Automated Experimental Setup to Measure Optical Power–Current Characteristics of Light Emitting Diodes

Abstract—**This paper presents a simple and low-cost setup to measure the optical power–current (L–I) characteristics of light emitting diodes (LEDs) without relying on expensive optical power meters. An Arduino microcontroller is used to generate a 0–5 V signal that drives the gate of a MOSFET, which controls the current through the LED. The LED is placed in a black box along with a Light Dependent Resistor (LDR), which changes resistance depending on the light intensity of the LED. The current through the LDR is measured as the output signal. Since the LDR response is nonlinear and varies with LED type, a two-step calibration process has been applied. First, the LDR current is mapped against the LED current. Then, the calibration is refined by comparing results with a standard L–I curve obtained using a PM100D optical power meter. This allows accurate estimation of LED optical power. Finally, MATLAB is used to plot the L–I curves of red, green and blue LEDs.**

Index Terms—**LED, Calibration, Arduino, LDR, Photodetector**

I. Introduction

Light emitting diodes (LEDs) have emerged as a dominant solid-state lighting technology because of their high efficiency, compact size, and long operational lifetime compared to conventional sources. Over the last decades, significant research has focused on improving the optical, electrical, and thermal characteristics of LEDs for diverse applications ranging from consumer electronics to high-precision instrumentation. A review of LED development highlights the continuous evolution of device efficiency, wavelength tuning, and reliability, making LEDs essential for modern optoelectronic systems [1].

The study of optical power characteristics, particularly the light-current (L–I) and current-voltage (I-V) behavior, remains fundamental for both device modeling and practical applications. Experimental setups for measuring optical power provide critical insights into device performance under different operating conditions [2]. High-power LEDs, including white and ultraviolet (UV) variants, are particularly relevant due to their use in sensing, communication, and instrumentation [3] [4]. Accurate characterization of these devices not only aids in system design but also ensures long-term reliability [5]. The setup draws inspiration from prior LED measurement and modeling studies [6] [7] but emphasizes accessible instrumentation with calibration to ensure reproducibility.

II. Literature Review

Early investigations into LED optical behavior established theoretical and experimental models of optical power emission, heat dissipation, and electro-thermal coupling [6]. Tao et al. characterized the emitted optical power of high-power white LEDs, highlighting L–I curves and providing theoretical modeling for device optimization [4]. Similarly, Li et al. demonstrated the role of UV-LEDs in analytical instrumentation, emphasizing wavelength dependence and intensity control [3].

The reliability and degradation mechanisms of LEDs have also been extensively reviewed, identifying thermal stress, material defects, and packaging as key factors influencing operational lifetime [5]. Compact multi-domain modeling approaches, such as those described by Poppe, integrate electrical, thermal, and optical domains, offering predictive frameworks for LED behavior under varying conditions [7]. Spice-based models further extend this approach by linking device performance with circuit-level design considerations [8].

Recent work has also addressed cost-effective instrumentation. Dos Santos et al. developed an affordable optical power meter for calibration in the 400–800 nm range [9], while Marinho et al. demonstrated the use of light-dependent resistors (LDRs) as simple yet effective detectors for light measurement in laboratory experiments [10]. Complementary designs using Arduino platforms and real-time acquisition systems have also been reported for broader applications in home automation and analog device testing [11] [12].

InGaN-based LEDs further expand the wavelength spectrum to red emission, demonstrating advancements from traditional devices to micro-LED structures [13]. Additional studies have reported calibration methods [14], automated sensing techniques [15], and security applications that take advantage of Light Dependent resistor (LDR) based configurations [16]. More recent efforts emphasize low-cost and thermally informed measurement strategies. Kim et al. introduced a photo-thermal sensor to measure both optical power and hot-spot temperature of high-power LEDs with good accuracy [17]. Strakowska et al. employed infrared thermography with thermal modeling to estimate optical power, achieving strong agreement with spectrometer data [18]. Du et al. extended this direction by using nanoparticle-based thermometry to map temperature distribution in multi-chip LEDs, revealing its strong influence on optical output [19].

Concurrently, these contributions trace the progression from fundamental modeling to practical and thermally guided low-cost measurement techniques. Despite these advances, there remains a need for an automated framework capable of generating real-time L–I and I-V characteristics of visible

LEDs without relying on expensive optical power meters. The present study addresses this gap by proposing a sensor-based acquisition system calibrated against standard references. The objective of this work is to develop an automated platform capable of generating real-time L–I characteristics of visible LEDs without the need for a dedicated optical power meter. The proposed setup acquires voltage, current, and optical power data through cost-effective sensors and transfers the information to MATLAB for processing and graphical visualization. This framework is designed to enable reliable comparison of measured characteristics with standard calibration curves, thereby providing an accessible and reproducible approach for LED performance analysis.

