Lab 1 Report
Safety and Basic Measurement

This lab was setup to get a basic understanding of the lab equipment. It was broken into 2 parts. The first part was getting information about the equipment. The second part was about how to use the equipment. There were a few pre-lab questions that were meant to better understand the lab equipment and the dangers in using them.

The objective in this lab was to get an understanding of the equipment and learn how to get basic measurements from the equipment.

Equipment and supplies used:
1) 0.5mW He-Ne laser and power supply
2) magnetic bases and rods to mount tools
3) power meter
4) photo detector
5) beam expanding lense
6) neutral density filter
7) laser manual & goggle specification sheet.
1) \( 450 \mu W \) at \\
\( 445 \mu W \) and \( 440 \mu W \)

2) The power reading stayed roughly the same at each location on the photodetector.

3) The beam diameter increased and the power stayed the same within fluctuation. The shape expanded into a larger circle of light.

4) \[
\frac{\text{Power out}}{\text{Power in}} = \frac{56 \mu W}{468 \mu W} = 0.12 = 10^{-0.7} = 0.92
\]

\[-8\%\text{ error}\]

5) \[
\frac{208 \mu W}{(0.55 \times 10^{-6} \text{m})^2} = 2.1 \frac{W}{m^2} \text{ irradiance inside}
\]

\[
\frac{262 \mu W}{(0.55 \times 10^{-6} \text{m})^2} = 27.6 \frac{W}{m^2} \text{ irradiance outside}
\]

\[27.6 \times 15\% = 4.1 \frac{W}{m^2}\]
1. Maximum power output of He-Ne laser: 14 mW
2. Class of He-Ne laser: Class 1
3. Wavelength of He-Ne laser: 632.8 nm
4. Maximum permissible contact exposure for continuous operation of He-Ne laser.
   \[
   x = \frac{700 \times 10^{-5}}{0.8} = 875 \text{ W/m}^2
   \]
5. If focused to 3 mm, what is intensity? \( I_{\text{int}} = \frac{700 \times 10^{-5}}{3^2} \)
   - Very hazardous to skin due to very dangerous at an intensity of 875 W/m^2.
   
6. Volume of He-Ne laser
   - Power density: \( 1.8 \times 10^5 \text{ W/cm}^2 \)
   - Volume: \( V = \frac{1.8 \times 10^5}{375} = 0.05 \text{ cm}^3 \)
   
7. OD of laser guide: 0.1 mm: \( \frac{1}{10} \)
After removing the beam expander we placed a neutral density filter into the path of the laser and measured the power. The last part of the experiment was to take the photodetector and measure the power from the lights and of the sun. To do this we adjusted the power meter for 600nm and put the detector under the lights in the room and took readings. We then went outside and positioned the photodetector in the direction of the sun and took readings.

**Data**

**Laser power readings from different locations on photodetector**

- 450 µW
- 445 µW
- 440 µW

**Reading from beam expander**

- 450 µW ± 20 µW (due to rapid fluctuations in readings)

**Neutral density filter**

\[
\frac{\text{power Out}}{\text{power In}} = \frac{56\mu\text{W}}{468\mu\text{W}}
\]

**Lights inside** - 208 µW
**Outside** - 2.42 mW

**Equations & Calculations**

**Neutral density filter**

\[
\text{Out} = \text{In} \times (0.12) \quad \text{to} \quad \text{0.08} \quad \text{or} \quad 0.92
\]

**% error**

\[
\frac{\text{actual}}{\text{expected}} = 0.92
\]

**Irradiance inside**

\[
\text{Irradiance inside} = \frac{208\mu\text{W}}{(155 \times 10^2 \text{m}^2)} = 2.1 \text{ W/m}^2
\]

**Irradiance outside**

\[
\text{Irradiance outside} = \frac{2.42 \text{ mW}}{(155 \times 10^2 \text{m}^2)} = 27.6 \text{ W/m}^2
\]
In lab question:

1. The power reading stayed fairly the same at each location on the photodetector.

2. The shape of the light after entering the zoom operator did just what was implied; it expanded the beam diameter. The light was slightly less intense, however the total power remained the same.

3. The neutral density filter caused about a 10x power drop with 8% error.

4. The irradiance inside was: \[ \frac{2.1 \text{ W/m}^2}{2.6 \text{ W/m}^2} \]
   outside was: \[ \frac{4.1 \text{ W/m}^2}{2.1 \text{ W/m}^2} \]

   a mirror with 15% efficiency would give \[ 4.1 \text{ W/m}^2 \] (would generate significantly more if sky and sun were a cloudy day.)
Lab 2 Report

Laser Beam Properties

This experiment had 2 parts. The first part was to determine the spot size of the laser by measuring the power drop as a knife edge was slowly inserted into the beam. After determining the spot size, the half divergence angle, radiance and minimum spot size were calculated. The second part of this lab was to observe the effects of coherence through the use of a beam splitter and two mirrors.

The objectives in this lab were to take measurements of a laser beam to determine spot size and from that determine divergence, radiance and minimum spot size. The other objective was to test for coherence of the laser.

Equipment and Supplies Used:
- Class 2 HeNe laser with stand and magnet base
- Power meter
- Translations stage with micrometer adjustment
- Six inch metal ruler
- 2 mirrors with stand and magnet bases
- Beam splitter and lens
Procedure:

For the first part we first set up the laser to point at the power meter which was more than 40 cm away. Next we fastened a six inch ruler with the flat side towards the beam onto a micrometer translation stage. The knife edge was placed at 30 cm from the laser and then again at 40 cm. At each of these locations the ruler was moved into the beam in 0.05 mm increments and a power reading was recorded. Once the ruler was blocking the beam entirely the process was repeated by removing the ruler in 0.05 mm increments.

For the second part we setup the laser to point toward a beam splitter on a stand. We then positioned the two mirrors to reflect the light coming straight through the splitter and reflecting off to the same location it was coming from (the beams were collinear). We then placed a lens (FL = 25.50 cm) in between the beam and screen and observed coherence. The mirrors were equal distance from the beam splitter. We then moved the mirrors such that they were 20-30 cm farther and observed coherence.

