

CMOS Based Compact Spectrometer

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Abstract –

Design of a portable, compact and robust UV-visible-IR spectrometer is described. The basic need of spectrometer lies in the detailed study of absorption, transmission and reflection coefficients for fabrication/analysis of any material/light source anywhere in the field. The whole table-top arrangement can't be carried along. Hence the main challenge lies in building a robust and compact spectrometer with high sensitivity which is also portable. Optical setup is optimized in a space of 15cm * 15cm * 5cm. The spectrum obtained is acquired using electronics, sent to PC and plotted as intensity vs wavelength.

Keywords: Spectrometer, Monochromator, CMOS detector, Analog frontend electronics, Microcontroller.

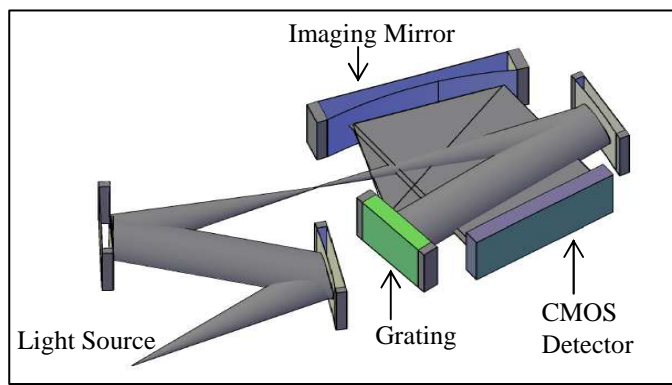


Fig. 2: AutoCAD design for monochromator

I. INTRODUCTION

Spectrometer is a device used to represent the intensity as a function of wavelength. It consists of two parts: a monochromator and a photodetector. Monochromator is an optical device used for separating component wavelengths of light. The preferable diffraction element used is a grating. The grating element is traditionally kept movable to get mechanically selectable wavelengths which can be detected using a photodiode. But due to advent of CMOS/CCD imaging sensors fixed and compact optical design is possible.

The design can be categorised into three basic parts: optical design, electronics for data acquisition as well as sending data to PC and image processing for plotting the obtained spectrum.

II. OPTICAL DESIGN

The Czerny – Turner monochromator configuration is used to model the optical setup. The design is simulated in COMSOL Multiphysics software [1]. A Czerny-Turner monochromator spatially separates polychromatic light into a series of monochromatic rays. The optical design and simulation for a grating of 1200 lines/mm is shown in Fig. 1.

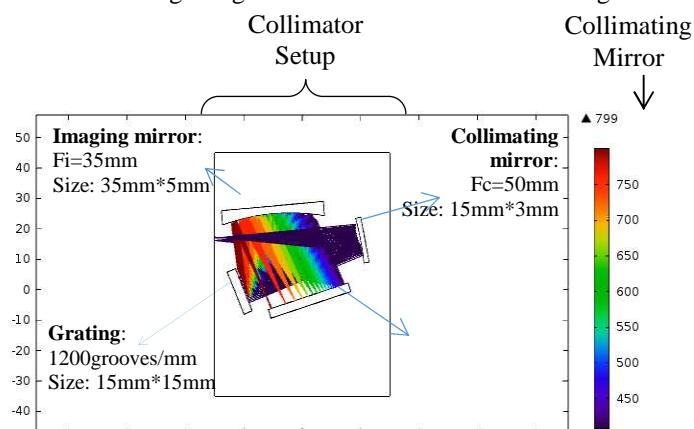


Fig. 1: Optical Simulation (2D) in COMSOL for 1200 lines/mm

In Fig.1 the input from source is given to the monochromator through input slit. The light entering from the source is collimated using the collimating mirror. Collimating mirror helps to produce parallel beam which is incident on the grating normally. 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 detector is kept at this focal plane in the setup [3]. A collimator arrangement is used to focus the beam of light from the source at the slit. The AutoCAD design of the optical setup for one grating along with the collimator arrangement is shown in Fig. 2.

