Bansilal Ramnath Agarwal Charitable Trust's

# Vishwakarma Institute of Information Technology

*Department of Electronics & Telecommunication*

(Affiliated to Savitribai Phule Pune University)

**A Project Report on**

# "DEVELOPMENT OF EMBEDDED SYSTEM FOR MONOCHROMATOR"

(SPONSORED BY: TIFR)

(Domain: VLSI)

Submitted to

Savitribai Phule Pune University

(Formerly University of Pune)

In Partial Fulfillment of the Requirement for the Award of
BACHELOR'S DEGREE IN
ELECTRONICS AND TELECOMMUNICATION ENGINEERING


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*Under the Supervision of*
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***Year 2018 – 2019***

Bansilal Ramnath Agarwal Charitable Trust's

# Vishwakarma Institute of Information Technology

*Department of Electronics & Telecommunication*

(Affiliated to Savitribai Phule Pune University)

## CERTIFICATE

This is to certify that project work entitled

**"Development of Embedded System for Monochromator"** carried out and submitted in the eight semesters by,

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in partial fulfillment for the award of **Bachelor of Engineering** degree in Electronics and Telecommunication Engineering from Vishwakarma Institute of Information Technology, Savitribai Phule Pune University, Pune during the academic year 2018-19.

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Following projects will be undertaken from the Department of Electronics and Telecommunication, Vishwakarma Institute of Information Technology, Pune during the period 2018-2019.

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| 3. | High Resolution Timing Measurement Using TDC For High Speed Photo-Detectors on FPGA | 1.Kiran Magar<br>2. Nikhat Khan<br>3. Venkatesh Kolpakwar<br>4. Kishan Patel | Mr. K.J.Raut | Prof (Dr) A V Gopal |
| 4. | Development Of Motor Drive For Self-Aligning Table | 1. Sahiel Uttarkar<br>2. Arshad Momin<br>3. Owais Shaikh<br>4. Swapnil Kulkarni | Mrs A.P.Navghane | Prof (Dr) S R Dugad and Dr Raghunandan Shukla |
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| 6. | Michelson Interferometer | 1. Rushikesh Bolaj<br>2. Akash Bansal<br>3. Urjita Jeure | Mrs. Dr. K.P.Kshirsagar | Prof (Dr) S S Prabhu |
| 7. | Real Time Imaging Through Strongly Scattering Media | 1. Nivedita Todkar<br>2. Tarunya Raj<br>3.Rajeshwari Baviskar<br>4.Manavendra Mehendale | Mrs.Dr. K.P.Kshirsagar | Prof (Dr) S S Prabhu |

# ABSTRACT

Spectrometers are the instruments used for measurement of properties of light over a specific portion of the electromagnetic spectrum. The basic need of spectrometer lies in the detailed study of absorption, transmission and reflection coefficients for analysis of any material/light source. Spectrometers to be used in harsh conditions like in satellites, chemical industry, etc. must be robust and compact in size. This project deals with the design and fabrication of portable, compact, low cost and robust spectrometer electronics on reconfigurable logic device i.e. on NUMATO board. The project is implemented in two stages viz. Analog Front End electronics for data acquisition and communication with PC for processing images and plotting the obtained spectrum to determine the purity of fluids and the concentration of elements in a given mixture or compound. Proposed system uses CCD based detectors that can convert charge to voltage at pixel by pixel. Fabrication using logic devices saves greatly on size, making it compact.

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# INDEX

# CHAPTER 1
# INTRODUCTION

# 1. INTRODUCTION

Spectrometer is a device used to represent the intensity as a function of wavelength. It consists of two main parts A Monochromator and a photo detector. Monochromator is an optical device used for separating component wavelengths of light. The diffraction element used is a grating. Optical setup is optimized in a space of 15cm * 15cm * 5cm.

Diffraction grating, with a periodic structure diffracts incident light into its constituent wavelengths. Reflection grating is used in this project. Angle at which incident spectral line gets diffracted depends upon the incident wavelength and the order of diffraction. If white light is incident on diffraction grating, then diffracted light consists of complete visible spectrum.

To study the behavior of synthesized material with respect to each wavelength diffracted from grating, we put an image sensor to cover the whole spectrum in a single sweep. We are using a CCD detector for capturing the spectrum.

To process the data that has been acquired by the spectrum, we are using Reconfigurable Logic Devices, as it can be reprogrammed according to user needs. We are using the NUMATO MIMAS SPARTAN6 Module, which has the capacity to acquire the data, process, and store and eventually send the data, to plot the graph on the PC for monitoring. USB is an interface for communicating with many types of peripherals without the limitations of older interfaces. Every recent PC includes USB ports that can connect to standard peripherals such as keyboards, mice, scanners, cameras, printers, and drives as well as custom hardware for just about any purpose. An interface must please the users who want to use the peripherals and the developers who design the hardware and write the code that communicates with the device. USB does that job.