Data:

<table>
<thead>
<tr>
<th>Position (mm)</th>
<th>0.00</th>
<th>570 µW</th>
<th>0.40</th>
<th>165 µW</th>
<th>0.80</th>
<th>3 µW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05</td>
<td>561 µW</td>
<td>0.45</td>
<td>107 µW</td>
<td>0.85</td>
<td>3 µW</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>544 µW</td>
<td>0.50</td>
<td>61 µW</td>
<td>0.90</td>
<td>3 µW</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>513 µW</td>
<td>0.55</td>
<td>37 µW</td>
<td>0.95</td>
<td>3 µW</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>466 µW</td>
<td>0.60</td>
<td>19 µW</td>
<td>1.00</td>
<td>2 µW</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>415 µW</td>
<td>0.65</td>
<td>10 µW</td>
<td>1.05</td>
<td>2 µW</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>340 µW</td>
<td>0.70</td>
<td>4 µW</td>
<td>1.10</td>
<td>2 µW</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>265 µW</td>
<td>0.75</td>
<td>1 µW</td>
<td>1.15</td>
<td>2 µW</td>
</tr>
</tbody>
</table>

knife edge at 20 cm from laser going into beam;
### Knife edge at 20 cm going out of beam

<table>
<thead>
<tr>
<th>Position (mm)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>2.0</td>
<td>0.46</td>
<td>1.5</td>
<td>0.80</td>
<td>3.12</td>
<td>1.20</td>
</tr>
<tr>
<td>0.05</td>
<td>2.0</td>
<td>0.45</td>
<td>2.5</td>
<td>0.85</td>
<td>2.30</td>
<td>1.20</td>
</tr>
<tr>
<td>0.10</td>
<td>2.0</td>
<td>0.50</td>
<td>6.0</td>
<td>0.90</td>
<td>3.00</td>
<td>1.20</td>
</tr>
<tr>
<td>0.15</td>
<td>3.0</td>
<td>0.55</td>
<td>11.0</td>
<td>0.95</td>
<td>3.70</td>
<td>1.20</td>
</tr>
<tr>
<td>0.20</td>
<td>3.0</td>
<td>0.60</td>
<td>28.0</td>
<td>1.00</td>
<td>4.36</td>
<td>1.20</td>
</tr>
<tr>
<td>0.25</td>
<td>3.0</td>
<td>0.65</td>
<td>55.0</td>
<td>1.05</td>
<td>4.95</td>
<td>1.20</td>
</tr>
<tr>
<td>0.30</td>
<td>4.0</td>
<td>0.70</td>
<td>97.0</td>
<td>1.10</td>
<td>5.41</td>
<td>1.20</td>
</tr>
<tr>
<td>0.35</td>
<td>4.0</td>
<td>0.75</td>
<td>150</td>
<td>1.15</td>
<td>5.68</td>
<td>1.20</td>
</tr>
</tbody>
</table>

### Knife edge at 40 cm going into beam

<table>
<thead>
<tr>
<th>Position (mm)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>5.76</td>
<td>0.40</td>
<td>3.96</td>
<td>0.80</td>
<td>3.2</td>
<td>1.20</td>
</tr>
<tr>
<td>0.05</td>
<td>5.60</td>
<td>0.45</td>
<td>2.75</td>
<td>0.85</td>
<td>2.2</td>
<td>1.25</td>
</tr>
<tr>
<td>0.10</td>
<td>5.46</td>
<td>0.50</td>
<td>2.20</td>
<td>0.90</td>
<td>1.5</td>
<td>1.30</td>
</tr>
<tr>
<td>0.15</td>
<td>5.27</td>
<td>0.55</td>
<td>1.68</td>
<td>0.95</td>
<td>1.0</td>
<td>1.30</td>
</tr>
<tr>
<td>0.20</td>
<td>5.03</td>
<td>0.60</td>
<td>1.30</td>
<td>1.00</td>
<td>0.7</td>
<td>1.30</td>
</tr>
<tr>
<td>0.25</td>
<td>4.78</td>
<td>0.65</td>
<td>0.97</td>
<td>1.05</td>
<td>0.5</td>
<td>1.30</td>
</tr>
<tr>
<td>0.30</td>
<td>4.50</td>
<td>0.70</td>
<td>0.67</td>
<td>1.10</td>
<td>0.4</td>
<td>1.30</td>
</tr>
<tr>
<td>0.35</td>
<td>4.01</td>
<td>0.75</td>
<td>0.47</td>
<td>1.15</td>
<td>0.3</td>
<td>1.30</td>
</tr>
</tbody>
</table>

### Knife edge at 40 cm going out of beam

<table>
<thead>
<tr>
<th>Position (mm)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
<th>Power (µW)</th>
<th>Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>3.0</td>
<td>0.40</td>
<td>19.0</td>
<td>0.80</td>
<td>2.94</td>
<td>1.20</td>
</tr>
<tr>
<td>0.05</td>
<td>3.0</td>
<td>0.45</td>
<td>27.0</td>
<td>0.85</td>
<td>3.44</td>
<td>1.25</td>
</tr>
<tr>
<td>0.10</td>
<td>4.0</td>
<td>0.50</td>
<td>41.0</td>
<td>0.90</td>
<td>3.96</td>
<td>1.30</td>
</tr>
<tr>
<td>0.15</td>
<td>5.0</td>
<td>0.55</td>
<td>61.0</td>
<td>0.95</td>
<td>4.36</td>
<td>1.30</td>
</tr>
<tr>
<td>0.20</td>
<td>6.0</td>
<td>0.60</td>
<td>90.0</td>
<td>1.00</td>
<td>4.69</td>
<td>1.30</td>
</tr>
<tr>
<td>0.25</td>
<td>8.0</td>
<td>0.65</td>
<td>136.0</td>
<td>1.05</td>
<td>5.03</td>
<td>1.30</td>
</tr>
<tr>
<td>0.30</td>
<td>11.0</td>
<td>0.70</td>
<td>185.0</td>
<td>1.10</td>
<td>5.30</td>
<td>1.30</td>
</tr>
<tr>
<td>0.35</td>
<td>15.0</td>
<td>0.75</td>
<td>235.0</td>
<td>1.15</td>
<td>5.51</td>
<td>1.30</td>
</tr>
</tbody>
</table>
Equations

