

B. Transmission

Experiment with inserting various materials between the source and the detector. Obvious things would be a book, your hand, or a piece of metal. It is interesting to try something wet - a damp (not sloppy) sponge, for example. Describe your observations. What conclusions do you draw about the transparency of materials to microwaves?

C. Reflection

While you're at it, look at reflection too. The easiest way is to set the two horns at 90°, and reflect the beam from the klystron into the detector horn with whatever is handy. Try a variety of dielectrics and conductors, describe your observations, and draw conclusions.

D. Polarization

The radiation from the klystron horn is polarized, that is the electric field oscillates in a fixed direction in space, perpendicular to the long dimension of the horn antenna. With the horn sitting on a table, this means that the electric field will be vertical. The
receiving antenna and diode are also only sensitive to radiation with an electric field oscillating in a vertical plane, perpendicular to the long dimension of its horn. When the two are pointing at one another, they are matched for polarization. If you pick up the detector, however, and rotate it 90° so that it is on its side but still pointing at the klystron horn, the signal should decrease dramatically because the radiation emitted by the klystron has the wrong polarization for the receiver. Try it.

Now suppose you were to rotate the receiver only 45°. How much does the signal change?

A conducting screen with parallel slots or wires closer than the wavelength of the microwaves will act to polarize the beam too. Set the detector so that it is pointing toward the source and adjust the attenuator for a signal that is nearly full scale on the meter. Insert the polarizer between the detector and the source and rotate the screen so that the wires are at first vertical and then horizontal. What are the orientations of the polarizer that produce the maximum and minimum signals? Does this make sense to you? Explain.

Measure the maximum signal and rotate the polarizer so that its wires make an angle of ≈ 45° with the vertical. Measure the signal again. What fraction of the signal is detected in this case? With the polarizer still at 45°, rotate the detector horn and determine the polarization of the microwaves passing through the polarizer. Explain these observations. (Hint: Read about the Law of Malus)

**E. Michelson interferometer**

Set up a Michelson interferometer according to the sketch in Figure 1. The mirrors are aluminum sheets, and the beamsplitter is a piece of coarse wire screening. Take some care to make certain that the mirrors are perpendicular to one another, and that the beam from
the source illuminates Mirror A on a line that is also perpendicular to its surface. You may need to move things just a little, but with minor adjustments you should find a strong signal with the detector at the position shown in the figure.

Carefully set a ruler next to Mirror A. Slowly move the mirror away from the beamsplitter and watch the strength of the signal. You should see a very clear drop in signal as you do this. For some positions of the mirror the signal will be nearly zero, and for others it will be quite strong. These are fringes caused by interference for the two possible paths through the interferometer. If \( y \) is the position of Mirror A, then a maximum will occur whenever

\[
m \lambda = 2(y + y_0)
\]

where \( y_0 \) is an unknown constant, and \( m \) is an integer order of interference.

Use this relationship to find the wavelength \( \lambda \) of the microwaves. Start with Mirror A close to the beamsplitter. Move it slowly back from the beamsplitter, and at each position where the signal drops to a minimum record the position of the mirror. Since \( y_0 \) is unknown, the initial starting point is immaterial, as is the point on the mirror support from which you take the position measurement. Be careful not to miss any minima, however. You should be able to find 10 or more in this way. Enter the data in a file with \( m \) as the “x” entry and \( y \) as the “y” entry. Use your favorite software (e.g. Excel) to display the results. If you accidentally missed a minimum you will notice it now as an extra step in the plot. If that happens, you should locate the missing minimum and include its position before continuing. Fit the data with a straight line. The line will be the solution.
\[ y = \frac{m \lambda}{2} - y_0 \]

The slope of this line is
\[ \frac{dy}{dm} = \frac{\lambda}{2} \]

What is the wavelength of the microwave emission from this klystron? Use \( c = \lambda \nu \) to evaluate the frequency of the microwaves.

Include screen dumps of the computer files with your lab report. Before you disturb the setup used for this measurement, you should complete the last part of the experiment described in the next section.

**F. Index of refraction**

The frequency of microwaves is very low compared to visible light, and for most materials the index of refraction \( n = c/\nu \) is determined by the dielectric constant \( \varepsilon \) for the response of the material to a fixed electric field

\[ n = \sqrt{\varepsilon} \]

Typically, dielectric constants of non-polar materials are somewhere between 2 and 10, but some materials have very large dielectric constants, most notably water with \( \varepsilon \approx 80 \).
Figure 1: With microwaves the Michelson interferometer is simple to set up, and not critically dependent on alignment. A parallel beam with a few milliwatts of microwave emission from the klystron is split at the Beamsplitter. Half of the beam goes to the right and half to back. After reflection, the two beams return to the Receiver where they interfere and are detected.
One way to measure the index is to use the material to change the path length on one arm of the Michelson interferometer. If the thickness of the material is $t$ and its index is $n$, when it is inserted into one side of the interferometer the path $t$ is replaced by the optical path $nt$. The increase in optical path for one pass is $nt - t = (n - 1)t$. When material is present, Mirror A would be closer to the beam splitter by just this amount to give the path difference it would have had without the material. If you can determine this shift when the material is inserted, then you can find the index. When the displacement of the mirror to restore the original condition is $\Delta y$, the index of refraction $n$ is given by

$$n = 1 + \frac{\Delta y}{t}$$

Locate a minimum in the signal without paraffin present. Insert the paraffin block in the path to Mirror A between the beam splitter and the mirror. Now move the mirror toward the beamsplitter until you find a new minimum. How much do you have to move the mirror? It would be best to repeat this several times and average the results. This is $\Delta y$. Calculate the index of refraction, $n$, and the dielectric constant, $\varepsilon$, of paraffin for microwaves.

There is an ambiguity about this measurement, since it is possible that the paraffin shifted the pattern more than one fringe. How would you modify the experiment to be sure that the shift was less than fringe, or to find the true shift if it were more?