# CHAPTER 2
# LITERATURE SURVEY

# 2. LITERATURE SURVEY

## 2.1 Monochromator

This is the generalized setup of Monochromator including the grating with input as white light. Once light enters from the entrance slit, it is redirected by the mirror arrangement towards the grating. After light is dispersed by the grating, it is captured by a second mirror and redirected towards the exit slit. The surface of these mirrors must be reflective in the wavelength region of the light involved. This can be polished aluminum, silver or gold. This metal is sometimes covered with a protective coating that prevents the metal from tarnishing, obviously also transparent to the light involved.

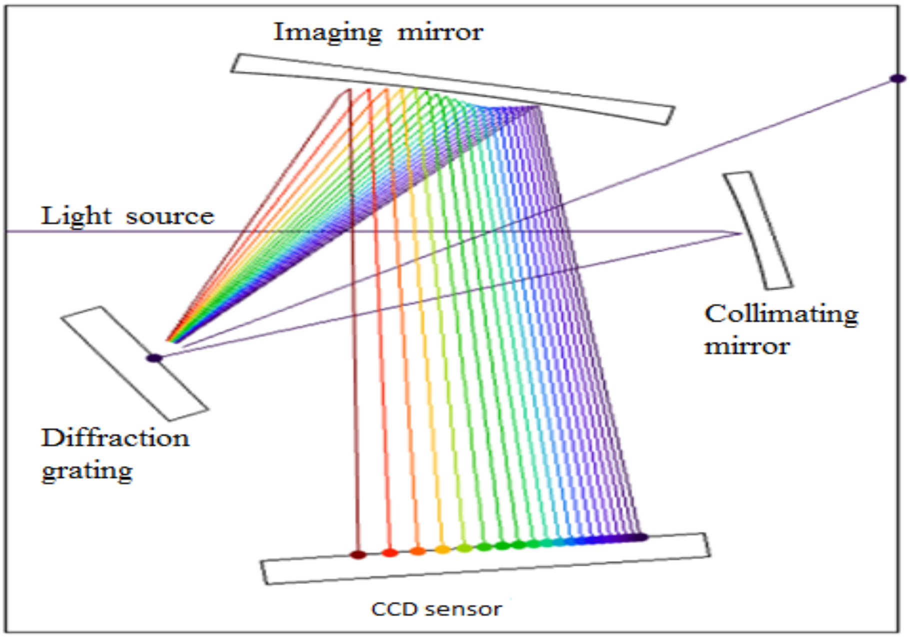


*Fig.2.1: Design for monochromator setup*

The dispersion element in this monochromator is a grating. Its job is to take parallel light incoming from the entrance slit, light that contains multiple different wavelengths, and to disperse the wavelengths in space such that they are no longer parallel but instead leave the grating at slightly different angles, angles dependent upon the wavelength. So, that means that at the second mirror the individual wavelengths are some distance apart and after reflecting off that mirror, the beams diverge even further. When they arrive at the detector they are so substantially separated in space that they fall like a rainbow across the plane of the exit slit.

## 2.2 Detector

CCD refers to a semiconductor architecture in which charge is read out of storage areas. The CCD architecture has three basic functions: (a) charge collection, (b) charge transfer, and (c) the conversion of charge into a measurable voltage. The basic building block of the CCD is the metal-oxide semiconductor (MOS) capacitor. The capacitor is called a gate. By manipulating the gate voltages, charge can be either stored or transferred. Charge generation in most devices occurs under a MOS capacitor (also called a photo gate). For some devices (notably interline transfer devices) photodiodes create the charge. After charge generation, the transfer occurs in the MOS capacitors for all devices

The architecture of CMOS is like CCD. The only difference in CMOS sensor is each pixel has its own charge to voltage conversion, and the sensor often includes amplifiers, noise correction and digitization circuits on the chip so the chip outputs digital bits. CMOS imagers offer superior integration, power dissipation and system size at the expense of image quality (particularly in low light) and flexibility. They are the technology of choice for high-volume, space constrained applications where image quality requirements are low. This makes them a natural fit for security cameras, PC videoconferencing, wireless handheld device videoconferencing, bar-code scanners, fax machines, consumer scanners, toys, biometrics and some automotive in vehicle uses