Since the monochromator is UV-visible-IR the wavelength range of 200 to 1000nm is detected. For this two grating elements are needed: 2400 lines/mm and 1200 lines/mm. These two gratings have been placed one below the other and simulated in 3D as shown in Fig. 3.

CMOS detector

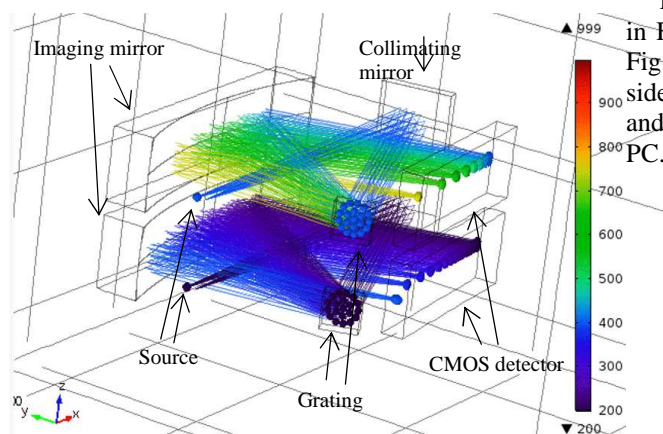


Fig. 3: Optical Simulation (3D) for 2 gratings: 2400 lines/mm & 1200 lines/mm

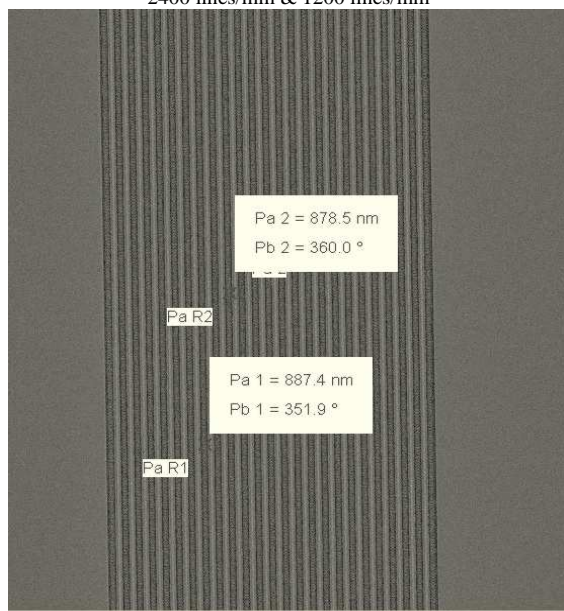


Fig. 4: Microscopic image of the fabricated grating

Fig. 4 shows microscopic image of the grating fabricated at TIFR, Mumbai. The grating has 1200 lines/mm and is 5mm×5mm in size. The substrate used is GaAs. Aluminum lines and gold lines of 150nm thickness are made for gratings of 2400 lines/mm and 1200 lines/mm respectively. The width of the lines is approximately 880nm.

For the optical setup of grating with 1200 lines/mm shown in Fig. 1 the plot of pixel number vs wavelength is shown in Fig. 5. As this plot is non-linear, calibration is done on the P.C. side. The spectrum obtained from the optical setup is acquired and processed by the electronic setup before sending it to the PC.

Fig. 5: Plot of Pixel number vs Wavelength (for 1200 lines/mm)

