PSE605A (Photonics Lab Techniques)

Lab Report: Experiment 4

POLARIZATION

Submitted by

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Contents

List of Tables

1 Studies on polarization

1.1 Objectives

- To check the polarisation of laser source
- To verify Malus law
- To characterize the functionality of HWP
- Generate circular and elliptical polarized light using QWP

1.2 Equipments

He-Ne Laser (632.8nm), Linear polarizers, Half wave plate, Quarter wave plate, Photo diode, Biasing circuit and multi-meter.

1.3 Observations and Calculations

Suppose, the output voltage is v.
Then, the current is

$$I = \left(\frac{v}{R}\right)$$

where R is the resistance.
We know, optical power,

$$P = \left(\frac{I}{R_p}\right)$$

where R_p is the responsivity of the detector.
So,

$$P = \left(\frac{v}{R_p R}\right)$$

Here R= 1 kW and the responsivity of the detector is 0.43 A/W.
Then,

$$P = \left(\frac{v}{430}\right)$$

1.3.1 Objective 1: To check the polarisation of laser source

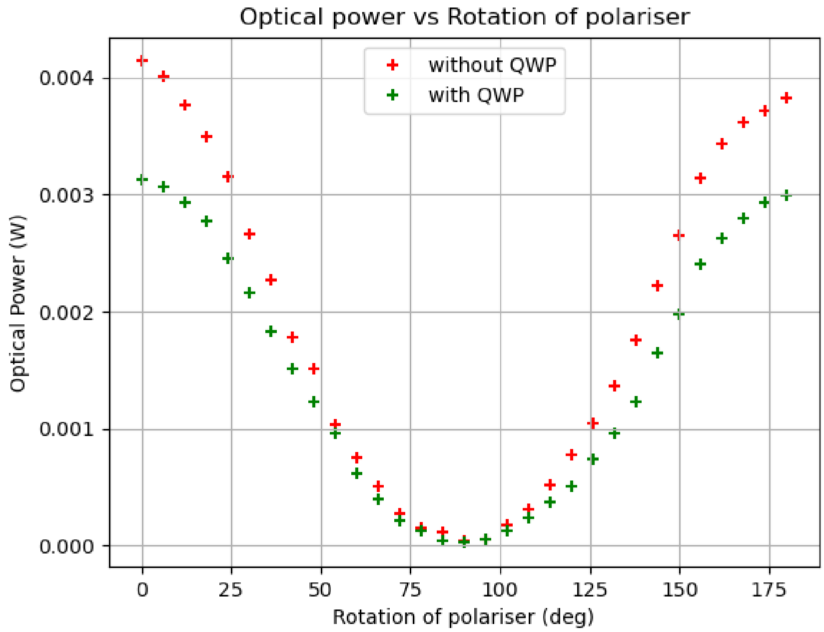


Figure 1: Polarisation of laser source

1.3.2 Objective 2: To verify Malus law

Maximum optical power of direct beam,

$$P_1 = 2.226/430 = 0.00517674\ W$$

Maximum Optical power after keeping polariser,

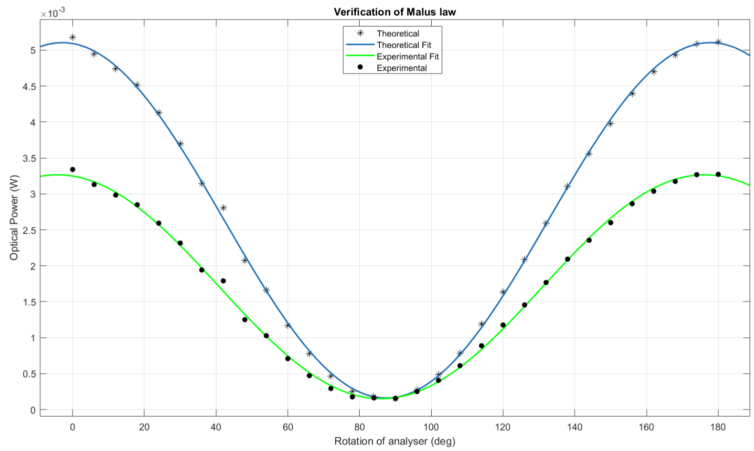
$$P_2 = 1.78/430 == 0.00413953\ W$$

Maximum Optical power after keeping analyser,

$$P_3 = 1.436/430 == 0.003339535\ W$$

So, polariser loss= $0.00517674 - 0.00413953 = 0.00103687\ W$
Analyser loss= $0.00413953 - 0.00339535 = 0.00074418\ W$
Total loss= $0.00103687 + 0.00074418 = 0.00178105\ W$

$$theoretical\ power = experimental\ power + loss * cos^2\theta$$



Results

Fit Name: Verification of Malus law (Experimental)