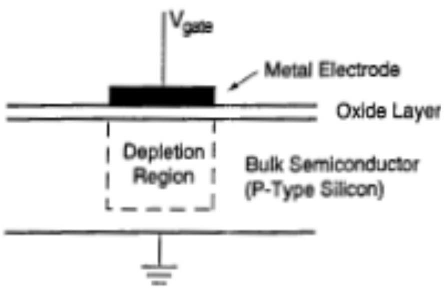


*Fig.2.2: Single gate of a pixel*

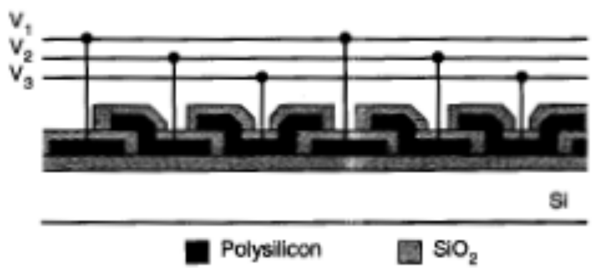


*Fig. 2.3: Charge transfer*

# CHAPTER 3
# OBJECTIVES

# 3. OBJECTIVES

**I.** Design and fabrication of spectrometer electronics for making it compact and portable and to plot intensity Vs Wavelength.

**II.** Use the Proposed Spectrometer for:

- **a.** To determine concentration of chemicals in a mixture/compound.
- **b.** Purity analysis of fluids/chemicals.

**III.** To achieve industry standards of output efficiency and quality.

# CHAPTER 4
# MOTIVATION

# 4. MOTIVATION

As the research in the field of spectroscopy continues to build, it has become important to use an instrument to analyze the properties of any material. Spectrometer basically is an instrument which can be used to study different properties of the material. The basic need of spectrometer lies in the detailed study of absorption, transmission and reflection coefficients for fabrication of any material. The type of spectrometer depends on the study of properties aimed at.

Spectrometers are used in many fields. For example, they are used in astronomy to analyze the radiation from astronomical objects and deduce chemical composition. The spectrometer uses a prism or a grating to spread the light from a distant object into a spectrum. This allows astronomers to detect many of the chemical elements by their characteristic spectral fingerprints. If the object is glowing by itself, it will show spectral lines caused by the glowing gas itself. These lines are named for the elements which cause them, such as the hydrogen alpha, beta, and gamma lines. Chemical compounds may also be identified by absorption. Typically these are dark bands in specific locations in the spectrum caused by energy being absorbed as light from other objects passes through a gas cloud. Much of our knowledge of the chemical makeup of the universe comes from spectra.

So, this instrument poses the need to be used at various levels. The whole table-top arrangement can't be carried along. The main challenge lies in building the robust, low cost and compact spectrometer with high sensitivity, basically portable.

Conventional spectrometers are typically created using specific grating that have mirrors and complex alignment controls. Resolution is limited to the spatial size of the device. Achieving very fine resolution may require complex machinery to move parts during the measurement process. The basic motivation behind our project is to develop a compact instrument which can be used to detect the whole spectrum for analysis. The aim of our project basically lies in using grating with different number of grooves so as to capture the whole spectra of light in Ultra-violet region and still keep the spectrometer compact.

