LABORATORY TECHNIQUES

PINHOLE ALIGNMENT

I. OBJECTIVE

To filter out unwanted light intensity variations across a light beam, using a spatial filter, for use in optical systems.

II. BACKGROUND

A spatial filter is essentially a beam diverging device coupled with a filter. The filter, or pinhole, is used to remove interference patterns in a laser beam caused by diffraction from dust, lint, lens imperfections, etc. that are part of any laser optical system. Diffraction interference degrades the laser beam by producing phase and amplitude variations, or modulation, on the otherwise uniphase laser output, leading to fresnel zone patterns in the beam. The interference is removed from the beam in the following manner the laser output appears as a point source at infinity; however, the interference producing sources appear as Huygens generators a finite distance from the filter, due to the difference in the point of origin, focusing the beam will produce an image of the "source" with all the "noise", or interference, defocused in an annulus around the focused beam at the pinhole; therefore, the focused beam will pass through the pinhole and the interference will be severely attenuated. Attenuations of 40dB or greater are readily produced by this filtering method.

III. PINHOLE / OBJECTIVE SELECTION

The optimum pinhole diameter is a function of the laser wavelength, laser beam diameter, and focal length of the microscope objective used. They are related by

\[
\text{Pinhole diameter} = \frac{8}{\pi} \times \frac{\text{Wavelength} \times \text{Focal length}}{\text{Beam diameter}}
\]

Applying the above formula, we can match commercially available pinhole sizes and objectives for spatial filtering purposes. Common helium-neon (HeNe) lasers have a wavelength of 0.6328\(\mu\)m and a beam diameter of 1mm, and using these parameters gives the following selection table:

<table>
<thead>
<tr>
<th>Pinhole diameter ((\mu)m)</th>
<th>Objective power</th>
<th>Focal length</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>5 x</td>
<td>25.5mm</td>
</tr>
<tr>
<td>25</td>
<td>10 x</td>
<td>14.8mm</td>
</tr>
<tr>
<td>15</td>
<td>20 x</td>
<td>8.3mm</td>
</tr>
<tr>
<td>10</td>
<td>40 x</td>
<td>4.3mm</td>
</tr>
<tr>
<td>5</td>
<td>60 x</td>
<td>2.9mm</td>
</tr>
</tbody>
</table>
In practice, a slightly larger pinhole size is preferable to one smaller than the calculated optimum size; this is reflected in the pinhole sizes above. In addition, the actual working distance between the objective and the pinhole is quite a bit smaller than the focal lengths listed above.

IV. PROCEDURE

1. Before attaching the magnetic pinhole mount (PM) to the micrometer spindles, mount the appropriate microscope objective (MO) onto the spatial filter unit; then align the MO so that it is as close to the laser beam axis as possible. This will reduce aberrations, provide optimum light economy, and ease alignment of the pinhole.

2. Use the z-axis adjustment micrometer to move the MO as far away as possible from the x and y micrometer spindles.

3. Carefully remove the PM from its storage box, holding it by its integral handle. Do not touch the flat pinhole substrate under any circumstances. Attach the PM first to the vertical y-axis spindle, making sure the machined lip on the PM is against the side of the spindle opposite the MO; then slide the PM towards the horizontal x-axis spindle. Before releasing the PM, make sure it is attached squarely onto both spindles.

4. While observing the output side of the PM, adjust the x and y-axes until a faint light spot is seen; be careful not to look straight into the output: always look from an angle. Place a white card near the output and adjust the x and y-axes for maximum output.

5. Slowly bring the MO closer in towards the PM with the z-axis control; the output will probably drift a bit, so use the x and y controls to keep the output centered and symmetric. As the focal point of the MO is brought closer-to-the pinhole location, the output will become brighter and more sensitive to adjustments.

6. Continue alternate z and x, y adjustments until the output is a smooth speckle pattern; it should look symmetric (round) with very faint or no ring patterns around it.

![Objective/pinhole spatial filter]

Fig. 1. Objective/pinhole spatial filter.
LABORATORY TECHNIQUES

COLLIMATING A LIGHT BEAM

I. OBJECTIVE

To convert a diverging spherical wave into a plane wave for optical processing systems.

II. BACKGROUND

Collimating lenses are used for two purposes: (a) collimating a diverging light beam, and (b) focusing a collimated light beam to a point. These lenses are usually achromatic, i.e. consist of two or more elements, and are highly directional: to minimize aberrations they must be aligned with the optical axis of the system and the correct side must face the collimated beam; the side with the greatest curvature usually should face the collimated beam.

There are two basic methods for collimation: (a) using an optical flat, and (b) using a mirror and an iris. An optical flat is an optical component with very flat (λ/20) surfaces, which are usually parallel to each other. When this flat is placed at an angle with respect to the optical axis of an incident beam, reflections from the two surfaces will interfere with each other, as shown in Fig. 2. When the beam is collimated, i.e. a plane wave, the interference pattern will have a large uniform central area since the two reflected plane waves are traveling parallel to each other.

Fig. 2. Examining the degree of beam collimation with an optical flat.
Some flats have surfaces that are at a slight angle to each other, forming a *wedged flat*. In this case the interference pattern due to a collimated beam will be alternating bright and dark fringes that are spaced as far apart as possible since the two reflected plane waves will be interfering at a slight angle. This kind of optical flat lends itself to a form of "calibration": by rotating the wedged flat in a suitable mount, the fringe pattern due to a previously collimated beam can be set to be either horizontal or vertical. Thus, any incident beam can be easily collimated by adjusting the collimating lens until the appropriate set fringe pattern is achieved. The setup for collimating using a mirror and an iris is shown in Fig. 3.

