THE THIRD EYE

Far Field Measurement of Optical Sources

Project Report by:-
Deepak Goyadi
Jashan Singhal
Mustafa Lokhandwala

Guide: Prof. Joseph John

Indian Institute of Technology Bombay
Department of Electrical Engineering

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Abstract

The project deals with a technique to rapidly scan the far field of optical sources and construction of an instrumentation system based on our measurement technique. Traditionally such an irradiance pattern is measured either by moving the detector about the source at a fixed radius or by rotating the source on a rotation stage with the detector stationary. In our endeavour, we choose to undertake the latter strategy so as to assimilate the far-field intensity data as a function of azimuthal/polar angle coupled with the extraction of useful information and angular plots on LabVIEW which would not only provide us automation of measurements, but also instrument control.

1. Aim

- To design an apparatus for the far field measurement of LEDs and optical fibers (if time permits) using a stationary detector and rotating source.
- To provide a user friendly interface for controlling the whole assembly including the control of stepper motor as well as acquisition of data using NI LabVIEW.

2. Introduction

Conventional techniques for measuring or characterizing the radiation pattern of optical sources utilize a goniometer in combination with an optical detector. These "gonioradiometric" measurements are typically made by rotating the detector on a radial arm of the goniometer about the optical source (light source) to be measured. The detector scans through angles and measures light output as a function of angle. In accordance with another conventional technique, a light source is mounted to a rotating goniometer which scans the optical beam from the light source across a detector that is fixed in position. The mechanical scanning apparatus associated with the above- described known techniques often occupy a rather large volume due to the necessity of scanning at specified radii which are on the order of tens of centimeters or larger in some cases. In addition, the mechanical scanning apparatus typically does not allow for rapid positioning. This results in lengthy scan times, often as much as thirty minutes or more per individual scan. This translates to characterization times on the order of hours or days for a full incremental scan of the radiation pattern of the source.

Also, from the discussion we had with the concerned faculty, he suggested to us that there is an abject requirement of such an apparatus as it is commercially unavailable and having such a framework would definitely help in easing a lot of trivial radiation measurements in the lab. So, we wish to provide an effortless and plain sailing solution to this problem and that our work will have immediate use in the lab motivates us.

Table 1: Specifications

Scan Radius	4 cm
Azimuthal Profile Acquisition Time	2 minutes
Photodetector responsivity	0.55 A/W
Steps per revolution	6000
Angular Resolution	0.06°
Holding Torque	80 Ncm
Typical Working Torque	80 Ncm
Maximum Continuous Torque	80 Ncm
Number of phases	4
Rated voltage (L/R Drive)	5 V
Current per phase	550 mA
Resistance per phase	9.1 Ohm
Inductance per phase	8.1 mH
Stepper motor shaft length	12.8 mm

3. Block Level Design

- *NI DAQ card:* The physical apparatus is interfaced with the computer using an NI DAQ card which performs the function of acquiring data from the photodetector as well as sending the control signal to the stepper motor driver.

