6. Experiments

Setup Option 1-- Manual Data Acquisition

1) Installation

a) Refer to Figure 7, place laser, diffraction element and photocell onto the optical rail. (Note: insert the diffraction element into the plate holder and tighten the locking screw with care).

b) The distance Z between the diffraction element and the photocell should be as far as possible to meet the far field condition (i.e. $Z >> a^2/8\lambda$， a is slit width).

c) Connect the photocell and the galvanometer using the 3-core cable.

d) Turn on power supplies of the laser and the galvanometer. Carefully adjust tilt, rotation and height of the laser, diffraction element, and photocell to make them coaxial.

e) With the assistance of a white paper, adjust the positions of the diffraction pattern and the photocell, let the diffraction pattern illuminate onto the center of the photocell window.

2) Cautions

a) Photocell has high sensitivity. When performing the experiment under ambient light, a light proof tube or shield could be used in the front of the photocell.

b) When the galvanometer is saturated, it displays “1”. In this case, one should reduce either the laser power or the galvanometer gain.

c) During the experiment, the position of the maximum light intensity should be located initially to ensure the meter is not saturated at this position. The gain of the meter cannot be changed during the experiment.

d) Normally, the diffraction pattern should be symmetrical about its center. If not, one should carefully adjust tilt and rotation of related components.

3) Experimental Procedure

Experiment 1: Fraunhofer diffraction of single slit

a) After power up, preheat the system for 10 minutes.

b) Adjust the 1-D translation stage of the photocell, let the zeroth order illuminate on the center of the photocell, and find the position of the maximum light intensity to adjust the gain of the galvanometer by let the meter reading close to maximum but not saturated. Record this reading as I_0 and position as X_0.

c) Starting from X_0, move the photocell in one direction in step of 0.5 mm while recording intensity I and position X at every point until the position of the third minima is achieved.

d) Measure the distance Z between diffraction element and photocell. Since the photocell is located in front of the center of the photocell carrier with a distance 7 mm, which should be deducted from the distance between the centres of the two carriers of diffraction element and photocell to get a true Z value.

	Position X (mm)	ΔX (mm)	Intensity I
0^{th} order			
1^{st} minima			
1^{st} maxima			
2^{nd} minima			
2^{nd} maxima			
3^{rd} minima			

e) From the above experimental data, the diffraction angle and relative intensity of each fringe can be calculated. Also, slit width a or wavelength λ can be calculated. Compare the experimental results with theoretical values, and conduct error analysis.

	Experiment results		Theoretical values	
	$\theta = \frac{\Delta X}{Z}$	Relative intensity $\frac{I}{I_0}$	$\theta = K\frac{\lambda}{a}$	Relative intensity $\frac{I}{I_0}$
0^{th} order				1
1^{st} minima				0
1^{st} maxima				0.0472
2^{nd} minima				0
2^{nd} maxima				0.0165
3^{rd} minima				0

Plot relationship graph between relative intensity and position, i.e. I/I_0—ΔX.

Using the 3 minima positions, calculate slit width using formula $a \sin\theta = k\lambda$ and then average the result.

Experiment 2: Double-slit interference

Choose diffraction features such as single-slit/double-slit of groups 3, 4 and 5 from the diffraction element. It is easy to show the phenomena of double-slit interference modulated by single-slit diffraction and "missing orders" of double-slit interference. "Missing orders" occur at orders of nd (d is the ratio of central spacing to slit width, and n is an integer).

Experiment 3: Multi-slit interference

For multi-slit interference, there exist (N-2) secondary maxima and (N-1) minima between two primary maxima (N is the number of slits). Choose diffraction features such as 3~5 slits of groups 6 and 7 from the diffraction element, this phenomenon can be clearly demonstrated.

Experiment 4: Measurement of thin wire diameter using diffraction method

Choose the wire feature from the diffraction element (group 1 or 2). Since the original beam overlaps onto the central maxima of the diffraction pattern, the meter will get saturated at this position. Therefore, the central primary maximum is not measured in this experiment.

Follow the procedure of "Experiment 1" to record the positions of these minima. Measure 3~5 times and take average for each minima. Then calculate the average interval of two adjacent minima. Use diffraction formula $a = \frac{\lambda}{\sin\theta} \approx \frac{\lambda}{d} \cdot Z$ to calculate the wire diameter.

4) Examples of Data Recording and Processing

<u>Experiment 1: Fraunhofer diffraction of single slit</u>

For single-slit of group 4 (a= 0.07 mm), distance Z is measured as Z=Z'-7=511-7=504 mm. Data is recorded in the table below (X is the position of the photocell).

X (mm)	Current (I)	X (mm)	Current (I)	X (mm)	Current (I)	X (mm)	Current (I)
11.0	19	18.5	31	26.5	774	34.5	12
11.5	16	19.0	46	27.0	682	34.9	11
12.0	12	19.5	49	27.5	578	35.0	12
12.5	9	20.0	48	28.0	438	35.5	15
13.0	8	20.5	36	28.5	305	36.0	19
13.5	14	21.0	19	29.0	188	36.5	21
14.0	17	21.5	13	29.5	84	37.0	25
14.5	20	22.0	28	30.0	30	37.5	21
15.0	24	22.5	81	30.5	14	38.0	18
15.5	20	23.0	182	31.0	21	38.5	14
16.0	18	23.5	301	31.5	40	39.0	8
16.5	13	24.0	432	32.0	52	39.5	9
17.0	11	24.5	570	32.5	53	40.0	13
17.1	10	25.0	675	33.0	47	40.5	16
17.5	12	25.5	769	33.5	34	41.0	18
18.0	19	26.0	808	34.0	21		

Based on the above data, the positions and relative intensities of the 1st and 2nd orders maxima, and the 1st, 2nd and3rd orders minima of both sides of the primary central order are given.

	ΔX (mm)		Relative Intensity I	
	Left	Right	Left	Right
0th order	0		808	
1st minima	26.0-21.5=4.5	30.5-26.0=4.5	13	14
1st maxima	26.0-19.5=6.5	32.5-26.0=6.5	49	53
2nd minima	26.0-17.1=8.9	34.9-26=8.9	10	11
2nd maxima	26.0-15.0=11.0	37.0-26.0=11.0	24	25
3rd minima	26.0-13.0=13.0	39.0-26.0=13.0	8	8