![Fig. 3. Beam collimation using a mirror and an iris.](image)

### III. PROCEDURE

**Collimating with an optical flat:**

1. Place the collimating lens approximately one focal length away from the diverging source (usually the output of a spatial filter). This will give an output beam that is almost collimated.

2. Insert the optical flat, at an angle, in the output beam path and place a white card to view the interference pattern. The angle should be chosen such that a complete interference pattern can be seen.

3. Adjust the position of the collimating lens until the desired interference pattern is obtained (uniform central area for parallel flat, largest fringe pattern for wedge flat).

**Collimating with a mirror and an iris:**

1. Place the collimating lens approximately one focal length away from the diverging source to get an almost collimated beam.

2. Insert an iris right at the output of the lens, center it on the beam, and adjust its size to allow about 80% of the light through.

3. Place an adjustable minor at the far end of the optical bench. Adjust it until the reflected beam is centered on the iris.

4. Adjust the position of the collimating lens until the reflected beam size is the same as the forward beam through the iris.
I. OBJECTIVE

To provide a very simple and accurate technique for locating filters at the focal plane.

II. PROCEDURE

1. Place the filter in its holder in the path of the focused beam and adjust its position for minimum light spot size.
2. Place a white card near the filter to observe the transmitted light from the filter. If the filter has a slightly irregular surface, i.e. the surface is somewhat diffuse, a speckle pattern will be seen on the card.
3. Alternatively, a piece of Scotch tape (type 810) taped tightly across a similar mount to that of the filter can be used in place of the filter if a speckle pattern is difficult to generate with the filter itself.
4. Slowly adjust the position of the filter (or the mounted tape) along the optical axis until the largest speckle pattern is seen on the card. This will indicate the best focus because the speckle size is inversely proportional to the focused spot size.
5. If the mounted tape was used to determine the focal plane, replace it with the filter. Be careful not to disturb the position of the holder.
LABORATORY TECHNIQUES

ALIGNING AN OPTICAL SYSTEM

I. OBJECTIVE

To properly align an optical system to minimize aberrations and distortions for improved performance and results.

II. BACKGROUND

Optical systems are designed and assembled according to the needs of each individual experiment. A typical system is shown in Fig. 4.

![Optical System Diagram](image)

Fig. 4. Typical optical image processing system.

The system shown is designed for imaging an object transparency (located at P₁) onto plane P₃, and for performing spatial filtering at plane P₂. Lens L₁ is an objective that expands the laser beam to utilize the diameter of lens L₂. L₂ collimates the beam, and L₃, L₄ are a pair of imaging lenses: L₃ forms the Fourier transform at P₂ of the object at P₁; L₄ takes the inverse Fourier transform and forms an image of P₁ at P₃. The pinhole P after L₁ provides a clean wavefront at L₂.

III. PROCEDURE

Aligning the optical system in Fig. 4:

1. Choose the height of the optical axis.

The first order of business is to decide on the height of the optical axis above the optical rail. Lay out all the components and determine the height of the tallest component. Choose the
optical axis to be ~1cm above this height. Our UCSD optics research labs have adopted 10cm as the height of the optical axis above the optical table surface.

2. Align the laser beam.

Mount the laser onto the optical rail using appropriate mounts and carriages. Adjust the height of the laser beam to the chosen optical axis height and adjust the direction of the laser beam to be parallel to the rail. Alignment can be checked, by mounting an iris on a carriage at the height of the beam, adjusting it to minimum aperture size, and sliding it along the rail; the beam should remain centered on the aperture.

3. Align the height of the components.

Mount L4 on a carriage and place near the far end of the rail. Slide the iris used above right next to the laser and adjust its aperture size to just let beam pass through. Center L4 on the optical axis by adjusting its height until all of the back reflections seen on the iris are centered on the aperture; look down at the lens and make sure it is not tilted with respect to the axis (if the reflected spots lay on two lines in space, rotational adjustment is required; if the spots lay on two lines parallel to each other, vertical and/or horizontal translation of the lens is required).

Repeat with L3, L2 and L1.

4. Expand and collimate the laser beam.

Place L1 ~10cm away from the laser output (this allows the insertion of future components, e.g. an attenuator). Then following the PINHOLE ALIGNMENT and COLLIMATING A LIGHT BEAM procedures, expand (using L1) and collimate (using L2) the beam.

5. Position the imaging lenses.

Lens L3 can be placed any distance from L2, but sufficient distance should be left between them to insert object slides or other components. For example, the object transparency at P1 should be placed one focal length (F3) away from L3; a distance of 2F3 is usually sufficient. After positioning and orienting L3 (see ORIENTING IMAGING LENSES), L4 should be positioned and oriented at a distance F3 + F4 away from L3 to give a collimated beam after L4, the collimation should then be verified.

Checking alignment of an existing optical system:

Optical systems may require readjustment after being left unused for a period of time. This is especially true of systems that do not have all of the components mounted on a single optical rail. The following procedure describes the alignment check on the system in Fig. 4.

1. Check the quality of the pinhole output and readjust if necessary.
2. Make sure the output is also centered on L2, since if this lens is not at the proper height, the optical axis will be tilted and all the other components will be out of alignment.
3. Check the beam collimation after L2 and L4 and make appropriate adjustments if necessary.
4. Check the back reflections off L3 and L4 and readjust if necessary.