Beam Instrumentation Lab Instructions

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Lab 1: Knife-Edge Scraper for Beam Profile and Halo Measurement

1.1 Aims and Objectives

This experiment aims to demonstrate the principle of a particle beam scraper for fast measurement of transverse beam parameters, by making an analogous transverse profile measurements of a laser beam with a knife-edge scanner. The measurement of a transverse beam profile is important for several methods to determine the emittance, namely the three-screen method, the quadrupole scan, and the pepperpot technique, which are explored further in the other laboratory experiments. The knife-edge scanner is also useful for beam halo measurement. The main objectives are:

- To set up the optics equipment to measure the transverse beam profile of a laser beam.
- To autonomously translate a knife-edge across a laser beam and record the transmitted intensity at a photodiode.
- To analyze the data by filtering, then differentiating the photodiode signal to generate the measured beam profile and determine the laser beam width via a Gaussian fit.
- To appreciate the dynamic range necessary to measure beam halo distributions, through measurements of the Fraunhofer diffraction pattern from a single slit.

1.2 Beam Profile Measurement Theory

Scanning a knife-edge across a particle beam allows the transverse beam profile to be measured from the differential of the transmitted intensity. See for example: J. A. Arnaud et al, *Technique for Fast Measurement of Gaussian Laser Beam Parameters*.

1.2.1 Beam Halo

The core profile of a particle beam may be measured using for example, a wire scanner that records the current resulting from secondary emission due to impacting particles. In addition, however, a particle beam normally has a halo distribution, which arises from various processes including: beam gas elastic and inelastic scattering, incoherent and coherent synchrotron radiation, scattering off thermal photons, intrabeam and Touschek scattering and ion or electron-cloud effects; beam optics, and collective effects. In synchrotrons, the beam halo is an important background source for the experimental detectors, and is also critical for radiation sensitive components in the accelerator. Beam losses at the level of $< 0.1\%$ lost particles per bunch can be harmful, therefore we require a beam monitor capable of measuring the transverse beam halo better than this. The required dynamic range is therefore of the order of 10^5 or better. To achieve this dynamic range, a combination of wirescanners and knife-edge scrapers is sometimes necessary to capture profile data from the intense core and the halo distributions respectively.

1.3 Experimental Setup

The equipment is in the dark room in section-C (far corner) of the RHUL Tolansky teaching laboratory.

Warning: the He-Ne laser in this experiment is a class IIIa laser. Avoid direct eye exposure to laser radiation. Do not stare into the beam and remove any reflective jewellery before operating the laser.

A HeNe $\lambda = 632.8$ nm laser is aligned on an optical rail such that light passes through a series of focusing lenses to converge on distant photodiode, as shown in Fig 1.1.

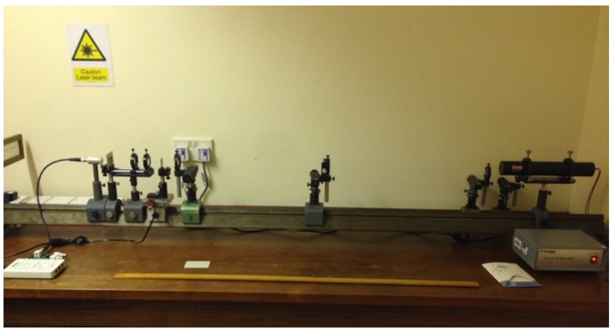


Figure 1.1: Overview of setup for knife-edge laser beam scraper

The photodiode signal is recorded via an National Instruments MyDAQ data acquisition card, as in Fig 1.2, connected to a laptop computer. The laptop also controls a New Focus pico-motor, that drives a knife-edge on a translation stage transversely across the laser beam. The laptop has LabView control software to automate the scan, that can be accessed from the desktop.

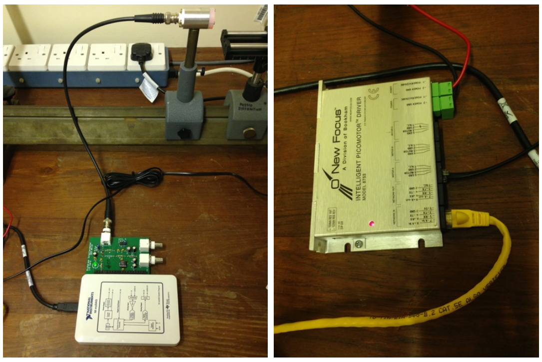


Figure 1.2: NI MyDAQ data acquisition card to record photodiode voltage and New Focus Pico Motor Controller connected via ethernet cable/USB adapter to laptop.

The New Focus pico motor can be incremented in precise 30 nm steps. To minimize the time required for a scan, the laser beam is focused to a tight laser waist, just after which the knife-edge is scanned, as in Fig. 1.3

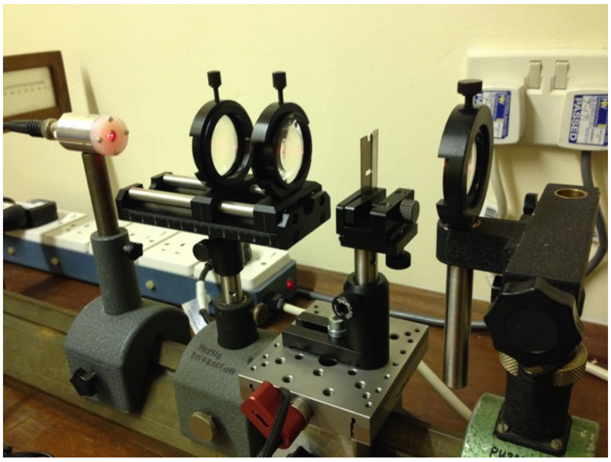


Figure 1.3: Knife-edge between focusing lenses, with the photodiode illuminated by a HeNe laser.

1.4 Measurements

1.4.1 Knife-edge Scans

After familiarizing yourself with the equipment, turn on the laser and observe the beam shape using the white-screen as in Fig 1.4 to image the laser beam spot at various locations through the setup, noting the focal lengths of the lenses used. The light should pass through all lens apertures to avoid clipping of the beam profile.

When the knife-edge is positioned half-way through the laser-beam, the pattern on the card appears as in Fig 1.4. You may notice there is a distortion of the geometric shadow on the card as the knife-edge passes through the laser-beam - why is this? Is this effect expected at a particle accelerator? Under what circumstances does this effect not matter for this experiment?

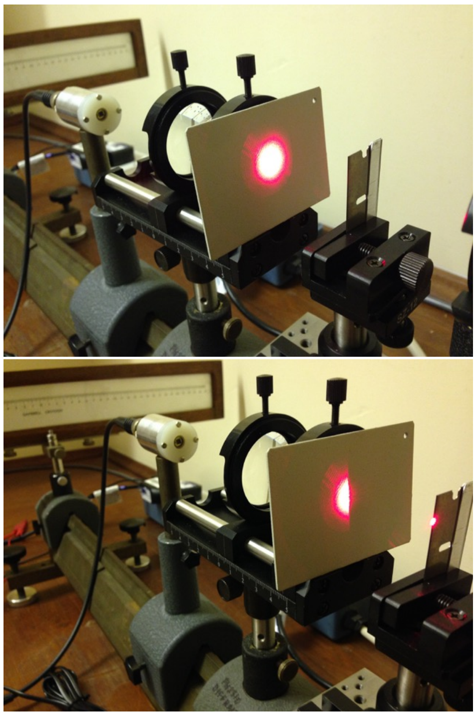


Figure 1.4: Beam imaged on white screen, without and with knife-edge in beam

The active area of the photodiode is small, therefore the light transmitted beyond the knife-edge must be refocused to be collected entirely by the photodiode, as in Fig 1.5.