# CHAPTER 5
# BLOCK DIAGRAM AND DESCRIPTION

# 5. BLOCK DIAGRAM AND DESCRIPTION

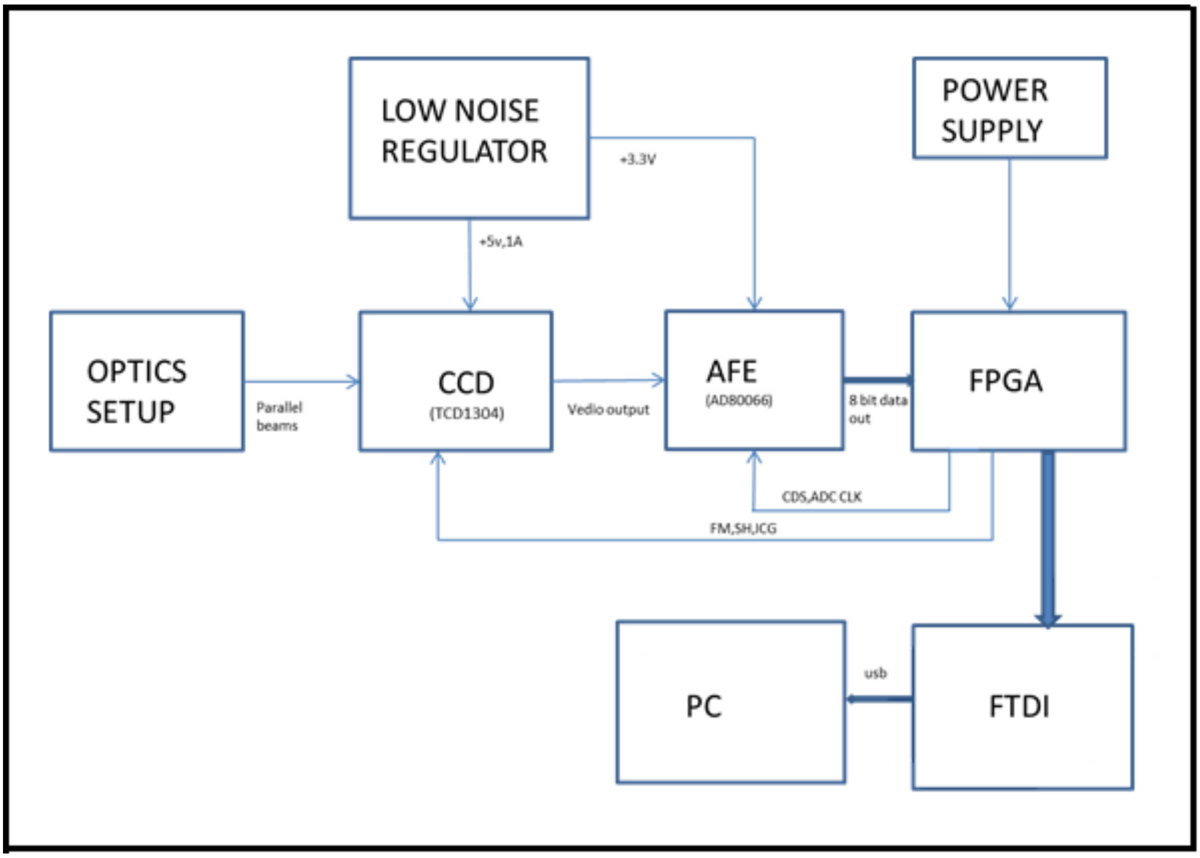


*Fig.5.1: Block diagram*

## 5.1 System Overview:

The system can be broadly constituted into two parts,

- Optical setup
- Electronics

The optical setup deals with the selection of appropriate light source and separation of wavelengths thereby using the Czerny-Turner Monochromator setup. The light spectrum obtained from Monochromator setup falls on the CCD detector where the conversion of the light signal to an electrical signal takes place. The signal conditioning is done by Analog Front End and the signal is further processed by FPGA. This data is sent to the PC by means of USB communication, where the spectrum is plotted.

## 5.2 System Working:

The input from source is given to the monochromator through input slit. The light entering from the source is collimated using a collimating mirror which helps to produce parallel beams which are directed to the dispersing element (grating). The grating element disperses the beam into different wavelengths. Depending on the angle of dispersion the corresponding wavelengths are received at the imaging mirror. The imaging mirror focuses the dispersed beam of wavelengths on to the focal plane. The CCD detector is kept at this plane.

CCD detector outputs electrical equivalent of the falling light spectrum. Analog Front End is used for digitizing the video output that arrives from the CCD detector. The necessary clock signals required for the operation of CCD sensor and Analog Front End are derived from an FPGA. The processed data is further converted by using serial to USB converter and then transferred to the PC by using FTDI for plotting of spectra.

The received byte are Stored By using Realterm/Twedge (serial terminal) to Excel and then the final plotting of Intensity Vs Wavelength is done. Thus, Spectroscopic analysis of Sample Material is Done.

# CHAPTER 6
# METHODOLOGY AND DESIGN STEPS

# 6. METHODOLOGY AND DESIGN STEPS

## 6.1 Methodology:

The system can be broadly constituted into two parts,

- Optical setup
- Electronics.

The optical setup deals with the selection of appropriate light source and separation of wavelengths thereby using the Czerny-Turner Monochromator setup. The light spectrum obtained from Monochromator setup falls on the CCD detector where the conversion of the light signal to an electrical signal takes place. The signal from CCD sensor is analog. Further it is digitized using AFE.

## 6.2 Design Steps:

Step1 : Design of Monochromator setup by performing beam characterization to know exact focal point of the mirror and size of the beam spot at this focal point.

Step2 : Selection of linear array detector.

Step3 : Selection of AFE.

Step4 : Selection of controller.

Step5 : Selection of programming language to be used for controller.

Step6 : Design of CCD and AFE PCB.

Step7 : Generation of CCD and AFE clocks using controller.

Step8 : To configure AFE through SPI lines.

Step9 : Testing and integration of the system .

# CHAPTER 7
# HARDWARE AND SOFTWARE

# 7. HARDWARE AND SOFTWARE REQUIREMENT

## 7.1 Monochromator System:

The input from source is given to the monochromator through input slit. The light entering from the slit is collimated using the mirror which helps to produce parallel beams which are directed to the dispersing element, grating. Depending on the angle of dispersion the corresponding wavelengths are received at the imaging mirror. The imaging mirror focuses the dispersed beam of wavelengths on to the focal plane. The detector is kept at this plane in the setup.

## 7.2 CCD Detector:

The typical CCD sensor is an integrated circuit with an array of pixel sensors. Each pixel sensors has its own charge to voltage conversion, its own light sensor, an amplifier and a pixel select switch. The function of the array is to capture the intensity of the light passing through. Each pixel sensor converts the sensitivity of the incoming light to the voltage signal which is then fed to ADC for converting it into digital format. The parallel beams of light coming from an imaging mirror are received by the CCD sensor and the video output is then given to AFE. The selection of image sensors depends on parameters like detector type, pixel size and number, spectral response, output signal format (Analog/digital). Based on all these parameters we have selected CCD TCD1304.