Custom Curve Fit
f(x) = a*cosd(b*(x-d))^2+c

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
a	0.0031	0.0031	0.0032
b	0.9977	0.9788	1.0165
c	0.0002	0.0001	0.0002
d	-4.2528	-6.0298	-2.4758

Goodness of Fit

	Value
SSE	0.0000
R-square	0.9984
DFE	27.0000
Adj R-sq	0.9982
RMSE	0.0000

Results

Fit Name: Verification of Malus law (Theoretical)

Custom Curve Fit
f(x) = a*cosd(b*(x-d))^2+c

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
a	0.0049	0.0049	0.0050
b	0.9965	0.9842	1.0087
c	0.0002	0.0001	0.0002
d	177.7579	176.6143	178.9016

Goodness of Fit

	Value
SSE	0.0000
R-square	0.9994
DFE	27.0000
Adj R-sq	0.9993
RMSE	0.0000

Figure 2: Verification of Malus law

1.3.3 Objective 3: To characterize the functionality of HWP

After putting HWP, maximum optical power after analyser is

$$P_4 = 0.98/430 = 0.00227907\ W$$

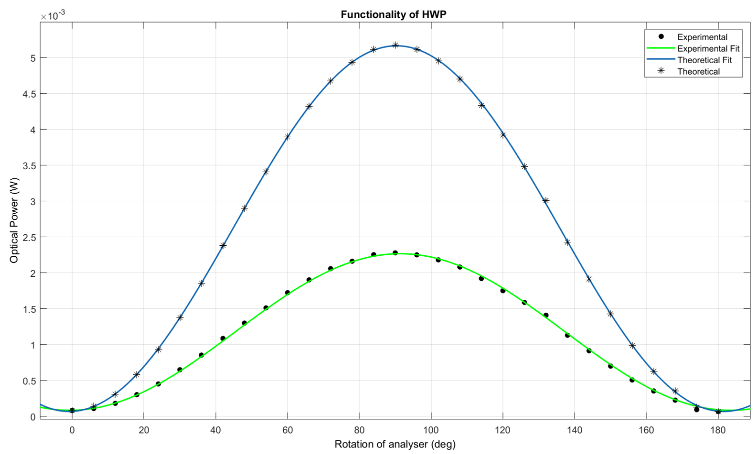
So, HWP loss= $P_2 - P_4 - analyserloss$

$$= 0.00413953 - 0.00227907 - 0.00074418 = 0.00111628\ W$$

total loss=

$$0.00103687 + 0.00074418 + 0.00111628 = 0.00289733\ W$$

$$theoretical\ power = experimental\ power + loss * sin^2\theta$$



Results

Fit Name: Functionality of HWP (Experimental)

Custom Curve Fit
f(x) = a*sind(b*(x-d))^2+c

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
a	0.0022	0.0022	0.0022
b	0.9776	0.9636	0.9917
c	0.0001	0.0001	0.0001
d	-0.6740	-2.0347	0.6867

Goodness of Fit

	Value
SSE	0.0000
R-square	0.9993
DFE	27.0000
Adj R-sq	0.9992
RMSE	0.0000

Fit Name: Functionality of HWP (Theoretical)

Custom Curve Fit
f(x) = a*sind(b*(x-d))^2+c

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
a	0.0050	0.0049	0.0051
b	0.9986	0.9825	1.0147
c	0.0002	0.0001	0.0002
d	1.0175	-0.4843	2.5193