From 20 cm graphs:

\[ \text{25\% power} = \frac{25}{42} = 0.592 \] \[ \text{75\% power} = \frac{42}{25} = 1.68 \]

\[ \frac{\text{25\% power}}{\text{75\% power}} = \frac{0.592}{1.68} = 0.352 \]

\[ \text{ep} = 0.337 \Rightarrow \text{0.085} = 0.337 \]

\[ w = 0.337 \text{ mm} \]

\[ \frac{w}{(38.6 \text{ mm})} = 0.085 \]

\[ w = 0.0504 \text{ mm} \]

\[ \frac{w}{(38.6 \text{ mm})} = 0.13 \]

\[ w = 0.386 \text{ mm} \]

\[ \frac{w}{(38.6 \text{ mm})} = 0.772 \]

\[ w = 0.772 \text{ mm} \]

\[ \text{min. inc. c.s.} \]

\[ \frac{1}{2} \left( \frac{w}{(38.6 \text{ mm})} \right) = \frac{1}{2} \left( \frac{0.085}{38.6 \text{ mm}} \right) = 0.0023 \]

\[ \frac{1}{2} \left( \frac{w}{(38.6 \text{ mm})} \right) = 0.0023 \]

\[ \frac{1}{2} \left( \frac{w}{(38.6 \text{ mm})} \right) = 0.0023 \]

\[ w_0 = 0.139 \text{ mm} \]

\[ \text{half divergence} \Rightarrow \frac{\Theta}{\pi w_0} \Rightarrow \frac{\Theta}{0.139 \text{ mm}} \]

\[ \frac{\Theta}{\pi w_0} = \frac{\Theta}{0.139 \text{ mm}} \]

\[ \text{radiance} \Rightarrow \frac{1.46 \text{ mm} 

\[ \frac{1}{2} \left( \frac{w}{(38.6 \text{ mm})} \right) = \frac{0.085}{38.6 \text{ mm}} = 0.0002 \]

\[ \frac{w}{(38.6 \text{ mm})} = 0.24 \text{ mm} \]

\[ \frac{w}{(38.6 \text{ mm})} = \frac{0.24}{38.6 \text{ mm}} \]

\[ r = 32.88 \text{ cm} \]

\[ A = \pi \left( 0.24 \text{ cm} \right)^2 = 1.81 \times 10^{-2} \text{ cm}^2 \]

\[ \eta = \frac{A}{T} = 1.81 \times 10^{-2} \text{ cm}^2 / 32.88 \text{ cm}^2 \]

\[ N = \frac{570 \text{ W}}{(1.81 \times 10^{-2})} = 1.89 \times 10^5 \text{ W/cm}^2 \]

\[ \text{Lab questions} \]

1. Spot size for 20 cm & 40 cm was 0.504 mm & 0.772 mm respectively.

2. Half divergence angle \[ \Theta = 1.46 \text{ mm} \] compared to 1.7 rad in the spec sheet which gives 14% error.

3. Radiance was 1.89 \times 10^5 \text{ W/cm}^2

4. Minimum spot size \( w_0 = 0.139 \text{ mm} \)

5. When the mirrors were equal distant, fringing could be seen which implies they are convergent. When the mirrors were moved at different distances, the fringing was more apparent which implies they are temporarily convergent.
Lab 3 Report

Diffraction and Polarization

This lab was broken into three parts. The first part was to find the Brewster angle using a glass plate and from that find the refractive index of the glass. The second part was to measure the amount of light going through a polarizing filter as its angle changed. The final part of this lab was to use a diffraction grating to find the number of modes diffracted from the laser.

The objectives in this lab were to calculate the refractive index of a material based off its Brewster angle measured. The second objective was to demonstrate how a polarizing filter works. The last objective was to calculate the number of modes present when using a certain diffraction grating.

Equipment and Supplies
- 4 mW and 0.5 mW lasers
- stands, magnetic bases, rotating stage
- glass plate, infrared card
- safety goggles
- polarizer and tape to hold it
- photodetector and attenuator
- 41028 diffraction grating
- paper protractor

Part A

Part B

Part C
polarizer:

<table>
<thead>
<tr>
<th>$\theta$ (°)</th>
<th>0° power</th>
<th>45° power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.55 mW</td>
<td>5.0 mW</td>
</tr>
<tr>
<td>10</td>
<td>3.42 mW</td>
<td>6.3 mW</td>
</tr>
<tr>
<td>20</td>
<td>3.03 mW</td>
<td>7.0 mW</td>
</tr>
<tr>
<td>30</td>
<td>2.48 mW</td>
<td>8.0 mW</td>
</tr>
<tr>
<td>40</td>
<td>1.87 mW</td>
<td>9.0 mW</td>
</tr>
</tbody>
</table>

Equations and Calculations:

Brewster equation: $\tan \theta = \frac{n_2}{n_1}$

$\theta = 144 - 90 = 54°$  $n_2 = ?$

$n_1 = 1$ (air)

$\tan 54 = \frac{n_2}{1}$

$n_2 = 1.38$ observed

1.45 reference

4.8% error

Polarization: measured

<table>
<thead>
<tr>
<th>$\theta$ (°)</th>
<th>3.55/3.55 = 100%</th>
<th>10/3.55 = 28.6%</th>
<th>20/3.55 = 57.4%</th>
<th>30/3.55 = 66.9%</th>
<th>40/3.55 = 54.1%</th>
<th>50/3.55 = 35.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60</td>
<td>1.70/1.355 = 19.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>70</td>
<td>2.20/1.355 = 7.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>80</td>
<td>1.03/1.355 = 1.05%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>1.00/1.355 = 0.13%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>1.662 m, m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$d = \frac{1}{600}$
<table>
<thead>
<tr>
<th>polarization - expected</th>
<th>$T = (\cos \theta)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$(\cos 0)^2 = 100%$</td>
</tr>
<tr>
<td>10</td>
<td>$(\cos 10)^2 = 97%$</td>
</tr>
<tr>
<td>20</td>
<td>$(\cos 20)^2 = 88.3%$</td>
</tr>
<tr>
<td>30</td>
<td>$(\cos 30)^2 = 75%$</td>
</tr>
<tr>
<td>40</td>
<td>$(\cos 40)^2 = 58.7%$</td>
</tr>
<tr>
<td>50</td>
<td>$(\cos 50)^2 = 41.3%$</td>
</tr>
<tr>
<td>60</td>
<td>$(\cos 60)^2 = 25%$</td>
</tr>
<tr>
<td>70</td>
<td>$(\cos 70)^2 = 11.7%$</td>
</tr>
<tr>
<td>80</td>
<td>$(\cos 80)^2 = 3%$</td>
</tr>
<tr>
<td>90</td>
<td>$(\cos 90)^2 = 0%$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>diffraction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>incident 0°</td>
<td></td>
</tr>
<tr>
<td>90-0° = 90°</td>
<td>$n(632.8\text{nm}) = 1.667\mu m \sin \theta$ $n=0$</td>
</tr>
<tr>
<td>90-45° = 45°</td>
<td>$n(632.8\text{nm}) = 1.667\mu m \sin \theta$ $n=1$</td>
</tr>
<tr>
<td>90-90° = 90°</td>
<td>$n(632.8\text{nm}) = 1.667\mu m \sin \theta$ $n=2$</td>
</tr>
</tbody>
</table>

$n \lambda = d (\sin \theta \pm \sin \psi)$  
$110-90 = 20°$ $n(632.8\text{nm}) = 1.667\mu m \sin \theta$ $n=1$  
$138-90 = 48°$ $n(632.8\text{nm}) = 1.667\mu m \sin \theta$ $n=2$

measured: $\theta = 0°$  
incident 0°  
$-2, -1, 0, 1, 2$  

incident 15°  
90-21° = 69°  
70-2° = 28°  
90-38° = 52°  
105-90° = 15°  
138-90° = 48°

incident 0°  
0°  
1°  
2°

incident 15°  
0°  
1°  
2°

incident 15°  
0°  
1°  
2°  
3°  
4°
Part A
- The Brewster angle was found to be 54.7° which made the glass plate's refractive index 1.38.