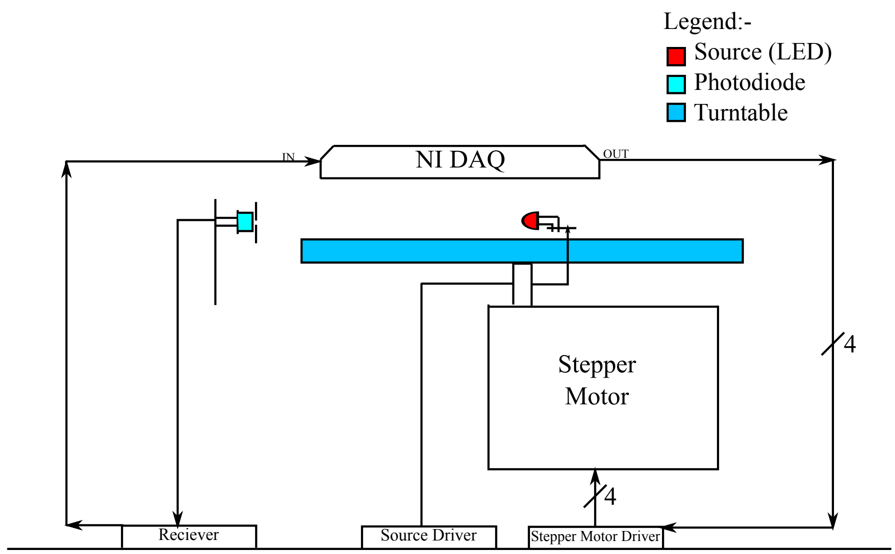

Figure 1: Block Diagram

For our application, we are using **NI 6008** DAQ card. It has 8 analog inputs and 12 digital I/O pins.

- *Stepper motor:* The stepper motor used in this apparatus is a geared stepper motor with a gear ratio of 125:1. Thus, one step of this stepper motor is $7.5^0/125 = 0.06^0$ as opposed to the usual 7.5^0 step angle of normal stepper motors. This allows us to take readings at very fine angular resolution resulting in greater precision.

- *Stepper motor driver:* The stepper motor driver is controlled from the input provided by the digital I/O pins of the NI DAQ card. To protect the DAQ card from sourcing/sinking currents above its rating, an inverting buffer is used between the L293D motor driver and the DAQ card.

- *Source Driver:* This circuit drives the optical source for which the radiation pattern needs to be measured. The design of the driver circuit for an LED is shown below. This circuit pumps approximately 90mA current for a red LED with 50% duty cycle. The input to this circuit is a pulse waveform of frequency 1 kHz and high/low levels of 5V/0V.

- *Receiver circuit:* This circuit will take the input signal from the pho-

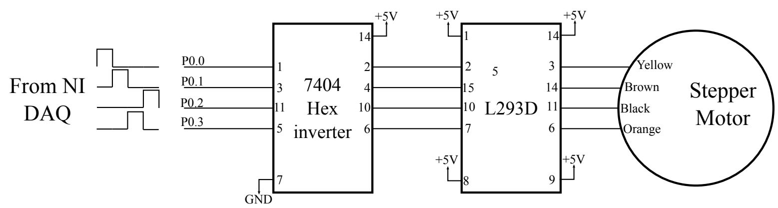

Figure 2: Stepper Motor Driver consists of an inverting buffer followed by an L293D, which is finally connected to the terminals of the motor. This circuit receives its input from NI DAQ card as shown above.

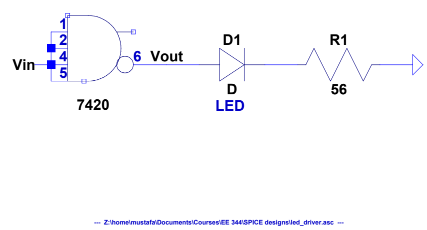

Figure 3: LED Driver

todiode terminals and condition it so that it can be read at the analog input pin of DAQ card. This circuit is a combination of three smaller circuits put in cascade, namely a transimpedance amplifier, an inverting amplifier and a peak detector.

1. A current to voltage converter using a high precision op amp with low input bias current. We are using an LM308 which has a maximum input bias current of 2 nA. This is crucial since the photocurrent generated by the BPX65 photodiode is of the order of nA and an opamp with bias currents of the order of 10 nA can significantly affect the meassurements. A capacitor is also added in parallel to the 1MΩ resistor so that this also acts as an antialiasing filter because the signal would be finally sampled at the input of the DAQ card.
2. The inverting gain stage amplifies the signal by 10X. The necessity of this amplification arises because this signal will undergo peak detection using an IN914 diode with a cut-in voltage of 0.7 V. So the original signal, which had a dynamic range of 0 mV to -600