Goodness of Fit

	Value
SSE	0.0000
R-square	0.9989
DFE	27.0000
Adj R-sq	0.9988
RMSE	0.0001

Figure 3: Functionality of HWP

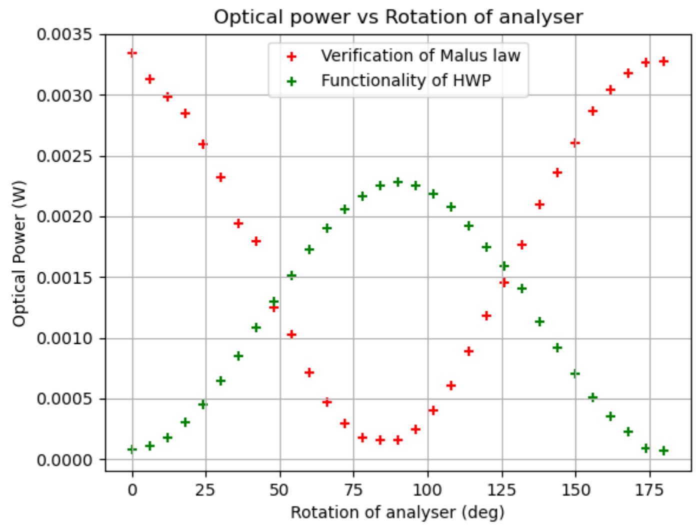


Figure 4: Comparison between with and without HWP

1.3.4 Objective 4: Generate circular and elliptical polarized light using QWP

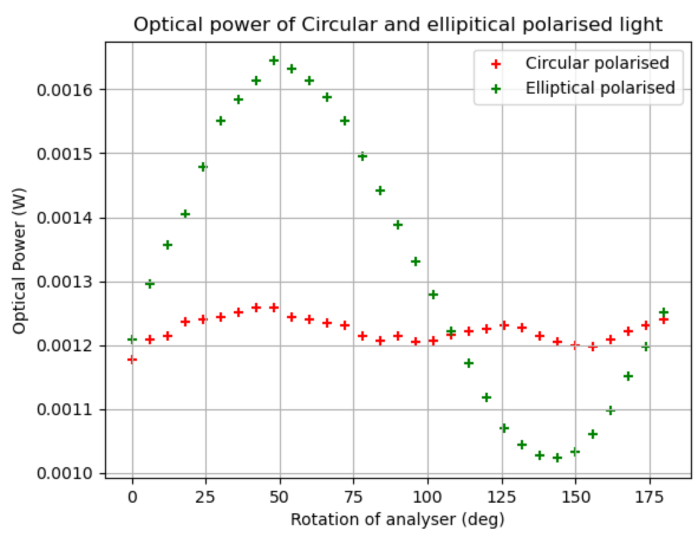


Figure 5: Circular and Polarised light

1.4 Error Analysis

1.4.1 For Objective 2

Suppose, for $0°$ rotation,
experimental optical power = 0.003340 W
Theoretical optical power = 0.005177 W
Then the maximum percentile error,

$$\left(\frac{\delta P}{P}\right) * 100\% = \left(\frac{(0.005177 - 0.003340)}{0.005177}\right) * 100\%$$
$$= 35.48\%$$

So, the maximum percentile error in calculating optical power is 35.48%.

1.4.2 For Objective 3

Suppose, for $90°$ rotation,
experimental optical power = 0.002279 W
Theoretical optical power = 0.005177 W
Then the maximum percentile error,

$$\left(\frac{\delta P}{P}\right) * 100\% = \left(\frac{(0.005177 - 0.002279)}{0.005177}\right) * 100\%$$
$$= 55.98\%$$

So, the maximum percentile error in calculating optical power is 55.98%.

1.5 Discussions and Conclusions

- **Polarisation of laser source:** For without QWP, we can see the optical power is varying with the rotation of polariser. At two points, there are very low optical power but not complete extinction. So, this is not a linear polarised light. after putting QWP, we can see the same situation but with relatively low power. From that it can be concluded that the source is a mixture of unpolarised and linear polarised light or a mixture of unpolarised and elliptical polarised light.

- **Verification of Malus law:** After putting analyser, we can see at $0°$ and $180°$, optical power is maximum. And at $90°$, the optical power is zero. With the change in rotation of analyser, the optical power is changing in $cos^2\theta$ manner. So, it verified malus law.

- **Functionality of HWP:** We can see from the table, at $0°$ and $180°$, optical power is zero. And at $90°$, the optical power is maximum. It looks like, HWP just adds $\pi/2$ phase difference. We can see from the comparison plot that after putting an HWP between polariser and analyser, it looks like the mirror image of the previous case. So, HWP does not change the polarisation type.

- **Generation of circular polarisation:** After replacing the HWP with the QWP, we put the QWP in the middle of the maximum and minimum positions. We tried to keep the optic axis of the QWP at 45° with pass axis of polariser. From the output, we can see that the optical power is almost the same for all the angle of rotations. From it, we can say it is a circular polarised light.

- **Generation of elliptical polarisation:** To get an elliptical polarised light, we just rotate the QWP 6°. And we get a continuous variation in optical power looking like a sinusoidal curve. From it, we can see that it is an elliptical polarised light.

1.6 Source of Error

- There is an error of perpendicularity. it comes from taking readings of rotation in polariser or analyser.

- Always there is fluctuation in output voltage. We tried to take the average of the readings. it is also a source of error.

- The room was not fully dark. So, always there is a noise in the output.