Part B
- The polarizer worked quite well. Our readings were very close to the expected values.

Part C
- From the angles observed at an incidence of 0° we found the modes to be \[5\text{ modes: } -2, -1, 0, 1, 2\].
- When we changed the angle of incidence to 15° some of our readings resulted in an unclear determination of a mode. For example, the reading of 6° resulted in \(n = 0.41\) which could be 0 or 1. This could have happened due to possible damage of the diffraction grating.
- Did not compare measured angles with calculated for diffraction grating (7).

![Polarization of 4mW laser](image)
Lab Report 4

Light Emitting Diodes (LEDs)

This lab was split into 3 sections. The first section was to get light output power and input current readings from a high efficiency red LED and infrared LED. The second part of the lab involved measuring readings from various LEDs including voltage and light power. From this data and data from the spec sheets we formed a table of information. The third section of the lab involved using a grating monochromator to measure the wave spectrum of the overhead light and the high efficiency red LED.

The objectives in this lab were to find the light output vs. input current characteristics of a red and infrared LED. The second objective was to find efficiencies of different color LEDs. The last objective was to get an understanding of how a grating monochromator can be used to find various elements in a light source and their corresponding wavelength spectrum.

Equipment & Supplies

- Variable DC power supply & cables
- LED specification sheets
- Multimeter/power meter
- IR sensor card
- LEDs (infrared, Hi-ef red, standard red, yellow, green, blue)
- 1200 line/mm grating monochromator
- Computer w/software for interfacing monochromator
Procedure:

In the first section of the lab we began by connecting the DC power supply to the high efficiency red LED. We then calibrated the power meter for the correct wavelength as specified in the specification sheet. We then took power output readings at 5 mA increments from 0 mA to 25 mA. We repeated this for the infrared LED. We also used the IR card (which had been charging in sunlight) to get an idea of what the infrared LED looked like.

For the second part of the lab we setup two multimeters, one to measure current of the LED and the other to measure voltage. Once they were in place we calibrated the power meter for each LED's wavelength as specified in the specification sheet. We set the current to 25 mA and measured the voltage and light power output for each LED. This was done with the red, green, standard red, infrared, yellow, green, and blue LEDs. The last section of the lab started with setting up the monochromator with the computer. Once that was done we calibrated the software for the light source and took a snapshot of the real-time graph. This was done for the overband lights and for the calibrated LED at 25 mA.
High Efficiency Red LED

SPECTRA ARRAY: LineSpec: Master: Sample
INTEGRATION TIME = 100
AVERAGE=1
SPECTRUM = Sample_row, nm
CALIBRATION : 610.62, 0.082809, -3.4671e-06 BL_Cor.
Ambient light

wavelength (nm)

light intensity

SPECTRA ARRAY: LineSpec: Master: Sample
INTEGRATION TIME = 80
AVERAGE=1
SPECTRUM = Sample_row, nm
CALIBRATION : 504.13; 0.08749; -3.888e-06 BL_Cor.
Data:
A) \( \lambda \) (red) - 665 nm  \( \lambda \) (infrared) - 880 nm
max mA - 30 mA max mA - 100 mA

<table>
<thead>
<tr>
<th>mA</th>
<th>Power (( \mu )W)</th>
<th>( \frac{P}{V} ) (\Omega)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>169</td>
<td>3.38</td>
</tr>
<tr>
<td>10</td>
<td>373</td>
<td>4.75</td>
</tr>
<tr>
<td>15</td>
<td>545</td>
<td>6.94</td>
</tr>
<tr>
<td>20</td>
<td>702</td>
<td>8.41</td>
</tr>
<tr>
<td>25</td>
<td>808</td>
<td>10.29</td>
</tr>
</tbody>
</table>

B) LED  \( \lambda \) Light power at 25mA Voltage \( \frac{P}{V} \) Efficiency

| 1   | Infrared, 880 nm | 1.06 \( \mu \)W | 1.3 V | \( \frac{P}{V} \) = 1.06/1.3 = 0.81 |
| 2   | Hi-ef RED, 665 nm | 8.08 \( \mu \)W | 1.74 V | \( \frac{P}{V} \) = 8.08/1.74 = 4.68 |
| 3   | Standard RED, 655 nm | 10.8 \( \mu \)W | 2.07 V | \( \frac{P}{V} \) = 10.8/2.07 = 5.22 |
| 4   | Yellow, 585 nm   | 78.9 \( \mu \)W | 2.4 V | \( \frac{P}{V} \) = 78.9/2.4 = 3.29 |
| 5   | Green, 565 nm    | 31.6 \( \mu \)W | 2.4 V | \( \frac{P}{V} \) = 31.6/2.4 = 1.32 |
| 6   | Blue, 470 nm     | 615 \( \mu \)W | 3.81 V | \( \frac{P}{V} \) = 615/3.81 = 163.8 |

C) Attached Graphs

Calculations:

B) Electrical power = \( IV \)

Efficiency = \( \frac{\text{Light power}}{\text{Electric power}} \)
### Part B

<table>
<thead>
<tr>
<th>LED</th>
<th>Light Power (0.5mA)</th>
<th>Voltage</th>
<th>Electric Power</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1.06 mW</td>
<td>1.3 V</td>
<td>1.41 mW</td>
<td>0.76%</td>
</tr>
<tr>
<td>High RED 665nm</td>
<td>8.08 mW</td>
<td>1.74 V</td>
<td>14.8 mW</td>
<td>0.56%</td>
</tr>
<tr>
<td>Blue</td>
<td>655nm</td>
<td>2.5 V</td>
<td>1.63 mW</td>
<td>0.83%</td>
</tr>
<tr>
<td>Yellow</td>
<td>645nm</td>
<td>2.24 V</td>
<td>1.44 mW</td>
<td>0.63%</td>
</tr>
<tr>
<td>Green</td>
<td>565nm</td>
<td>2.4 V</td>
<td>1.34 mW</td>
<td>0.64%</td>
</tr>
<tr>
<td>Blue</td>
<td>470nm</td>
<td>3.8 V</td>
<td>1.81 mW</td>
<td>0.65%</td>
</tr>
</tbody>
</table>

The standard Red, Yellow, and Green all had opaque plastic to transmit through, this most likely contributed to their low efficiencies.