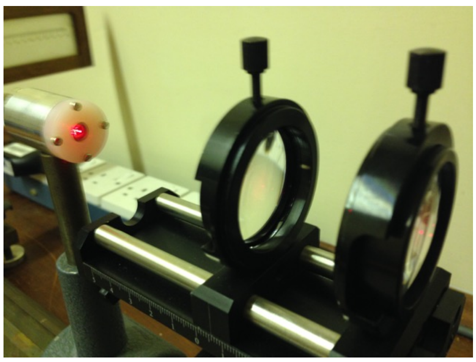


Figure 1.5: Laser spot focused onto photodiode

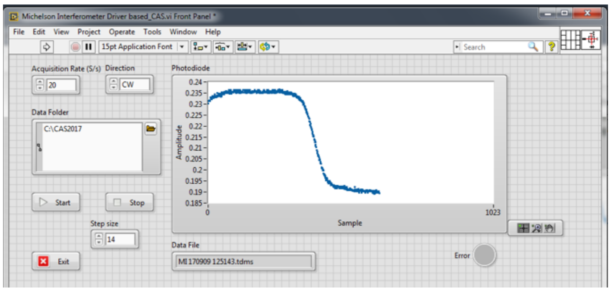


Figure 1.6: LabView software to control the stage and read out the photodiode during a scan of the knife-edge.

Performing a scan:

- Open the LabView software in Fig. 1.6 and use it to record a scan, by running the program, then pressing the start and stop buttons. Select COM3 when prompted.
- The voltage signal at each sampling point is recorded to a timestamped data file in the C:/CAS2017/ folder.
- Check that the scan records the full beam profile as an error function; you may wish to adjust the step size and sampling time for a more rapid scan, within the limits of the driver.

1.4.2 Beam profile extraction

The recorded data file may be analyzed by the CAS_readata.vi LabView software shown in Fig. 1.7. The raw data are filtered by averaging over a certain number of samples, then the signal is differentiated to obtain a plot of the beam profile versus knife-edge position.

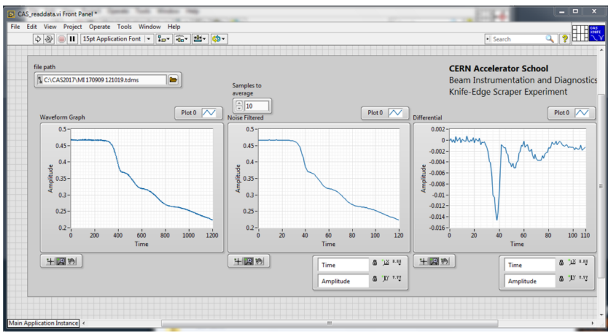


Figure 1.7: Analysis software to read the photodiode data, filter for noise and differentiate to obtain the profile.

1.4.3 Gaussian beam profile

Fit a Gaussian (or otherwise) to the beam profile to extract the width. Compare this with the width of the Gaussian waist you would expect at the focus of the lenses. How would you improve / calibrate the setup?

If there is sufficient time, replace the knife-edge with the adjustable slit and repeat the scan. Can you optimize the slit size to obtain the best beam profile?

1.4.4 Beam Halo measuring a single-slit diffraction pattern

When the first lens in the setup is replaced with an adjustable single slit, a diffraction pattern is produced in the far field with the intensity: $I(x) = \frac{\sin^2(x)}{x^2}$, as in Fig. 1.8. Thus the distribution has a central *"core"* and an interesting side patterns that can be considered as the *"beam halo"*.

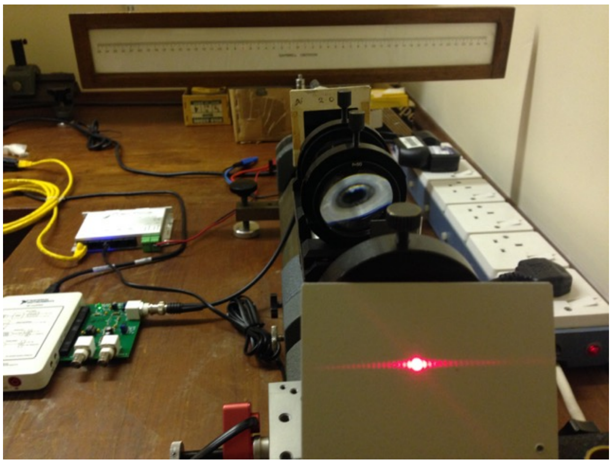


Figure 1.8: Single slit diffraction pattern.

Use the apparatus to obtain beam profiles showing clear features of the core and halo. Consider whether the photodiode will saturate when exposed to the full laser beam. Place different optical filters (ND > 2.0) in front of the photodiode, as in Fig 1.9 to obtain profiles with the necessary dynamic range. How could the setup be modified to obtain both sides of the halo distribution?

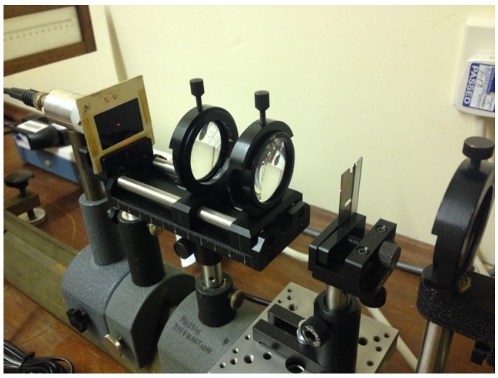


Figure 1.9: Filter inserted in front of photodiode.

Lab 2: Beam Emittance by the Three Screen Method

2.1 Aims and Objectives

The experimental aim is to measure the emittance of a laser beam. The main objectives are to:

- understand the theory of emittance measurement by the three screen method.
- calibrate a CCD camera and use it to record multiple beam profiles of a laser beam.
- calculate the beam widths using a Gaussian fit to the recorded profiles.
- apply the three-screen method matrix formalism to determine the horizontal emittance of the laser beam.

2.2 Emittance Measurement Theory

If β is known unambiguously as in a circular machine, then a single profile measurement determines ϵ by

$$\sigma_y^2 = \epsilon \beta_y .$$

But it is not easy to be sure in a transfer line which β to use, or rather, whether the beam that has been measured is matched to the β-values used for the line. This problem can be resolved by using ***three monitors (see Fig. 2.1), i.e. the three width measurement determines the three unknown α, β and ϵ of the incoming beam.***

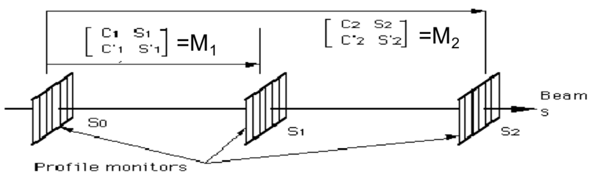


Figure 2.1: Overview of three screen profile measurement technique for emittance measurement.