1.7 Appendices

Table 1: Polarisation of Laser source

Rotation of polariser (deg)	Output Voltage WITHOUT QWP (V)	Output Power WITHOUT QWP (W)	Output Voltage WITH QWP (V)	Output Power WITH QWP (W)
0	1.780000	0.004140	1.347000	0.003133
6	1.723000	0.004007	1.320000	0.003070
12	1.619000	0.003765	1.263000	0.002937
18	1.501000	0.003491	1.190000	0.002767
24	1.355000	0.003151	1.055000	0.002453
30	1.144000	0.002660	0.928000	0.002158
36	0.975000	0.002267	0.784000	0.001823
42	0.768000	0.001786	0.649000	0.001509
48	0.650000	0.001512	0.526000	0.001223
54	0.443000	0.001030	0.413000	0.000960
60	0.324000	0.000753	0.267000	0.000621
66	0.216000	0.000502	0.170000	0.000395
72	0.115000	0.000267	0.089000	0.000207
78	0.066000	0.000153	0.053000	0.000123
84	0.047000	0.000109	0.018000	0.000042
90	0.015000	0.000035	0.010000	0.000023
96	0.023000	0.000053	0.022000	0.000051
102	0.077000	0.000179	0.053000	0.000123
108	0.135000	0.000314	0.101000	0.000235
114	0.222000	0.000516	0.160000	0.000372
120	0.334000	0.000777	0.218000	0.000507
126	0.447000	0.001040	0.319000	0.000742
132	0.585000	0.001360	0.414000	0.000963
138	0.757000	0.001760	0.528000	0.001228
144	0.957000	0.002226	0.710000	0.001651
150	1.140000	0.002651	0.849000	0.001974
156	1.350000	0.003140	1.032000	0.002400
162	1.474000	0.003428	1.131000	0.002630
168	1.558000	0.003623	1.202000	0.002795
174	1.600000	0.003721	1.259000	0.002928
180	1.647000	0.003830	1.285000	0.002988

Table 2: Verification of Malus law

Rotation of analyser (deg)	Output Voltage (V)	Output Power Experimental (W)	Output Power Theoretical (W)
0	1.436000	0.003340	0.005177
6	1.346000	0.003130	0.004947
12	1.283000	0.002984	0.004742
18	1.225000	0.002849	0.004511
24	1.115000	0.002593	0.004126
30	0.996000	0.002316	0.003694
36	0.835000	0.001942	0.003144
42	0.770000	0.001791	0.002805
48	0.538000	0.001251	0.002074
54	0.442000	0.001028	0.001663
60	0.305000	0.000709	0.001169
66	0.203000	0.000472	0.000776
72	0.126000	0.000293	0.000468
78	0.076000	0.000177	0.000256
84	0.070000	0.000163	0.000183
90	0.067000	0.000156	0.000156
96	0.108000	0.000251	0.000271
102	0.175000	0.000407	0.000486
108	0.263000	0.000612	0.000787
114	0.382000	0.000888	0.001192
120	0.506000	0.001177	0.001636
126	0.626000	0.001456	0.002091
132	0.760000	0.001767	0.002590
138	0.900000	0.002093	0.003108
144	1.013000	0.002356	0.003558
150	1.118000	0.002600	0.003978
156	1.231000	0.002863	0.004396
162	1.306000	0.003037	0.004699
168	1.365000	0.003174	0.004932
174	1.405000	0.003267	0.005085
180	1.407000	0.003272	0.005109

Table 3: Functionality of HWP

Rotation of analyser (deg)	Output Voltage (V)	Output Power Experimental (W)	Output Power Theoretical (W)
0	0.035000	0.000081	0.000081
6	0.047000	0.000109	0.000141
12	0.078000	0.000181	0.000307
18	0.130000	0.000302	0.000579
24	0.194000	0.000451	0.000931
30	0.279000	0.000649	0.001373
36	0.367000	0.000853	0.001855
42	0.467000	0.001086	0.002383
48	0.559000	0.001300	0.002900
54	0.650000	0.001512	0.003408
60	0.741000	0.001723	0.003897
66	0.818000	0.001902	0.004321
72	0.885000	0.002058	0.004679
78	0.930000	0.002163	0.004935
84	0.969000	0.002253	0.005120
90	0.980000	0.002279	0.005177
96	0.968000	0.002251	0.005117
102	0.938000	0.002181	0.004954
108	0.895000	0.002081	0.004702
114	0.826000	0.001921	0.004339
120	0.753000	0.001751	0.003924
126	0.683000	0.001588	0.003485
132	0.606000	0.001409	0.003010
138	0.486000	0.001130	0.002428
144	0.393000	0.000914	0.001915
150	0.301000	0.000700	0.001424
156	0.218000	0.000507	0.000986
162	0.152000	0.000353	0.000630
168	0.097000	0.000226	0.000351
174	0.040000	0.000093	0.000125
180	0.029000	0.000067	0.000067