### Part C

In its normal light, we obtained approximately 5% 550 nm, 570 nm, and 615 nm. For the infrared LED, we found the

\[ P = \frac{1}{2} \int P(\lambda) \, d\lambda \]

The curve shows that the LED produces more power at shorter wavelengths.
Lab Report 5

Photodetectors

This lab was broken into five parts. The first part involved using a photodiode in the photovoltaic mode. The second part used the photodiode in the photoconductive mode. The third part involved using a phototransistor. The fourth part was similar to the others except it used a photoconductor. The last part was to measure the I-V characteristics of a solar cell.

Here were quite a few objectives in this lab. The first objective was to get measurements from a photodiode operating in the photovoltaic mode. The second objective was to measure the same photodiode except running in the photoconductive mode. The third objective was to take light intensity and current readings of a phototransistor. The fourth objective was to get resistance and light input intensity readings from a photoconductor. The last objective was to measure the I-V characteristics of a solar cell.

Equipment and Supplies:

- DC power supply/cables
- Multimeters
- High efficiency red LED
- Power meter
- 1 MΩ / 10 kΩ
- Photodiode / Phototransistor / Photoconductor / Solar cell
- decade resistor box
Procedure:

To start out we ran an initial test to make some preliminary measurements of high-efficiency red LED (later parts would require data). We first connected the DC power supply to the LED and then connected the power meter and calibrated — 0 mV, 0 mA, and 0.1 V, 0 mA. Then we:

We then read power (measured at 0 mA and 0.1 V, 0 mA and 0.01 V, etc.).

After these initial measurements we set up for part A of the test. This part started out by measuring the voltage across a photovoltaic open circuit. We did this by varying the LED intensity at 3 mA, 5-25 mA, 50 steps. We then attached a 10 kΩ resistor in series — the Photodiode and reverse biased in with 0 V (no light) and 1 V open (+). For the next part we did the same thing except we used an LCD resistor and instead of the resistor we varied the LED intensity at 2 mA, 5-25 mA, 50 steps. Part C was to some procedures as before except instead of the Photodiode we used a phototransistor. Part D was the next step as we saw LED and interference. We connected a multimeter to a photovoltaic and read the resistance of various intensities. We tested to see if the readings were different. We then by inserting a decade position box to see if we had the right resistance. We checked a few more to make sure we had the correct readings. We repeated several more times and got consistent.


**Data:**

Preliminary data of high red LED

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Power (μW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>65.3</td>
</tr>
<tr>
<td>5</td>
<td>173</td>
</tr>
<tr>
<td>10</td>
<td>369</td>
</tr>
<tr>
<td>15</td>
<td>550</td>
</tr>
<tr>
<td>20</td>
<td>706</td>
</tr>
<tr>
<td>25</td>
<td>819</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LED</th>
<th>Photodiode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>2mA</td>
<td>0.267v</td>
</tr>
<tr>
<td>5mA</td>
<td>0.298v</td>
</tr>
<tr>
<td>10mA</td>
<td>0.321v</td>
</tr>
<tr>
<td>15mA</td>
<td>0.333v</td>
</tr>
<tr>
<td>20mA</td>
<td>0.342v</td>
</tr>
<tr>
<td>25mA</td>
<td>0.349v</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LED</th>
<th>10K Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>2mA</td>
<td>0.059v</td>
</tr>
<tr>
<td>5mA</td>
<td>0.174v</td>
</tr>
<tr>
<td>10mA</td>
<td>0.390v</td>
</tr>
<tr>
<td>15mA</td>
<td>0.610v</td>
</tr>
<tr>
<td>20mA</td>
<td>0.805v</td>
</tr>
<tr>
<td>25mA</td>
<td>0.990v</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Power (μW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.002v</td>
</tr>
<tr>
<td>2</td>
<td>3.34v</td>
</tr>
<tr>
<td>5</td>
<td>4.83v</td>
</tr>
<tr>
<td>10</td>
<td>4.89v</td>
</tr>
<tr>
<td>15</td>
<td>4.90v</td>
</tr>
<tr>
<td>20</td>
<td>4.91v</td>
</tr>
<tr>
<td>25</td>
<td>4.91v</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Light</th>
<th>Neutral density filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139</td>
<td>0.2v</td>
<td>4.23v 8.33v 12.64v 16v</td>
</tr>
<tr>
<td>1570</td>
<td>0.4v</td>
<td>4.8v 17.05v 0.8v</td>
</tr>
<tr>
<td>2543</td>
<td>0.6v</td>
<td>7.2v 21.73v 1.0v</td>
</tr>
<tr>
<td>3710</td>
<td>0.8v</td>
<td>12.8v 27.08v 1.2v</td>
</tr>
<tr>
<td>5184</td>
<td>1.0v</td>
<td>17.3v 33.40v 1.4v</td>
</tr>
<tr>
<td>7136</td>
<td>1.2v</td>
<td>25.0v 43.30v 1.6v</td>
</tr>
<tr>
<td>9870</td>
<td>1.4v</td>
<td>34.0v 64.00v 1.8v</td>
</tr>
<tr>
<td>13840</td>
<td>1.6v</td>
<td>45.0v 94.00v 2.0v</td>
</tr>
<tr>
<td>20225</td>
<td>1.8v</td>
<td>65.0v 111.0v 2.2v</td>
</tr>
<tr>
<td>32087</td>
<td>2.0v</td>
<td>86.0v 147.0v 2.4v</td>
</tr>
</tbody>
</table>
Photodiode in Photovoltaic mode

- LED intensity (W/m²) vs. Voltage (V)
- Measured voltage
- Equation 3

Voltage (V) is independent and always on x^-0.5

Photodiode in photoconductive mode

- LED light intensity (W/m²) vs. Photocurrent (μA)
- Photocurrent (μA) = 0.5

Phototransistor

- LED light intensity (W/m²) vs. Current (mA)
- Lamp light vs. Lamp light with neutral density filter

\[ \text{Current (mA)} = \frac{1.4 \times 10^4}{\text{LED light intensity} (W/m²)} \]
\[ V = IR \quad I = \frac{V}{R} \quad R = 10k\Omega \]

**Part C**

\[ 10k\Omega = R \]