Introducing the σ-matrix (see for example, K. Wille; Physik der Teilchenbeschleuniger, Teubner):

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \begin{pmatrix} \sigma_y^2 & \sigma_{yy'} \\ \sigma_{y'y} & \sigma_{y'}^2 \end{pmatrix} = \epsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

where $\beta\gamma - \alpha^2 = 1$, then the rms emittance is given by

$$\epsilon_{rms} = \sqrt{\det \sigma} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}$$

The rms beam width of the measured profile is

$$\sigma_y = \sqrt{\sigma_{11}} = \sqrt{\beta(s) \cdot \epsilon} \, .$$

Transformation of σ-matrix through the elements of an accelerator:

$$\sigma_{s1} = M \cdot \sigma_{s0} \cdot M^T$$

where $M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$, $M^T = \begin{pmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{pmatrix}$.

$L_1,\ L_2$ = distances between screens or from Quadrupole to screen and Quadrupole field strength are given, therefore the transport matrix M is known.

Applying the transport matrix gives (now time for exercise):

$$\begin{aligned}
\sigma_{s1} &= M \cdot \sigma_{s0} \cdot M^T \\
&= \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \cdot \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} \cdot \begin{pmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{pmatrix} \\
&= \sigma^{meas} = \begin{pmatrix} \sigma_y^2 & \sigma_{yy'} \\ \sigma_{y'y} & \sigma_{y'}^2 \end{pmatrix}_{s1}^{meas} = \epsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} \\
&= \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \cdot \begin{pmatrix} \sigma_{11}M_{11} + \sigma_{12}M_{12} & \sigma_{11}M_{21} + \sigma_{12}M_{22} \\ \sigma_{21}M_{11} + \sigma_{22}M_{12} & \sigma_{12}M_{21} + \sigma_{22}M_{22} \end{pmatrix} \\
&= \begin{pmatrix} M_{11}(\sigma_{11}M_{11} + \sigma_{12}M_{12}) + M_{12}(\sigma_{21}M_{11} + \sigma_{22}M_{12}) & \ldots \\ \ldots & \ldots \end{pmatrix}
\end{aligned}$$

therefore

$$\begin{aligned}
\sigma(s_1)_{11}^{meas} &= \sigma^2(s_1)_y^{meas} \\
&= M_{11}^2\sigma(s_0)_{11} + 2M_{11}M_{12}\sigma(s_0)_{12} + M_{12}^2\sigma(s_0)_{22}
\end{aligned}$$

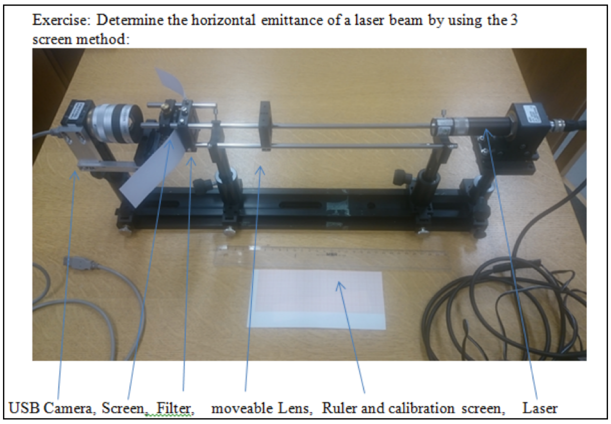
where $\sigma_{12} = \sigma_{21}$). Solving $\sigma(s_0)_{11}$, $\sigma(s_0)_{12}$ and $\sigma(s_0)_{22}$ while the matrix elements are known ***needs minimum of three different measurements, either three screens or three different quadrupole settings with different field strength***.

$$\boxed{\epsilon_{rms} = \sqrt{\det \sigma} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}}$$

2.3 Experimental Setup

2.3.1 Overview

By moving the lens one can take pictures from the camera in the focus (not preferred due to limited resolution of the optic system) and on other positions. The distance of the lens to various screen positions can be measured by a simple ruler[1]. The camera is connected to a Computer where the readout software is installed. The pictures (.jpg) can be saved and can be loaded into a free software called “ImageJ” where a profile of an area can be displayed and the curser position and the value is displayed (8 bit). The σ of the profile have to be found for each screen (camera) position and the emittance have to be calculated.



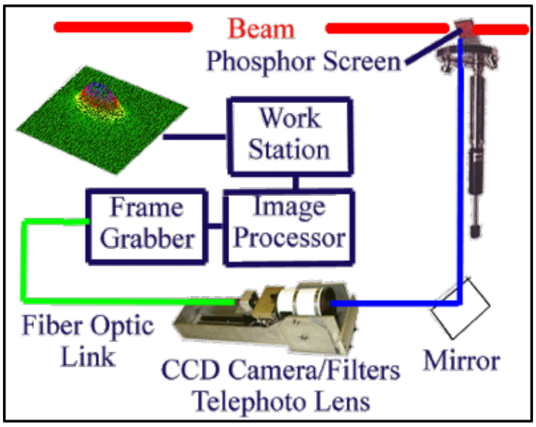


Figure 2.2: Experimental setup for three screen emittance measurement

2.3.2 Hardware parameters

Parameters for the hardware are provided below and in Fig. 2.3.

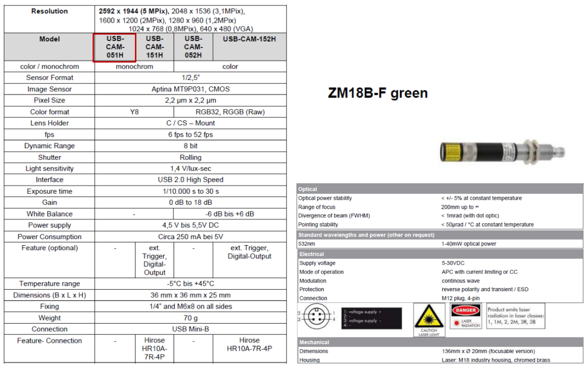
CCD Phytec USB-CAM 051H

screen material: white paper

grid target spacing 1mm

laser Z-Lasers

[1]Move the lens to simulate different screen positions



Resolution	2592 x 1944 (5 MPix), 2048 x 1536 (3,1MPix), 1600 x 1200 (2MPix), 1280 x 960 (1,2MPix) 1024 x 768 (0,8MPix), 640 x 480 (VGA)			
Model	**USB-CAM-051H**	**USB-CAM-151H**	**USB-CAM-052H**	**USB-CAM-152H**
color / monochrom	monochrom		color	
Sensor Format	1/2,5“			
Image Sensor	Aptina MT9P031, CMOS			
Pixel Size	2,2 µm x 2,2 µm			
Color format	Y8		RGB32, RGGB (Raw)	
Lens Holder	C / CS – Mount			
fps	6 fps to 52 fps			
Dynamic Range	8 bit			
Shutter	Rolling			
Light sensitivity	1,4 V/lux-sec			
Interface	USB 2.0 High Speed			
Exposure time	1/10.000 s to 30 s			
Gain	0 dB to 18 dB			
White Balance	-		-6 dB bis +6 dB	
Power supply	4,5 V bis 5,5V DC			
Power Consumption	Circa 250 mA bei 5V			
Feature (optional)	-	ext. Trigger, Digital-Output	-	ext. Trigger, Digital-Output
Temperature range	-5°C bis +45°C			
Dimensions (B x L x H)	36 mm x 36 mm x 25 mm			
Fixing	1/4“ and M6x8 on all sides			
Weight	70 g			
Connection	USB Mini-B			
Feature- Connection	-	Hirose HR10A-7R-4P	-	Hirose HR10A-7R-4P