Table 4: Circular and Elliptical Polarisation

Rotation of analyser (deg)	Output Voltage for circular polarisation (V)	Output Power for circular polarisation (W)	Output Voltage for elliptical polarisation (V)	Output Power for elliptical polarisation (W)
0	0.506000	0.001177	0.520000	0.001209
6	0.520000	0.001209	0.557000	0.001295
12	0.522000	0.001214	0.583000	0.001356
18	0.532000	0.001237	0.604000	0.001405
24	0.533000	0.001240	0.636000	0.001479
30	0.535000	0.001244	0.667000	0.001551
36	0.538000	0.001251	0.681000	0.001584
42	0.541000	0.001258	0.694000	0.001614
48	0.541000	0.001258	0.707000	0.001644
54	0.535000	0.001244	0.702000	0.001633
60	0.533000	0.001240	0.694000	0.001614
66	0.531000	0.001235	0.683000	0.001588
72	0.529000	0.001230	0.667000	0.001551
78	0.522000	0.001214	0.643000	0.001495
84	0.519000	0.001207	0.620000	0.001442
90	0.522000	0.001214	0.597000	0.001388
96	0.518000	0.001205	0.572000	0.001330
102	0.519000	0.001207	0.550000	0.001279
108	0.523000	0.001216	0.525000	0.001221
114	0.525000	0.001221	0.504000	0.001172
120	0.527000	0.001226	0.481000	0.001119
126	0.529000	0.001230	0.460000	0.001070
132	0.528000	0.001228	0.449000	0.001044
138	0.522000	0.001214	0.442000	0.001028
144	0.518000	0.001205	0.440000	0.001023
150	0.516000	0.001200	0.444000	0.001033
156	0.515000	0.001198	0.456000	0.001060
162	0.520000	0.001209	0.472000	0.001098
168	0.525000	0.001221	0.495000	0.001151
174	0.529000	0.001230	0.515000	0.001198
180	0.533000	0.001240	0.538000	0.001251

2 Simulation study of Polarization Experiment using Fred software

2.1 Objectives

- To verify Malus law
- To characterize the functionality of HWP
- Generate Circular and Elliptical polarized light using QWP

2.2 Observations

2.2.1 Verification Of Malus law

Rotation of analyser (deg)	Irradiance (power/area)
0	3.485
90	0.000
180	3.485

2.2.2 Functionality of HWP

Rotation of analyser (deg)	Irradiance (power/area)
0	0.000
90	3.510
180	0.000

2.2.3 Circular Polarisation

Rotation of analyser (deg)	Irradiance (power/area)
0	1.755
90	1.755
180	1.755

2.2.4 Elliptical polarisation

Rotation of analyser (deg)	Irradiance (power/area)
0	1.550
60	2.340
90	1.965
180	1.550
190	1.750