<table>
<thead>
<tr>
<th>mA</th>
<th>( \frac{0.059}{10k} )</th>
<th>( 0.0059 \mbox{ mA} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mA</td>
<td>( \frac{0.097}{10k} )</td>
<td>( 0.0097 \mbox{ mA} )</td>
</tr>
<tr>
<td>10mA</td>
<td>( \frac{0.240}{10k} )</td>
<td>( 0.024 \mbox{ mA} )</td>
</tr>
<tr>
<td>15mA</td>
<td>( \frac{0.410}{10k} )</td>
<td>( 0.041 \mbox{ mA} )</td>
</tr>
<tr>
<td>20mA</td>
<td>( \frac{0.805}{10k} )</td>
<td>( 0.0805 \mbox{ mA} )</td>
</tr>
<tr>
<td>25mA</td>
<td>( \frac{0.990}{10k} )</td>
<td>( 0.099 \mbox{ mA} )</td>
</tr>
</tbody>
</table>

**Part E**

<table>
<thead>
<tr>
<th>Lamp Light</th>
<th>Power max</th>
<th>Neutral density filter</th>
<th>Power or</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2/139 = 1.44 mA</td>
<td>( \frac{288}{\mu W} )</td>
<td>( \frac{0.2}{4123} = 0.0485 \mu A )</td>
<td>9.7 \mu W</td>
</tr>
<tr>
<td>0.4/1570 = 254.8 mA</td>
<td>101.9 \mu W</td>
<td>0.4/8388 = 0.048 \mu A</td>
<td>19.2 \mu W</td>
</tr>
<tr>
<td>0.6/2543 = 235.9 mA</td>
<td>141.5 \mu W</td>
<td>0.6/12410 = 0.0475 \mu A</td>
<td>28.5 \mu W</td>
</tr>
<tr>
<td>0.8/3710 = 215.6 mA</td>
<td>172.5 \mu W</td>
<td>0.8/17050 = 0.0469 \mu A</td>
<td>37.5 \mu W</td>
</tr>
<tr>
<td>1.0/5184 = 192.9 mA</td>
<td>192.9 \mu W</td>
<td>1.0/21730 = 0.0460 \mu A</td>
<td>46.0 \mu W</td>
</tr>
<tr>
<td>1.2/7736 = 168.2 mA</td>
<td>201.8 \mu W</td>
<td>1.2/27000 = 0.0449 \mu A</td>
<td>53.3 \mu W</td>
</tr>
<tr>
<td>1.4/9800 = 141.9 mA</td>
<td>192.5 \mu W</td>
<td>1.4/33400 = 0.0418 \mu A</td>
<td>58.7 \mu W</td>
</tr>
<tr>
<td>1.6/13840 = 115.4 mA</td>
<td>185.0 \mu W</td>
<td>1.6/53330 = 0.0309 \mu A</td>
<td>59.3 \mu W</td>
</tr>
<tr>
<td>1.8/20225 = 89.0 mA</td>
<td>160.8 \mu W</td>
<td>1.8/144000 = 0.0281 \mu A</td>
<td>50.6 \mu W</td>
</tr>
<tr>
<td>2.0/28027 = 62.3 mA</td>
<td>124.1 \mu W</td>
<td>2.0/111110 = 0.0177 \mu A</td>
<td>34.5 \mu W</td>
</tr>
</tbody>
</table>
Part C
From the graph it is evident that the phototransistor will allow relatively low intensity light to generate a large amount of current. In fact it seemed that as long as the LED appeared on the current was large. The intensity of the LED didn't change the current much after 5 mA. Is this correct?

Part D
From the graph it appears that as the light intensity increases the resistance goes down. This indeed makes sense because as the light intensity rises one would expect the phototransistor to conduct more, by lowering the resistance the current would therefore increase. $\frac{V}{I} = \text{i}

Part E
The maximum power the solar cell generated was:

- Lamp light: $1288 \text{ mW}$
- Lamp light: $159 \mu\text{W}$ with neutral density filter.
Lab Report 6

Semiconductor Laser Properties

This lab was broken into three parts. The first part dealt with finding the threshold current of a laser diode. The second part involved measuring polarization percentages of the laser diode. The last part was to find the spectral output of the laser diode at threshold and above and below threshold.

The objectives in this lab were to: one, find the threshold current for the laser diode and find the light power vs. input current characteristics. The second objective was to find the polarization percentage of the laser diode at threshold and above threshold. The last objective was to measure the spectral output of the laser diode in three areas: at threshold, above threshold and below threshold.

Equipment & Supplies
- laser diode w/470k resistor
- DC power supply w/ cables
- multimeter
- power meter
- grating monochromator (1200 lin/mm)
- computer with software for monochromator
- IR card
For the consumption of water and power in this year, we find no cause to press upon us any measure. We
have taken to our own account in the amount of $10 per month, as an allowance for water and power.
We shall be made responsible for charges over this amount. We understand the rates as follows: $1 for 500
gallons of water and 100 units of power. We do not exceed these limits in our consumption and pay for the
amount over these limits. We understand this at 50¢ per unit and for water.
laser diode at 4mA above threshold

SPECTRA ARRAY: LineSpec: Master: Sample
INTEGRATION TIME = 80
AVERAGE=1
SPECTRUM = Sample_row, nm
CALIBRATION: 717; 0.077745; -2.9075e-06 BL_Cor.
SPECTRA ARRAY: LineSpec: Master: Sample
INTEGRATION TIME = 80
AVERAGE=1
SPECTRUM = Sample_row, nm
CALIBRATION : 717; 0.077745; -2.9075e-06 BL_Cor.
laser diode at 5mA below threshold

SPECTRA ARRAY: LineSpec: Master: Sample
INTEGRATION TIME = 80
AVERAGE=1
SPECTRUM = Sample_row, nm
CALIBRATION: 717; 0.077745; -2.9075e-06 BL_Cor.
\[ \frac{10^{5}}{ \frac{1}{ \Delta x} = \frac{c \Delta R}{h f \Delta I} } \]

\[ h = 6.63 \times 10^{-34} \text{ s} \]
\[ c = 1.602 \times 10^{-19} \text{ m/s} \]
\[ \Delta R \text{ in } \Omega \]
\[ \Delta I \text{ in mA} \]

\[ R = \frac{h f}{c} \frac{1}{\Delta x} = \frac{e^{\frac{c}{h f}}}{2} \]

\[ f = \frac{c}{2} \]
\[ \frac{3e^8}{788\text{nm}} \]

\[ \eta_{\text{ex}} = \frac{4.602 \times 10^{-19} \text{ W}(210 \text{ nm})}{(6.626 \times 10^{-34}) \frac{3e^8}{788\text{nm}} \times 1 \text{ mA}} = 13.33\% \]

\[ \frac{341.3}{14.6} = 23.54\% \]

\[ \frac{8.25}{5.24} = 1.57\% \]

**Laser LED threshold current**

![Laser LED threshold current graph](graph.png)
Part A) The shape of laser diode on the IR card was a long oblong disc. It was not round at all. The external differential quantum efficiency (\(\eta_{ex}\)) we found to about 13.33%.

