Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project: DECAM

Title: Diffraction Patterns for Testing CCDs

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Abstract Summary:
Diffraction patterns projected onto a CCD can be used to measure different CCD characteristics such as diffusion and the Modulated Transfer Function which is related to the Point Spread Function. Diffraction patterns can be used to produce dark and light contrast patterns on the CCD. Patterns with fringe spacings from 1 pixel to 100 pixels are required to characterize the CCD. The Dark Energy Survey uses CCDs with a pixel size of about 15 microns.

Applicable Codes:
Reference: Halliday and Resnik, "Fundamentals of Physics", Chapter 40 Diffusion

Introduction:

Displaying diffraction patterns on CCDs is useful for measuring CCD characteristics. Three devices are described for displaying diffraction patterns. A single slit device, a double slit device and a variable double slit device is described. PinHole Cameras are also discussed as a tool for displaying an image on the CCD.

Single Slit Device:

Description of the Device:

Two razor blades are mounted on a block can form a single parallel slit. Coherent light from a 550 nm red laser is shown incident on the single slit. The block has a hole in the center to allow the light to pass through.

Description of the diffraction pattern on the CCD:

The gap "a" between the razor blades is approximately 50 microns. The distance "D" from the single slit to the CCD is 13 cm. The diffraction pattern formed follows

There is a central maxima and the first minima is found at a distance "Y" from the maxima.

$aY/D = m\lambda$

where,
Y is the horizontal distance from the slit on the CCD,
m=1 is the first minima
$\lambda = 550$ nm wavelength of light

$Y = m \lambda D/a$

m=1
Y= 1* 550e-9 m * 13 e-2 m / 50e-6 m = 1.43 mm

The first minima from the slit is 1.43 mm, or about 95 pixels
The smaller the gap "a" the wider the central maxima.