2.3 Computional Observations

2.3.1 Verification Of Malus law

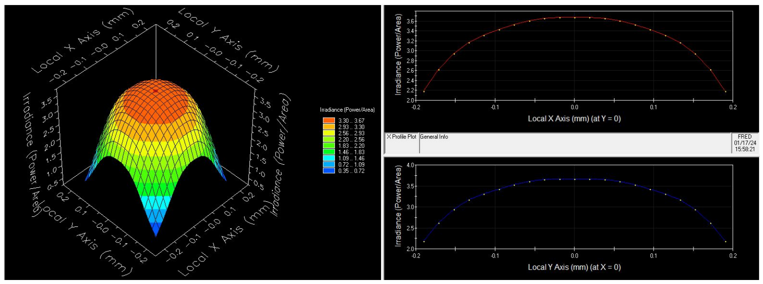


Figure 6: For 0°

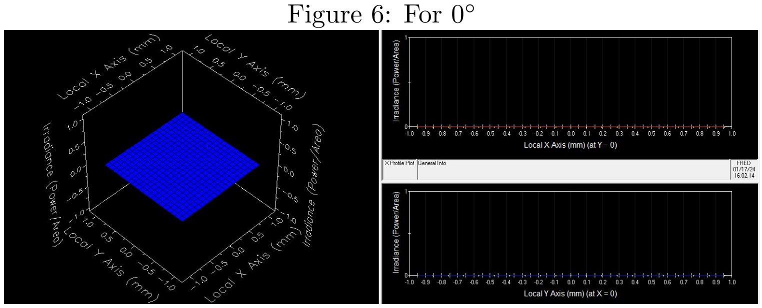


Figure 7: For 90°

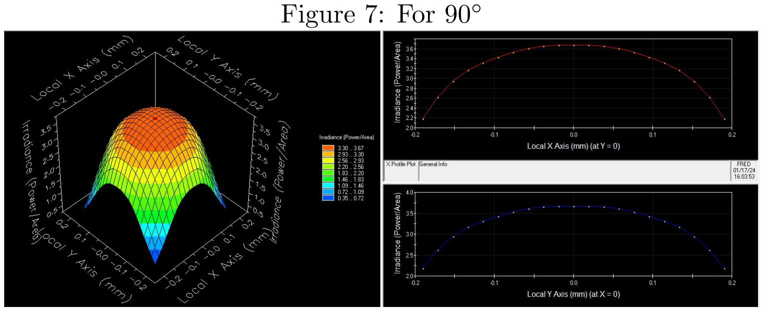


Figure 8: For 180°

2.3.2 Functionality of HWP

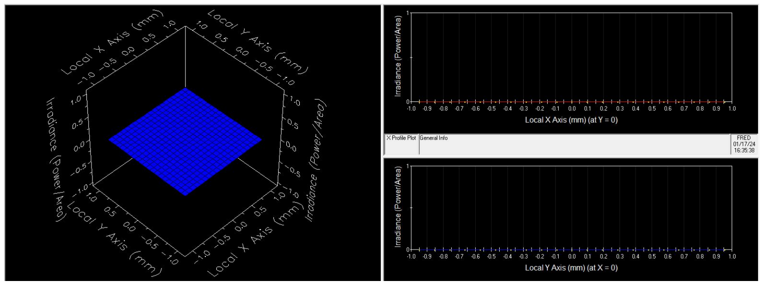


Figure 9: For 0°

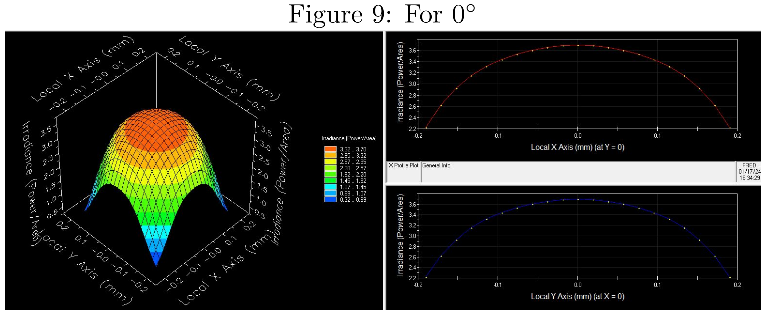


Figure 10: For 90°

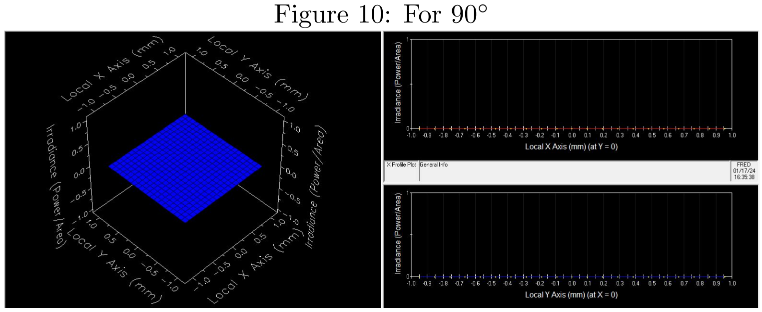


Figure 11: For 180°

2.3.3 Circular Polarisation

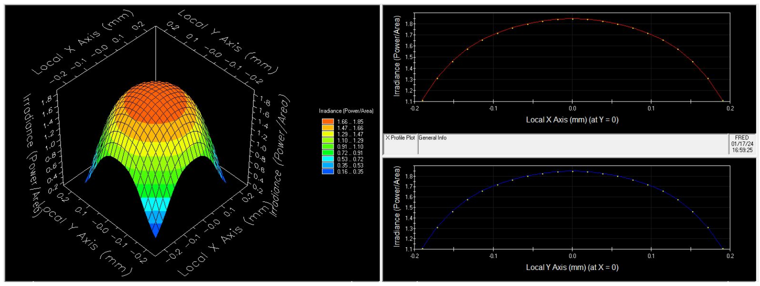


Figure 12: For 0°

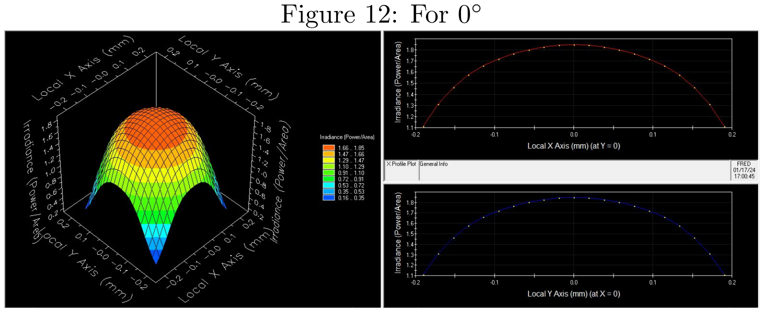


Figure 13: For 90°

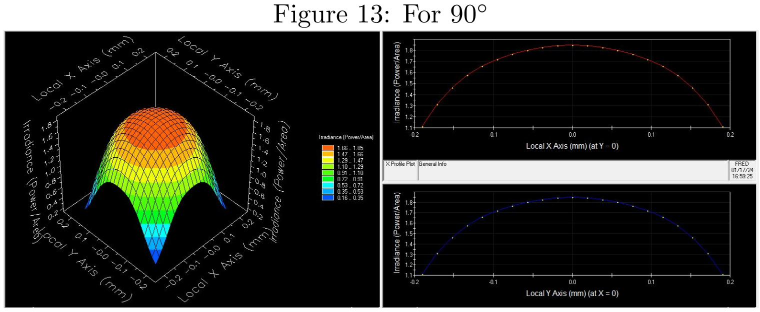


Figure 14: For 180°

2.3.4 Elliptical Polarisation

