PSE605A (Photonics Lab Techniques)

Lab Report: Experiment 6

DIFFRACTION GRATING & FABRY-PEROT

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1 Diffraction grating characterization

1.1 Objectives

- **To find the ruling density (grooves/mm) of the given grating**
- **To find the deviation as a function of wavelength for 1st order diffraction at different incident angle**
- **To find the Littrow condition and then the blazing angle**
- **To find the relative efficiency as a function of wavelength**

1.2 Apparatus

Grating, Laser source (457 nm, 532 nm, and 632.8 nm), Photo detector, Mirror etc.

1.3 Observations & Calculations

1.3.1 Ruling Density Calculation

- **For RED laser:**
  Wavelenth of the Red laser is 632.8 nm.
  The Reference angle is 206^0

Table 1: Diffraction using RED laser

Angle of incident α (deg)	β' (deg)	Diffracted angle $\beta = (2\beta' - \alpha)$ (deg)	Angle of Deviation $\beta - \alpha$ (deg)	Groove density $n = \left(\frac{sin\alpha + sin\beta}{m\lambda}\right)$ (grooves per mm)
0	17	34	34	883.680315
2	19	36	34	873.713267
4	21	38	34	862.681734
6	24	42	36	892.228418
8	26	44	36	877.821222
10	28	46	36	862.344536
12	30	48	36	845.817217
Average			35.14	871.183816

- **For GREEN laser:**
  Wavelenth of the Red laser is 532 nm.
  The Reference angle is 208^0

Table 2: Diffraction using GREEN laser

Angle of incident α (deg)	β' (deg)	Diffracted angle $\beta = (2\beta' - \alpha)$ (deg)	Angle of Deviation $\beta - \alpha$ (deg)	Groove density $n = \left(\frac{sin\alpha + sin\beta}{m\lambda}\right)$ (grooves per mm)
0	14	28	28	882.465344
2	16	30	28	874.249066
4	18	32	28	864.967651
6	20	34	28	854.632406
8	22	36	28	843.255924
10	24	38	28	830.852063
12	27	42	30	866.952849
14	29	44	30	851.008411
16	31	46	30	834.027151
18	34	50	32	859.074152
20	36	52	32	838.328215
Average			29.27	854.528476

- **For BLUE laser:**
  Wavelenth of the Red laser is 457 nm.
  The Reference angle is 208^0

Table 3: Diffraction using BLUE laser

Angle of incident α (deg)	β' (deg)	Diffracted angle $\beta = (2\beta' - \alpha)$ (deg)	Angle of Deviation $\beta - \alpha$ (deg)	Groove density $n = \left(\frac{sin\alpha + sin\beta}{m\lambda}\right)$ (grooves per mm)
0	12	24	24	890.014536
2	14	26	24	882.870131
4	17	30	26	941.451917
6	19	32	26	930.833263
8	22	36	28	981.645845
10	23	36	26	906.208041
12	26	40	28	951.588444
14	28	42	28	934.811183
16	30	44	28	916.894999
Average			26.44	926.257596