**Specifications:**

1 Spectrum range : 400nm to 1000nm
2 CCD sensor: TCD 1304
3 Reconfigurable logic device: Numato Mimas Spartan 6
4 Analog Front End: AD80066,16 bit AFE

Fig:7.1: CCD TCD1304

## 7.3 Analog Front End (AFE):

Analog Front End conditions sensor output. It basically converts sensor’s analog output into digital form. It includes the circuits as sample and hold circuit or correlated double sampler, timing core generator, analog to digital converter.

*Table 7.1: Comparison of AFEs*

| Specifications | AD80066 | AD9923A | AD9974 | VSP2582 |
|---|---|---|---|---|
| ADC | 16 bit | 12 bit | 14 bit | 12 bit |
| Clock generation & output processing | Both | Both | Both | Only Output processing |
| Precision in timing core | 0.6 ns | 0.6 ns | 0.24 ns | - |
| Max. Operating Freq. | 24 MHz | 36 MHz | 65 MHz | 36 MHz |

## 7.4 FPGA Board:

The FPGA is used to provide USB interface to the PC as well as control signals to the image detector. It is also used to process the data acquired from the CCD sensor.

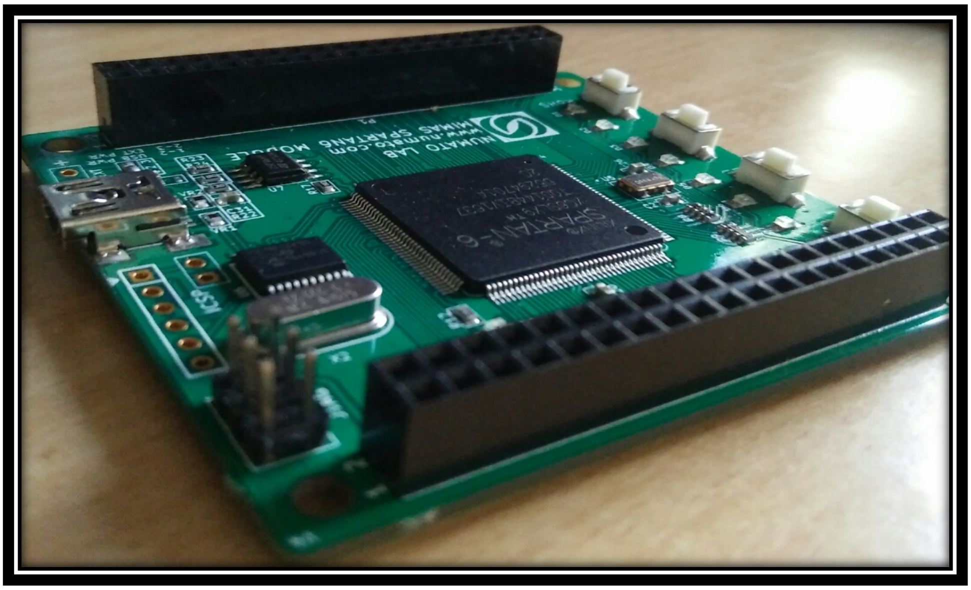

Fig:7.2: Mimas Spartan 6

*Table 7.2: Comparison of Controllers*

| Parameters | STM32F401RE | PIC18F87J50 | PIC24FJ256GA705 | SPARTAN 6 |
|---|---|---|---|---|
| RAM | 768 kb | 31 kb | 128 kb | 576 kb |
| Flash Memory | 512 kb | 128 kb | 256 kb | 16 Mb |
| Operating Voltage | 3.3V | 3.3V | 3.3V | 5V |
| GPIO | 50 | 65 | 40 | 70 |
| Oscillator | 2-26 MHz | 48 MHz | 48 MHz | 100 MHz |

## 7.5 CLOCK GENERATION

*Table 7.3: Clock frequencies*

| CLOCK SIGNALS | FREQUENCY OF SIGNAL | DUTY CYCLE OF SIGNAL | REF.CLOCK FREQ. |
|---|---|---|---|
| FM | 800kHz | 50% | 100MHz |
| SH | 100kHz | 20% | 100MHz |
| ICG | 50Hz | 10% | 100MHz |
| CDSCLKC1 | 200kHz | 50% | 100MHz |
| ADCCLK | 200kHz | 50% | 100MHz |

