Lab 1 Session 6: Spatial Filtering (Fraunhofer Diffraction and Making Masks)

Date: 27 January 2026 Lab Partner: Nathan Unrhu

For Table of Contents, refer to session 4,
Pg 40

1. Session Goals
 i) Compare diffraction pattern to theory
 ii) Calibrate the Ronchi ruling (slit spacing a and slit width b)
 iii) Establish a quantitative baseline for spatial filtering 4. Complete spatial filtering mask cases (a), (b), (d), (e), (f), (j), (k)

2. Reference: Pages 39-43 (Part A: Fraunhofer Diffraction, Part B: Spatial

3. Variables

**Independent:** Mask configuration (orders transmitted) **Dependent:** Real-space image intensity profile, Fourier-space diffraction pattern

**Control**: Camera settings (gain, exposure, gamma), LED wavelength, grating period, optical alignment

4. Apparatus:

In Addition to the Material listed on Pg 2-3. We need
 i) Additional Translational Stage
 ii) Wires, Black Tape, Allen Key of different Size
 iii) A rectangular Frame with a Post and Saddle

5. Additional Background

6. Procedure:

A: Fraunhofer Diffraction

Following procedure on Lab Script pg. 39-40 3.1 Procedure 1.

- Replaced variable diffraction grating with 10 lp/mm Ronchi ruling microscope slide
- Set camera parameters: Exposure = 43000, Gamma = 1, Gain = 18
- Focused on "ZERO" lettering on Ronchi ruling for coarse focus
- Fine focused on blemishes (chipped metal on lettering) for optimal sharpness
- Inserted 10 nm bandpass filter in front of LED
- Verified Fourier image centro-symmetry
- Recorded real-space and Fourier-space images
- Extracted line profiles for calibration measurements

Observation:

Despite turning the dial on the condenser lens, the focus appeared to change unexpectedly. Fine focusing required locating small defects (chipped metal) on the ruling surface rather than the grating lines themselves. This provides sharper focus targets than the periodic structure due to the Talbot effect creating multiple focal planes for periodic objects.

Observation:

The Fourier image was centro-symmetrical, confirming that the optical elements are properly
aligned square to the optical axis. This symmetry verification is essential before quantitative measurements.

## Calibiate the Real image:

10 lines on the camera's from 602px → 1150px

Pixel span 1150 - 602 = 548 pixel for 10 period

$$\text{Seal factor} = \frac{a}{\text{Pixel per period}} = \frac{100\,\mu m}{54.8\,px} = 1.82\,\mu m/\text{pixel}$$

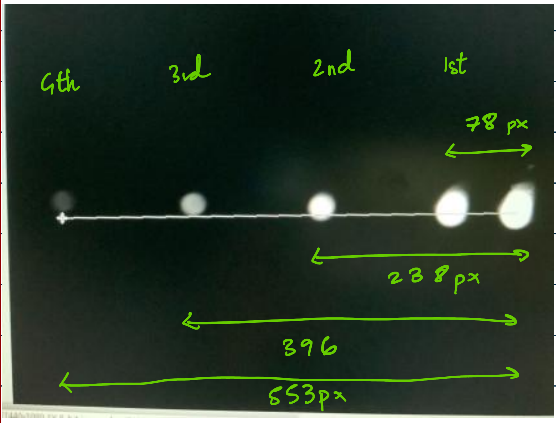
With the Real space camera having a pixel size $\Delta_{Pixel} = 3.45\,\mu m$.

$$M_{real} = \frac{\text{image scale}}{\text{pixel size}} = \frac{54.8 \times 3.45\,\mu m}{100\,\mu m} = \frac{189\,\mu m}{100\,\mu m} = 1.89\times$$

$$\text{Expected magnification} = \frac{f_5}{f_4} = \frac{300}{150} = 2.0\times$$

The values are close, but the difference is from the lens position not being exactly at focal length

## Calibration for fourier Image:




| Your label | Pixel distance | Ratio to 1st | Actual order $m$ | Values |
|---|---|---|---|---|
| "1st" | 78 px | 1.00 | m = 1 | 200 (1600, Exposure time, 1s, 18 Gain) |
| "2nd" | 238 px | 3.05 | m = 3 | 100 |
| "3rd" | 396 px | 5.08 | m = 5 | |
| "4th" | 553 px | 7.09 | m = 7 | |

800 Exposure
120
50

1200 ps
100
50

We Note that we only see odd orders $m = 1, 3, 5, 7$.