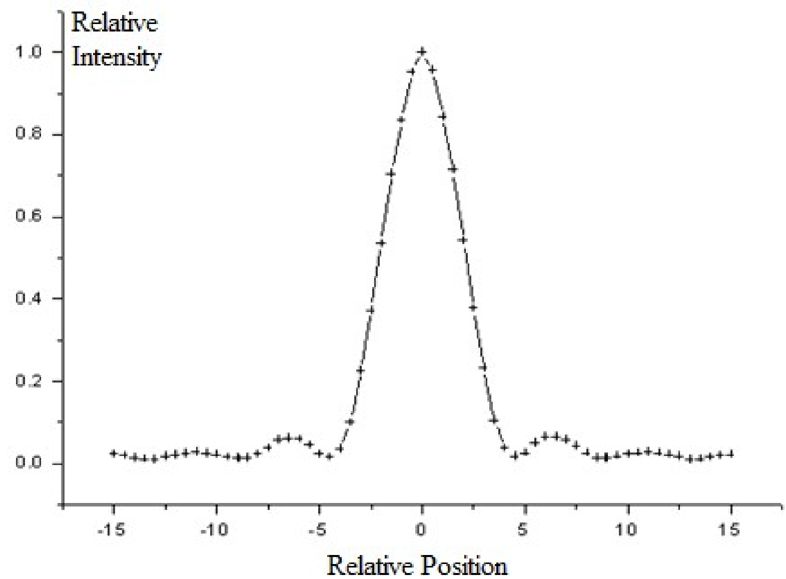
	ΔX (mm)		$\overline{\Delta X}$ (mm)
	Left	Right	
0^{th} order	0		0
1^{st} minima	4.5	4.5	4.5
1^{st} maxima	6.5	6.5	6.5
2^{nd} minima	8.9	8.9	8.9
2^{nd} maxima	11.0	11.0	11.0
3^{rd} minima	13.0	13.0	13.0

	Intensity I			$\overline{I}$
	Average intensity of all minima orders	Left	Right	
0^{th} order	$\overline{I}$ '=(13+14+10+11+8 +8)÷6≈10.7	808-10.7=797.3		797.3
1^{st} maxima		49-10.7=38.3	53-10.7=42.3	(38.3+42.3)/2=40.3
2^{nd} maxima		24-10.7=13.3	25-10.7=14.3	(11.3+12.3)/2=13.8

Calculation and Comparison:

	Experimental values		Theoretical values	
	$\theta = \frac{\Delta X}{Z}$	I/I_0	$\theta = K\frac{\lambda}{a}$	I/I_0
0^{th} order	0	1	0	1
1^{st} minima	$\theta_1' = \frac{4.5}{504} \approx 0.962\frac{\lambda}{a}$		$\frac{\lambda}{a}$	0
1^{st} maxima	$\theta_1 = \frac{6.5}{504} \approx 1.389\frac{\lambda}{a}$	$\frac{40.3}{797.0} \approx 0.0505$	$1.43\frac{\lambda}{a}$	0.0472
2^{nd} minima	$\theta_2' = \frac{8.9}{504} \approx 1.902\frac{\lambda}{a}$		$2\frac{\lambda}{a}$	0
2^{nd} maxima	$\theta_2 = \frac{11}{504} \approx 2.350\frac{\lambda}{a}$	$\frac{13.8}{797.3} \approx 0.0173$	$2.46\frac{\lambda}{a}$	0.0165
3^{rd} minima	$\theta_3' = \frac{13}{504} \approx 2.778\frac{\lambda}{a}$		$3\frac{\lambda}{a}$	0

By setting the coordinate origin of x-axis at the central maximum position, normalized light intensity distribution I/I_0—ΔX can be plotted as shown below.



According to the positions of the 3 minima, calculate slit width and take an average.

For $K = 1$, $$a_1 = \frac{K\lambda}{\theta_1} = \frac{650}{\frac{4.5}{504}} nm = 0.0728mm$$

For $K = 2$, $$a_2 = \frac{K\lambda}{\theta_2} = \frac{2\times 650}{\frac{8.9}{504}} nm \approx 0.0736mm$$

For $K = 3$, $$a_3 = \frac{K\lambda}{\theta_3} = \frac{3\times 650}{\frac{13.0}{504}} nm = 0.0756mm$$

$$\bar{a} = \frac{a_1 + a_2 + a_3}{3} = \frac{0.0728 + 0.0736 + 0.0756}{3} = 0.074mm$$

Experiment 4: Measurement of thin wire diameter using diffraction method

Choose the lower portion thin wire of group No. 1. Record positions of all minima fringes.
$Z = Z' - 7mm = 558 - 7 = 551mm$.

	X (mm)	*ΔX*
1^{st} minima	20.1	
2^{nd} minima	17.0	20.1-17.0=3.1 mm
3^{rd} minima	14.0	17.0-14.0=3.0 mm
4^{th} minima	11.1	14.0-11.1=2.9 mm
5^{th} minima	7.9	11.1-7.9=3.2 mm
6^{th} minima	5.0	7.9-5.0=2.9 mm

$$\overline{\Delta X} = \frac{3.1+3.0+2.9+3.2+2.9}{5} = 3.02mm$$

Use diffraction formula to calculate diameter:

$$a = \frac{\lambda}{\sin\theta} \approx \frac{\lambda}{\Delta X} Z = \frac{650\times10^{-6}}{3.02}\times551 \approx 0.119mm .$$

Conclusion: the experimental result is 0.119 mm, while the reference data is 0.12 mm.

Setup Option 2—Oscilloscope Observation

1) **Installation**

   a) Refer to Figure 7, place laser, diffraction element and CCD light intensity measurement device onto the optical rail. (Note: insert the diffraction element into the plate holder and tighten the locking screw with care).

   b) The distance *Z* between the diffraction element and the CCD should be as far as possible to meet the far field condition (i.e. $Z >> a^2/8\lambda$, a is slit width).

   c) Connect "Sync." and "Signal" terminals on the back of the CCD to the "Trigger" and "X-channel" of an oscilloscope, respectively.

   d) Turn on power. Carefully adjust tilt, rotation and height of laser, diffraction element and CCD to make them coaxial.

   e) With the assistance of a white paper, adjust the positions of the diffraction pattern and the CCD by letting the diffraction pattern illuminate into the window on front of the CCD.

2) **Cautions**

   a) CCD has high sensitivity. When performing the experiment under ambient light, a light proof tube or shield can be used in front of the CCD.

   b) If the CCD is saturated, one needs to reduce the laser power.

   c) Normally, the diffraction pattern should be symmetrical about its center. If not, one should carefully adjust tilt and rotation of related components.

3) **Experimental Procedure**

<u>Experiment 1: Fraunhofer diffraction of single slit</u>

   a) After setting up, a proper curve can be observed on the oscilloscope.

   b) Record horizontal distance *ΔX* between the central primary maxima and every specified point and corresponding height *Y* (i.e. light intensity). Use a ruler to measure the distance *Z* between the diffraction element and the CCD sensor.

	Position ΔX	Intensity Y
0^{th} order		
1^{st} minima		
1^{st} maxima		
2^{nd} minima		
2^{nd} maxima		
3^{rd} minima		

Note:

- There is a distance 4.5 mm from the CCD sensor to the front edge of the CCD box.
- If the intensity of low minima orders and high maxima orders has large variation, the setup may not meet the far field condition; if the intensity of the same-order minima located on the two sides of the central maxima has large variation, it means the CCD is not perpendicular to the optical path.
- **When calculating relative intensity, each *Y* value must subtract the average value of all *Y* values**.
- In this experiment, relative intensity equals the intensity at a certain point divided by the intensity of central maxima.
- $\sin\theta$ equals $\Delta X / Z$.
- Length calibration: adjust the horizontal scale of the oscilloscope so that the complete waveform is displayed. Count how many divisions are covered by the complete waveform. Then, we know one division represents how many pixels on the sensor (CCD pixel number divided by total divisions). Finally we get the length of one division (pixel amount of one division multiplied by pixel size).

c) Based on the experimental data, calculate diffraction angle and relative intensity of each minima and maxima, and calculate slit width a or wavelength λ.

