3.13 Abbe Imaging Principle and Optical Spatial Filtering

Objective: Understand the basic principle of Fourier optics, and the concepts of optical frequency spectrum and spatial filtering

Experimental Setup

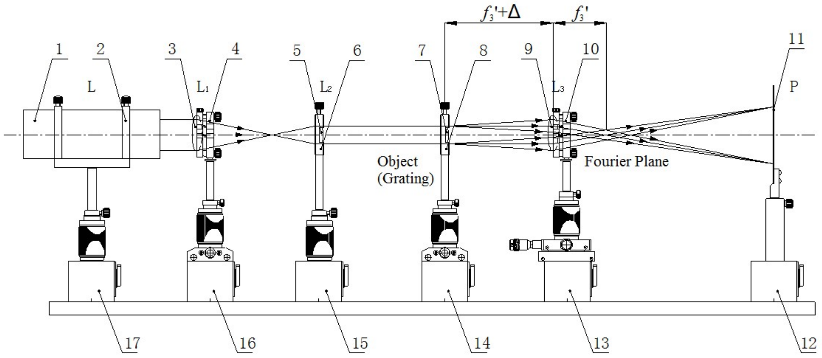


Figure 13-1 Configuration of components

1: He-Ne Laser (LLL-2)
2: Laser Holder (SZ-42)
3: Beam Expander Lens L_1 (f' =6.2 or 4.5 mm)
4: Two-axis Tilt Holder (SZ-07)
5: Collimating Lens L_2 (f'=190 mm)
6: Two-axis Tilt Holder (SZ-07)
7. Grating (20 lines/mm)
8: Lens Holder (SZ-08)
9: Fourier Transform Lens L_3 (f'=225 mm)
10: Lens Holder (SZ-08)
11: White Screen (SZ-13)
12: Magnetic Base (SZ-04)
13: Three-axis Stage (SZ-01)
14: Magnetic Base (SZ-04)
15: Z-adjustable Holder (SZ-03)
16: Three-axis Stage (SZ-01)
17: Z-adjustable Holder (SZ-03)
Others: Character with Grid, Combined Grating, Paper Clip (SZ-50), Adjustable Slit (SZ-40), Spatial Filter, Iris Diaphragm (SZ-15), Hollow Cross Plate.

Principle

Abbe's theory assumes that an object to be imaged can be decomposed into a number of elementary gratings - each grating diffracts light at an angle that is a function of the grating period and the groove orientation. The diffracted beams are plane waves that can be focused by a lens to form diffraction patterns in the back focal plane of the lens, as seen in Figure 13-2. These diffraction patterns in turn act as the sources of waves that propagate from the focal plane to the image plane where the image is produced. Simply speaking, it can be considered as two steps: the first step is to resolve the information, and the second step is to synthesize the information.

Experimental Procedure:

1) Refer to Figure 13-1, align all components in same height along one line;
2) Use lenses L_1 and L_2 to build a beam expander (an inverted telescope structure), to obtain a collimated beam with a larger beam size and then illuminate the collimated beam on the transmission grating (1-D grating) whose grating grooves are in vertical direction;

3) Place screen *P* about 2 meters away from the grating, move transform lens L_3 back or forth to form a clear grating image on the screen;