The single slit diffracted intensity for a given diffraction angle is given by

$I = Im (\sin \alpha/\alpha)^2$

Where

$\alpha=\pi a/\lambda * Y/D$

Plotting I/Im vs Y

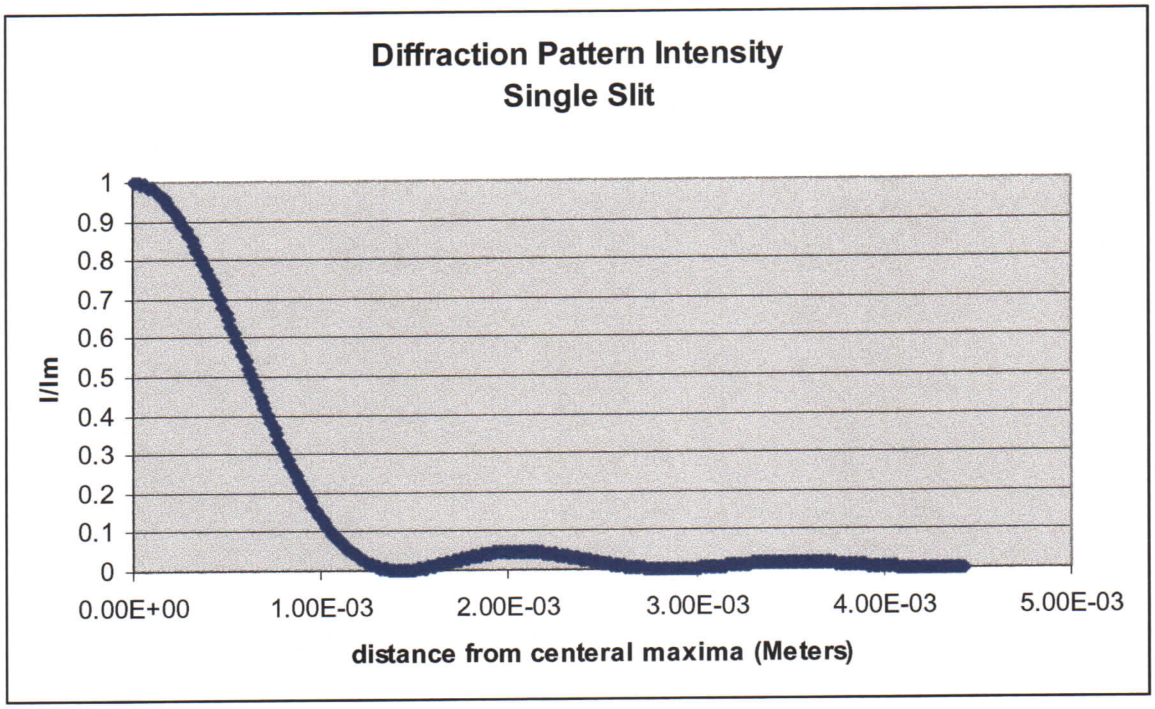

CHART 1, DIFFRACTION PATTERN FROM A SINGLE SLIT

Double Slit Device:

Description of the Device:

Two razor blades are mounted on a block and are separated by a dowel pin. The razor blades have parallel edges that form two narrow slits, one on each side of the dowel pin. Coherent light from a 550 nm red laser is shown incident on both slits. The block has a hole in the center to allow the light to pass through.

Description of the fringe pattern on the CCD:

The gap "a" between the razor blade and the dowel pin is approximately 50 microns. The dowel pin diameter "d" is 1 mm. The distance "D" from the single slit to the CCD is 13 cm. The fringe space is determined by

$dY = \lambda D/d$

Using the values from the single slit case:

dY= 550 nm * 13cm / 1mm = 71.5 e-6 meters

The fringe pattern is 71.5 microns or about 4.7 pixels
As the spacing between slits increases, the fringe pattern decreases.