	Experiment value		Theoretical value	
	$\theta = \frac{\Delta X}{Z}$	$\frac{I}{I_0}$	$\theta = K\frac{\lambda}{a}$	$\frac{I}{I_0}$
0^{th} order				1
1^{st} minima				0
1^{st} maxima				0．0472
2^{nd} minima				0
2^{nd} maxima				0．0165
3^{rd} minima				0

Experiment 2: Double-slit interference

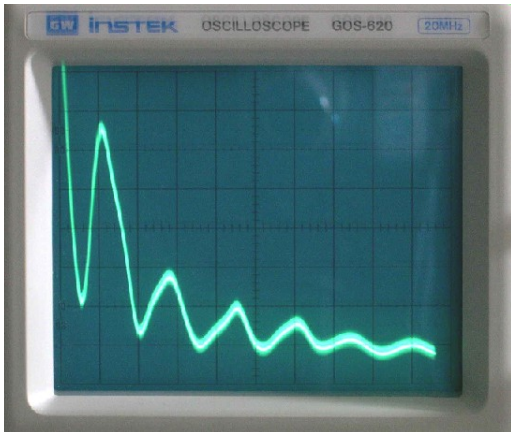
Similar to that described on page 10.

Experiment 3: Multi-slit interference

Similar to that described on page 10.

Experiment 4: Measurement of thin wire diameter using diffraction method

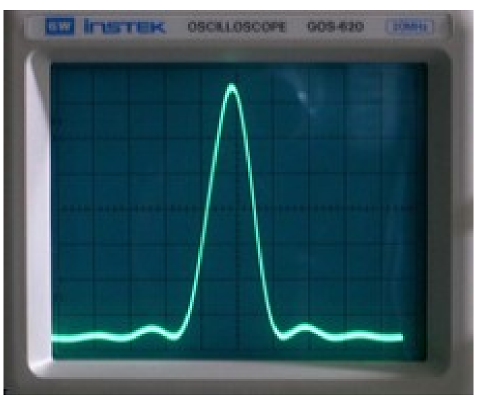
Choose the wire feature of the diffraction element (group 1 or 2). Since the original beam overlaps with the central maxima of the diffraction pattern, CCD will get saturated at this position. In this experiment, the central 0^{th} order is moved outside of the CCD sensing window, and only half of the diffraction pattern is acquired (either left side or right side), as shown below.



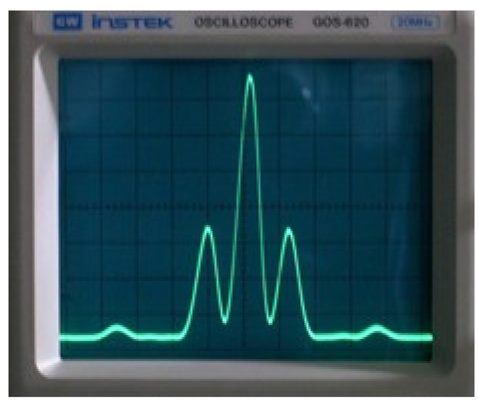
Follow the procedure of "Experiment 1" by recording the positions of these minima and calculating the average interval of two adjacent minima.

Use diffraction formula $a = \dfrac{\lambda}{\sin\theta} \approx \dfrac{\lambda}{d} \cdot Z$ to calculate wire diameter.

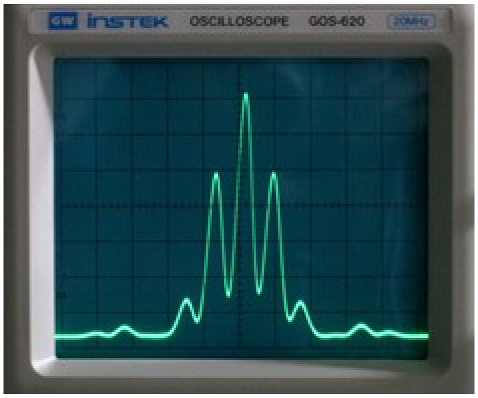
4) Examples of Data Recording and Processing



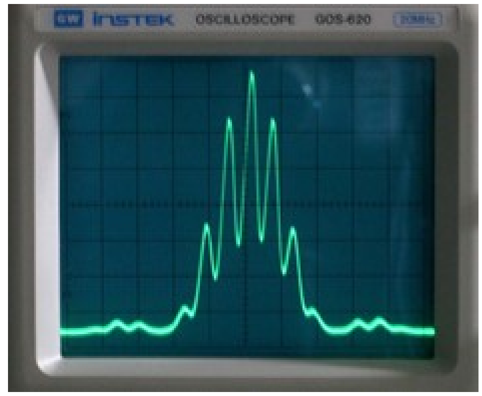
(a) Diffraction of single slit.



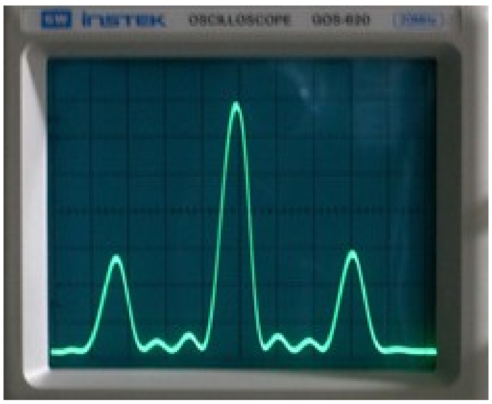
(b) Diffraction of double-slit (d=2)



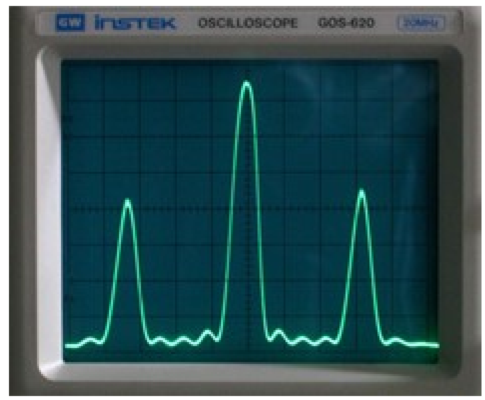
(c) Diffraction of double-slit (d=3)



(d) Diffraction of double-slit (d=4)



(e) Diffraction of multi-slit (N=4)



(f) Diffraction of multi-slit (N=5)

<u>Experiment 1: Fraunhofer diffraction of single slit</u>

For upper single-slit of group 1 (a= 0.12 mm), adjust optical path to achieve a symmetrical curve about the central primary maxima on the oscilloscope. In this experiment, the distance between diffraction element and CCD sensor is Z=541+4.5=545.5 mm. Data is recorded below.