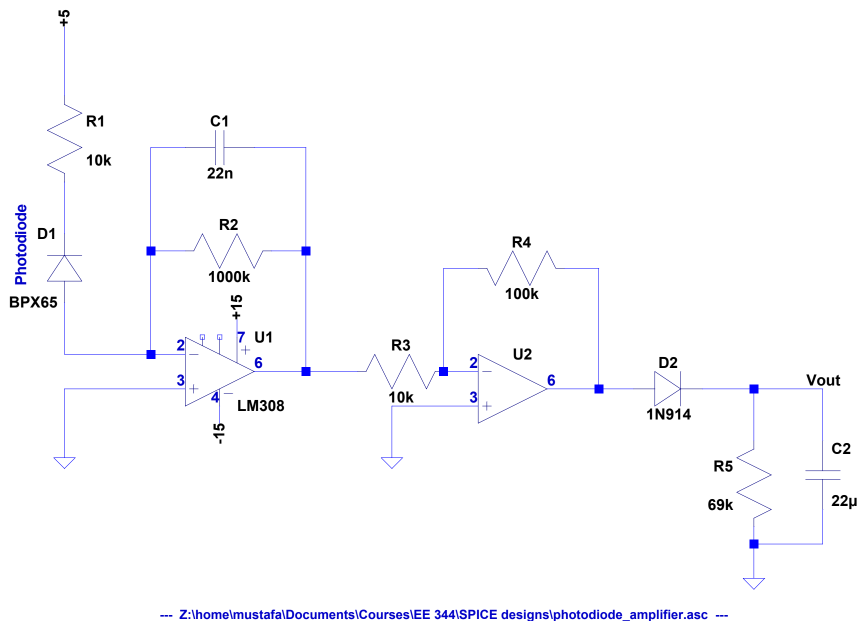

Figure 4: Photodetector Amplifier Circuit

mV cannot be fed directly to the peak detector and needs to be amplified as well as inverted for positive peak detection.

3. The third part is a simple peak detector which consists of an IN914 diode followed by a parallel combination of a resistor and a capacitor.

- *Photodiode with pinhole:* A BPX65 photodiode with a radiant sensitive area of 1 mm^2 is used for measuring the light intensity of the source. A pinhole is kept in front of the photodiode to cut down ambient light from falling upon it and generating any photocurrent. The diameter of the pinhole is 1.5 mm.

- *LabVIEW:* The entire working of the project is controlled as well as analyzed using LabVIEW. The program can be distributed into two parts:

  1. **Motor driver control**
     The platform used to rotate the source is controlled by this part with the option of rotating in both the directions using a single click. In order to control the stepper motor, we need to give

certain pulse sequence to the four input wires of the motor. Analyzing this, results in giving a digital waveform to these inputs in a particular pattern for clockwise and anticlockwise rotation. These digital waveform are generated by creating a sequence of 4 bit data forming the required pattern. The sequence of data is stored in an array and is passed on sequentially to the output. The speed of rotation is also controlled by giving an appropriate delay. The various blocks used and their functions are as follows:

- **While loop**: all the iterative blocks are placed inside this. This block repeats itself after t time which is set using the timer block.
- **Array**: Stores data in an m x n array, used to store the sequential values in decimal of the 4-bit patterns needed.
- **Index Array**: Used to access a particular index of the array and to switch between the data corresponding to the two direction of rotation.
- **Boolean_Switch and boolto(0,1) converter**: Used as a switch which gives the index value to the above mentioned Index array block.
- **Unsigned byte to integer converter**: Used to convert the unsigned valued row accessed from the index array to integer form. The above row is passed on to another index array block which gets access to the column and gives a single integer value as output.
- **Number to Boolean converter**: the above output is then converted to Boolean form using this block.
- **DAQmxwrite**: writes the Boolean data obtained into the DAQ digital output pins. One instance of this block is used outside the loop to reset the data after each loop.
- **DAQmx create channel block**: creates virtual channel for the input/output of data. This channel is connected to the DAQmx write block and set to digital output.
- **DAQmx clear task**: clear task after each loop. Placed outside the loop.