III. ELECTRONIC DESIGN

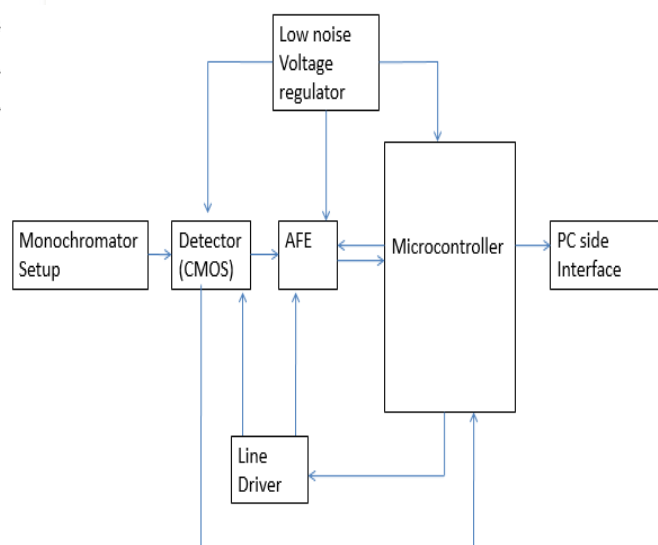
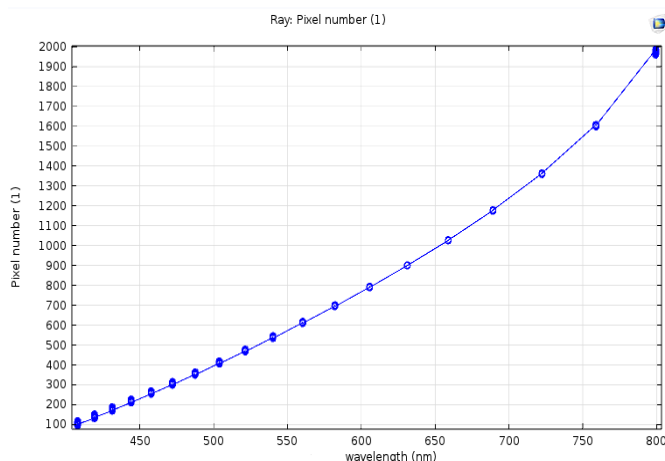


Fig. 6: Electronic setup

Fig. 6 shows the block diagram of the electronic setup. The electronic setup has following components:

A. CMOS Sensor

The CMOS sensor S11639 shown in Fig. 7 has 1×2048 pixels and the size of one pixel is 14 μm×200 μm [4]. The sensor is driven by 2 clock pulses- ST and CLK. The data output is obtained on the video pin which will be buffered by op-amp LT1818. The buffered signal is given to analog frontend electronics for further signal processing.



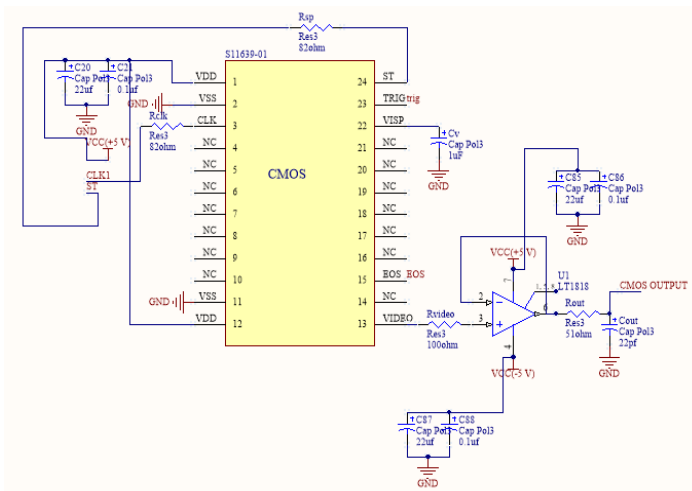


Fig. 7: CMOS sensor

B. Analog Frontend Electronics (AFE)

The AD80066 is a 4-channel analog signal processor. The video signal obtained from the CMOS sensor goes to AFE as one input say on pin VINA [4]. Each channel consists of programmable gain amplifier (PGA), multiplexed to 16-bit ADC. The CDSCLK1 is grounded for SHA mode (sample and hold mode). CDSCLK2 and ADCCLK (CLOCK INPUTS) are given from the microcontroller. The 16-bit digital output is multiplexed into an 8-bit output word available on the 8 data pins D0 to D7, which is accessed using two read cycles. The registers in the AFE are set by using serial interface from the microcontroller.