	Horizontal Position X (Divisions)		Intensity Y(Divisions)	
	Left	Right	Left	Right
0^{th} maxima	0		38.0	
1^{st} minima	5.0	5.0	1.5	2.0
1^{st} maxima	7.0	7.2	2.8	3.0
2^{nd} minima	9.5	10.0	1.0	1.8
2^{nd} maxima	11.5	11.5	1.6	2.2
3^{rd} minima	14	13.8	0.5	1.0

Convert divisions into actual length in unit *mm*, we get

	ΔX		$\overline{\Delta X}$
	Left	Right	
0^{th} maxima	0		0
1^{st} minima	(5.0/50)×29.7mm=2.970mm	(5.0/50)×29.7mm=2.970mm	2.970mm
1^{st} maxima	(7.0/50)×29.7mm=4.158mm	(7.2/50)×29.7mm=4.277mm	4.218mm
2^{nd} minima	(9.5/50)×29.7mm=5.643mm	(10.0/50)×29.7mm=5.940mm	5.792mm
2^{nd} maxima	(11.5/50)×29.7mm=6.831mm	(11.5/50)×29.7mm=6.831mm	6.831mm
3^{rd} minima	(14.5/50)×29.7mm=8.613mm	(15.0/50)×29.7mm=8.910mm	8.762mm

	Intensity Y(Divisions)			$\overline{Y}$
	Average Y of all minima	Left	Right	
0^{th} maxima	$\overline{Y'}$=(1.5+2.0+1.0+1.8+0.5+1.0)÷6≈1.3	38.0-1.3=36.7		36.7
1^{st} maxima		2.8-1.3=1.5	3.2-1.3=1.7	(1.5+1.9)/2=1.7
2^{nd} maxima		1.6-1.3=0.3	2.2-1.3=0.9	(0.3+0.9)/2=0.6

Calculation and comparison

	Experiment values		Theoretical values	
	$\theta = \frac{\Delta X}{Z}$	$\frac{I}{I_0}$ (Relative)	$\theta = K\frac{\lambda}{a}$	$\frac{I}{I_0}$ (Relative)
0^{th} maxima	0	1	0	1
1^{st} minima	$\theta_1' = \frac{2.970}{545.5} \approx 1.005\frac{\lambda}{a}$		$\frac{\lambda}{a}$	0
1^{st} maxima	$\theta_1 = \frac{4.218}{545.5} \approx 1.428\frac{\lambda}{a}$	$\frac{1.7}{36.7} \approx 0.0463$	$1.43\frac{\lambda}{a}$	0.0472
2^{nd} minima	$\theta_2' = \frac{5.792}{545.5} \approx 1.960\frac{\lambda}{a}$		$2\frac{\lambda}{a}$	0
2^{nd} maxima	$\theta_2 = \frac{6.831}{545.5} \approx 2.312\frac{\lambda}{a}$	$\frac{0.6}{36.7} \approx 0.0163$	$2.46\frac{\lambda}{a}$	0.0165
3^{rd} minima	$\theta_3' = \frac{8.762}{545.5} \approx 2.965\frac{\lambda}{a}$		$3\frac{\lambda}{a}$	0

Experiment 2: Double-slit interference

We get the following:

curve (b) (for diffraction feature of upper portion of group No. 6, double-slit, d=2). It is seen that orders ±2 are missed, satisfying the law of "missing orders" described previously.

curve (c) (for diffraction feature of lower portion of group No. 4, double-slit, d=3). It is seen that orders ±3 are missed, satisfying the law of "missing orders" described previously.

curve (d) (for diffraction feature of upper portion of group No. 5, double-slit, d=4). It is seen that orders ±4 are missed, satisfying the law of "missing orders" described previously.

Experiment 3: Multi-slit interference

We get the following:

curve (e) (for diffraction feature of upper portion of group No. 7, quadruple-slit). It is seen that there are 2 secondary maxima and 3 minima between 2 primary maxima. It accords to the law that there exists (*N*-2) secondary maxima and (*N*-1) minima between two primary maxima (*N* is the number of slits).

curve (f) (for diffraction feature of lower portion of group No. 7, pentuple-slit). It is seen that there are 3 secondary maxima and 4 minima between 2 primary maxima. It accords to the law that there exists (*N*-2) secondary maxima and (*N*-1) minima between two primary maxima (*N* is the number of slits).

Experiment 4: Measurement of thin wire diameter using diffraction method

Move the central 0^{th} order outside of the CCD sensing window, only half of the diffraction pattern is acquired. Choose diffraction feature of lower portion of group 1.

	Horizontal Position *X* (Divisions)	*ΔX*
1^{st} minima	5.0	
2^{nd} minima	9.8	((9.8-5.0)/50)×29.7mm=2.851mm
3^{rd} minima	14.8	((14.8-9.8)/50)×29.7mm=2.970mm
4^{th} minima	19.5	((19.5-14.8)/50)×29.7mm=2.792mm
5^{th} minima	24.2	((24.2-19.5)/50)×29.7mm=2.792mm
6^{th} minima	29.0	((29.0-24.2)/50)×29.7mm=2.851mm
$\overline{\Delta X} = \dfrac{2.851+2.970+2.792+2.792+2.851}{5} \approx 2.851mm$		

Use diffraction formula to calculate diameter of the thin wire:

$$a = \frac{\lambda}{\sin\theta} \approx \frac{\lambda}{\Delta X} \cdot Z = \frac{650\times10^{-6}}{2.851} \times 545.5 \approx 0.124\,\text{mm}$$

Conclusion: the experimental result is 0.124 mm while the given reference is 0.12 mm.

Setup Option 3—PC Data Acquisition

1) Installation

a) Refer to Figure 7, place laser, diffraction element and CCD light intensity measurement device onto the optical rail. (Note: insert the diffraction element into the plate holder and tighten the locking screw with care).

b) The distance *Z* between the diffraction element and the CCD should be as far as possible to meet the far field condition (i.e. Z >> $a^2/8\lambda$， a is slit width).

c) Turn on power. Carefully adjust tilt, rotation and height of laser, diffraction element and CCD to make them coaxial.

d) Connect CCD with data acquisition box using the DB9 cable. Connect the data acquisition box with computer using a USB cable.

e) With the assistance of a white paper, adjust the position of the diffraction pattern and the CCD by letting the diffraction pattern illuminate into the window on front of the CCD.

f) Run LEOI-30A application program (i.e. “Measurement of Light Intensity Distribution” program), click “Start Acquisition”, diffraction curve should be shown.

2) Cautions

a) Follow the sequence: turn on CCD firstly; then connect DB9 cable; finally, connect USB cable.

b) CCD has high sensitivity. When performing the experiment under ambient light, a light proof tube or shield can be used in front of the CCD.

c) If CCD is saturated, one needs to reduce either the laser power or reduce “Gain” of the program.

d) Normally, the diffraction pattern should be symmetrical about its center. If not, one should carefully adjust tilt and rotation of related components.