The double slit diffracted intensity for a given diffraction angle is given by

$I = Im\ cos(\beta)^2 * (sin\ \alpha/\alpha)^2$

Where
$\beta = \pi d/\lambda * Y/D$
$\alpha = \pi a/\lambda * Y/D$

Plotting I/Im vs Y

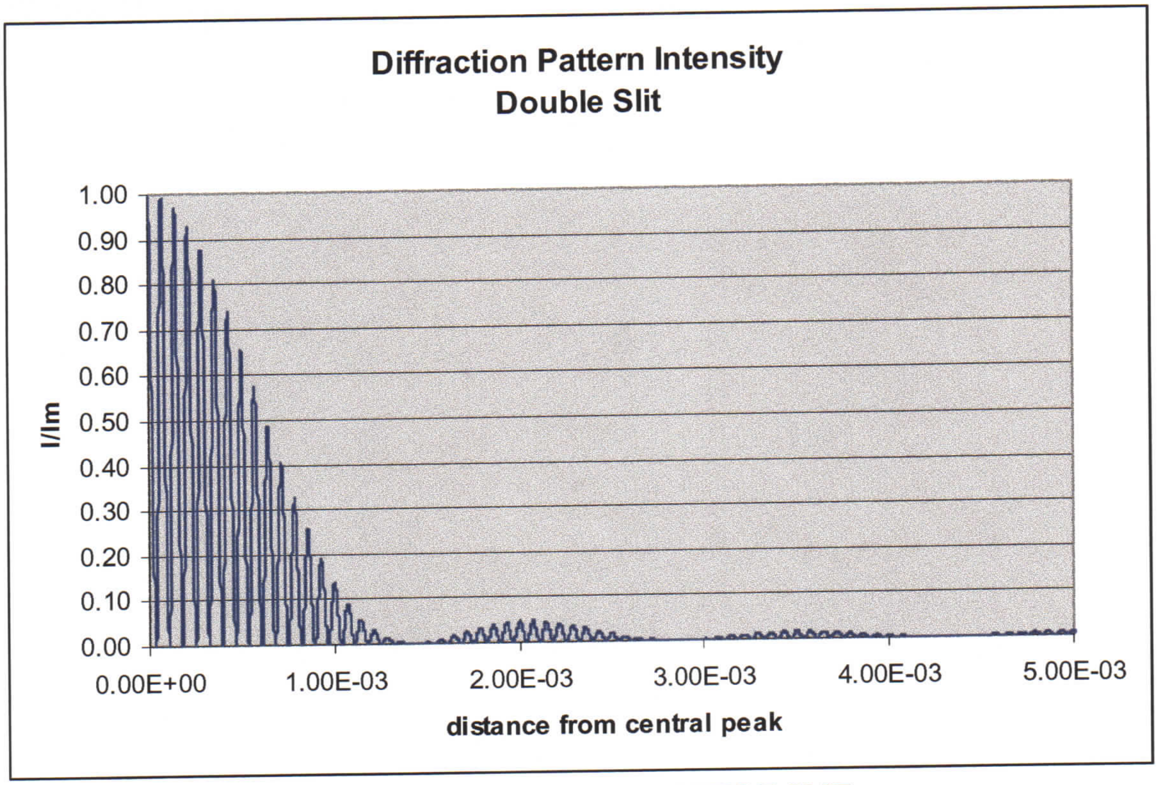

CHART 2, DIFFRACTION PATTERN FROM A DOUBLE SLIT

Note if one of the slits is covered, the single slit pattern in chart 1 is displayed. By allowing the two single slit diffraction patterns to interfere with each other, a higher frequency fringe pattern is overlaid on top of the single slit pattern.

Variable Double Slit Device:

A variable double slit device is desired so that with the same setup, a range of fringe pattern spacings can be displayed on the CCD. Replacing the dowel pin with a tapered dowel pin allows the spacing between slits to be varied from the top to the bottom of the device. The slit fixture is put on an adjustable slide so that the device can be adjusted such that the desired spacing is placed in front of the laser. Calculating the fringe pattern spacing for a tapered dowel pin with a diameter of 0.5 mm to 3 mm:

$dY = \lambda D/d$

Using the values from the single slit case:

dY= 550 nm * 13cm / 0.5 mm = 143 e-6 meters

The fringe pattern is 143 microns or about 9.5 pixels
As the spacing between slits increases, the fringe pattern decreases.

dY= 550 nm * 13cm / 3 mm = 23.8 e-6 meters

The fringe pattern is 23.8 microns or about 1.6 pixels

Using a tapered dowel pin with a diameter of 0.5 mm to 3 mm allows for a range of fringe patterns between what is shown in Charts 3 and 4.