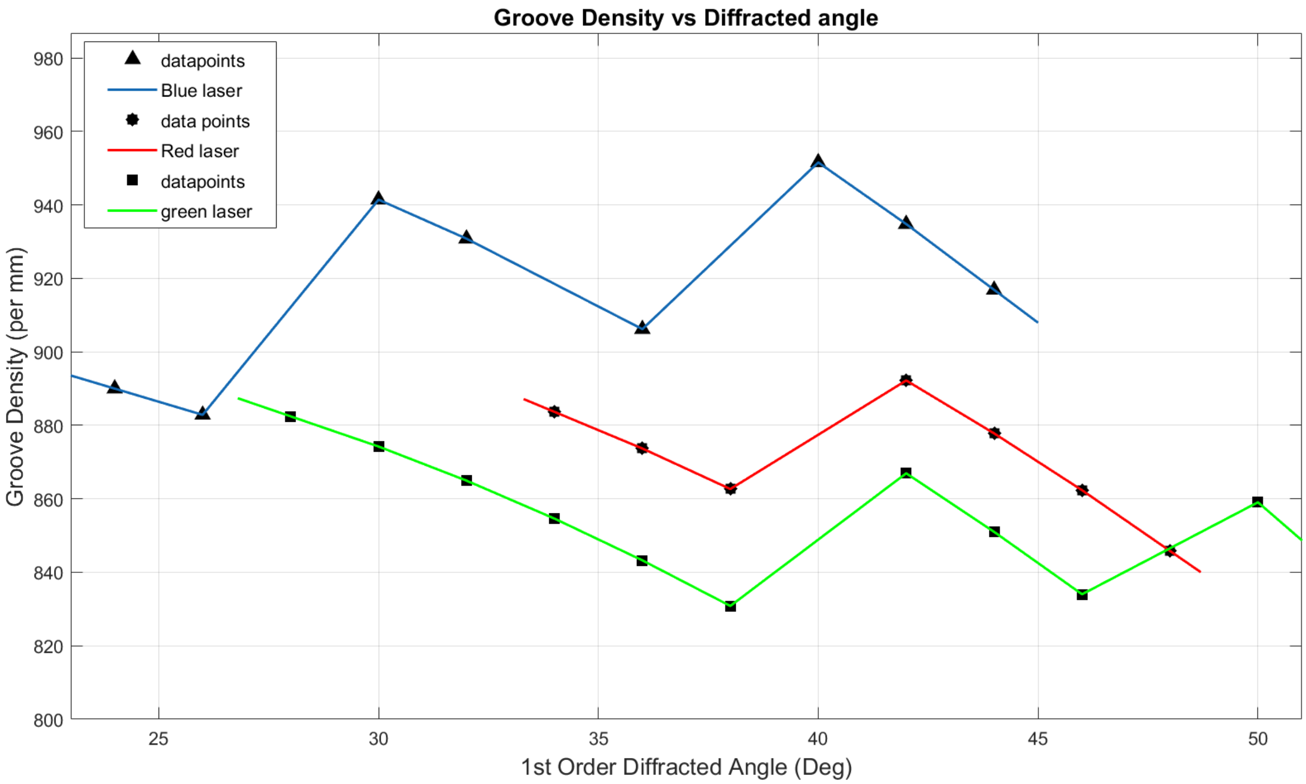


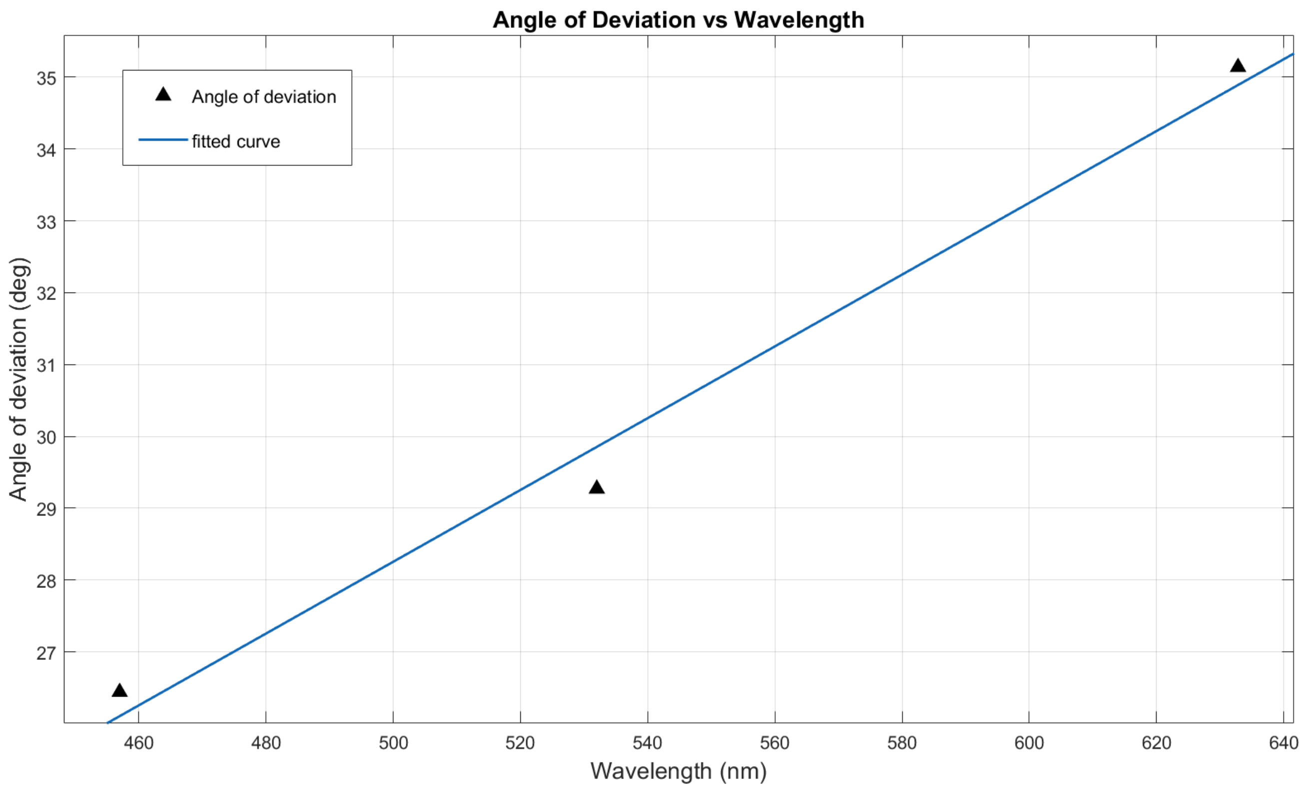
Figure 1: Groove density for different wavelengths