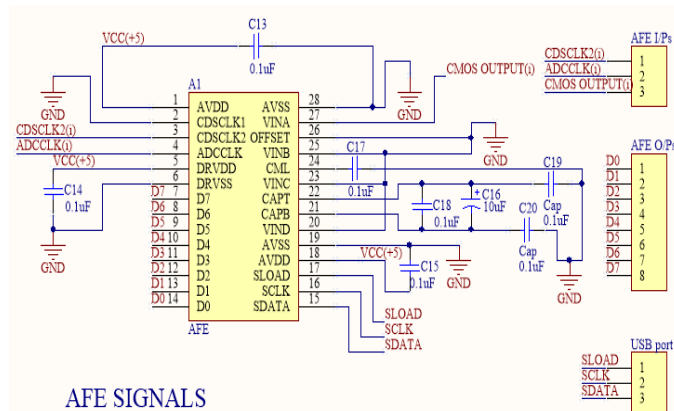


Fig. 8: AFE IC

C. Line driver

The clocks from the microcontroller are given to the line driver. The line driver improves the rise and fall times of the clock pulses as well as the strength of the signal. Fig. 9 shows the schematic of the line driver IC 74HC541.

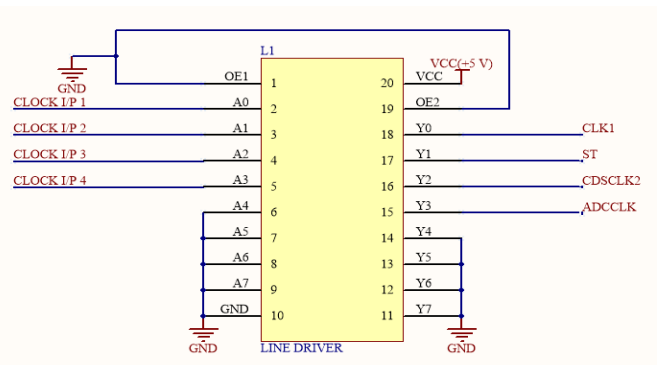


Fig. 9: Line Driver

D. Microcontroller

The PIC 18F87J50 microcontroller is used in this design [4]. The clocks driving CMOS Sensor and AFE IC are generated from microcontroller's CCP/ECCP modules as PWM pulses. The SPI protocol is used to set the registers of AD80066. The data available from AFE is sent to the PC via the microcontroller using USB.

E. Low Noise Voltage Regulator

The CMOS sensor must be protected from any surge voltages which might be caused by peripheral equipment. The CMOS sensor converts charge to voltage at its pixels. Hence the supply of the sensor must be low noise. The low noise regulator LT1965 has low noise of 40μV rms [4].

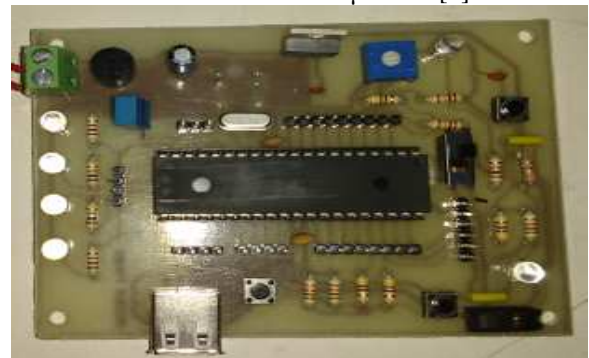
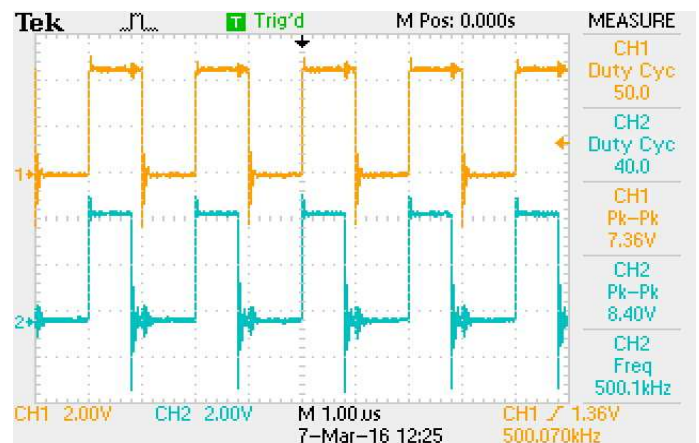


Fig. 10: Board for PIC18F4550

The experimental board with microcontroller PIC18F4550 shown in Fig. 10 is used to generate PWM pulses and for USB



communication [5].