2. **Data acquisition and analysis**
The final output of the detector circuit is taken through the NI-DAQ using the DAQ Assistance block and the obtained waveform

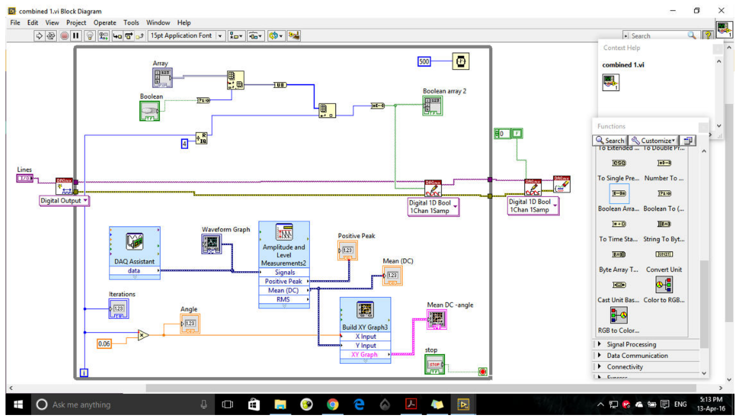

Figure 5: LabVIEW program

is presented on the screen. Different characteristics of the graph like the Peak value, Mean DC value, Peak to Peak, RMS, Frequency etc. can be obtained using the measurement blocks available. Finally, we plotted the Mean DC voltage against the angle of the source. The curve represents its values from 0 degree to 180 degrees with the peak around 90 degrees. This data also gives us the viewing angle of the source. The various blocks used and their functions are as follows:

- **DAQ Assistant**: This block is used to input the data. Samples to read and rate are set in this block.
- **Waveform Graph**: Used to plot the waveform graph of the input signal.
- **Amplitude and Level Measurement**: Used to measure different characteristics like amplitude, peak to peak, RMS, DC voltage etc. of the input waveform.
- **Build XY graph**: Used to build a graph between X and Y input of the block.
- **Waveform chart**: Used to plot the graph formed by the above block.
- **Numeric Indicators**: Used to indicate different numerical values.

• *Pin diagram of the screw terminal block*:

<table>
<tr><td>DBG2</td><td>DBG1</td><td>A3</td><td>A2</td><td>A1</td><td>-15V</td><td>+15V</td><td>+5V</td><td>GND</td><td>GND</td><td>DAQ Dig. GND</td><td>Pulse</td><td>MI4</td><td>MI3</td><td>MI2</td><td>MI1</td></tr>
<tr><td colspan="2">Debug Pins</td><td colspan="3">Analog Outputs to DAQ</td><td colspan="5">Power Supply</td><td colspan="6">Motor Control and Pulse Output from DAQ</td></tr>
</table>

Figure 6: Pin diagram of the screw terminal block

Table 2: Connections

Pin	**Connect to**
MI1	P0.0 of NI DAQ
MI1	P0.1 of NI DAQ
MI1	P0.2 of NI DAQ
MI1	P0.3 of NI DAQ
Pulse	P1.0 of NI DAQ
DAQ Dig. GND	Digital Ground of NI DAQ
GND	Ground of +5V supply
GND	Ground of +15V/-15V supply
+5V	+5V from Power Supply
+15V	+15V from Power Supply
-15V	-15V from Power Supply
A1	AI0 of NI DAQ (rectified output)
A2	AI4 of NI DAQ (ground)
A3	Not connected (unrectified output)
DBG1	Not connected (pin for debugging)
DBG2	Not connected (pin for debugging)