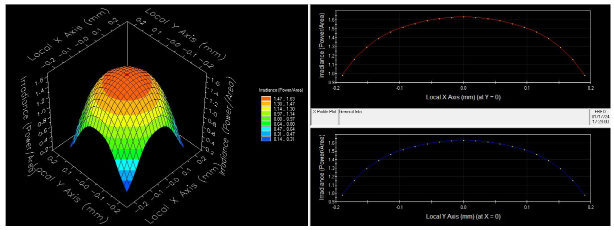


Figure 15: For 0°

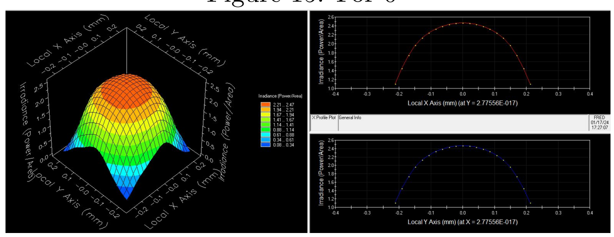


Figure 16: For 60°

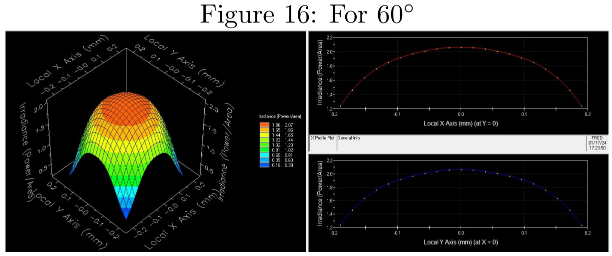


Figure 17: For 90°

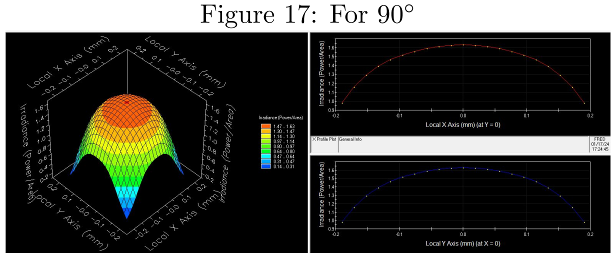


Figure 18: For 180°

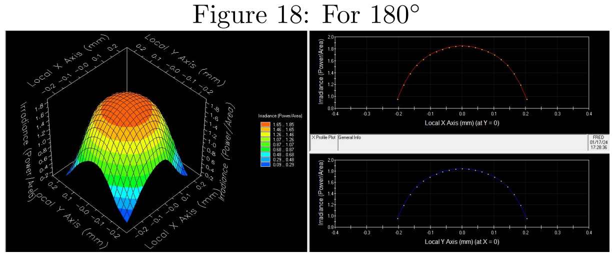


Figure 19: For 190°

2.4 Appendices

Table 5: Verification Of Malus law

Rotation of analyser (deg)	Irradiance range	Average Irradiance (power/area)
0	3.30-3.67	3.48
15	2.56-2.93	2.75
30	1.83-2.20	2.01
45	1.09-1.46	1.28
60	0.72-1.09	0.90
75	0.35-0.72	0.53
90	0.00-0.00	0.00
105	0.35-0.72	0.53
120	0.72-1.09	0.90
135	1.09-1.46	1.28
150	1.83-2.20	2.01
165	2.56-2.93	2.75
180	3.30-3.67	3.48