ZM18B-F green

Optical	
Optical power stability	< +/- 5% at constant temperature
Range of focus	200mm up to ∞
Divergence of beam (FWHM)	< 1mrad (with dot optic)
Pointing stability	< 50µrad / °C at constant temperature
Standard wavelengths and power (other on request)	
532nm	1-40mW optical power
Electrical	
Supply voltage	5-30VDC
Mode of operation	APC with current limiting or CC
Modulation	continous wave
Protection	reverse polarity and transient / ESD
Connection	M12 plug, 4-pin
Mechanical	
Dimensions	136mm x Ø 20mm (focusable version)
Housing	Laser: M18 industry housing, chromed brass

Figure 2.3: Parameters for CCD and laser

2.4 Measurements

2.4.1 CCD control

Start by becoming familiar with how to acquire data from the CCD, which is readout by the program PHYTEC Vision Demo 2.2, as in Fig. 2.4.

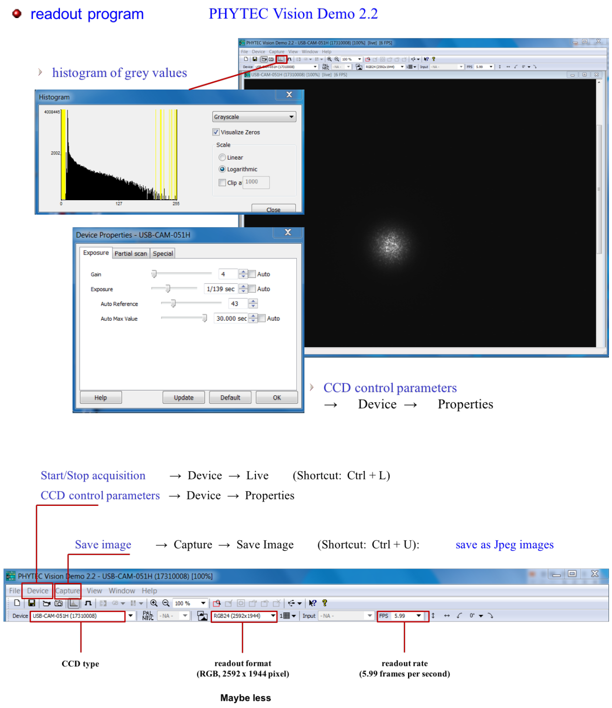


Figure 2.4: CCD control and readout.

2.4.2 Data analysis with ImageJ

After acquiring a CCD image, use the software ImageJ to select a region of interest and plot the horizontal projection, as in Fig 2.5. Save the data in Excel format for profile fitting.

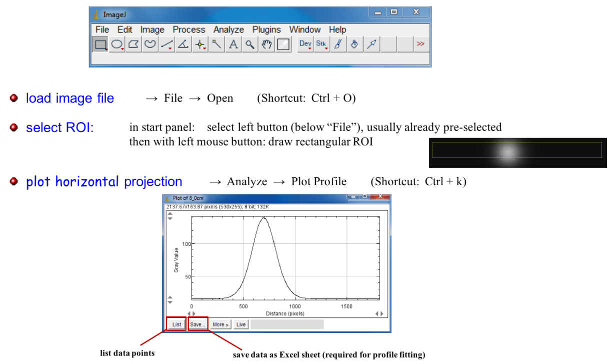


Figure 2.5: Selection of beam profile data for fitting.

Load the recorded profile data and fit a Gaussian as in Fig. 2.6.

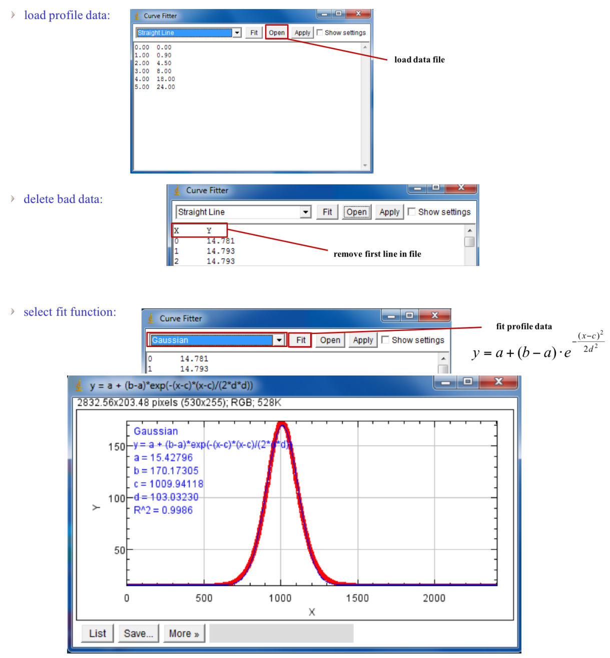


Figure 2.6: Gaussian fit to profile data.

2.4.3 *Calibration*

Square grid paper can be used to calibrate the distance to pixel size of the camera, as in Fig. 2.7.

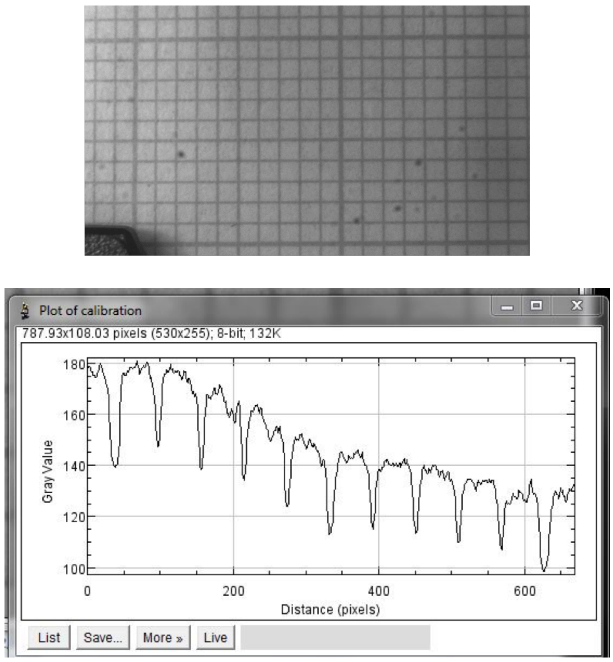


Figure 2.7: Calibration of readout setup using a mm-grid

2.5 Calculation of emittance

Take profiles at three different distances between the lens-screen, using the formula from the theory section and below to calculate to the emittance.