4. Photographs

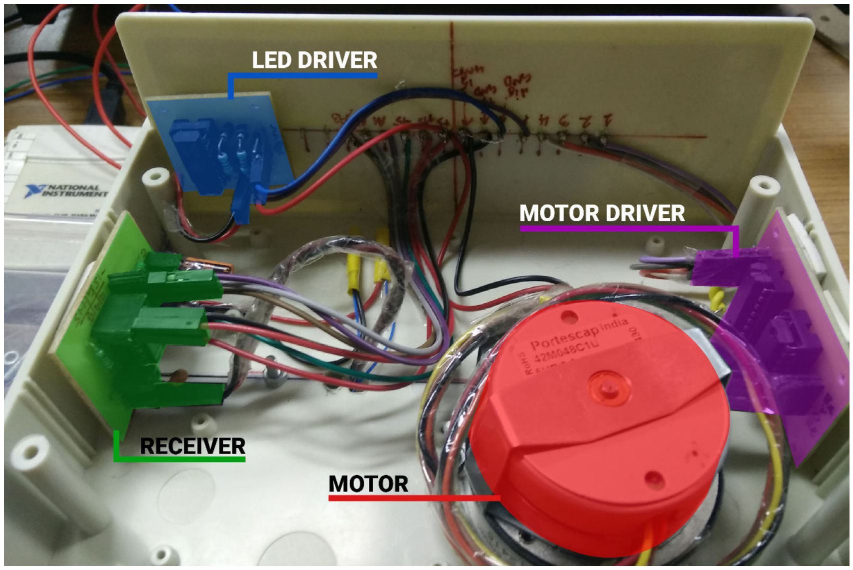

Figure 7: Interior view of the box showing the assembly and circuits

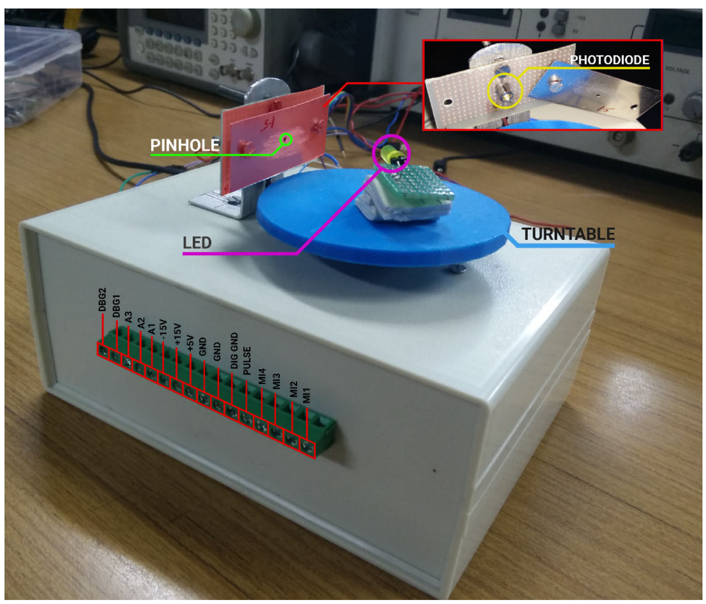

Figure 8: Exterior view showing supply & I/O pins, turntable, LED, pinhole, photodiode and the box itself

5. Results

We measured the azimuthal angular profile of a 6 different LEDs using our apparatus and obtained the following results:

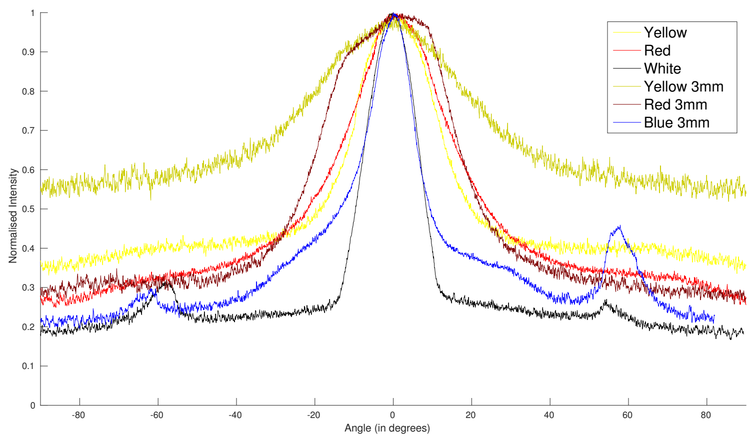

Figure 9: The angular far field radiation profile of different LEDs

On performing the Gaussian curve fitting over the obtained data, the Full Width at Half Maximum (FWHM) angles for various LEDs are as mentioned in the table below.