Plotting I/Im vs Y

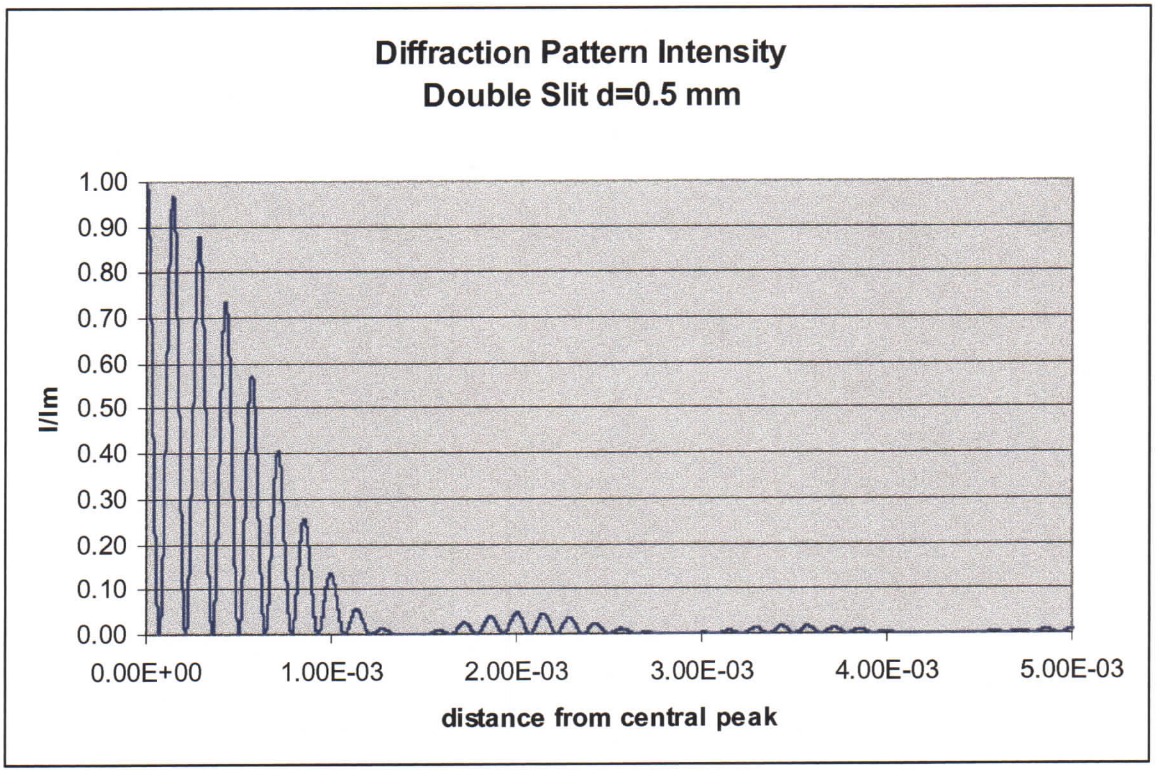

CHART 3, DIFFRACTION PATTERN FROM A DOUBLE SLIT d=0.5 mm

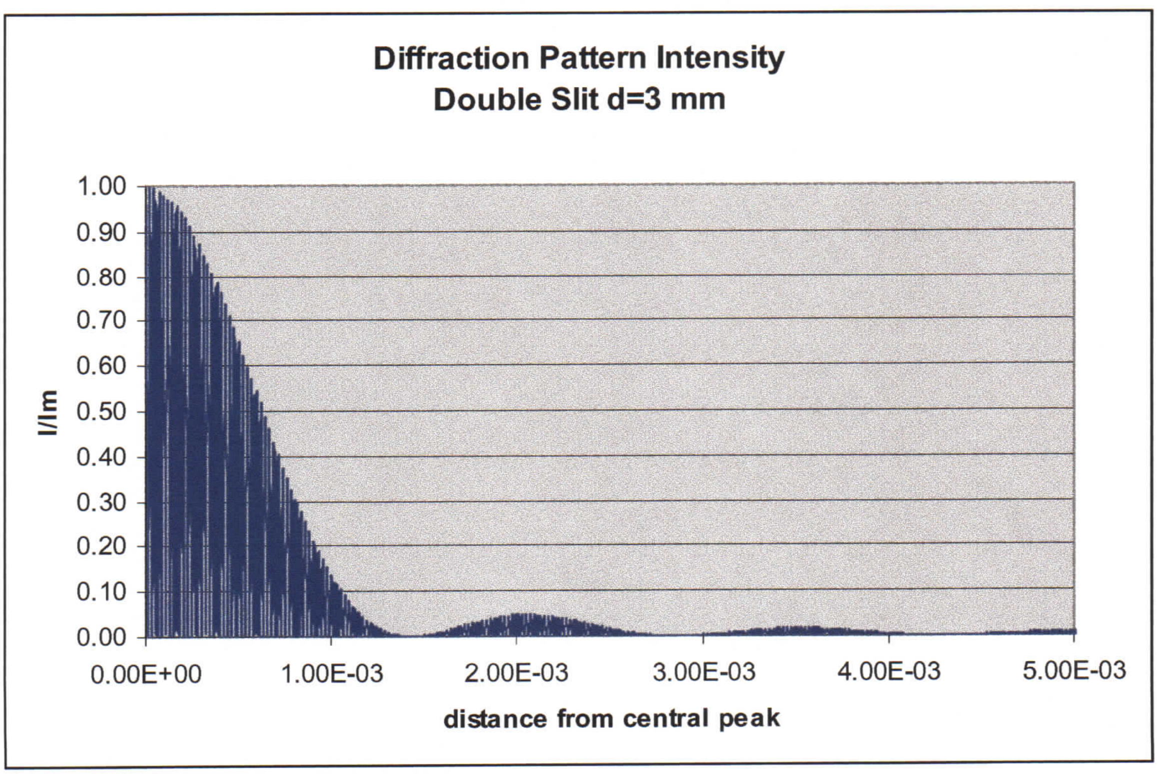

CHART 4, DIFFRACTION PATTERN FROM A DOUBLE SLIT d= 3 mm

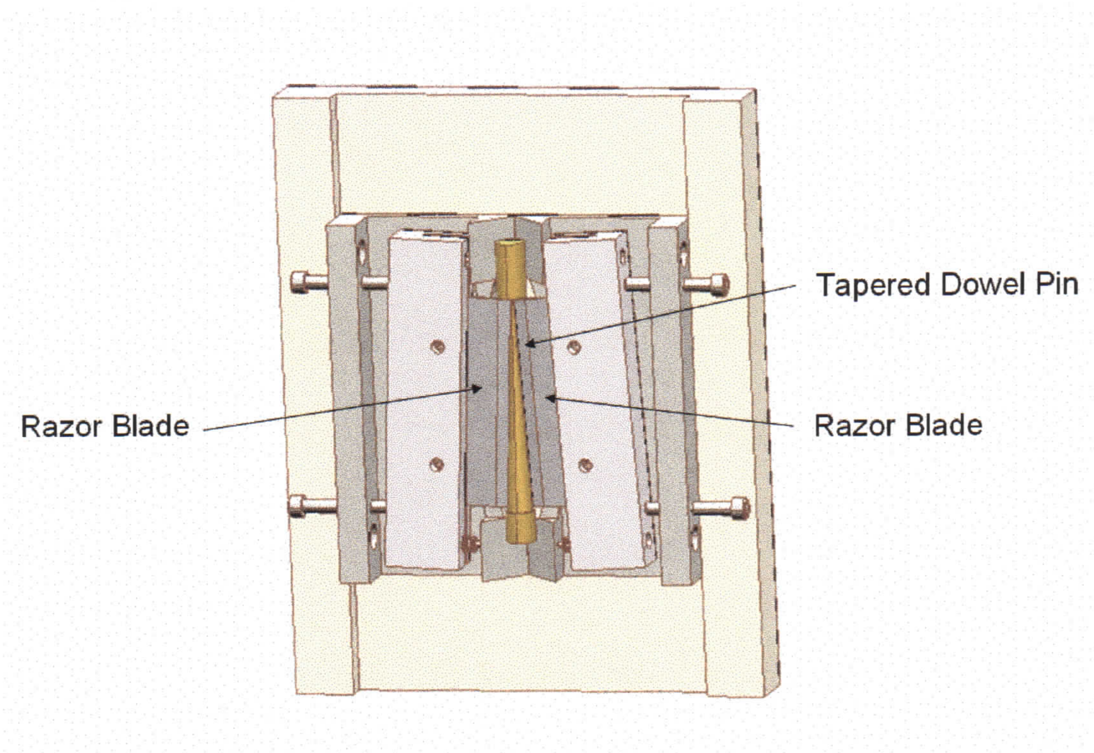

Figure 1. Example of a design for a variable double slit device.

PinHole Camera:

A Pin Hole Camera is a camera without a lens. A smaller hole will produce better resolution using geometric optics, however if the hole is too small, the image will be degraded due to diffraction.

Using geometric optics, The resolution Y is roughly half the pinhole diameter.
$Y = 0.5 * d$

Where the smaller the hole the better the resolution.

The diffraction resolution, or airy disk, of the pin hole camera is defined by Rayleigh's Criteria:
$Y = 1.22\,\lambda * D / d$

Where the larger the hole, the better the resolution.

The optimum hole diameter is determined where these two lines cross each other.

The optimum hole diameter d is calculated from:

$d = \mathrm{sqrt}(2.44 * \lambda * D / (1 + D/\text{object distance}))$
Ref : http://www.huecandela.com/hue-x/**pin**-pdf/Prober-%20Wellman.pdf
Ref: http://www.pinhole.com/index.php?pid=archive&id=371

Where
d is the hole diameter
$\lambda =$ is the wavelength of the light ~550 nm
D = distance from the hole to the film or CCD.