III. Design & Methodology

In the experimental setup, a single 12 V voltage source was used to bias both the LED and LDR circuits simultaneously, shown in Fig. 1. The L-I characteristics of the LED that is to be measured is placed in the LED circuit. Our goal is to change the current in the LED and measure the corresponding light intensity using the LDR.

First of all, we had to change the current through the LED. To do so, an enhancement type MOSFET is used. A series network of LED and resistor is connected parallel to the MOSFET. The gate voltage of the MOSFET was varied using an Arduino UNO, which generates a voltage ranging from 0 to 5V. The value of the resistor R3 (120 ohm), situated between the LED and the electrical ground, chosen to be 120 ohm, so that the voltage drop due to the resistor is not significant. We measured the voltage across the resistor using an Arduino output port. The current flowing through the LED can be calculated from the voltage drop across the R3 resistor.

The resistor R1 (470 ohm) has been used across the voltage supply and drain of the power MOSFET. When the MOSFET is turned on, it can have a huge current which might damage the components. This resistor value is chosen so that it does not affect the swing of the output drain voltage greatly.

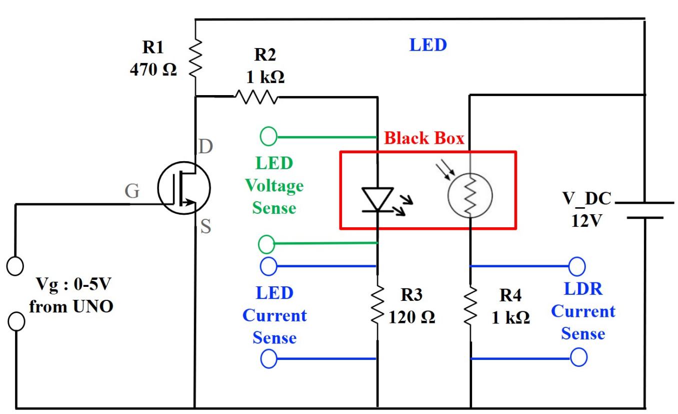

Fig. 1. Circuit diagram for L-I measurement of LED

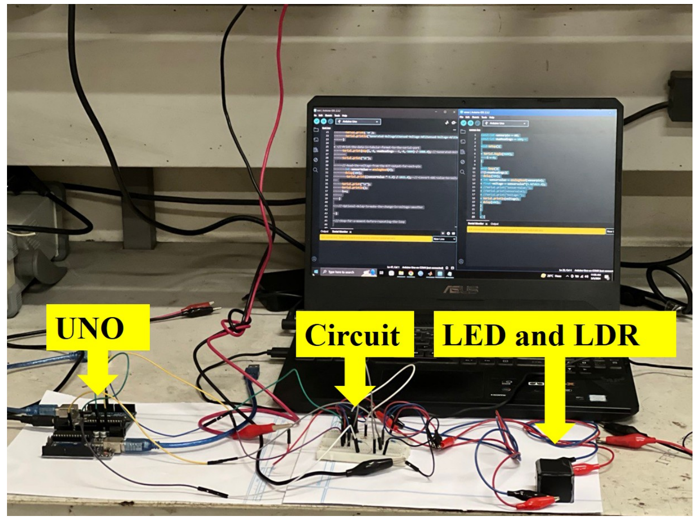

Fig. 2. Hardware setup for the experiment

THe LED and LDR were placed in a black box in order to optically isolate them, shown in Fig. 2. This ensures that the LDR is responsive only to the light flux generated by the LED. The apparatus used here are fairly cheap and mainstream which give huge advantages to replicate the process for future case.