# CHAPTER 8
# ENCLOSURE DESIGN

# 8. ENCLOSURE DESIGN

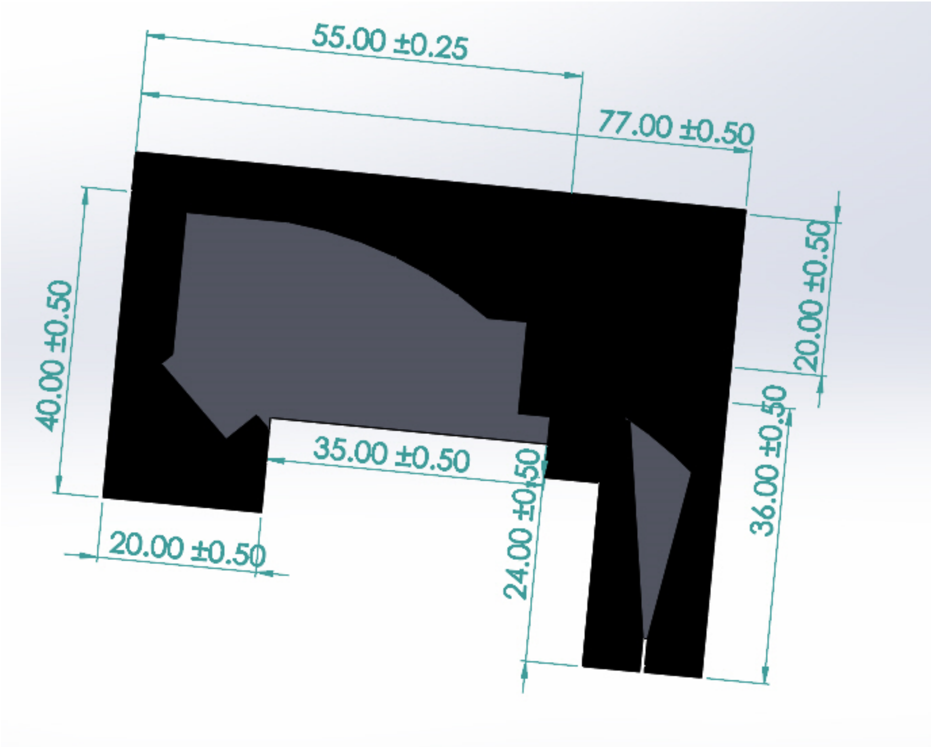


*Fig. 8.1: Czerny-Turner Monochromator setup*

# CHAPTER 9
# RESULT ANALYSIS AND DISCUSSION

# 9. RESULT ANALYSIS AND DISCUSSION

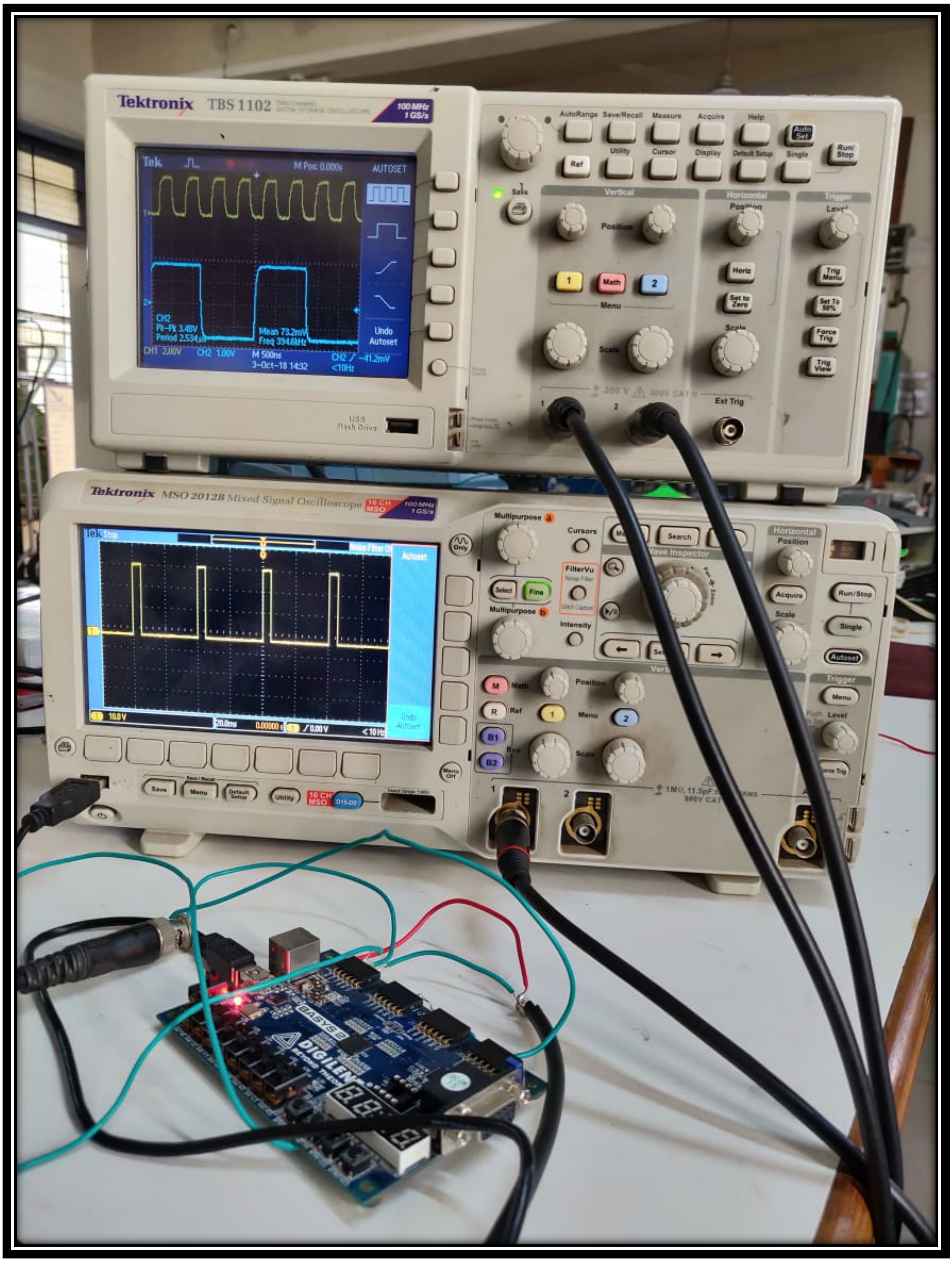


*Fig. 9.1: Hardware implementation*

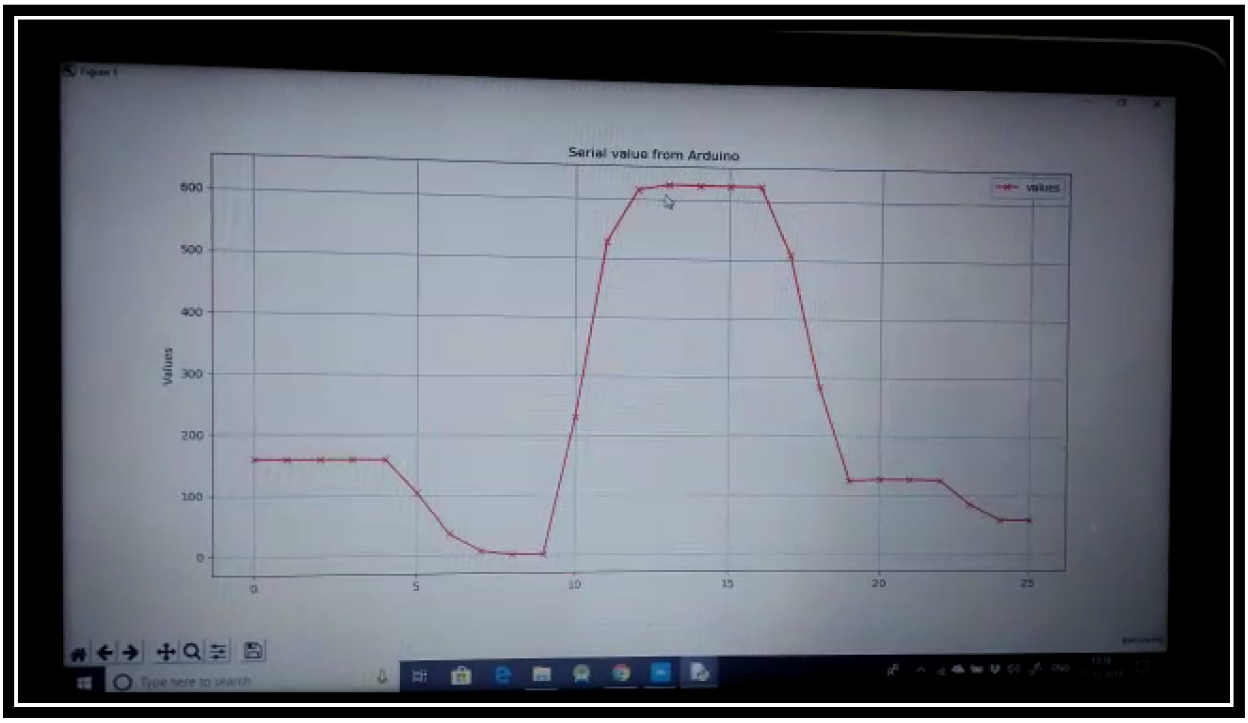


*Fig. 9.2: ADC Spectrum demo*

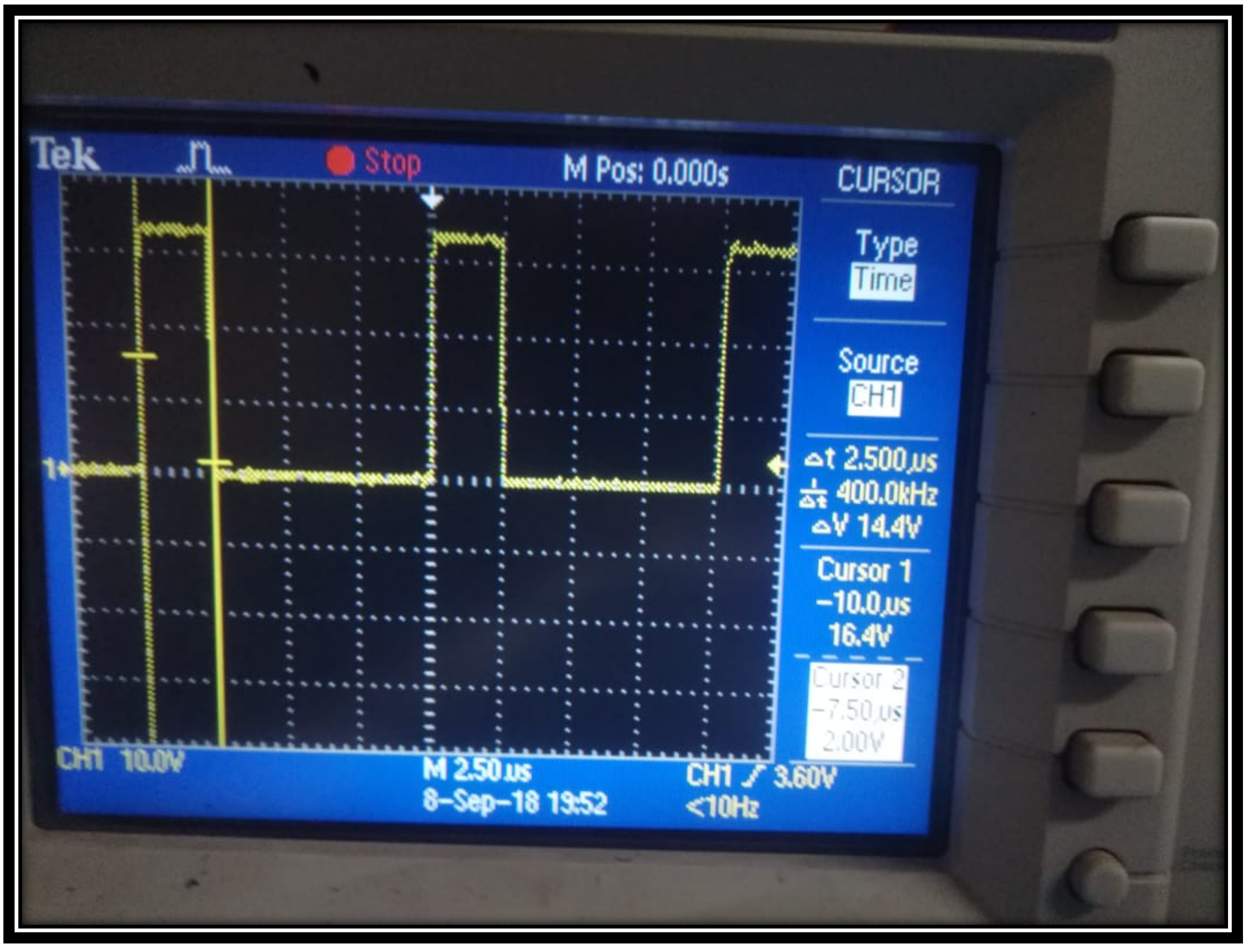


*Fig. 9.3: PWM Generation*

# CHAPTER 10
# APPLICATIONS AND CONCLUSION

# 10. APPLICATIONS AND CONCLUSION

## 9.1 APPLICATIONS:

1) Observation of Spectra of various light sources and their analysis.

2) Study of composition of materials depending on their emission and absorption spectra.

3) Identification of materials depending on their emission and absorption spectra.

4) Soil testing.

5) To know the chemical composition of any unknown material.

## 9.2 CONCLUSION:

Optical alignment required for spectrometer is studied. Beam characterization is performed to determine the actual size of beam spot at focal point falling on the detector. Timing and clock requirements of CCD are studied and accordingly they are generated using FPGA. The PCB for driver circuit of CCD and AFE is designed using ALTIUM software. The analog output of FPGA is digitized using AFE. AFE is specific ADC with co-related double sampling feature. The configuration of AFE is done through SPI interface.

# CHAPTER 11
# SCOPE FOR FUTURE WORK

# 11. SCOPE FOR FUTURE WORK

We can interface FTDI and PC such that to plot spectrum on real time data coming from FPGA. Also, the system can be made portable. On board screen can be interfaced with FPGA to plot spectrum on LCD only.

# CHAPTER 12
# PROJECT SNAPS

# 12. PROJECT SNAPS

# DATASHEETS

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