1.3.2 Deviation & 1st order diffraction

- **Deviation at different wavelenths:**

Table 4: Angle of Deviation at different wavelenths

Sl. no	Wavelength (nm)	average angle of deviation (deg)
1	632.8	35.14
2	532	29.27
3	457	26.44



Fit Name: Angle of deviation vs Wavelength

Polynomial Curve Fit (poly1)

f(x) = p1*x + p2

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
p1	0.0500	-0.0231	0.1230
p2	3.2667	-36.5743	43.1077

Figure 2: Angle of deviation for different wavelengths

- **1st order diffraction**

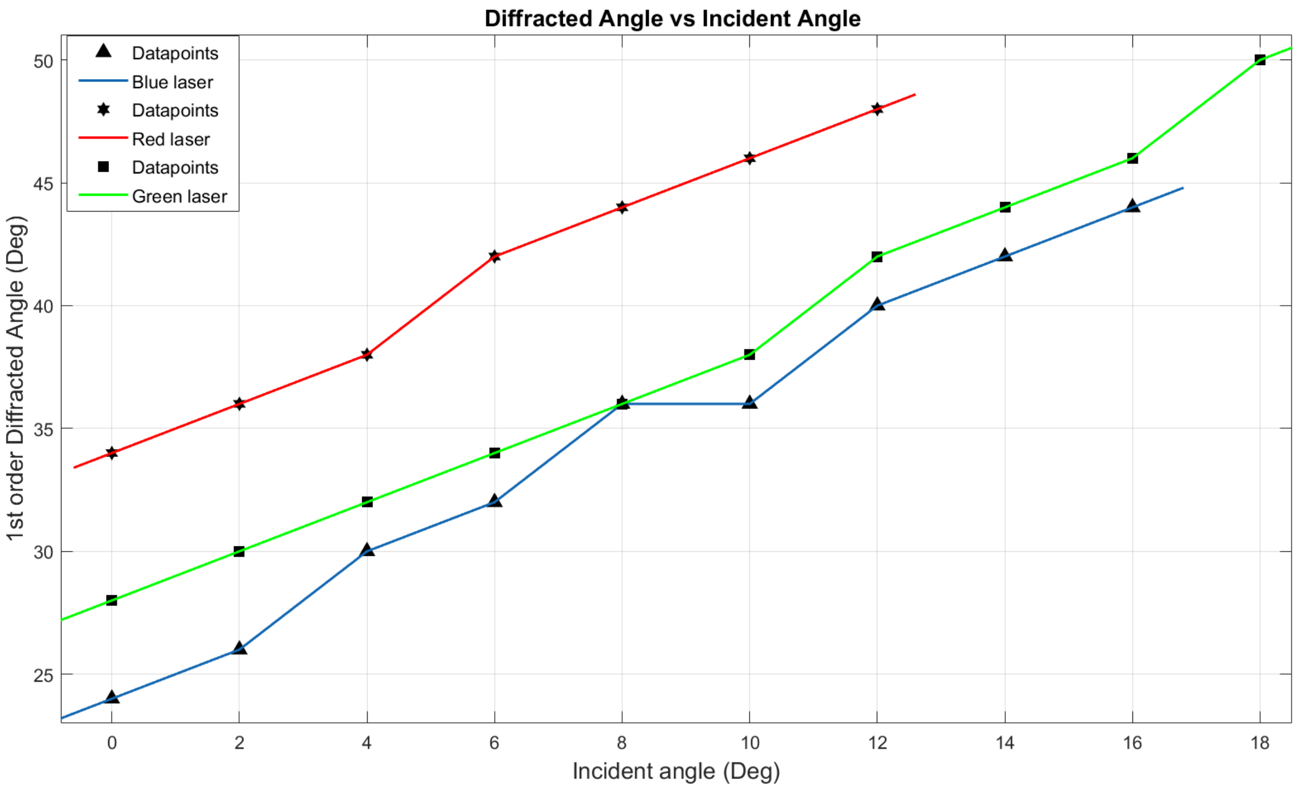
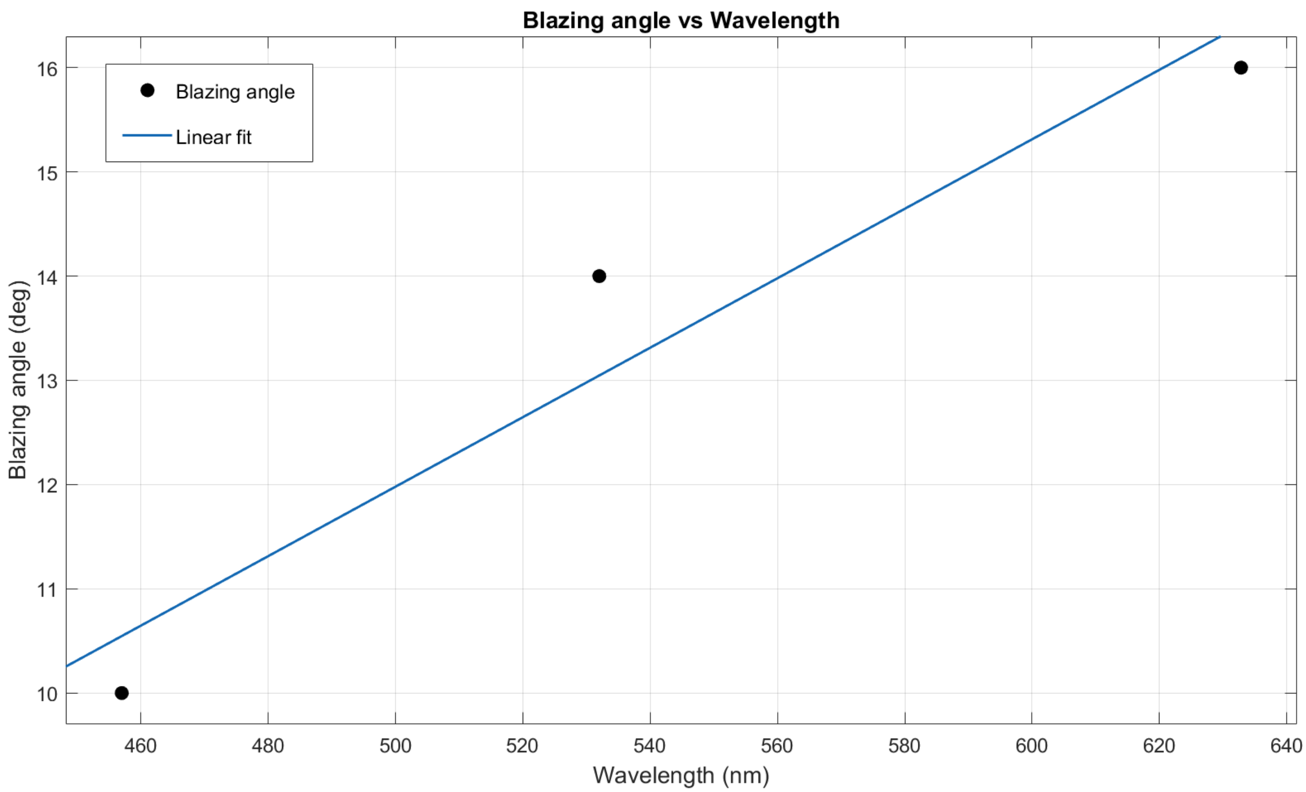
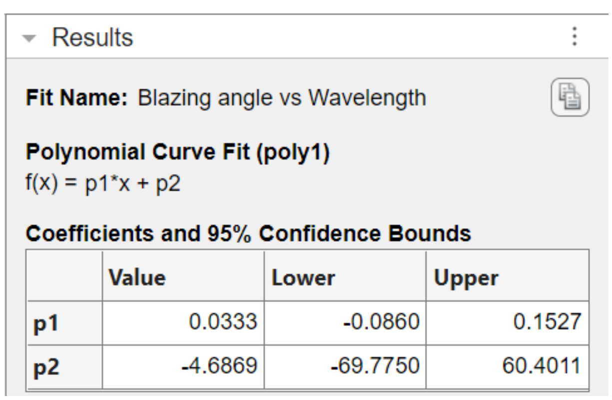