3) Experimental Procedure

Experiment 1: Fraunhofer diffraction of single slit

a) After setting up, a proper curve can be acquired by the program.

b) Click “Stop Acquisition” to freeze the curve on the screen. On the global primary window (left), select the region of the curve to be measured by moving the blue frame. On the local window (right), move the cursor slowly to a specified point, corresponding data of X (position: unit in pixel) and Y (relative intensity) of the specified point are displayed in the data frame below. Use a ruler to measure the distance Z between the diffraction element and the CCD sensor. Data is given in table below:

	Position X (pixel)	ΔX	Intensity Y
0^{th} order			
1^{st} minima			
1^{st} maxima			
2^{nd} minima			
2^{nd} maxima			
3^{rd} minima			

Note:

- There is a distance 4.5 mm from the CCD sensor to the front edge of the CCD box.
- If the intensity of low minima orders and high maxima orders has large variation, the setup may not meet the far field condition; if the intensity of the same-order minima located on the two sides of the central maxima has large variation, it means the CCD is not perpendicular to the optical path.

- **When calculating relative intensity, each *Y* value must subtract the average value of all *Y* values**.
- In this experiment, relative intensity equals the intensity at a certain point divided by the intensity of central maxima.
- $\sin\theta$ equals $\Delta X / Z$.
- Length calibration: adjust the horizontal scale of the oscilloscope so that the complete waveform is displayed. Count how many divisions are covered by the complete waveform. Then, we know one division represents how many pixels on the sensor (CCD pixel number divided by total divisions). Finally we get the length of one division (pixel amount of one division multiplied by pixel size).

d) Based on the experimental data, calculate diffraction angle and relative intensity of each minima and maxima, and calculate slit width *a* or wavelength λ.

	Experiment value		Theoretical value	
	$\theta = \dfrac{\Delta X}{Z}$	$\dfrac{I}{I_0}$	$\theta = K\dfrac{\lambda}{a}$	$\dfrac{I}{I_0}$
0^{th} order				1
1^{st} minima				0
1^{st} maxima				0．0472
2^{nd} minima				0
2^{nd} maxima				0．0165
3^{rd} minima				0

<u>Experiment 2: Double-slit interference</u>

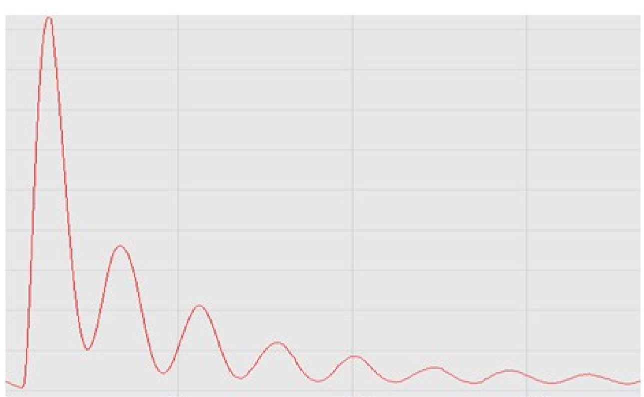
Similar to that described on page 10.

<u>Experiment 3: Multi-slit interference</u>

Similar to that described on page 10.

<u>Experiment 4: Measurement of thin wire diameter using diffraction method</u>

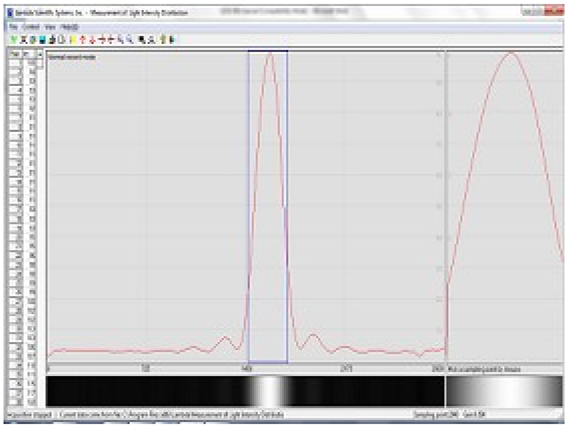
Choose the wire feature of the diffraction element (group No. 1 or 2). Since the original beam overlaps the central maxima of the diffraction pattern, CCD will get saturated at this position. In this experiment, the central 0^{th} order is moved outside of the CCD sensing window, only half of the diffraction pattern is acquired (either left side or right side) as shown below.



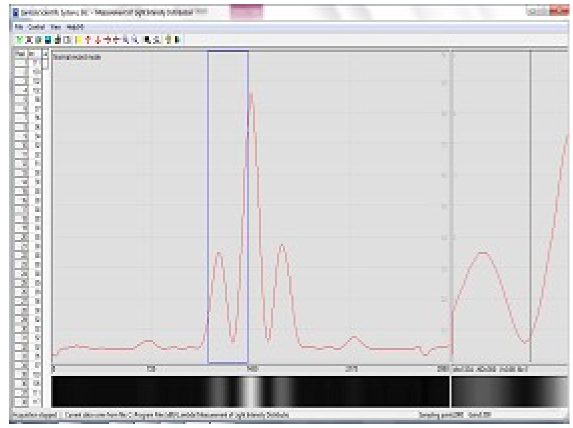
Follow the procedure of "Experiment 1" by recording the positions of these minima and calculating the average interval of two adjacent minima.

Use diffraction formula $a = \dfrac{\lambda}{\sin\theta} \approx \dfrac{\lambda}{d} \cdot Z$ to calculate wire diameter.

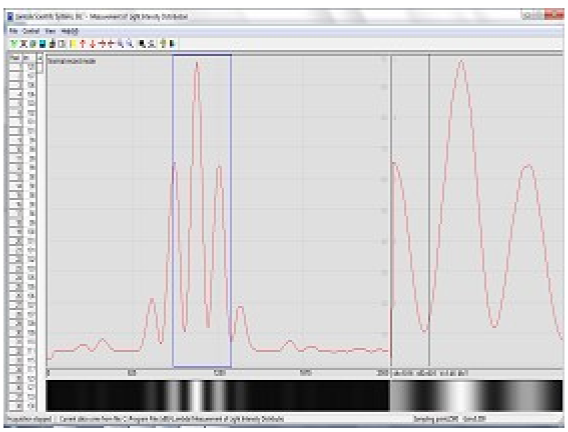
4) Examples of Data Recording and Processing



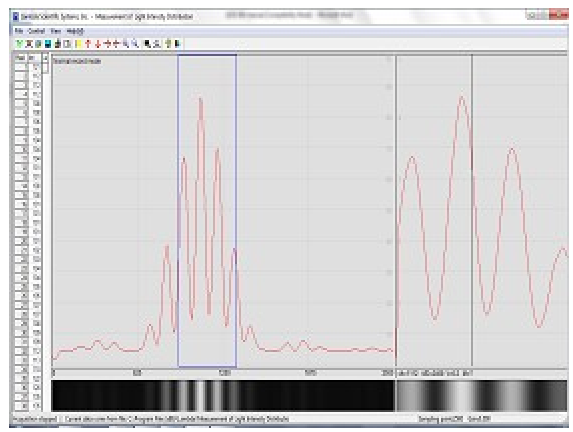
(a) Diffraction of single slit.