Part B) The polarization percent for above threshold was quite high (23.54%), this would make sense since the diode is acting more like a laser above threshold than an LED. It would therefore be more susceptible to polarization. The polarization percent for below threshold was pretty low (16.79%). This also makes sense since below threshold the diode should be acting like an LED. Since LEDs aren't polarized it makes sense to have a very low polarization percent.

Part C) For the laser diode above threshold it was found to have a FWHM of about 0.5 nm. This would make sense because above threshold it should act as a laser with a very low spectrum range. A 0.15 nm FWHM supports this. For the laser diode at threshold it was found to have a FWHM of about 3.3 nm. This also makes sense because at threshold it's not quite a laser and not quite an LED. Its spectrum should therefore have a FWHM between that of a laser and LED, which it does. The FWHM at below threshold was found to be about 7.25 nm. This is in keeping with an LED's spectrum, the FWHM should be quite higher at below threshold than at above threshold, which it is, because an LED is not as focused as a laser so its spectrum should be more spread out.
Lab 7 report

Multimode Optical Fibers

This lab had three parts to it. The first part was to prepare an optical fiber for the transmission of laser light. The second part was to use the optical fiber to transmit light, this was accomplished by coupling the laser light with a 20x microscope lens into the core of the fiber. The last part of the lab was to calculate a rough approximation of the numerical aperture of the fiber.

The objectives in this lab were to one, learn how to properly cleave an optical fiber for optical transmission. The second objective was to couple laser light into an optical fiber and get optimal transmission. The last objective was to use the optical fiber to get an approximation of its numerical aperture.

Equipment & Supplies
- 1 meter of optical fiber
- Fiber cleaver
- Microscope
- 0.5mW HeNe laser
- Fiber coupler & holder
- 20x microscope lens
- Ruler
- Power meter

[Diagram of HeNe laser setup]
Procedure

We first started by burning off the protective coating around the cladding of the fiber. Once about an inch of cladding was exposed we used the fiber cleaver to make a crack in the cladding. After cracking it we pulled on either side of the crack to get a clean cut in the fiber. We examined the end of the fiber in a microscope to make sure it was a straight clean cut. We repeated this for the other end of the fiber. Once the prep work was done we setup the fiber coupler by attaching a 20x lense to couple the light into the fiber. We then attached the fiber into the fiber holder and then setup the laser to shine into the 20x lense. Once the laser was setup we positioned the fiber to get as best a power reading as possible from the fiber. We compared this reading to the reading of the laser to get a power transmission percent. We then positioned the fiber along a ruler and measured its distance from a piece of paper and then measured the width of the beam onto the paper.

Data:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser power</td>
<td>661.3 µW</td>
</tr>
<tr>
<td>Fiber power</td>
<td>339.0 µW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from</td>
<td>3 cm</td>
</tr>
<tr>
<td>Diameter of</td>
<td>1.3 cm</td>
</tr>
<tr>
<td>Beam (W)</td>
<td></td>
</tr>
</tbody>
</table>

Calculations:

\[
\text{percentage of light} = \frac{339 \mu W}{661.3 \mu W} \times 100\% = 51.24\%
\]

Numerical Aperture:

\[
\sin^{-1}\left(\frac{W}{2L}\right) = \sin^{-1}\left(\frac{1.3}{2(3)}\right) = 0.218 < 0.25
\]
For the percentage of light coupled into the fiber we got [57.26%]. While the percentage is not too bad, there were a few factors that could have gotten it higher. One was the cleaved end. It may have gotten damaged while it was being mounted to the coupler. Another factor could have been the laser light going into the fiber. The laser may not have been at optimal positioning to the fiber core.

For the numerical aperture we calculated about 0.218, which is close to the actual value of 0.2. The approximation of the beams diameter held the biggest area for error.
Lab 9 Report

Fiber Optics Application

In this lab we experimented with transmitting and receiving signals using an LED and fiber optics. The lab was split up into 3 parts: the first part was to test the quality of the fiber optic cable. The next part was to transmit a signal through the optical fiber. The last part was to transmit and receive the signal and test for the maximum transmission rate of the LED.

The objectives in this lab were to one, find the characteristics of the fiber optic cable using an HeNe laser. The other objective was to learn how to transmit a signal using an LED and fiber optic cable and function generator. The last objective was to build onto the transmitted signal and receive it through an oscilloscope.

Equipment & Supplies
- 0.5 mW HeNe laser
- DC power supplies w/cables
- LED transmitter & receiver board
- multimeter
- function generator/oscilloscope
- power meter
- ruler/IR card
- specification sheet

DC psu's

function generator

1200.00 V/1A

multi meter
Procedure

To begin with we setup the 0.5mW laser to shine into a plastic fiber optic cable. We measured the power through the cable using a power meter and compared it to the laser power by itself. We then measured the numerical aperture by measuring the beam diameter and distance of the optical cable. Then we attached another piece of fiber optic cable to the first one and measured the loss.

For the next part we attached the coupled fiber to the transmitter of the LED board and then attached power to the 5V line of the board. We then measured the power of the LED through the cable using the wavelength of the LED from the spec sheet. After that we attached the function generator to the LED board and the second DC PSU to raise the voltage of the output signal to 0-5V range. We then setup the function generator to generate a 1Hz pulse to the LED board. To make sure it was working we put the IR card in front of the fiber optic cable and observed the blinking light at 1Hz.

For the last part we attached the other end of the cable into the receiver of the LED board and then attached the oscilloscope to view both the input and output signals. Using the oscilloscope and function generator we increased the frequency and measured the time delay from the input to the output. We did this for the rising edge and falling edge. We then increased the frequency until the signal became flat (max frequency).
Data

A) light power through single fiber
light power through coupled fiber

B) wavelength of LED: 950 nm
light power of LED: 3.14 μW
in coupled fiber

C) falling edge: 32.4 μs
rising edge: 44.88 μs
maximum frequency: 17.4 kHz

Calculations:

Numerical:
\[ \sin^{-1}\left(\frac{w}{2L}\right) = \frac{1}{2}\sin^{-1}\left(\frac{1.75}{3}\right) = 0.62 \text{ in radians} \approx 36.0^\circ \]

A) Apparatus
Coupling loss: 10 log \( \left(\frac{32.4}{330}\right) \) = 6.05 dB

C) Fast estimate of maximum frequency:
\[ \frac{1}{(32.4 + 44.88)^2} = 13.4 \text{ kHz} \]

For the first part we measured the numerical apparatus to be 0.62°. We calculated the coupling loss to be 6.05 dB which is in keeping with the specification of the fiber. We measured the power output of the LED to be 3.14 μW. At 1 Hz we observed the light blinking through the fiber onto the IR card at 1 sec intervals (1 Hz). For the falling edge we measured 32.4 μs and 44.88 μs for the rising edge. We measured the maximum frequency of the LED to be 17.4 kHz. At that frequency and above, the LED appears on constantly. (No data can transmit)
Lab 10 Report

This lab was broken into six parts. We were to first construct a photodiode receiver circuit. The next part was to setup an LED circuit with a function generator. After that we were to construct a simple RC high pass filter. The fourth part was connect the high pass filter to the output of the photodiode receiver circuit. The fifth step was to build upon the high pass filter and add another high pass filter to the previous one. The last step was to measure how the LED circuit could be placed and still receive a good signal from the photodiode receiver circuit.