Figure 3: 1st order diffracted angle vs Incident angle

1.3.3 Blazing angle calculation

- **From direct experiment:**





Results

Fit Name: Blazing angle vs Wavelength

Polynomial Curve Fit (poly1)
f(x) = p1*x + p2

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
p1	0.0333	-0.0860	0.1527
p2	-4.6869	-69.7750	60.4011

Figure 4: Blazing angle at different wavelengths

Table 5: Blazing angle at different wavelengths

Wavelength (nm)	Angle when 0th order coincide with incident ray (i) (deg)	Angle when 1st order coincide with incident ray (j) (deg)	Blazing angle $\theta_b = i - j$
632.8	218	202	16
532	220	206	14
457	218	208	10

- **Calculation from experimental Groove density:**
We know, at Littrow condition,$\alpha = \beta = \theta_b$.
Then the blazing angle can be written as

$$\theta_b = sin^{-1}\left(\frac{mn\lambda}{2}\right)$$

For Red laser,
λ=632.8 nm, m=1, n= 871.183816 per mm (from Table 1).

$$\theta_b = sin^{-1}\left(\frac{1 * 871.183816 * 632.8}{2}\right)$$

$$\theta_b = 16.00^0$$

so, the blazing angle of the grating for red laser is 16.00^0.

- **Theoretical Value:**
The theoretical value of the groove density is n=900 grooves per mm.

  - For red laser:

$$\theta_b = sin^{-1}\left(\frac{1 * 900 * 632.8}{2}\right)$$

$$\theta_b = 16.54^0$$

    so, the theoretical value of the blazing angle of the grating for the red laser is 16.54^0.

  - For green laser:

$$\theta_b = sin^{-1}\left(\frac{1 * 900 * 532}{2}\right)$$

$$\theta_b = 13.85^0$$

    so, the theoretical value of the blazing angle of the grating for the green laser is 13.85^0.

– For blue laser:

$$\theta_b = sin^{-1}\left(\frac{1 * 900 * 457}{2}\right)$$

$$\theta_b = 11.87^0$$

so, the theoretical value of the blazing angle of the grating for the blue laser is 11.87^0.

1.3.4 Relative Efficiency calculation

For red laser:
Incident voltage is 528 mV
Voltage for 0th order diffracted ray is 510 mV
Voltage for 1st order diffracted ray is 477 mV

- $Mirrorefficiency = \left(\frac{0th\ order\ power}{Incident\ power}\right) * 100\%$

$$= \left(\frac{510}{528}\right) * 100\%$$

$$96.59\%$$

- $Grating\ efficiency = \left(\frac{1st\ order\ power}{Incident\ power}\right) * 100\%$

$$= \left(\frac{477}{528}\right) * 100\%$$

$$= 90.34\%$$

- $Relative\ efficiency = \left(\frac{Grating\ efficiency}{Mirror\ efficiency}\right) * 100\%$

$$= \left(\frac{0.9034}{0.9659}\right) * 100\%$$

$$93.53\%$$

So, the relative efficiency for red laser is 93.53%

Similarly, we can calculate for green and blue laser.
The calculated values are shown in Table 6.

Table 6: Relative efficiency at different wavelenths

Wavelenth (nm)	Incident voltage (mV)	0th order Voltage (mV)	1st order Voltage (mV)	Mirror efficiency (%)	Grating effiency (%)	**Relative efficiency** (%)
632.8	528	510	477	96.59	90.34	93.53
532	503	485	456	96.42	90.66	94.03
437	388	332	301	85.57	77.58	90.66