This is what we observe from a 50% duty Cycle Ronchi ruling.

The even orders are suppressed because $n = 2, 4, 6$, because $\sin\left(\frac{m\pi b}{a}\right) = \sin\left(\frac{m\pi}{2}\right) = 0$ for even m when $\frac{b}{a} = \frac{1}{2}$

Fourier Camera Calibrate

$$\theta_m = \frac{m\lambda}{a} = \frac{m \times 525 \times 10^{-9}}{100 \times 10^{-6}} = m \times 5.2 \text{ mrad}$$

$$K_{cal} = \frac{\theta_1}{\Delta P_1} = \frac{5.25 \text{ mrad}}{78 \text{ px}} = 0.0673 \text{ mrad/pixel}$$

**Verification: Measured vs Theory**

| Order $m$ | Measured (px) | Theory: $m \times 78$ px | Discrepancy |
|---|---|---|---|
| 1 | 78 | 78 | 0% (reference) |
| 3 | 238 | 234 | +1.7% |
| 5 | 396 | 390 | +1.5% |
| 7 | 553 | 546 | +1.3% |

Excellent linearity! The small systematic offset (~1.5%) could be due to:

- Slight deviation from small-angle approximation at higher orders
- Minor lens aberrations
- Grating period slightly different from nominal 100 μm

⇒ Extracting Grating Period

$$\Delta p = \frac{78 + 238/3 + 396/5 + 553/7}{4} = \frac{78 + 79.3 + 79.2 + 79.0}{4}$$

$$= 78.9 \text{ px/order}$$

$$a = \frac{\lambda \cdot f_{obj}}{\Delta x} = \frac{\lambda}{\theta_1} = \frac{525 \text{ nm}}{5.25 \text{ mrad}} = 100 \text{ μm}$$

**Summary: Both Calibrations**

| Method | Parameter | Value |
|---|---|---|
| **Real-space** | Scale | 1.82 μm/pixel |
| | Magnification | 1.89× |
| | Period $a$ | 100 μm (known) |
| **Fourier-space** | Calibration | 0.0673 mrad/pixel |
| | Period $a$ (verified) | 100 μm ✓ |
| | Duty cycle $b/a$ | ~0.5 (even orders absent) |