- *Hint 1: Make the distances equal, set* $s_1 = 0$*,* $s_2 = -s_0$
- *Hint 2: Avoid position at waist (why?)*

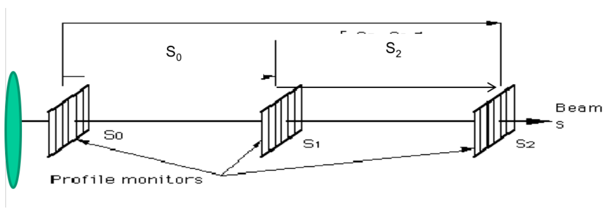


Figure 2.8: Three profiles

Recall from above that:

$$\sigma_{y,meas}^2 = M_{11}^2\sigma(s_0)_{11} + 2M_{11}M_{12}\sigma(s_0)_{12} + M_{12}^2\sigma(s_0)_{22}$$

The drift matrix for no optical elements is simply $M = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix}$

Note that:

$$\begin{aligned}
\sigma^2(s1)_{meas} &= \sigma_{11} + 2s1\sigma_{12} + s_1^2\sigma_{22} \\
\sigma^2(s0)_{meas} &= \sigma_{11} + 2s0\sigma_{12} + s_0^2\sigma_{22} \\
\sigma^2(s2)_{meas} &= \sigma_{11} + 2s2\sigma_{12} + s_2^2\sigma_{22}
\end{aligned}$$

with

$$\begin{aligned}
\sigma_{11} &= \sigma_y^2(0) \\
\sigma_{12} &= \frac{\sigma_y^2(+s) - \sigma_y^2(-s)}{4s} \\
\sigma_{22} &= \frac{\sigma_y^2(+s) - 2\cdot\sigma^2(0) + \sigma_y^2(-s)}{2\cdot s^2}
\end{aligned}$$

$$\boxed{\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \begin{pmatrix} \sigma_y^2 & \sigma_{yy'} \\ \sigma_{y'y} & \sigma_{y'}^2 \end{pmatrix} = \epsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}}$$

$$\boxed{\epsilon_{rms} = \sqrt{\det\sigma} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}}$$

For reference, some preliminary measurements of the beam sigma versus lens distance is given in Fig. 2.9.

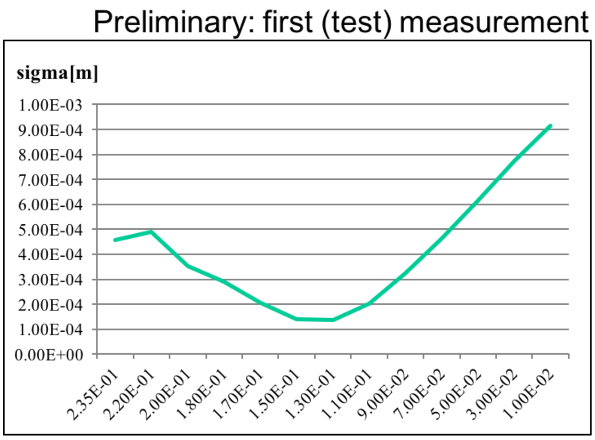


Figure 2.9: Preliminary test measurements of laser beam in this setup.

Lab 3: Pepperpot Emittance Measurement

3.1 Aims and Objectives

These hands on exercises aim to introduce emittance measurements by the pepperpot technique. An optical bench with a light source, a pepperpot plate, several lenses and a GigaBit Ethernet camera is provided.

3.2 Experimental Setup

3.2.1 The Optical Bench

The optical bench shown in Fig. 3.1 consists of the following parts:

- a particle source (powerful red LED)
- a collimator producing a point like source
- the lenses with the following focal length: 24, 30, 43, 54, 76 and 100 mm.
- a pepperpot plate with 9x9 holes (200 μm) of 2 mm distance
- a screen
- a Prosilica-GC750 GigaBit Ethernet camera

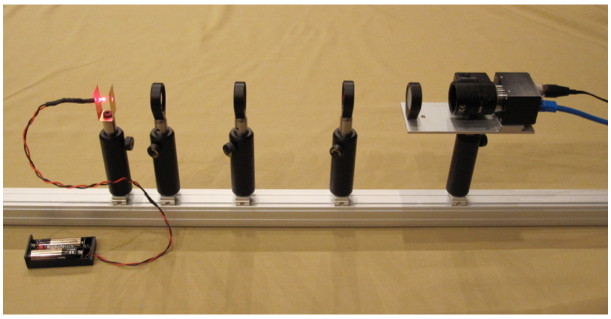


Figure 3.1: Optical bench pepperpot setup.

3.2.2 Software

The following software is part of the system:

GigEViewer This program as well as a LabView equivalent is delivered by the supplier of the camera. It allows modifying the settings of the camera (exposure time, gain ...) and can display the camera image in real-time. Snapshots can also be taken. The program allows saving the camera image in Microsoft tif (.tif) format, the LabView program also permits .png, which is the preferred format.

OpticalRayTrace is a simulation program for optical benches. This program is used to understand the optical properties of the pepperpot bench.

QPepperpot is a program that allows evaluation of the bitmap file. You can:

- load an image
- find x and y coordinates of a point within the image
- find and plot a single row or column to find the pixel intensities
- define an area of interest (AOI)
- calculate and plot projections to the x or y axis
- save the image in ASCII format for evaluation with standard tools like excel, MatLab etc.
- save the projections (in ASCII)
- enter the center position of the image
- enter the scaling factor (number of pixels / mm)
- calculate and plot the emittance mountain
- save the emittance data (in ASCII) for further evaluation or plotting with an external program

3.3 Calculation of the Optics

Measure the distances between the light source, the lenses and the screen and simulate the optical properties of your line with *OpticalRayTracer* [1], as in Fig. ref-fig:PepperPotRayTrace. The physics background used by this program can be found in the document 'OpticalRayTracer Technical Discussion' of which you have a printed copy. Details on how to use the program you find in its help file.

[1] http://arachnoid.com/OpticalRayTracer/index.html

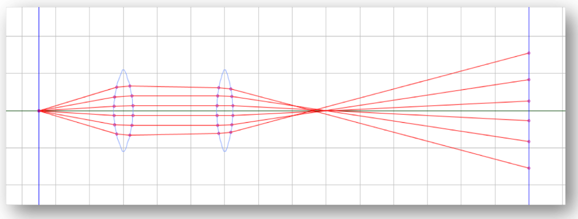


Figure 3.2: Optical ray trace of the lenses in the setup.