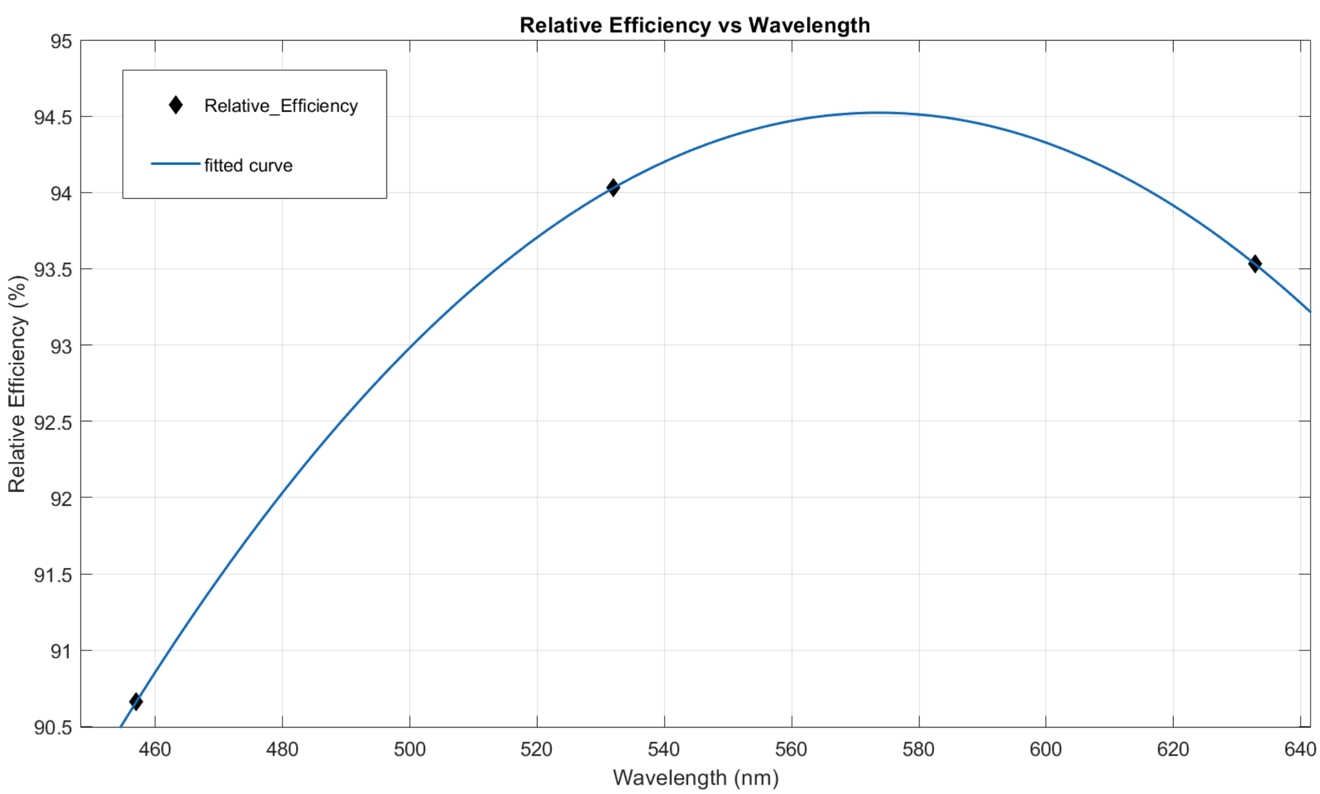


Figure 5: Relative Efficiency at different wavelengths

Results

Fit Name: Relative Efficiency vs Wavelength

Polynomial Curve Fit (poly2)
f(x) = p1*x^2 + p2*x + p3

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
p1	-0.0003	NaN	NaN
p2	0.3256	NaN	NaN
p3	1.1246	NaN	NaN

1.4 Error Analysis

1.4.1 Error in groove density

The theoretical value of groove density is 900 grooves per mm.

$$Percentile\ error = \left| \frac{Theoretical\ value - Experimental\ value}{Theoretical\ value} \right| * 100\%$$

- When using RED laser:

$$\begin{aligned} Percentile\ error &= \left| \frac{900 - 871.183816}{900} \right| * 100\% \\ &= 3.20\% \end{aligned}$$

- When using GREEN laser:

$$\begin{aligned} Percentile\ error &= \left| \frac{900 - 854.528476}{900} \right| * 100\% \\ &= 5.05\% \end{aligned}$$

- When using BLUE laser:

$$\begin{aligned} Percentile\ error &= \left| \frac{900 - 926.257596}{900} \right| * 100\% \\ &= 2.92\% \end{aligned}$$

1.4.2 Error in Blazing angle

- For RED laser:

$$Percentile\ error = \left|\frac{16.54 - 16}{16.54}\right| * 100\%$$
$$= 3.26\%$$

- For GREEN laser:

$$Percentile\ error = \left|\frac{13.85 - 14}{13.85}\right| * 100\%$$
$$= 1.08\%$$

- For BLUE laser:

$$Percentile\ error = \left|\frac{11.87 - 10}{11.87}\right| * 100\%$$
$$= 15.75\%$$

1.5 Discussions and Conclusions

- **Groove density:**
  Errors in calculating groove density are 3.20% (using Red laser), 5.05% (using Green laser), and 2.92% (using Blue laser). I think the error is not much. But error could be reduced by using fine scaling in calculating the angle.