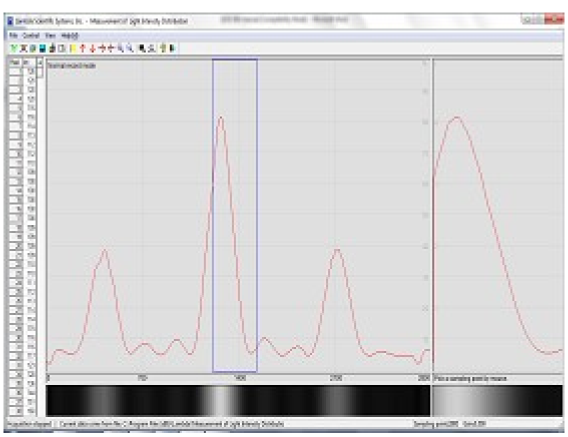
(b) Diffraction of double-slit (d=2)



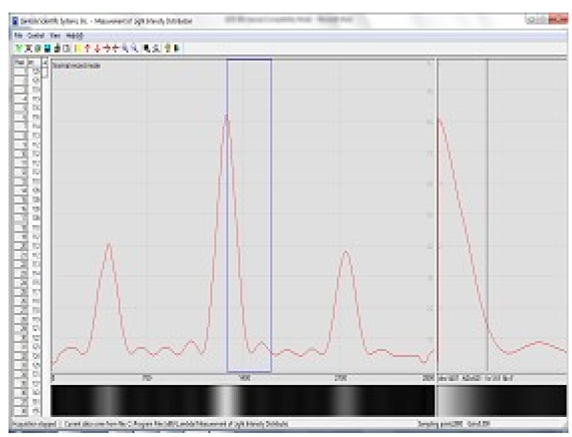
(c) Diffraction of double-slit (d=3)



(d) Diffraction of double-slit (d=4)



(e) Diffraction of multi-slit (N=4)



(f) Diffraction of multi-slit (N=5).

Experiment 1: Fraunhofer diffraction of single slit

For the upper single-slit of group 1 (*a*= 0.12 mm), adjust optical path to achieve a symmetrical curve about the central primary maxima on the screen. In this experiment, the distance between diffraction element and CCD sensor is Z=456+4.5=460.5 mm. Data is recorded below.

	Position *X* (Pixels)		Intensity *Y*	
	left	right	left	right
0^{th} order	1628		4071	
1^{st} minima	1388	1847	182	189
1^{st} maxima	1302	1947	330	359
2^{nd} minima	1175	2073	156	150
2^{nd} maxima	1076	2178	225	221
3^{rd} minima	949	2304	148	143

	ΔX		$\overline{\Delta X}$
	left	right	
0^{th} order	0		0
1^{st} minima	(1628-1388)×11μm=2.640mm	(1847-1628)×11μm=2.409mm	2.525mm
1^{st} maxima	(1628-1302)×11μm=3.586mm	(1947-1628)×11μm=3.509mm	3.548mm
2^{nd} minima	(1628-1175)×11μm=4.983mm	(2073-1628)×11μm=4.895mm	4.939mm
2^{nd} maxima	(1628-1076)×11μm=6.072mm	(2178-1628)×11μm=6.050mm	6.061mm
3^{rd} minima	(1628-949)×11μm=7.469mm	(2304-1628)×11μm=7.436mm	7.453mm

	Intensity *Y*			$\overline{Y}$
	Average *Y* of all minima	left	right	
0^{th} order	$\overline{Y'}$=(182+189+156+150+148+143)÷6≈161	4071-161=3910		3910
1^{st} maxima		330-161=169	359-161=198	(169+198)/2=184
2^{nd} maxima		225-161=64	221-161=60	(64+60)/2=62

	Experiment value		Theoretical value	
	$\theta = \dfrac{\Delta X}{Z}$	Relative I/I_0	$\theta = K\dfrac{\lambda}{a}$	Relative I/I_0
0^{th} order	0	1	0	1
1^{st} minima	$\theta_1' = \dfrac{2.525}{460.5} \approx 1.012\dfrac{\lambda}{a}$		$\dfrac{\lambda}{a}$	0

1st maxima	$\theta_1 = \frac{3.548}{460.5} \approx 1.423\frac{\lambda}{a}$	$\frac{184}{3910} \approx 0.0471$	$1.43\frac{\lambda}{a}$	0.0472
2nd minima	$\theta_2' = \frac{4.939}{460.5} \approx 1.980\frac{\lambda}{a}$		$2\frac{\lambda}{a}$	0
2nd maxima	$\theta_2 = \frac{6.061}{460.5} \approx 2.430\frac{\lambda}{a}$	$\frac{60}{3910} \approx 0.0153$	$2.46\frac{\lambda}{a}$	0.0165
3rd minima	$\theta_3' = \frac{7.453}{460.5} \approx 2.988\frac{\lambda}{a}$		$3\frac{\lambda}{a}$	0

Experiment 2: Double-slit interference

We get the following:

curve (b) (for diffraction feature of upper portion of group No. 6, double-slit, d=2). It is seen that orders ±2 are missed, satisfying the law of "missing orders" described previously.

curve (c) (for diffraction feature of lower portion of group No. 4, double-slit, d=3). It is seen that orders ±3 are missed, satisfying the law of "missing orders" described previously.

curve (d) (for diffraction feature of upper portion of group No. 5, double-slit, d=4). It is seen that orders ±4 are missed, satisfying the law of "missing orders" described previously.

Experiment 3: Multi-slit interference

We get the following:

curve (e) (for diffraction feature of upper portion of group No. 7, quadruple-slit). It is seen that there are 2 secondary maxima and 3 minima between 2 primary maxima. It accords to the law that there exist (N-2) secondary maxima and (N-1) minima between two primary maxima (N is the number of slits).

curve (f) (for diffraction feature of lower portion of group No. 7, pentuple-slit). It is seen that there are 3 secondary maxima and 4 minima between 2 primary maxima. It accords to the law that there exist (N-2) secondary maxima and (N-1) minima between two primary maxima (N is the number of slits).

Experiment 4: Measurement of thin wire diameter using diffraction method

Move the central zeroth order outside of the CCD sensing window, only half of the diffraction pattern is acquired. Choose diffraction feature of lower portion of group No. 1.

	Position X (pixels)	ΔX
1st minima	2466	
2nd minima	2206	(2466-2206)×11μm=2.860mm
3rd minima	1946	(2206-1946)×11μm=2.860mm
4th minima	1681	(1946-1681)×11μm=2.915mm
5th minima	1416	(1681-1416)×11μm=2.915mm
6th minima	1155	(1416-1155)×11μm=2.871mm
$\overline{\Delta X} = \frac{2.860+2.860+2.915+2.915+2.871}{5} \approx 2.884mm$		

Use diffraction formula to calculate diameter of the thin wire:

$$a = \frac{\lambda}{\sin\theta} \approx \frac{\lambda}{\Delta X} \cdot Z = \frac{650 \times 10^{-6}}{2.844} \times 537.5 \approx 0.121\,\mathrm{mm}$$

Conclusion: experimental result is 0.121 mm while the given reference is 0.12 mm.

Appendix: Instruction for Software

1. Software Installation

CCDWIN software package consists of intensity measurement application program and USB driver, in folders <Application> and <USB2.0driver>, respectively.