Table 3: Full Width at Half Maximum (FWHM) Angle

LED	**Angle** (in degrees)
Yellow	25.54
Red	34.49
White	14.70
Yellow 3mm	46.03
Red 3mm	36.49
Blue 3mm	23.11

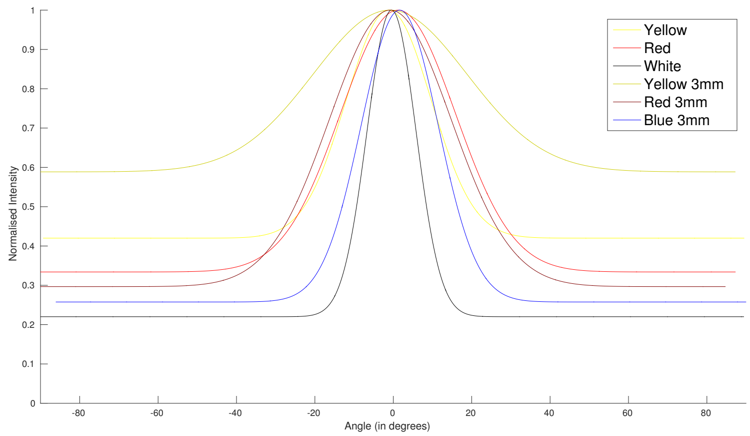

Figure 10: Gaussian fitted curves in the measured data for different LEDs

Before inserting the pinhole, a few readings were taken. The graph below shows the measured data before and after inserting the pinhole for the yellow LED. The lower intensity at oblique angles clearly indicates that pinhole mitigates the effect of ambient light to a large extent.

