L11 Microwave Optics

Austin Irvine

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October 24, 2017

Tuesdays from 12PM – 2PM

Objective

The main objective of this lab was to measure the distance between a microwave emitter and detector while gauging the intensity of the waves. Furthermore, we were also tasked finding maximum wave intensities and noting their vertical degree to test Malus’s Law. The last objective, for the double-slit experiment, was to measure distances for maximum wave intensities taken by the detector. The equations used in this lab involved amplitude, intensity, distance, and their connection to the electric field. Additionally, Malus’s Law was used to compare intensity to angles of detection. Similar to lab 10, theories of interference and diffraction were also taken into account. A microwave emitter, microwave detector, a stand for the microwave devices, pieces of metal for the slit tests, and measuring rulers on the stand were used in developing this experiment.

Setup

-Basic Physics-

The theories involved in this lab included Malus’s Law, the theory of diffraction from Francesco Grimaldi, and the theory behind interference from Davisson and Germer.

Etienne-Louis Malus developed Malus’s Law a long time ago to describe the polarization of electromagnetic waves. Specifically, he developed an equation to show the irradiance of light. In the equation below, I stand for irradiance, stands for initial wave intensity, and stands for the angle between the axis of the polarizer and light’s initial polarization.

Other theories involved in the inception of this lab were similar those found in lab 10. Specifically, the theories of interference and diffraction were used on a different scaled of electromagnetic waves. Previously, we studied how visible light was diffracted. In this lab, we were challenged by solving the same problems, but with microwaves which have a much larger and invisible wavelength. Briefly, the equations for interference and diffraction absolve that waves and/or particles can both interfere and diffract creating local minimas and maximas. With the detector we found the maximas or areas where the signal and intensity were greatest. These are similar to the bright bands of light found in the previous lab. The, , is the angular deviation of nth maximum, measured all the way to the center of the brightest band. The, , is the spacing between slits, which can be described as the center to center, center of a fringe to the central light band. Lamda is the wavelength of the microwave and n stands for the nth maxima. This can be found on page 21 of the lab manual.

The last basic equation that was used was for finding wavelength. Lamda is wavelength, velocity is c or the speed of light, and f is for frequency.

Lambda = velocity/frequency

The instrumental error was for the most part negligible inside of this lab experiment.

-SETUP-

The setup for this experiment involved adjusting the microwave emitter and detector along a rail measuring device.

In the first part of this experiment, we measured the distance and wave amplitude strength at multiple distances. The setup looked very basic. The emitter and detector were placed opposite of one-another along a rail. We moved the detector along the rail and measured separate distances.

The next part of the experiment involved horizontally rotating the detector. With the changes in rotation being twenty degrees, we were able to see changes in the wave amplitude strength. Similar to the last setup the emitter and detector place opposite from one another in a linear path. The distance of separation was kept at a constant 80 centimeters. This experiment was to test part of Malus’s law.

Following that experiment, we performed a double slit experiment. The setup for this experiment was a bit more interesting. Beginning the setup, we placed three sheets of metal vertically between the emitter and the detector. The gap distances and width of the middle sheet of metal were measured ten times each. After measuring the gaps and width between the gaps, we placed the detector 102 centimeters from the emitter on the rail stand. We vertically rotated the detector on the rail stand and found three maximas for the wave amplitude strength. With each maxima, we moved the rail and measured ten separate angle measurements.