For objects at infinity and D = 13 cm,
d= sqrt (2.44 * 550 nm* 13 cm / (1 + 0)) = 4.2 e-4 meters = 0.42 mm (.016 inch)

The diffraction resolution and the geometric resolution are equal to each other and is about half the hole diameter.
Y= 0.5 * 0.42mm = 207 microns

Picture 1 shows a picture taken using a 725 micron pinhole at a distance of 13 cm from the CCD. The resolution dominated by geometric optics and is about 360 microns,

Picture 1.

Results:

Diffraction patterns from a single slit and interference patterns from a double slit can produce patterns on the CCD for measuring the characteristics of the CCD. Fringe patterns with a spacing from 1 pixel to 100's of pixel can be reliably produced.

Figure 2 is an example of a double slit fixture used to create the diffraction and interference patterns. The spacing between slits is 1 mm. Figure 3 is an example setup of a laser spot on the double slit. The diffraction pattern is then displayed on the CCD in the cryostat. Actual interference patterns using a double slit with a spacing d=1mm is shown. Pictures taken of the diffraction pattern by Juan Estrada using a CCD in one of the test Cubes are shown in Figures 4 and 5.

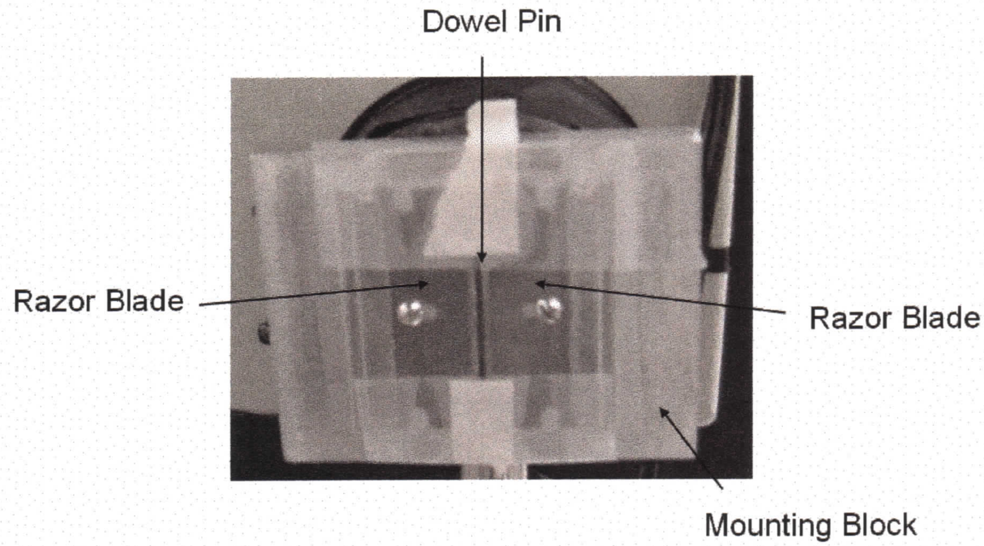

Figure 2 , Example of a double slit fixture.