3.4 Emittance Measurements from a Pepperpot Image

3.4.1 Calibration

Before starting to take any measurements the device needs to be calibrated. We need to know the relationship between the distance of 2 points on an image in pixels and this same distance in reality, in mm. In order to do this calibration the screen is replaced by the pepperpot plate and an image is taken. The center of the image in pixels must also be determined.

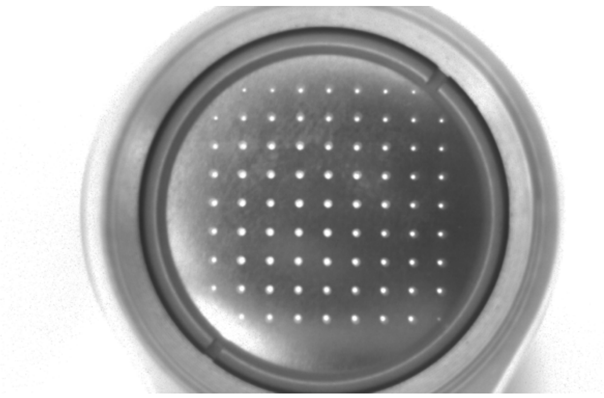


Figure 3.3: The pepperpot plate.

The pepperpot evaluation program brings up a cursor if you press the first mouse button on the pepperpot image and the current cursor position is shown on the LCD display (bottom left in Figure 3). The screen is then put back and the distance between camera and screen stays fixed from then on.

3.4.2 Evaluating a 'good' measurement

The image in Fig. 3.4 shows a typical "good" measurement. The image of each pepperpot hole is clearly visible, the signal to noise ration is good.

In order to extract the emittance from this image first start the pepperpot evaluation program QPepperpot and read in an image from a measurement file (File → Open image). The image file must be a valid pixmap file e.g. "screenimage.bmp". Then enter the calibration values,

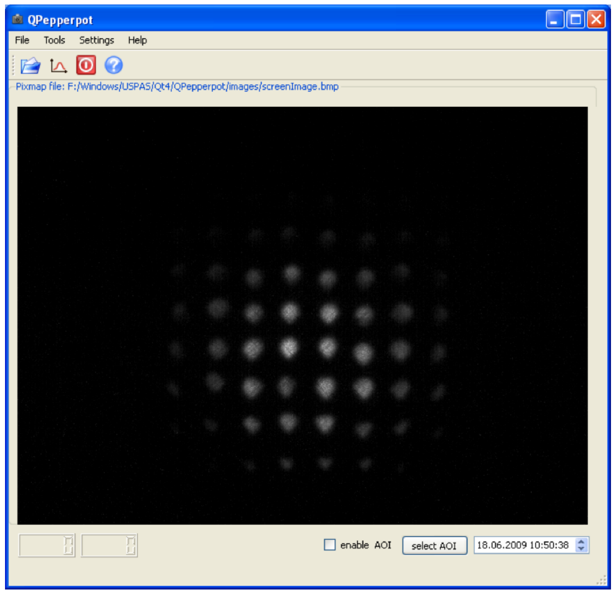


Figure 3.4: OPepperpot evaluation program.

scaling factor in pixels/mm (32.6 in Fig. 3.5) and the center of the pepperpot plate in pixels (320,240).. Only the horizontal value will be used. The settings dialog box (Settings → Configure Pepperpot) is foreseen for this purpose.

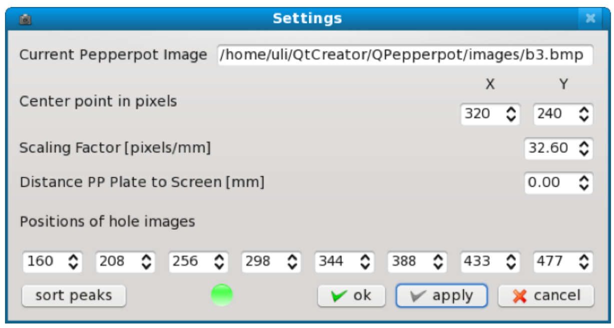


Figure 3.5: OPepperpot settings diaglog box.

The next step is to calculate the projection of the image to the horizontal axis (Tools → Projections or the Toolbar button showing the histogram)

The Tools menu in the menu bar allows selection of options for display of the projection. You may

- Display only the raw data. Display of raw data may be switched of if low-pass filtering is enabled.
- Low-pass filter the data and show the filtered data
- Automatically find the 8 peaks in the histogram that correspond to the image of the 8 pepperpot holes.
- Switch display of the peak positions on or off.

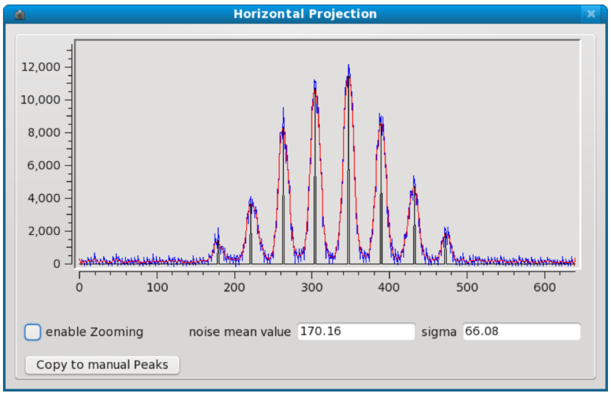


Figure 3.6: Projection of pepperpot image.

In Fig. 3.6 all curves are shown on a single plot: The blue curve shows the raw data. On the red curve the projection is filtered and the black curve shows the peaks found. The mean noise value and its variance, calculated over the first 50 points is also displayed. You may also read the peak positions by pushing the first mouse button

Now that the positions of the image of all 8 pepperpot holes is known and the calibration has been entered the emittance ellipse can be determined. Tools → Emittance will display the results. Fig. 3.7 shows a typical emittance plot for a converging beam.

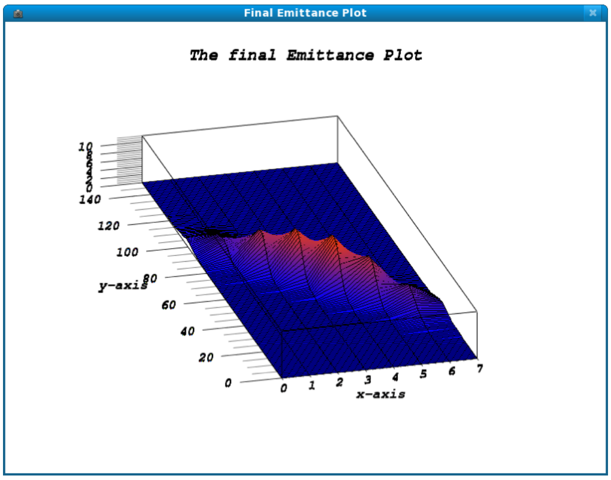


Figure 3.7: Emittance plot derived from pepperpot image.

3.4.3 *Evaluating a measurement that is less clean*

Unfortunately not all measurements are as clean as the one shown in the previous section. If the camera settings as not perfect e.g. the aperture is not opened enough, if the contrast settings are not perfect … we may end up trying to analyse an image who's projection looks like the one shown in Fig. 3.8. Since even a human has a hard time to see the hole images, it is even more difficult for a program to automatically evaluate such an image.