- **Angle of deviation:**
  We can see from Figure 2, that the angle of deviation increases with the wavelength. And it increases linearly. The experimental data is slightly deviated from the straight line.

- **1st order Diffraction:**
  We can see from Figure 3, that the angle of diffraction increases with the wavelength.

- **Blazing angle:**
  We can see from Figure 4, that the blazing angle increases with the wavelength. We can see from the error calculation, the errors in calculating the blazing angle are 3.26% for Red laser, 1.08% for the Green laser, and 15.75% for the Blue laser. Errors for red and green lasers are less but for blue laser error is significant.

- **Relative efficiency:**
  Relative efficiencies are 93.53% for the Red laser, 94.03% for the Green laser, and 90.66% for the Blue laser. So the relative efficiency of the blue laser is comparatively less than that of the other two lasers. It might be due to less intensity.

1.6 Appendix

- Calculation for groove density:
  For Red laser, suppose, $\alpha = -2^0$,
  $\beta = 36^0$,
  $\lambda = 632.8\ nm$
  m=1
  We know,Groove density,

$$n = \left(\frac{sin\alpha + sin\beta}{m\lambda}\right)$$

$$n = \left(\frac{sin36^0 - sin2^0}{1 * 632.8}\right)$$

$$= 873.713267\ grooves\ per\ mm$$

1.7 References

- "Introduction to Optics" by Frank L. Pedrotti, S.J. Leno M. Pedrotti and Leno S. Pedrotti, Pearson publication, 3rd edition (2008)

2 Fabry-Pérot Interferometry

2.1 Objectives

- **To determine transmittance curve for He-Ne laser source**
- **To determine finesse for He-Ne laser source**

2.2 Apparatus

Laser source, Fabry-Perot interferometer, Spectrum analyser controller (SA-201), Oscilloscope

2.3 Results

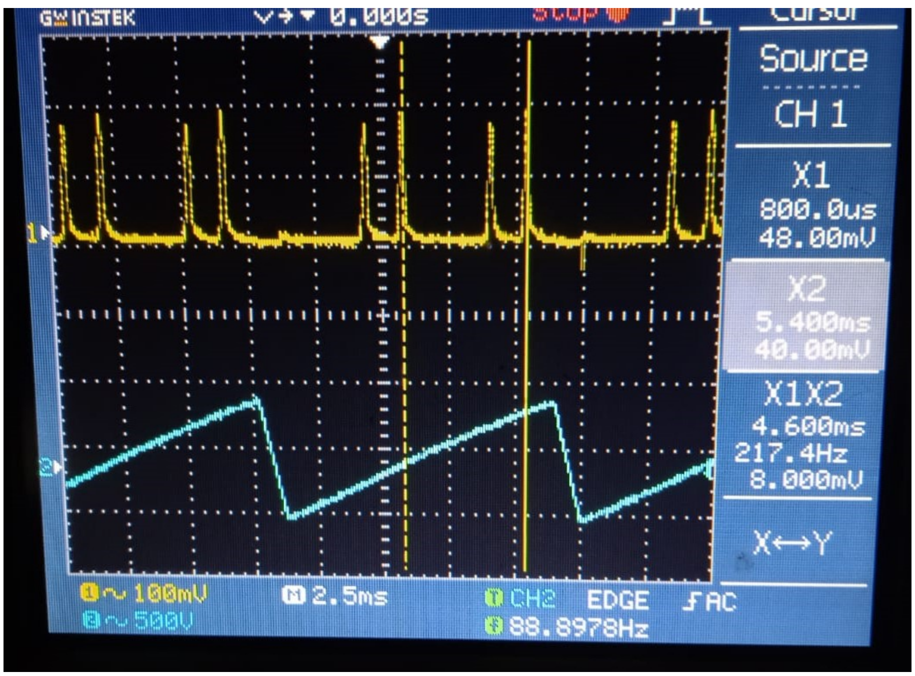


Figure 6: Transmission curve

- Position of the left peak, $x1 = 800\ \mu S = 0.8\ mS$
  Position of the right peak,$x2 = 5.4\ mS$
  Time difference between two peaks is,