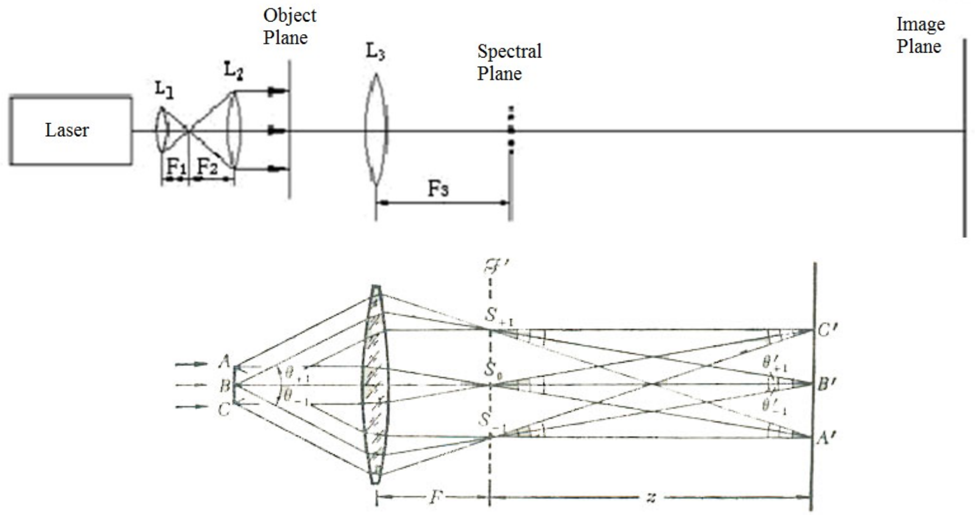


Figure 13-2 Schematic of Abbe's imaging

4) Insert an adjustable slit at the back focal plane of L_3, block all higher-order spectra except the zero-order, check whether there are still grating lines in the image;

5) Adjust the slit width so that the zero-order and the first-order spectra pass through, observe the grating image, then remove slit, observe grating image again, compare the two cases;

6) Replace the transmission grating (1-D grating) with a 2-D grating (a cross grating), place an adjustable slit on the Fourier plane and set slit direction in the vertical direction to pass the spectrum on Y axis, observe the direction of the grating lines on the image screen;

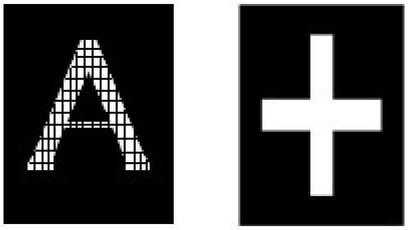
7) Rotate slit direction by 90° to let the X axis spectrum pass, observe the direction of the grating lines on the image screen;

8) Further rotate slit direction by 45°, observe the direction of grating lines direction on the image screen;

9) Place an iris diaphragm on the Fourier plane, reduce its aperture slowly, till only the zero-order passes through, observe the image on screen;

10) Replace the 2-D grating with the Character on Grid as shown in Figure 13-3 (a).

11) Place an iris diaphragm on the spectral plane, reduce the aperture gradually, observe the image (the grid should disappear but the character should still be there) Explain the results (i.e. optical low-pass filtering).



(a) (b)

13-3

12) Replace the Character with the Hollow Cross Plate (13-3(b)), observe image; place a circle piece to block the central portion of the spectrum on spectral plane, see image changes on the image plane. (optical high-pass filtering).

3.16 Optical Image Addition and Subtraction

Objective: Understand the principle of optical image addition and subtraction.

Experimental Setup

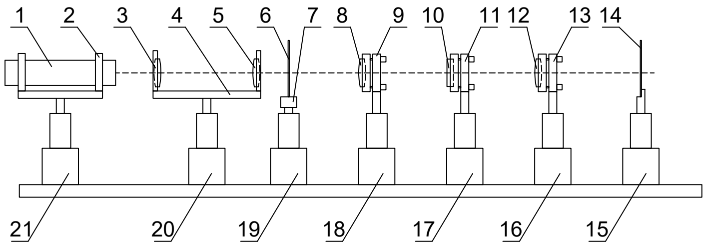


Figure 16-1 Configuration of components

1: He-Ne Laser (LLL-2)
2: Laser Holder (SZ-42)
3: Lens L_1 (f' =4.5 mm)
4: Beam Expander Holder (SZ-60)
5: Lens L_2 (f'=190 mm)
6: Aperture Pattern
7: Plate Holder *A* (SZ-12)
8: Lens L_3 (f'=150 mm)
9: Two-axis Tilt Holder (SZ-07)
10: Sinusoidal Grating (100 *l/mm*)
11: Lens Holder (SZ-08)
12: Lens L_3 (f'=150 mm)
13: Two-axis Tilt Holder (SZ-07)
14: White Screen (SZ-13)
15: Magnetic Base (SZ-04)
16: Magnetic Base (SZ-04)
17: 3-axis Stage (SZ-01)
18: Z-adjustable Holder (SZ-03)
19: Magnetic Base (SZ-04)
20: 3-axis Stage (SZ-01)
21: Z-adjustable Holder (SZ-03)

Principle

Image addition/subtraction is an optical operation in coherence optics, and it is a method of image recognition. This experiment kit employs a sinusoidal grating as the spatial light filter for optical image addition and subtraction. Through this kit, students can get a better understanding of the principles of optical image addition/subtraction, spatial light filtering, and 4*f* optical systems.