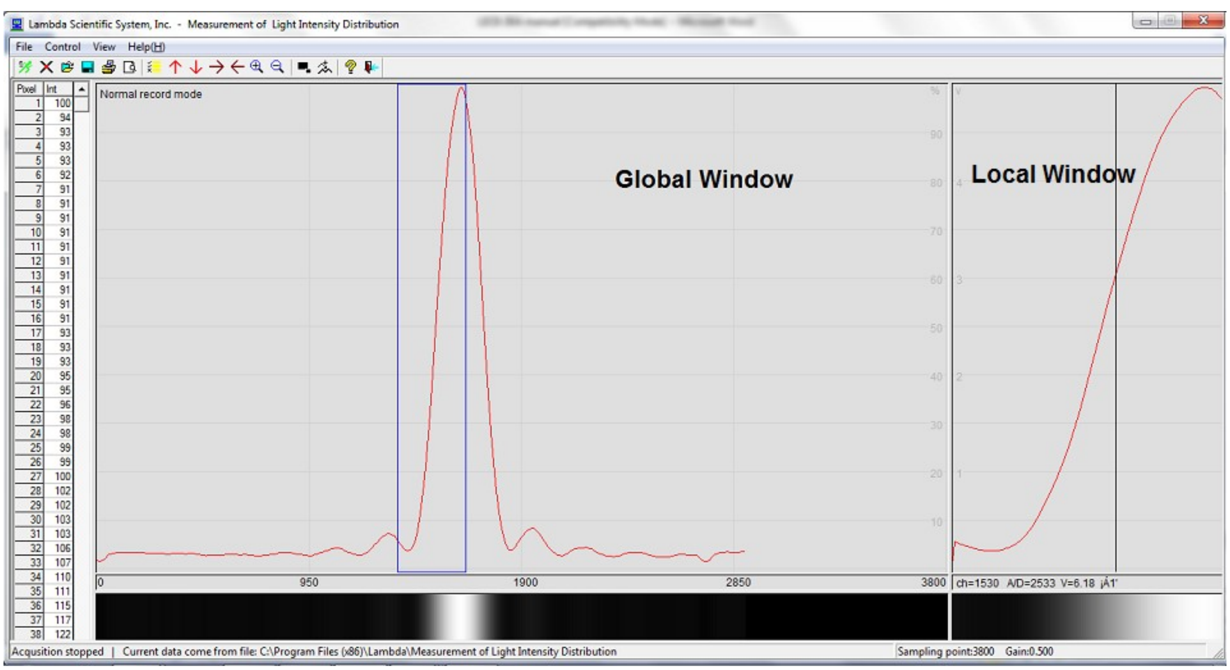
To install application program, simply run the executable file setup.exe in folder <Application>. The default installation path is C:\Program Files\Lambda\Measurement of Light Intensity Distribution.

To install USB driver, connect the USB Acquisition Box to the computer using a USB cable. Follow prompts to complete the installation. The driver file is in folder <USB2.0driver>. During the installation process, if the system reports a non-compatible message, just ignore it. **Note:** if USB driver installation fails, manually copy two files **"ezmon.sys"** and **"ezusb.sys"** from the installation CD to C:\Windows\System32\Drivers. Then resume USB driver installation process.

2. Software Operation

2.1 Description of Software User Interface

The program interface panel consists of 5 areas, as shown below:



Global or primary window: it is for data display with horizontal axis representing the sequence of sampling points (channels or pixels) and vertical axis representing light intensity with 100% corresponding to 4096. There is a blue frame for a selected local area, which is enlarged and displayed on the right region (i.e. Local window). The size of the blue frame can be dynamically adjusted. To move the frame, use keys ←/→ or PgDn/PgUp on the keyboard, or place the cursor inside the frame and click/hold the left key to draw.

Local enlarged window: it is the enlarged display of the blue frame in global window. When the cursor enters into this window, a line at the cursor location will pop-up, and the serial number (CH) and signal intensity (in A/D and V, respectively) of the sampling point on the line and the times of zoom-in/zoom-out of the local curve (M) will be shown in the frame below the window. The vertical axis at the left displays the signal voltage (V) before A/D conversion. To view larger local window, the global window can be hidden by checking menu command “Enlarge Local”.

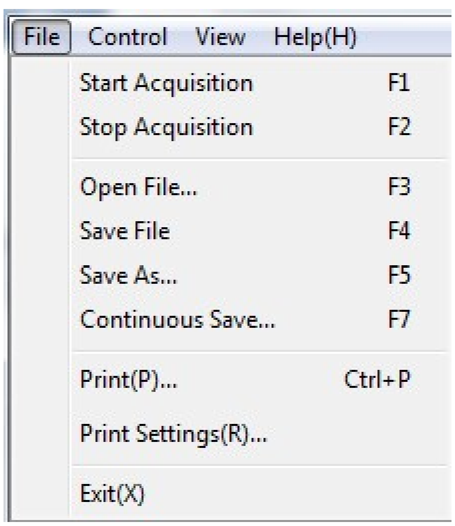
Image windows: under the global and the local windows, there are two black/white strips, which are the simulated exposure effects of the corresponding curves, respectively.

A/D conversion table: i.e. the vertical form on the left. It shows the A/D conversion value of every sampling point.

Status bar: shows current status of program running.

2.2 Menu Description

(1) File:



Most of these commands are obvious literally.

“Start Acquisition (F1)”: start to acquire data according to settings and display curve in real time.

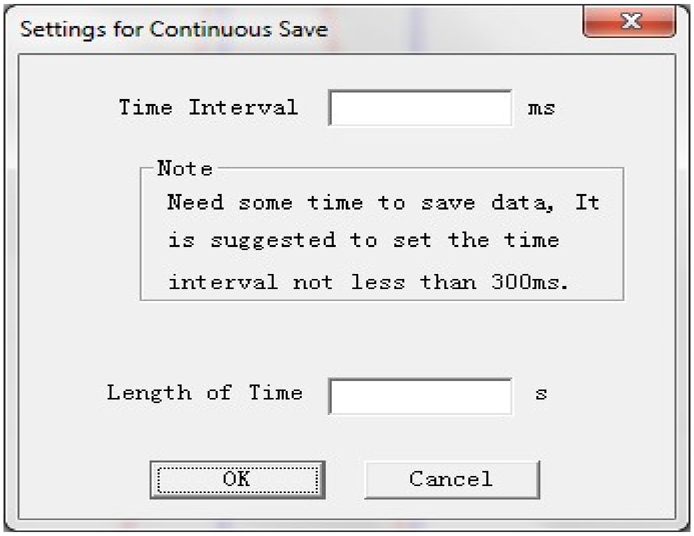
“Stop Acquisition (F2)”: the last frame of data before stopping will be displayed on screen.

“Open File (F3)”: open a file with format *.ccd that was saved previously. Gain and sampling length will be resumed to the values when they were saved.