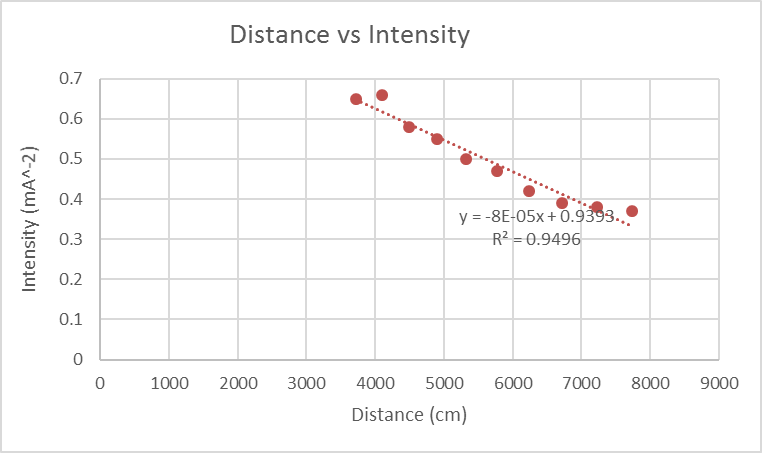
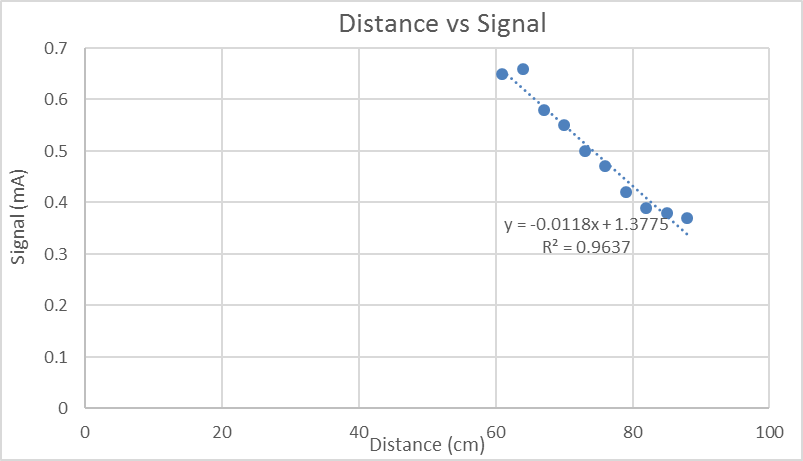
The last experimental setup had the detector and emitter placed orthogonally to each other. Opposite from each was a sheet of metal on another rail stand system that was attached to the base rail. In the center of the apparatus, a flat image or screen was placed to reflect and change the path of the emission. The detector was then moved along the rail and stopped once a max wave amplitude signal was found. At that point, the distance from the center of the apparatus was measured.

Sources of error from this experiment could likely come from several sources. One of the first sources of error is that the sheets of metal used were bent a little and not uniform in size. I think this may cause some skewing in data. The second source of error that I noticed was how there was a gap in the measuring tool used. Between the first half of the ruler and the second half, there is a space where no measurements can be taken, and likely this may affect the distances measured between the emitter and detector. The last source of error that I noticed could have come from the detector which measured the wave intensity on a gauge. I believe that the intensity measurements could have been off due to the age in the equipment, having been used a lot over the years. Likely the friction created within the arrow pointing gauge has created slight inaccuracies in the measurements.

I believe that the biggest source of error came from the distance measuring tool on the rail. The disconnection of the measuring tool in the middle, likely created some issues and imperfection in measuring distance from the emitter to the detector. While the error produced may be small, it would have some effect on results. This will be restated in the uncertainty.

Sample Calculations

**-Part 1A: Plots and Linest-**

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*Linest Calculations*

**Plot 1:** Distance vs. Signal Amplitude || **Linest = 0.006**

**Plot 2:** Distance vs. Intensity || **Linest = 0.00008**

**Equation:** Relating Signal and Intensity: **y =** -8E-05**x** + 0.9393

**-Part 1B: Malus’s Law Comparison-**

|  |  |  |
| --- | --- | --- |
| **Part 1 b** | | |
| **Radians** | **Actual** | **I=I0cos^2(theta)** |
| 0 | 0.55 | 0.57 |
| 0.349066 | 0.51 | 0.503322666 |
| 0.698132 | 0.41 | 0.334489731 |
| 1.047198 | 0.24 | 0.1425 |
| 1.396263 | 0.04 | 0.017187603 |
| 1.745329 | 0.02 | 0.017187603 |
| 2.094395 | 0.19 | 0.1425 |
| 2.443461 | 0.41 | 0.334489731 |
| 2.792527 | 0.53 | 0.503322666 |
| 3.141593 | 0.57 | 0.57 |