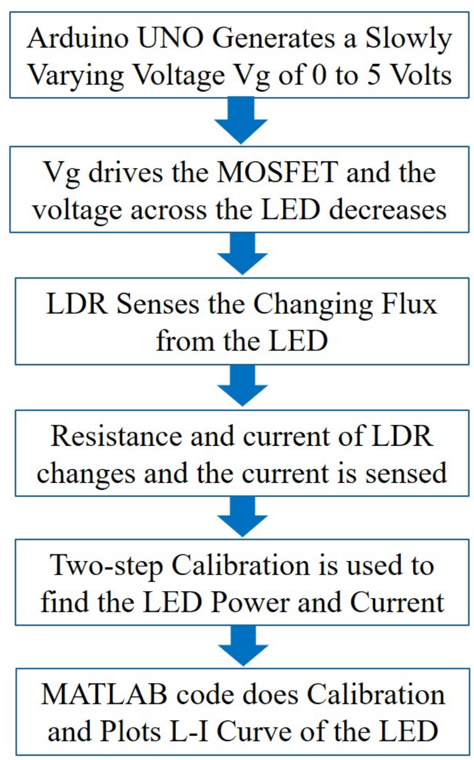

Fig. 3. Flow chart of the design

The overall methodology is depicted in the flowchart in Fig. 3. Initially, an Arduino UNO microcontroller generates a slowly varying analog output voltage ranging from 0 to 5

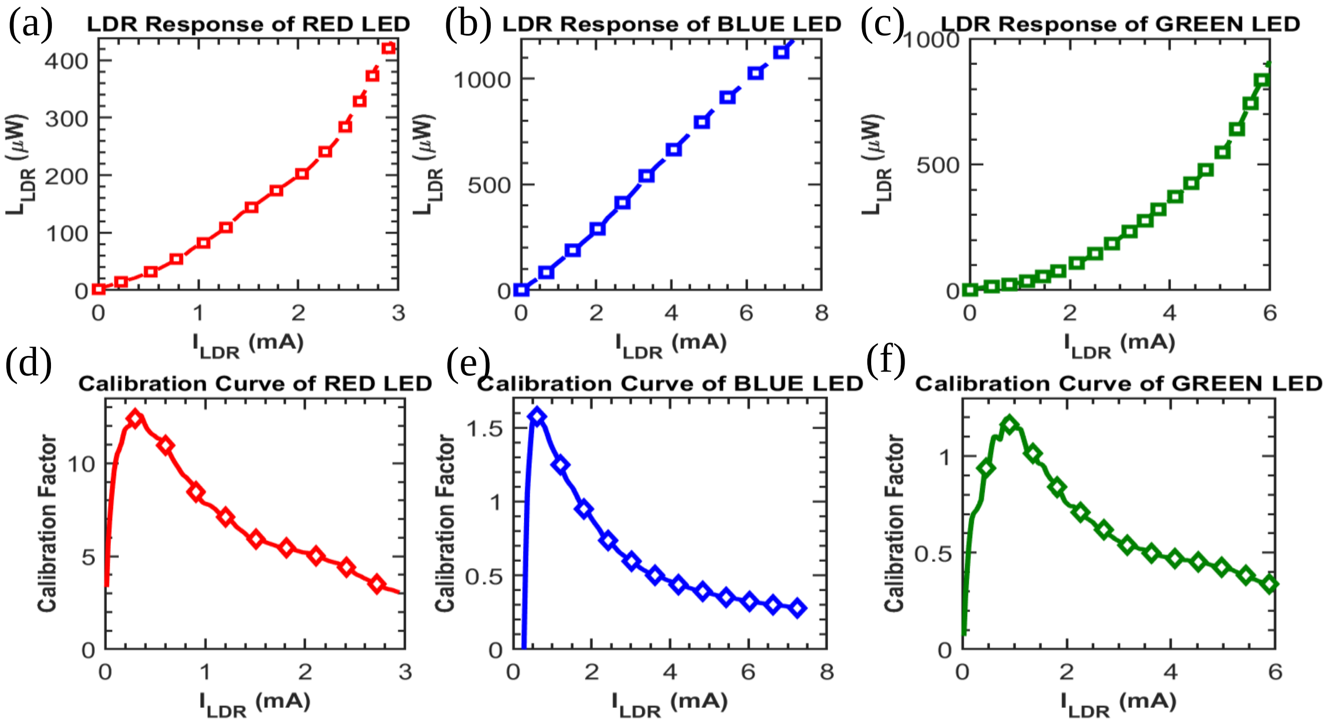

Fig. 4. Light power measured by LDR with respect to current through it for (a) red, (b) blue, and (c) green LED. Calibration factor used for (d) red, (e) blue, and (f) green LED.