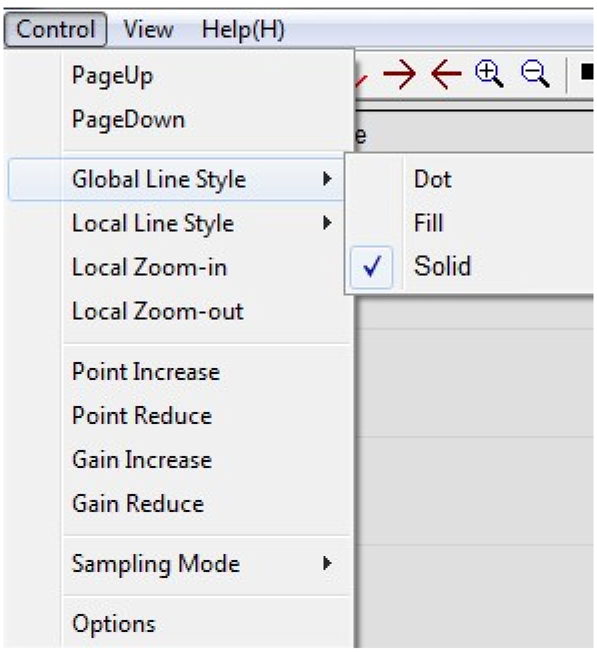
“Save File (F4)”: save current screen data to the folder “Measurement of Light Intensity Distribution” with file name: *mmddxxxx.ccd*, here *mm* and *dd* represent month and date, respectively; *xxxx* is the serial number. Sampling points, gain and A/D values are all saved.

“Save As (F5)”: similar to “Save File”.

“Continuous Save (F7)”: it will show a pop-up window to set time interval and time length, as shown below. The acquired curves will be automatically saved one by one.



(2) Control



"PageUp" and "PageDown": click to move the blue frame to left/right in global window with a step size of the frame size. Accordingly, causes the change of curve in local window. They are correspond to fast keys PgDn and PgUp.

"Global Line Style": check to select line style for curve in global window: dot, fill or solid.

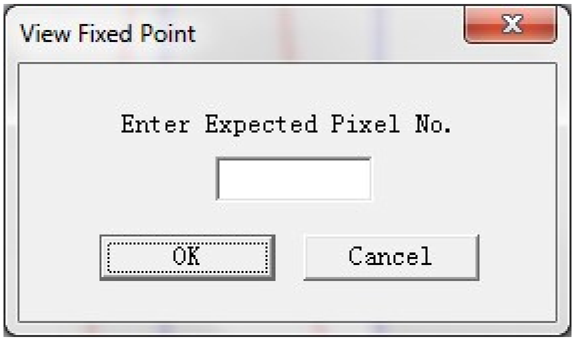
"Local Line Style": check to select line style for curve in local window: dot or fill.

"Local Zoom-in"/"Local Zoom-out": every click of this command, the curve in local window will be enlarged/reduced 1×. The total magnification (M) is shown in the frame below the local window. When × is greater than 1, the displayed sampling points are discontinuous. When the cursor is not placed on a certain sampling point, there is no data shown in the frame.

"Point Increase" and "Point Reduce": used to change the number of sampling point (or length) in the global window. The change of step size is set in the command "Options"→ "Sampling Step".

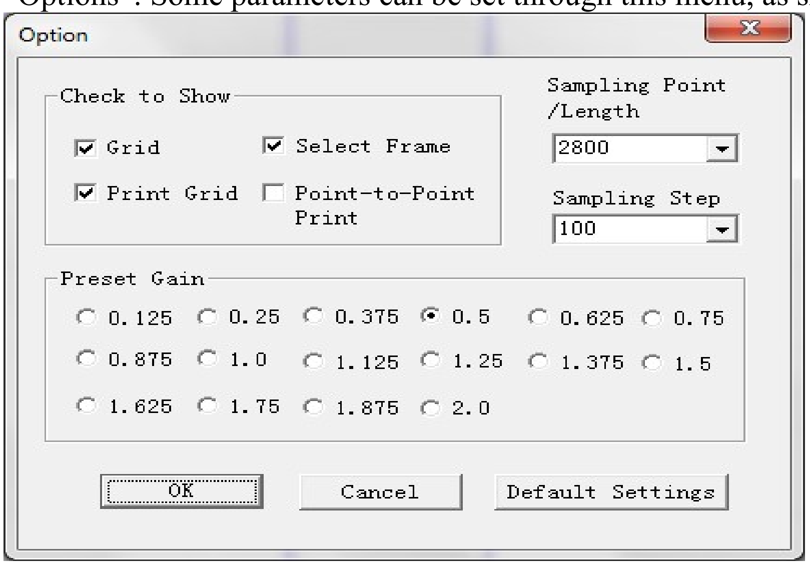
"Gain Increase" and "Gain Reduce": to control gain of circuit amplifier according to actual light intensity in order to achieve good quantization accuracy, changes in 16 levels.

"Sampling Mode": alternatively "Normal" or "Fixed-point". Once "Fixed-point" mode is checked, the below window pops out.

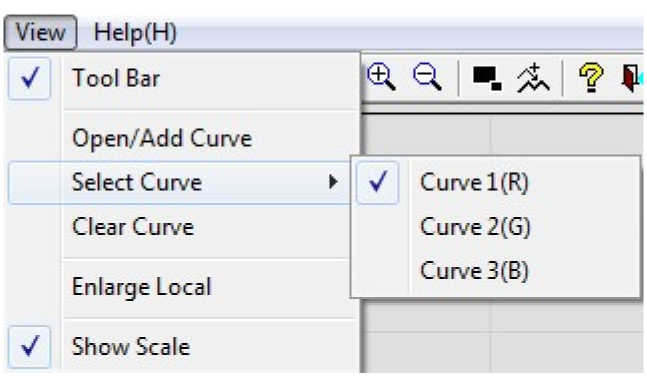


Enter the expected pixel position (e.g. 2400) and click OK, the program will repeat and continue to acquire data of the fixed pixel # 2400.

"Options": Some parameters can be set through this menu, as shown below.



(2) View



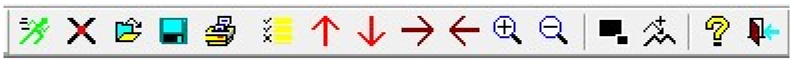
"Tool bar": check/uncheck to show/hide tool bar.

“Open/Add Curve”: can open and display at most 3 curves for comparison at the same time, with color respectively in red, green and blue. Execute “Star acquisition” or “Open” command or “Clear Curve” to exit comparison state.

“Select Curve”: to select one curve in comparison state. Once a certain curve is selected, the A/D conversion form and the horizontal axis of local window will show data of the corresponding curve.

“Enlarge Local”: check to hide the global window, so the local window is enlarged.

(3) Tool bar and data frame



The tool bar covers most of the menu commands, from left to right: (1) Start acquisition, (2) Stop acquisition, (3) Open file, (4) Save file, (5) Print, (6) Options, (7) Gain increase, (8) Gain reduce, (9) Point increase, (10) Point reduce, (11) Local zoom-in, (12) Local zoom-out, (13) Enlarge local window, (14) Open comparison curve, (15) About, (16) Exit.

The status frame consists of two portions: one displays current working status of the program (acquiring or stop) and opened files (if files opened), the other one displays current sampling points and gain value.