Using this board two PWM signals of 500 KHz frequency with 50% and 40% duty cycle respectively were generated. The obtained PWM signals are shown in Fig. 11.

Fig. 11: PWM of 50% & 40% duty cycle at 500 KHz.

The spikes in voltage are suppressed using a 4.7V Zener diode. The PWM so obtained is shown in Fig. 12.

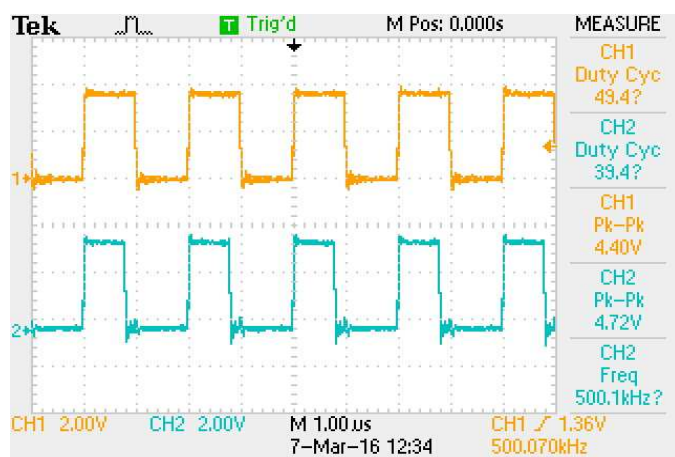


Fig. 12: PWM (40% duty cycle) without spikes in voltage.

IV. IMAGE ANALYSIS

In the design, data values sent to the PC using USB communication are extracted and stored to form a matrix. An image is constructed using this matrix. This grayscale image is the spectrum.

Some spectra like the one shown in Fig. 13 are obtained from a camera to work on the image analysis simultaneous. The colored image is first converted to grayscale image and a horizontal line is taken from the vertical center of the image. The intensity vs distance in pixels is plotted as shown in Fig. 13. This plot gives peaks at those wavelengths present in the spectrum. First peak in the Fig. 13 shows saturation. Saturation in the setup is avoided by using small integration time (high frequency clock) for the CMOS sensor. The distance in pixels between two particular wavelengths follows the non-linearity shown in Fig. 5. This non-linearity is used for calibration. When two wavelengths and their distance in pixels are known then the next wavelength is predicted as its distance in pixels is also known.

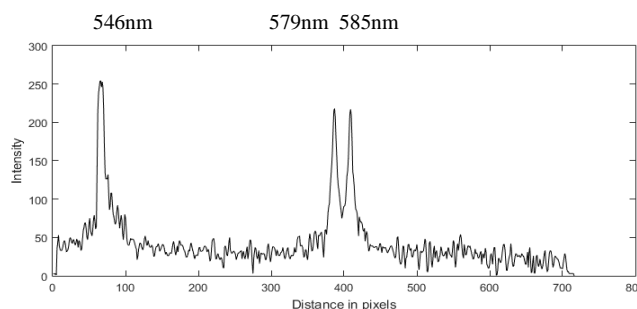


Fig 13: Spectrum of a light source captured with camera and its Intensity vs Distance in pixels plot.

V. LIMITATIONS

The designed spectrometer is not standalone in complete sense. It needs to be wired to the PC for sending data.

VI. APPLICATIONS

- Study of composition and identification of materials depending on their transmission and absorption spectra.
- Observation of spectra of various light sources and their analysis.
- Astronomical applications such as analysis of light from different stars.

VII. CONCLUSION

The “CMOS Based Compact Spectrometer” is a system designed for the ever growing material science and astronomical field, for analysis and identification of new materials and light sources. The system fabrication and overall cost is much less than the expensive spectrometers each costing tens of lakhs currently being imported in India. The designed system is very economical and can have great market in today’s technology driven and research oriented world.

ACKNOWLEDGMENT

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