**-Part 2: Microwave Double-Slit Error Propagation-**

*Single Slit Diffraction Equation;*

**-Distance and Intensity-**

*Single Slit Diffraction Equation:*

*Single Slit Diffraction Equation Solved For ‘a,’ slit width:*

1. First we found the average values for: d = distance to detector, , and then n which is the current maximum signal found.
2. After finding the average values, plug them into the equation. For example:
   1. = 2.65 cm

Partial Derivatives:

d = slit distance, = maxima angle, = wavelength of microwave, n = which maxima found

**|** **|**

Error Propagation

=

= 2.65 cm

= 2.32 cm

= 0.81 cm

Uncertainties

\*Note: Instrumental Error is .5 mm.

= = = 0.20 cm

= = = 0.18 cm

= = = 0.06 cm

Lamda

**-Part 3: Simple Interferometer Comparison-**

|  |
| --- |
| **Successive Diffs. 2** |
| 1 |
| 1.4 |
| 1.9 |
| 1.4 |
| 1.3 |
| 1.6 |
| 1.4 |
| 1.4 |
| 1.5 |
| 1.2 |
| **Average** |
| 1.41 |

The **average wavelength is 2.82** for part three compared to…

In part 2, we had **about 2.65, 2.32, and 2.45**.

Results

Below are the results for double-slit experiment for microwaves.

**-Wavelength of Microwaves-**

Table 1: Lambda Values

|  |  |  |  |
| --- | --- | --- | --- |
| **Values** | **Experimental** | **Total Error** | **Actual** |
| Lambda 1 | 2.65 | 0.20 |  |
| Lambda 2 | 2.32 | 0.18 |  |
| Lambda 3 | 2.45 | 0.06 |  |

**- Discussion –**

The values contrived from part one, two, and three of this experiment were generally what we would expect. When the lambda values were plugged into a general equation solving for 10.525 GHz as the frequency, with the speed of light as the velocity, the answers were very close, not perfect, but close. Most of the answers were close to each other, and quite frankly, they made sense. The value for the first maxima in part 2 was almost exactly correct with the error. As we moved to the other maximums, the answer began to differentiate. I would say that our answers, for the most part, were correct. The error created in our experiment was not a major issue.

The answers in part 3 were also extremely close to what we’d expect for the wavelength of a microwave. We were barely off the mark for the average wavelength.

**Questions**

**1.** The detector was measuring the current and strength of the signal from the microwave emitter. This helped solve for the connection between intensity and signal strength which helped us find the wavelength of the microwave.

**2.** The results from Malus’s law were very close to the actual results we found. Some of the measurements had some major differences, but they seemed to be outliers from the majority of our data.

**3.** The distance is half-lambda because of the angle we had the detector compared to the emitter.

**- Discussion of Uncertainty -**

The error values we calculated seemed to be fairly accurate, but I think there were some points in which the error values diminished and did not correlate with the data. On the latter two maximums in part two, the error values did not seem to match up as well as the first maxima. Likely the largest source of error came from the measuring device that we were using on the stand apparatus. While the device was sturdy, the actual number and lines were at times hard to read and the separation in the center of the measuring device created some points of disassociation in our data. Other sources of possible error sources could have been the emitter and detector not being exactly level or the technology being old. I would take more measurements, buy higher quality laser measuring devices, and use a digital signal detector to avoid age depreciation and friction of a gauge.

**-Concluding Statement of Results -**

In conclusion, the use of Malus’s law, the basic wavelength equation, and the Fraunhofer equation for diffraction played heavy role in the calculations in this experiment. Maximas were measured to find the true wavelength of a microwave, and the results showed a fair amount of success. This experiment was very similar to lab ten, but I thought it was twice as important to perform this experiment that that one. Not being able to see the wave and making clear arguments about the wavelengths felt like a valuable experience.