V. This gradual variation is used to control the brightness of the LED. The output signal from the Arduino is applied to the gate terminal of a power MOSFET, which acts as a switching device. When the MOSFET turns on, it reduces the corresponding current to the LED, thereby regulating its intensity. As the LED emits light at varying intensities, an LDR is placed in proximity to detect the light flux emitted. The LDR's resistance changes inversely with the intensity of incident light. Therefore, when the light intensity decreases, its resistance increases, resulting in a decrease in the current flowing through the LDR. This current variation has been converted to a measurable voltage across the R4 (1 kohm) resistor connected in series with the LDR (output current sensing). The voltage across this resistor is continuously measured to determine the instantaneous power or response of the LDR. Finally, these measured voltage data have been processed using a MATLAB script. The script performs calibration to correlate the LDR output with the optical power of the LED and then plots the L–I characteristic curve (Optical power vs. Current) of the LED.

The calibration curve used to correlate the LDR current with the optical power varries according to the type of LED. To choose the calibration curve, the threshold voltage or the turn-on voltage of the LED has to be determined. For this, another Arduino output port measures the voltage across the LED, when it is in on-state. The threshold voltage refers to the minimum voltage needed to turn on the LEDs and emit a discernible amount of light. This varying voltage depends on the color of the LED as different materials are used to build these LEDs. Threshold voltage range of the three types of LEDs are discussed below:

- Red LED: threshold voltage lies between 1.7V and 2V.
- Green LED: Vth falls between 2.9V and 3.1V.
- Blue LED: Vth is generally between 3V and 3.3V.

From the experimental setup, a 1k ohm resistor is used between LDR and ground point of the to measure the current through the LDR. It was found that the resistance of LDR varies between 5k and 60k ohm for red LEDs. The range is 2k-35k ohm and 1.5k-30k ohm for the green and blue LEDs, respectively. After conducting multiple tests, it has been deducted that voltage drop remains between 0-5V if 1k ohm resistor is used like the setup. It is necessary, as the Arduino Uno board can only sense between 0 and 5V. The LDR sensor model is chosen such that its resistance goes from Mega ohm to kilo ohm; setup will be widely adjustable for all types of LEDs in the future. The cost of the experimental setup is summarized in Table I.

TABLE I
APPROXIMATE COST BREAKDOWN OF THE EXPERIMENTAL SETUP

Component	**Cost (BDT)**
Arduino UNO	988
Breadboard	145
LDR	50
MOS TTC5200	120
Wires	50
Resistors	10
Total	**1363**

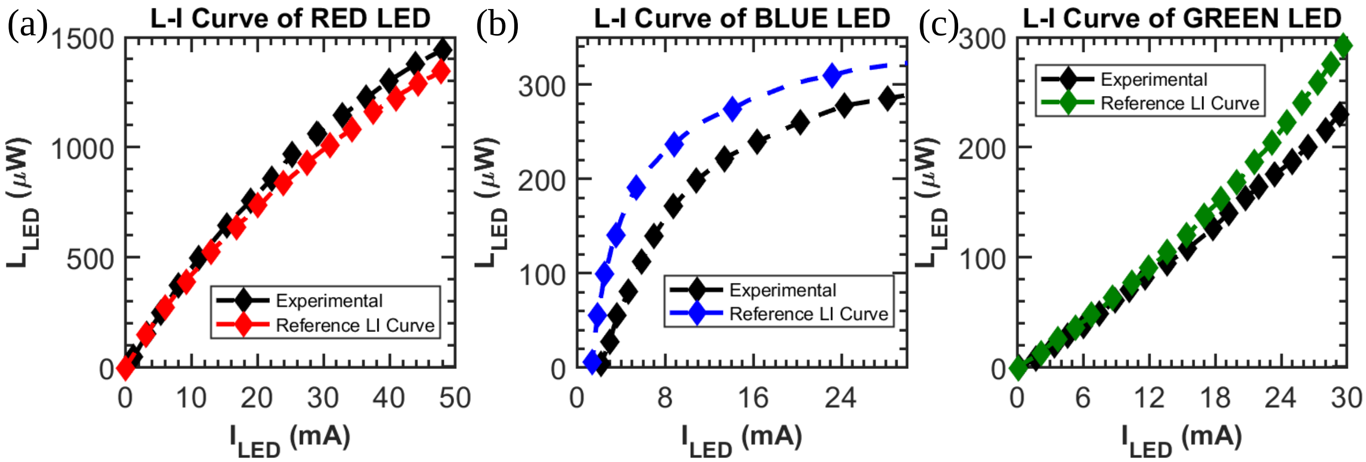

Fig. 5. Comparison between experimental and reference data of (a) red, (b) blue, and (c) green LED.