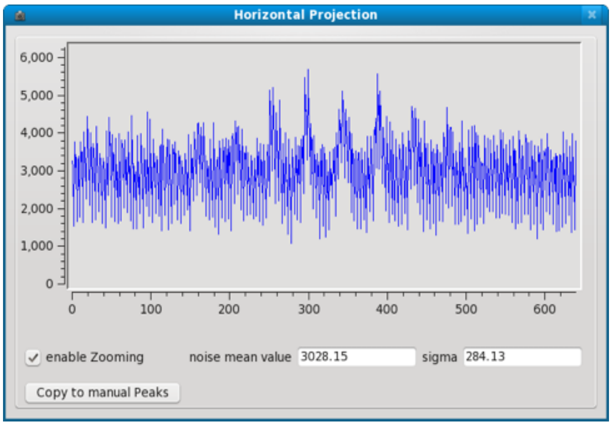


Figure 3.8: Projection of a pepperpot image with excess noise.

The pepperpot evaluation programs help through low pass filtering and offset suppression (Tools → Show filtered and Tools → Subtract Offset).

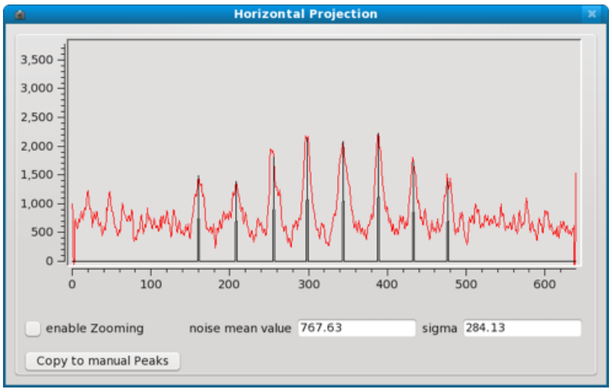


Figure 3.9: Projection of a pepperpot image cleaned of noise.

If you try to automatically find the peaks however, the program will only find four out of the eight peaks. These peaks can be copied to the settings dialog box with the *copy to manual peaks* button. After having copied the peaks, switch off automatic peak finding (Tool → Automatically find peaks must be switched off). You may now define the peaks by hand in the settings dialog box. The plot will show you how you placed them. All 8 peaks must be defined. Clicking the left mouse button on the projection plot brings up a cursor whose current position is shown. This may help you when finding the peaks. You may also have a closer look at the background in order to see if the are any systematic errors by switching on the zooming.

Click and drag to zoom into the picture. Once you finished defining the peaks by hand you may again try to plot the emittance. The emittance plot will use the manually defined peaks instead of the automatically found ones.

3.5 Acknowledgements

This experiment was initially developed for the USPAS (the US particle accelerator school) in Albuquerque 2009 that had a session that is dedicated to accelerator and beam diagnostics.

In the preparation of the lectures on emittance measurements I had help from several people. In particular I would like to thank:

Dr. Peter Forck, GSI Darmstadt, Germany, whose lecture notes (http://www-bd.gsi.de/conf/juas/juas.html) were used as a basis for the lectures. Dr. H. Braun PSI Villigen Switzerland, who gave me his transparencies on emittance measurements for the CERN School of Accelerators (CAS) on beam diagnostics, Gif-sur-Yvette 28.May - 7.June 2008 Dr. Brennan Goddard, CERN, Geneva, Switzerland who prepared the slides on filamentation Dr. Tom Shea, ORNL, who assembled the experimental setups for the laboratory session several collegues at CERN who gave me photographs or slides, used during the lecture.

U. Raich, CERN, 22. July 2009

Lab 4: Imaging Techniques

4.1 Aims and Objectives

This Laboratory exercises introduces to the basic properties of imaging techniques which are widely used in accelerator for transverse profile measurements. The main subjects covered in this lab are:

- To become familiar with the imaging using camera lenses and lenses
- To perform low and high magnification optical system
- To observe field depth limitation and try compensating scheme based on the Scheimpflug principle
- To become familiar with the principle of pinhole cameras and design/test pinhole cameras with either low or high optical magnification

4.2 The Basics of Optical System Design

Imaging with lenses is the simplest and most common practice in beam imaging system. A schematic of such a system is presented in Figure 4.1. A definition of the optical magnification and the relationship between the focal length of the lens and the distances between the image and object planes and the lens are also mentioned.

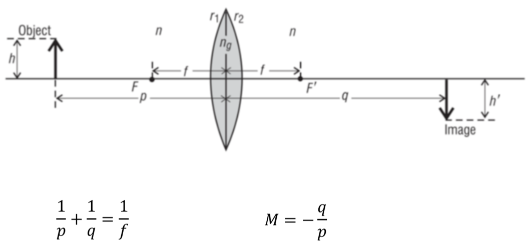


Figure 4.1: Imaging using a single lens.

4.3 Scheimpflug Principle

Normally, the lens and image (film or sensor) planes of a camera are parallel, and the plane of focus (PoF) is parallel to the lens and image planes. If a planar subject (such as the side of a building) is also parallel to the image plane, it can coincide with the PoF, and the entire subject can be rendered sharply. If the subject plane is not parallel to the image plane, it will be in focus only along a line where it intersects the PoF, as illustrated in Figure 4.2.

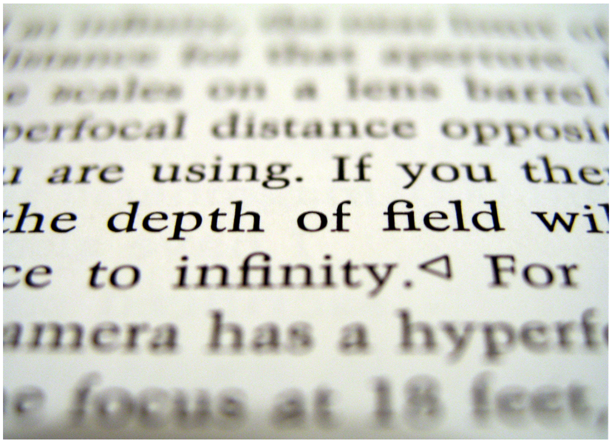


Figure 4.2: Depth of Field limitation when imaging an object tilted with respect to the lens/camera planes cavities.

But when a lens is tilted with respect to the image plane, an oblique tangent extended from the image plane and another extended from the lens plane meet at a line through which the PoF also passes, as illustrated in Figure 4.3. With this condition, a planar subject that is not parallel to the image plane can be completely in focus.

4.4 Pinhole Camera

A pinhole camera is a imaging system without a lens but with a tiny aperture, a pinhole – effectively a light-proof box with a small hole in one side. Light from a scene, as depicted in 4.4. passes through the aperture and projects an inverted image on the opposite side of the box, which is known as the camera obscura effect.