The objectives in this lab were to build a photodiode receiver circuit to measure the noise of the room lights and to build an LED circuit to transmit a signal. Another objective was to build onto the photodiode circuit with a high pass filter (RC) to decrease the noise from the room lights. The last objective was to test how far the LED circuit could be placed and still have a good signal.

Equipment and Supplies

- DC power supply w/cable
- Multimeter
- Oscilloscope
- Function generator
- Red high efficiency LED
- 10nF, 1nF capacitors
- 4700, 47kQ, 10kQ, 100kQ resistors
- Wire
- Ruler
- Photo transistor
Procedure

We began by constructing a photo-transistor circuit. This was done by connecting a phototransistor in series with a 4.7kΩ resistor and supplying the circuit with 5V dc. We then connected the oscilloscope to the output of the resistor. We sketched the waveform for the overhead lights and measured voltage levels along with the period. The next step was to construct the LED circuit. This was done by attaching a high-efficiency red LED in series with a 1.7kΩ resistor and supplying the circuit with power via the function generator (1 kHz square wave, Vp=5V, offset=+15V). After verifying that the LED was blinking at 1 kHz we increased the frequency until the LED appears constantly on. We then set the frequency for 5 kHz and positioned the LED circuit about 5 cm from the phototransistor circuit. We then sketched the waveform of the LED circuit with ambient light. Next we constructed a RC high pass filter by connecting a 10 nF capacitor in series with a 10 kΩ resistor and supplying the circuit with frequencies from the function generator in sinewave format. We measured the output voltage across the 10 kΩ resistor for frequencies of 1, 10, 30, 100, 300, 1 k, 3 k, 10 k, 30 k, 100 kHz Hertz. We then connected the input of the RC circuit to the output of the phototransistor circuit and measured the amplitude of the signal from the LED circuit. We then connected another RC circuit to the output of the first RC circuit. It was made from a 1 nF capacitor in series with a 10 kΩ resistor. We then measured the amplitude of that display. Now with 5V LED circuit.
The last part we did was move the LED circuit away from the photoresistor until the signal became degraded and measured the distance.

**Frequency Response of 1st-order high-pass filter**

- **Gain**
  - Measured
  - Calculated

**Frequency Response of 2nd-order high-pass filter**

- **Gain**
  - Measured
  - Calculated

1.00000 | 9.8 V | 10 V | 0.98 | 100000 | 8.8 V | 10 V | 0.88

4) **Room Light**: 1.6 V

5) **Room Light**: 2.6 kW

- **LED**: 1.2 V

LED: 1.72 V

6) **22 cm**
Calculations & Equations

1) Frequency = \frac{1}{\text{Period}} = \frac{1}{0.0565 \text{ ms}} = 17.8 \text{ Hz}

2) \text{LED+light (amplitude)} = \frac{2 \times \text{amp}}{5} = 3.8 \text{ mV}

3) \frac{V_{\text{out}}}{V_{\text{in}}} = \left( \frac{f_{0}}{2\pi RC} \right) = \frac{1}{2\pi RC}

<table>
<thead>
<tr>
<th>Hz</th>
<th>V_{\text{out}}</th>
<th>Gain (V_{\text{out}}/V_{\text{in}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.00628 V</td>
<td>0.00628</td>
</tr>
<tr>
<td>100</td>
<td>0.00628 V</td>
<td>0.00628</td>
</tr>
<tr>
<td>1000</td>
<td>0.00628 V</td>
<td>0.00628</td>
</tr>
<tr>
<td>10000</td>
<td>0.00628 V</td>
<td>0.00628</td>
</tr>
</tbody>
</table>

4) \text{Rand light amplitude} = \frac{V_{\text{in}}(0.8mV)}{2} = 0.4 \text{ mV}

5) \text{LED amplitude} = \frac{1}{2} \times 0.00628 \text{ mV}

Vin = 0 V
R = 10 k\Omega
C = 10 nF
f = frequency (Hz)

\text{LED amplitude} = \frac{1}{2} \times 0.00628 \text{ mV} = 0.00314 \text{ mV}

\text{Gain} (V_{\text{out}}/V_{\text{in}}) = \frac{1}{2\pi RC}

\frac{V_{\text{out}1}}{V_{\text{in}1}} = \frac{1}{\sqrt{1 + \left( \frac{f_{01}}{f} \right)^2}}

\text{Gain} (V_{\text{out}2}/V_{\text{in}2}) = \frac{1}{\sqrt{1 + \left( \frac{f_{02}}{f} \right)^2}}

\text{Gain} (V_{\text{out}3}/V_{\text{in}3}) = \frac{1}{\sqrt{1 + \left( \frac{f_{03}}{f} \right)^2}}

\text{Gain} (V_{\text{out}4}/V_{\text{in}4}) = \frac{1}{\sqrt{1 + \left( \frac{f_{04}}{f} \right)^2}}

\text{Gain} (V_{\text{out}5}/V_{\text{in}5}) = \frac{1}{\sqrt{1 + \left( \frac{f_{05}}{f} \right)^2}}

\frac{V_{\text{out}1}}{V_{\text{in}1}} = \frac{1}{2\pi RC}

\frac{V_{\text{out}2}}{V_{\text{in}2}} = \frac{1}{2\pi RC}

\frac{V_{\text{out}3}}{V_{\text{in}3}} = \frac{1}{2\pi RC}

\frac{V_{\text{out}4}}{V_{\text{in}4}} = \frac{1}{2\pi RC}

\frac{V_{\text{out}5}}{V_{\text{in}5}} = \frac{1}{2\pi RC}

\text{LED amplitude} = \frac{1}{2} \times 0.00628 \text{ mV} = 0.00314 \text{ mV}