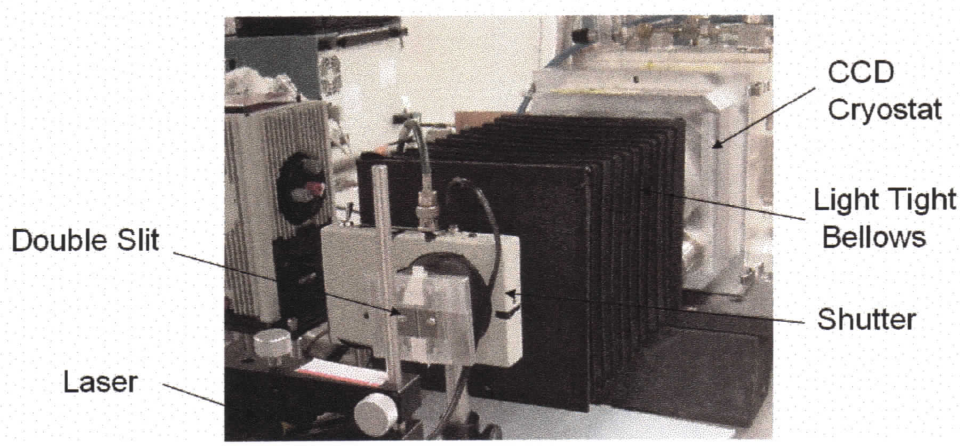

Figure 3, Setup of double slit and CCD cryostat

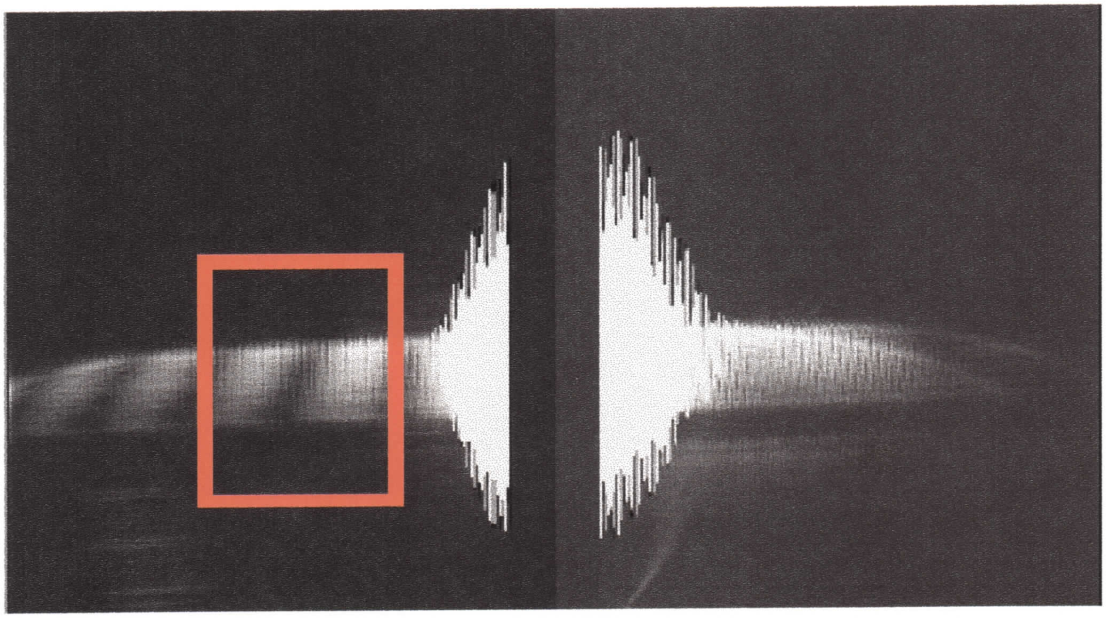

Figure 4. CCD display of a double slit interference pattern. The black section in the middle is an artificial separation of the two sides of the CCD.

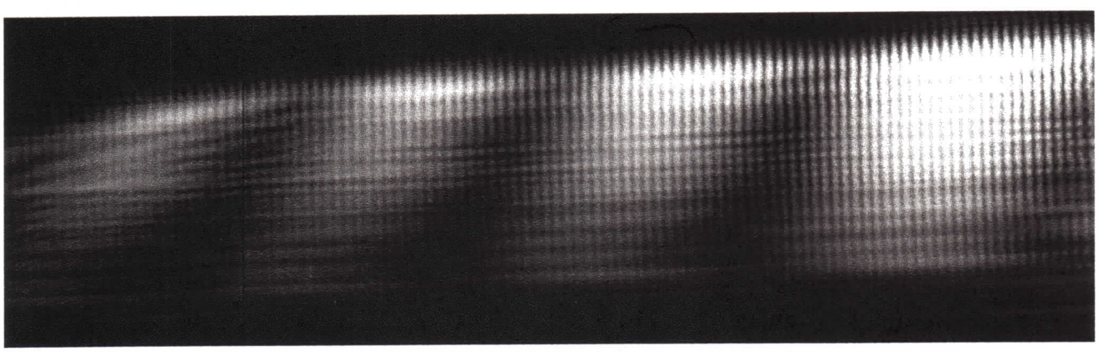

Figure 5. Closeup of the above interference pattern. Spacing between fringes was measured as ~69 microns using a slit spacing of 1 mm.