$$\delta t = x2 - x1$$

$$\delta t = 5.4 - 0.8 = 4.6\ mS$$

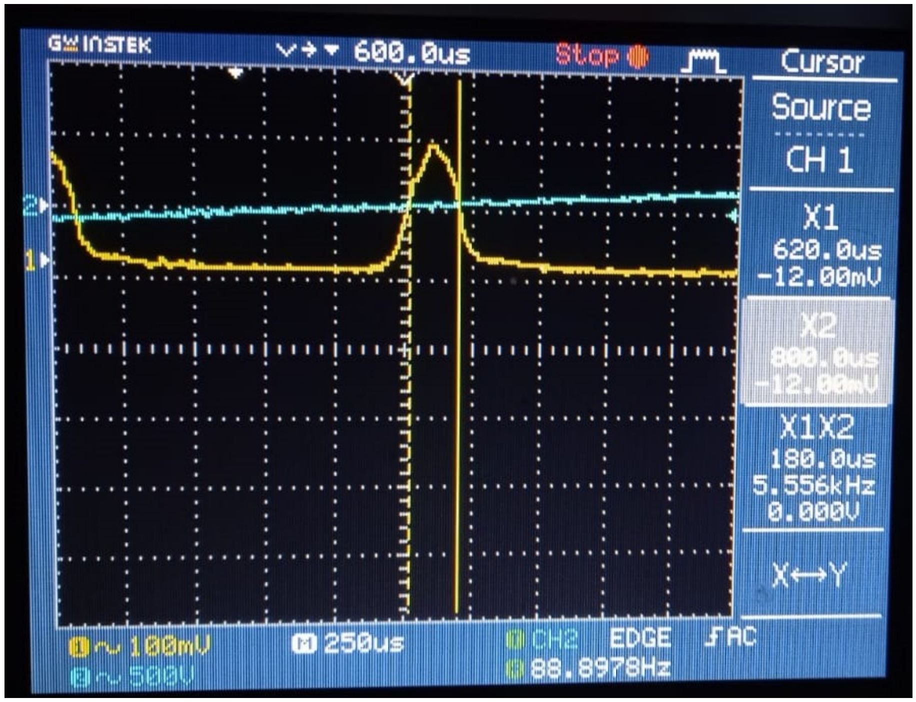


Figure 7: Showing FWHM of one of the peaks

- At FWHM,
  $x1 = 620\ \mu S,\ x2 = 800\ \mu S$
  So,

$$FWHM = (800 - 620)\ \mu S = 180\ \mu S$$

$$FWHM = 0.18\ mS$$

2.4 Calculations

2.4.1 Resolution

Given, $FSR = 1.5\ GHz$ & $\delta t = 4.6\ mS$ $FWHM = 0.18\ mS$
We know,

$$Resolution(\Delta) = \left(\frac{FSR * FWHM}{\delta t}\right)$$

$$Resolution(\Delta) = \left(\frac{1.5 * 10^9 * 0.18 * 10^{-3}}{4.6 * 10^{-3}}\right)$$

$$Resolution(\Delta) = 58.69\ MHz$$

2.4.2 Length of the Cavity

Velocity of light in air $(c) = 3 * 10^8\ m/s$

$$length\ of\ the\ cavity = \left(\frac{c}{4 * FSR}\right)$$

$$= \left(\frac{3 * 10^8}{4 * 1.5 * 10^9}\right)$$

$$length\ of\ the\ cavity = 5\ cm$$

2.4.3 Finesse

$$Finesse(f) = \left(\frac{FSR}{\Delta}\right)$$

$$= \left(\frac{1.5 * 10^9}{58.69 * 10^6}\right)$$

$$Finesse(f) = 25.6$$

2.5 Discussions & Conclusions

- **finesse:**
  We know that higher finesse means higher selectivity of transmission. It indicates a higher resolving power. For our case, the finesse(f) parameter is calculated as 25.6. This is not a high finesse value.
  The reason might be the lack of proper alignment. Another reason might be the less reflectivity of the mirrors.

- **Errors:**
  Reading should be taken after keeping the cursor perfectly aligned. During calculating the FWHM, the blue line is not perfectly horizontal. So, it is the another source of the errors.

2.6 References

- “Optics” by E Hecht, Pearson publication, 4th edition (2003)
- $https : //www.thorlabs.com/newgrouppage9.cfm?objectgroup_id = 859$