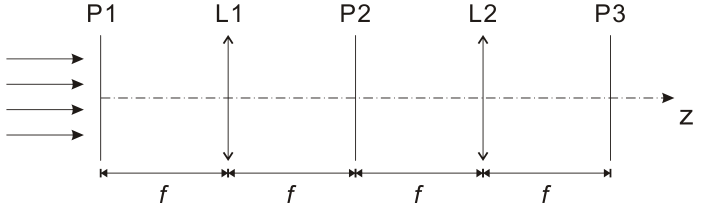


Figure 16-2 Schematic of 4f optical system

Figure 16-2 shows the schematic of a typical coherent optical system (also called as 4*f* system). A collimated beam illuminates on a transmissive object (i.e. to be processed image). Object *g* locates at the front focal plane P_1 of Fourier lens L_1. The spatial frequency spectrum $G(f_x,f_y)$ of object

$g(x_0,y_0)$ is presented at the back focal plane P_2 of lens L_1. P_2 also locates at the front focal plane of Fourier Lens L_2. After Fourier transform by L_2, the image of the original object is recovered on plane P_3 (an inverted image). If modifying the frequency spectrum on plane P_2 using a spatial frequency filter, the output image will be modified accordingly. This experiment uses a sinusoidal grating as the filter.

Experimental Procedure:

1) Set up 4*f* optical path

   Refer to Figure 16-1, align all components in same height along a line;

   Adjust Laser and Beam Expander assembly to get a collimated beam;

   Place Image Pattern $f(x_1, y_1)$ at P_1 plane and White Screen at P_3 plane, per Figure 16-2.

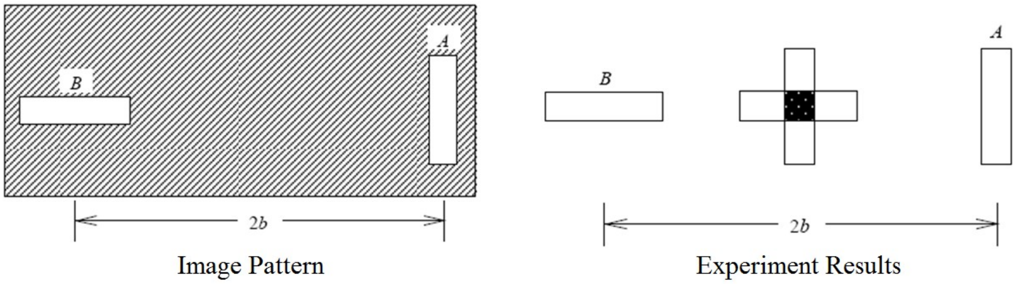


Figure 16-3 Image pattern and corresponding experimental results

2) Grating filtering

   Place the Grating on the back focal plane of Lens L_1, i.e. plane P_2,

   Observe images on plane P_3,

   Shift the Grating horizontally with the 3-D Adjustable Holder, observe the +1st order image of pattern *A* and the -1st image of pattern *B* on the screen,

   Carefully shift the Grating, let the centers of the two diffracted images overlap. See results shown in Figure 16-3.

   If necessary, the Image Pattern can be slightly shifted in horizontal direction.

3) Observe image addition and subtraction

   If the Grating is shifted continuously in one direction, the results of *A*+*B* and *A*-*B* can be observed alternatively; bright overlapping area is seen for *A*+*B* case while dark overlapping area is observed for *A*-*B* case as shown in Figure 16-3.

Note:

If a completely dark overlapping area cannot be observed for *A*-*B* case, it could be due to the following factors:

a) The illumination fields for *A* and *B* are not even;
b) The deviations of f_0 (spatial frequency of grating) and *b* between desired and actual values;
c) 4*f* optical paths are not coaxial.