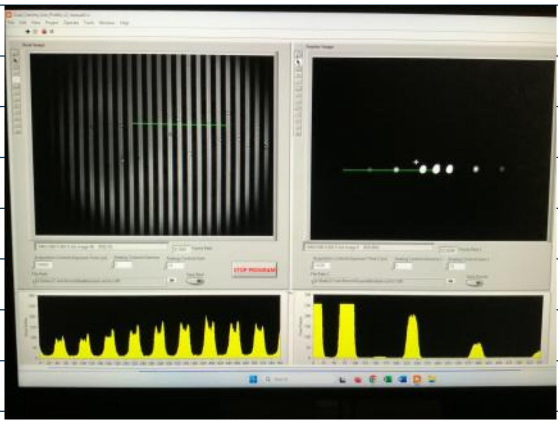
⇒ PixelValues

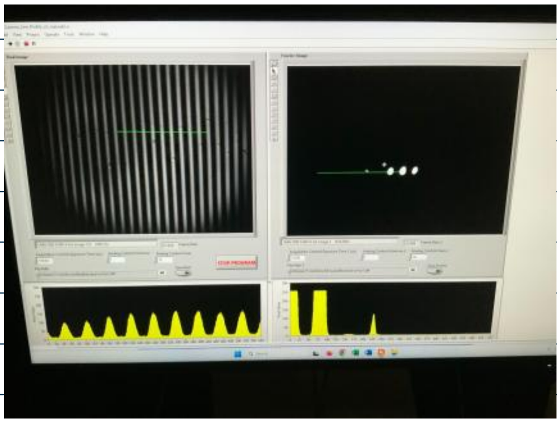
B. Spatial Filtering

Following procedure on Lab Script pg.
2:57 PM 41-43

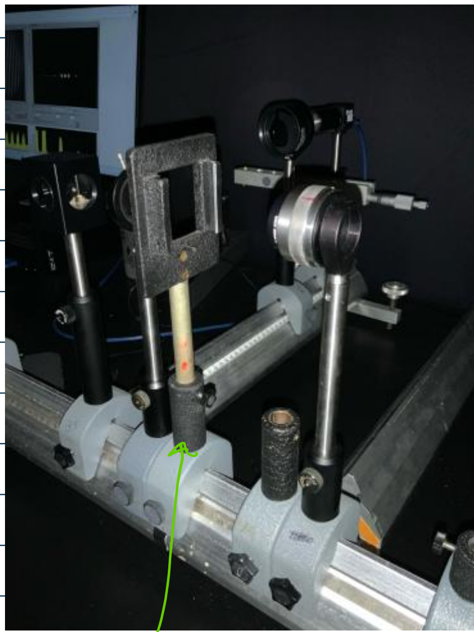
- 1. Verified Fourier patterns are symmetrical and well focused
- 2. Placed mask post at Fourier plane (after condenser lens, before beam splitter)
- 3. Mounted translational stage for precise mask positioning

Saved as file: Defualt and blocked-ve1to1

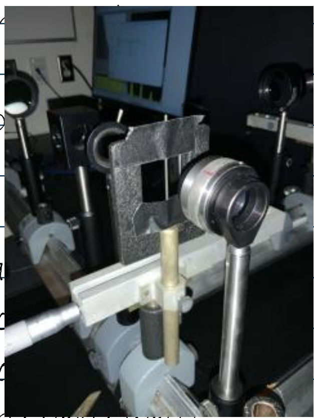




At (



At the Fourier Plane, afte
tht econdesnor lense,
before the Beam Splitter.
We placed a post, on this
post we ar
masks to
diffractio



TIP: We a
hellend so
translati
works very very well!

Placing the fourier mask
after the condensor lense.
at the fourier plane

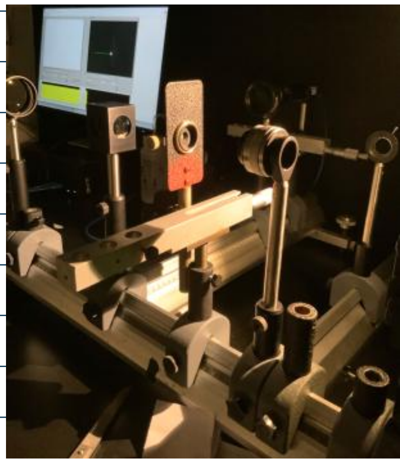
(a) All orders (reference case)
Saved Images as "RonchiReal-A.tiff"
"RonchiFourier-A.tiff"
Default image. Looks bright and the real
image is all well illuminated

We accidenlty increased the Irirs so new
images as

Saved Images as "RonchiReal-A2.tiff"
"RonchiFourier-A2.tiff"

(b) Zero order only;
Intensity Reduced

(b) Zero order only;
Intensity Reduced



Saved Images as "RonchiReal-B.tiff"
"RonchiFourier-B.tiff"

(c) +1 only;
(d) 0, +1 (Abbe minimal criterion);

We have moved it forwards, to make the mask larger and slided it on the trnaslatinal stage.

Saved Images as "RonchiReal-D.tiff"
"RonchiFourier-D.tiff"

Doing B2

Following procedure in B2

More noticeable lines in-between each solid white line

| $m_{\max}$ | Orders Transmitted | Iris Setting |
|---|---|---|
| 1 | −1, 0, +1 | Smallest (just fits ±1) |
| 3 | −3, −1, 0, +1, +3 | Medium (just fits ±3) |
| 5 | −5 to +5 | Larger (just fits ±5) |
| 7 | −7 to +7 | Even larger (just fits ±7) |
| All | Reference | Fully open |

(f) +1, −1;

Uisng the thinnst Allen key and a similar size Screw driver.
Saved Images as "RonchiReal-F.tiff"
"RonchiFourier-F.tiff"

(g) +2, 0, −2 and also +2, −2 (note: for a perfect square wave, even harmonics such as ±2 would
be suppressed);

~~(h) All positive orders (oblique dark field);~~
~~(i) All positive orders and the zero order (half shadow);~~
~~(j) All orders except zero (dark-field / dark-ground method);~~

Uisng a Slit Mask, just blocked the Centeral Maximum
Saved Images as "RonchiReal-F.tiff"
"RonchiFourier-F.tiff"

Just a uniform dark screen on the Real image.
(k) −mmax, . . . ,−1, 0, +1, . . . ,+mmax
(low-pass filtering; choose at least two values of mmax in

addtiton to 1 e.g. 1, 3, 5);

Doing outer Filtering, from -2 to + 2.

And

Saved Images as "RonchiReal-K2.tiff"
"RonchiFourier-K2.tiff"