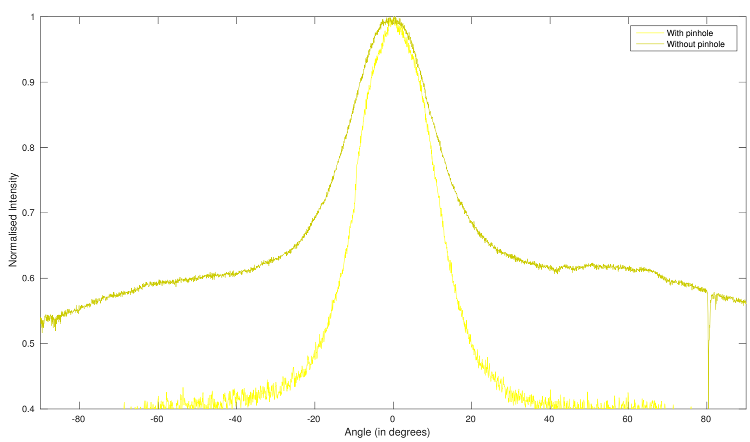

Figure 11: Measurements with and without the pinhole for the yellow LED

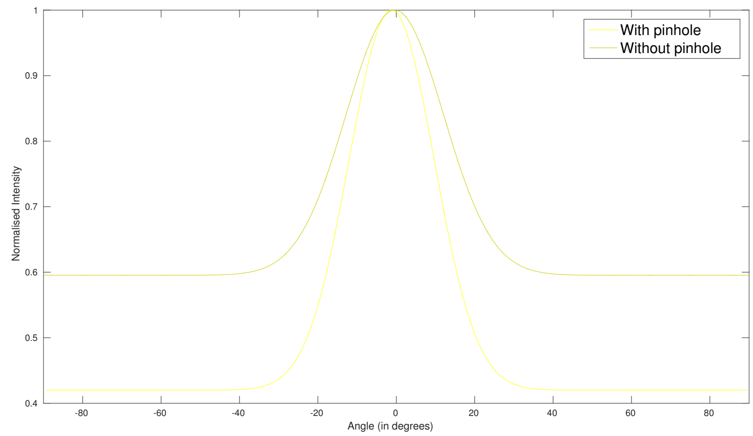

Figure 12: Gaussian fitted curves for the above measurements

6. Problems faced

- **Mechanical Subsystem**: Designing a robust assembly which would accomodate our stepper motor+gear arrangement along with the photodetector was a challenging task. We had to select the radius of our turntable in such a fashion that the optical source placed at its center could cause significant response to a detector placed at the circumference of the turntable. Once the appropriate radius was selected, we got the turntable 3D printed. One of the challenges was to select the type of material on which we can mount all our assembly so that irregularities and roughness do not cause a hindrance in the precision of our measurements. First we came up with a wooden prototype since it was readily available and it was supported by 4 long bolts. Though the measurements we carried out with this arrangement looked more or less fine, but we needed a more resilient design which could also accomodate all our PCBs and support our other hardware as well. After a lot of searching we found the right plastic box which is sturdy enough to support our motor and provides easy access to our circuitry as well.

- **Electrical Subsystem**: Our initial challenge was to select the appropriate motor driver which could drive our Stepper motor. Since our unipolar stepper motor runs on 5V and 550 mA, we first decided to use the IC ULN2003A but the current it provided was low. Finally, we decided to use L293D IC to drive our stepper motor. One of our tasks was also to find out the right sequence in which the coils needed to be excited to drive the motor, which we got by hit and trial.

- **Optical Subsystem**: The reliability of our data is based upon the response of our photodiode. If it is easily corrupted by noise or doesn't respond to the required optical source at a particular angle then our readings can be altered. One of the biggest devils in our optical measurements is background light which serves as a noise. In order to lessen the effect of this noise, we started pulsing our LED. Pulsing our LED served two purposes

  1. We could increase the peak current flowing through the LED, so as to increase the possibility of the response being captured by photodiode.
  2. We could observe the frequency of the phtodiode response and make out which part is from light source and which part is background noise.

  In order to reduce the surrounding light entering the photodiode, we also used a pinhole which could cover our photodiode. But, we ran into some problems as the pinhole size seemed to be very small and it cut out even the light entering from the LED at oblique angles. We are yet to make slightly larger pinholes and experiment with them.

- **LabVIEW**: The main problem lied in getting the input data for each rotation of the source. For this, the sampling rate has to be changed accordingly and set to ensure that enough data is collected for each angle.

7. Conclusion

We would like to conclude that our system has yielded results which are in sync with the viewing angle data available on internet. There is a good amount of correlation between result obtained by our apparatus and results obtained by much costlier goniometers. Thus, we have provided a cheap and easy solution to this problem of far field measurement.

8. Future Work Suggestions

According to us, this work can be extended to add two more features in the same apparatus.

1. **Far Field Measurement at varying polar angle**: As of now, we are measuring the far field only at one polar angle, which can be thought of as the equator of the 3D far field. A mechanism to move the source in vertical direction can used to acquire the far field data at varying polar angles and ultimately generate the 3D plot with varying azimuthal as well as polar angle.
2. **Measuring numerical aperture of fiber optics**: The obstacle that must be overcome to take measurements for the optical fiber relate to its precise mechanical placement right in front of the photodiode. If this is accomplished somehow, then the setup can measure the viewing angle of the optical source, from which its numerical aperture can be calculated.
3. **Programmable gain amplifier in post-amplification stage**: The currently chosen value of gain saturated the amplifier in the case of IR LED. The gain of the inverting amplifier in the post-amplification stage can be kept programmable so that it can be varied for different sources.

9. References

1. Goniometric scanning radiometer, US 5949534 A
2. Far-field scanning apparatus and method for rapid measurement of light source characteristics with high dynamic range, WO 2001036931 A2