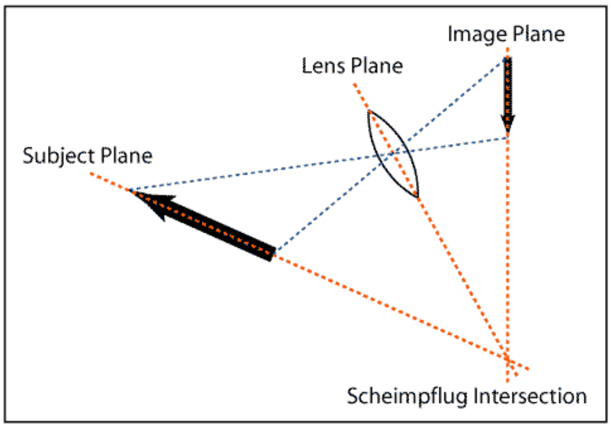


Figure 4.3: The Scheimpflug principle.

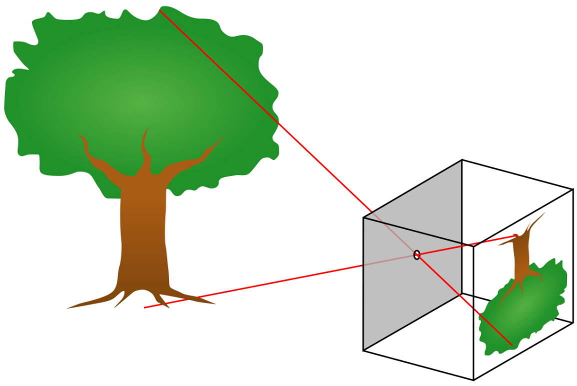


Figure 4.4: The principle of a pinhole camera.

4.5 Measurements

4.5.1 *Imaging with camera lenses*

Build an optical imaging system using camera lenses with a magnification of 0.1 and 1

4.5.2 *Imaging with lenses*

Build an optical imaging system using lenses with a magnification of 0.1 and 1

4.5.3 *Imaging a tilted object*

For a high magnification optical system (1 or more), tilt the lens by 45degree or more and using the Scheimpflug principle obtain an image with minimum blurring

4.5.4 *Imaging using a pinhole*

Build an pinhole camera with a magnification of 0.1 and 1 with the minimum exposure time and best possible image quality.

What are the best parameters of the best configurations you found ?

The best picture wins a beer !

Lab 5: Electro-Optic Modulator

5.1 Aims and Objectives

This experiment aims to demonstrate the potential in using of electro-optic modulators in beam instrumentation. EO crystals have a time response that expands from DC to tens of GHz which clearly surpass the typical bandwidth of electromagnetic monitors. It can thus be used for the detection and/or the transmission of electric beam signal over an very large bandwidth. The main objectives are:

- Apply a DC voltage pulse across an electro-optic modulator (EOM).
- Observe the modulation of light passing through the EOM recorded by a photodiode
- Measure electric to optical to electric conversion ratio
- Measure the dynamic range of the system
- Apply fixed frequency RF signals and measure the bandwidth of the setup.
- Observe the effect of modifying the EOM bias on the RF signal.

5.2 Electro-Optic Modulator

Electro-Optic Modulators (EOMs) are commonly used in telecommunications for rapidly modulating optical intensity to transmits high bandwidth signals over optical fibre. An EOM relies on the electro-optic Pockels effect in a lithium niobate crystal, which modifies the polarization state of the light, when a transverse electric field is applied.

5.3 Experimental setup

Warning: the laser enclosed in this experiment is a class IV laser. DO NOT OPEN THE SAFETY BOX. Avoid eye exposure to laser radiation.

The present system is an optical fibre based system. It uses a DC fiber laser connected to a commercial electro-optical modulator. The RFin voltage signals, provided by a pulsed generator, are encoded onto the laser beam and measured by a fast photodiode, which provides an output signal denominated RFout. The latter is finally acquired by an oscilloscope. The EO modulator crystal can also be biased by an external DC voltage to tune and keep the system performance optimal.

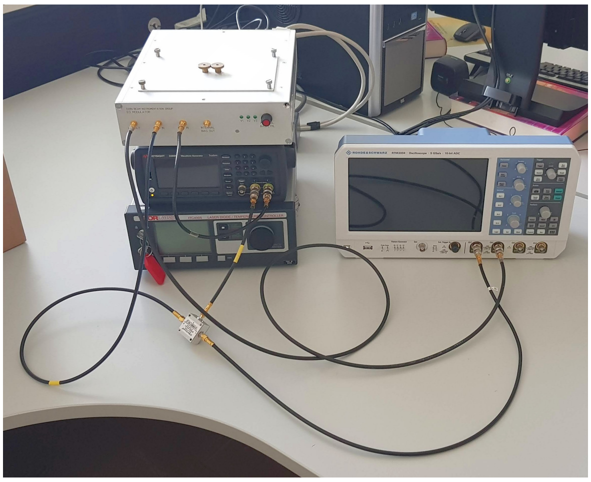


Figure 5.1: Electro-Optic modulator test bench.

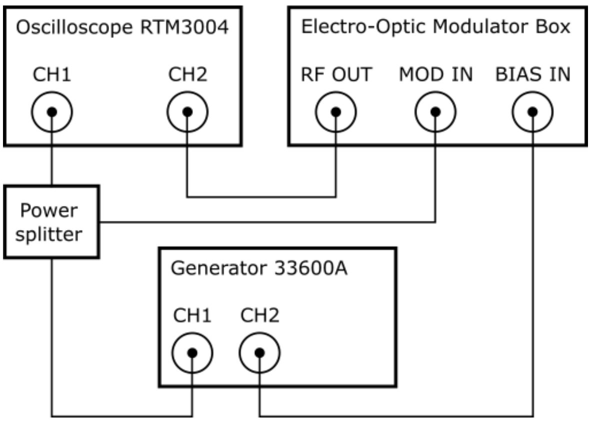


Figure 5.2: Connection diagram for the electro-Optic modulator test bench.

5.4 Measurements

5.4.1 Detecting Fast Pulses

- Apply a DC pulse (on RFin) across the pickup, can you see it on the scope?
- Set the oscilloscope to measure both the input RFin and output RFout voltages simultaneously.
- Plot the evolution of the signal RFout as a function of the amplitude of the RFin DC signal. What shape does it have ? What is the electric-to-optical-to-electric conversion ratio of the present system in dB ? What is the dynamic range of the system ? DO you observe over rotation ?
- Apply now shorter or shorter pulse (RFin) across the pickup, can you see it on the scope? What is the minimum pulse length you can reproduce and measure efficiently ? What will be the corresponding bandwidth of the system

5.4.2 Bias scans

- Turn on the bias voltage
- Scan the bias voltage by small step (i.e. 0.1volts) and plot the amplitude of the RFout signal as a function of the bias voltage. Find the best DC bias voltage that would provide the highest output voltage RFout.
- For a pulse length of your choice, increase the amplitude of the RFin signal and adjust the dc bias to keep the output voltage Rfout constant. Plot then the curve RFin as function of DC bias for a constant output signal RFout. What do you conclude ?
- Change the pulse length of RFin and redo the bias voltage scan. Do you find the same optimum as before ?