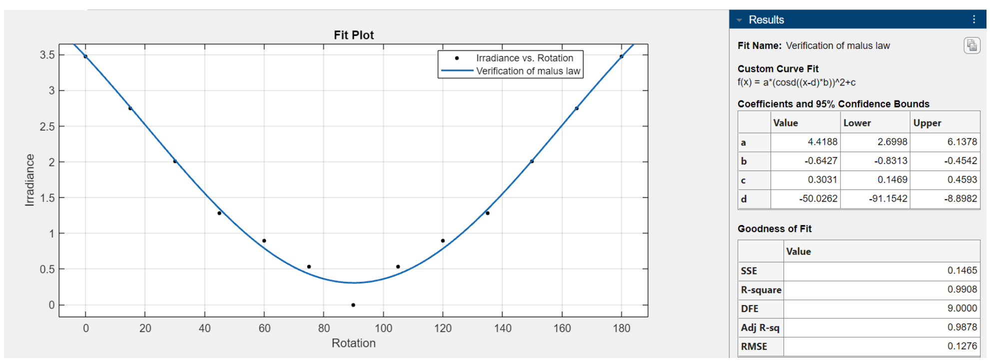


Figure 20: Verification of malus law

Table 6: Functionality of HWP

Rotation of analyser (deg)	Irradiance range	Average Irradiance (power/area)
0	0.00-0.00	0.00
15	0.32-0.69	0.51
30	0.69-1.07	0.87
45	1.07-1.45	1.26
60	1.82-2.20	2.01
75	2.57-2.95	2.76
90	3.32-3.70	3.51
105	2.57-2.95	2.76
120	1.82-2.20	2.01
135	1.07-1.45	1.26
150	0.69-1.07	0.87
165	0.32-0.69	0.51
180	0.00-0.00	0.00

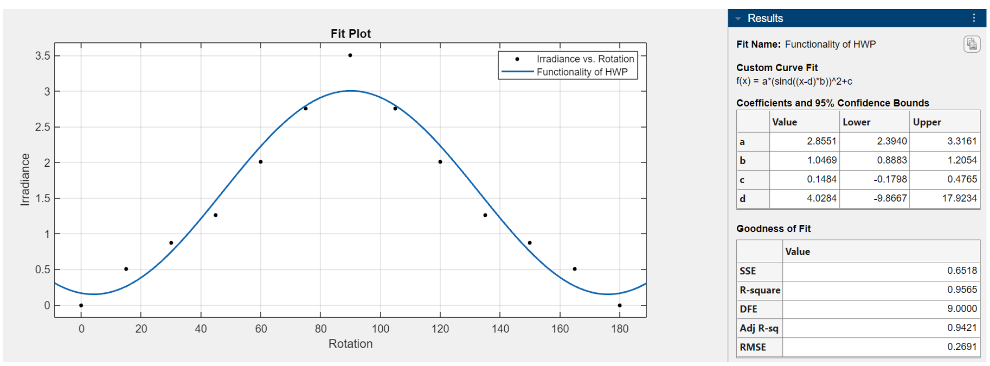


Figure 21: Functionality of HWP

Table 7: Circular Polarisation

Rotation of analyser (deg)	Irradiance range	Average Irradiance (power/area)
0	1.66-1.85	1.75
15	1.66-1.85	1.75
30	1.66-1.85	1.75
45	1.66-1.85	1.75
60	1.66-1.85	1.75
75	1.66-1.85	1.75
90	1.66-1.85	1.75
105	1.66-1.85	1.75
120	1.66-1.85	1.75
135	1.66-1.85	1.75
150	1.66-1.85	1.75
165	1.66-1.85	1.75
180	1.66-1.85	1.75

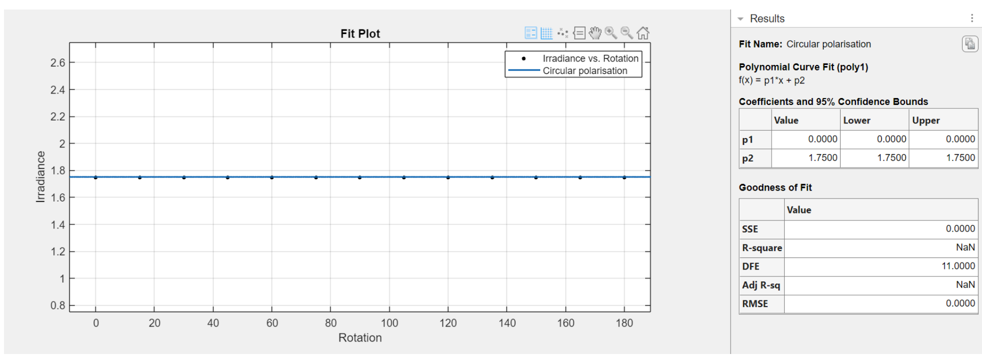


Figure 22: circular polarisation

2.5 Discussions and Conclusions

- **Verification Of Malus law:** we can see at 0° and 180°, irradiance is maximum. And at 90°, the irradiance is zero. With the change in rotation of analyser, the irradiance is changing in $cos^2\theta$ manner. So, it verified malus law.
- **Functionality of HWP:** We can see from the table, at 0° and 180°, irradiance is zero. And at 90°, the irradiance is maximum. It looks like, HWP just adds $\pi/2$ phase difference. So, HWP does not change the polarisation type.
- **Generation of circular polarisation:** In this case we can see that the irradiance is the same for all the angles of rotations. From it, we can say it is a circularly polarised light.

2.6 References

- "Optics" by Ajoy Ghatak, Tata McGraw-Hill, 1st edition (2010)
- "Optics" by E. Hecht, Pearson Education, 4th edition (2003)