Calibration is the process of comparing and adjusting the measurements of a device (like a sensor) to match a known, accurate standard (like a power meter or multimeter). The LDR sensor does not provide power or current output values. It changes its resistance in response to the light intensity of the diodes. Moreover, LDR does not have a linear response to light. Even the same LDR can respond differently to different types of LEDs. Hence, LDR is calibrated by comparing its readings with known power outputs with an optical power meter (PM100D). And, calibration graphs have been plotted beforehand in the experiment which are shown in Fig. 4.

Arduino UNO microcontroller has been used both as an input voltage source and output sensor. Thus, two separate codes have been written in the arduino IDE.

Algorithm 1 Voltage Generator Algorithm

Initialize variables:
`pwmPin` = 10, `analogInPins` = {A0}, `numReadings` = 100
Start serial communication at 9600 baud rate
Initialize variable `i` to 0
while `i < numReadings` **do**
    Map the value of `i` to PWM range and write to `pwmPin`
    Delay for 1000 ms
    if `i == 0` **then**
        Print header row: "Generated Voltage Sensed Voltage A0 Sensed Voltage A1 Sensed Voltage A2 Sensed Voltage A3"
    end if
    `Generated Voltage` = map(`i`, 0, `numReadings` - 1, 0, 5000) / 1000.0
    Print `Generated Voltage`
    `sensorValue` = analogRead(A0)
    `voltage` = (`sensorValue` * 5.0) / 1023.0
    Print `voltage`
    Increment `i`
end while =0

The voltage generator code generates a gradually increasing voltage using PWM signal. Furthermore, it senses voltage drop from the 120 ohm resistor and stores both generated and sensed voltage in a table format. The *NumOfReadings* variable is declared to vary the number of readings taken for the plot accuracy. The table has been printed for convenience but can easily be omitted in the code. Voltage values are converted using the following equation.

$$Voltage = \frac{SensorValue * 5}{1023} \tag{1}$$

The multiplication by 5 in the equation is used to define the (0-5V) range. Arduino UNO's Analog to Digital converter (ADC) is 10 bit and so it can have $2^{10} = 1024$ values; where 0 denotes 0V and 1023 denotes 5V. Subsequently, the microcontroller needs to read (sense) the resistance of the LDR sensor from the output circuit.

Algorithm 2 Sensing Algorithm

Initialize variable `sensorPin` = A0, `numReadings` = 100
Start serial communication at 9600 baud rate
Initialize variable `i` to 0
while `i < numReadings` **do**
    Delay for 500 ms
    `sensorValue` = analogRead(sensorPin)
    `voltage` = (`sensorValue` * 5.0) / 1023.0
    Print `voltage`
    Delay for 600 ms
    Increment `i`
end while =0

The sense code takes readings through an analog pin and converts into voltage using equation 1. One thing to keep in mind is that the voltage variable needs to be declared as having floating point values. The *NumOfReadings* variable determines how many times the microcontroller needs to take readings.

IV. RESULTS

The PM100D optical power meter is used to measure the actual power output of the red, green, and blue LEDs. Calibration factor vs LDR current plot for three types of LEDs are shown below in Fig. 4. Since the resistance of the LDR decreases with increased light, more current means more light falling on the LEDs. In order to derive the calibration factor, the input voltage/current to the LEDs needs to vary gradually. Current through the LDR(I_{LDR}) was recorded at each light intensity. PM100D was used to measure the actual optical power (P_{actual}) before conducting the experiment. The measurement power is calculated using ohm's law.

$$P_{measured} = V_{resistor} * I_{LDR} \tag{2}$$

The calibration factor is the ratio between the actual and measured power.

$$CalibrationFactor = \frac{P_{actual}}{P_{measured}} \tag{3}$$

The LDR current vs Intensity curves of Fig. 4. represent the LDR response to varying light intensity from the red, blue, and green LEDs. These curves illustrate the relationship between the LDR current (iLDR) and the corresponding light intensity (LLDR) for each LED color.

The LDR current vs calibration factor curves of Fig. 4. demonstrate the calibration factors derived for each LED. These curves reflect the relationship between the LDR current and enabling LED power estimation.

Fig. 5. illustrates a comparison between the L-I curves obtained using our setup and the reference data from the PM100D optical power meter. The red LED yields the most accurate results, while the green and blue LEDs produce slightly lower power readings. This discrepancy is due to the LDR's inability to capture the full power emitted by the LED. Although the LED and LDR are enclosed in a black box, some of the LED's emitted power is not captured by the system.

The deviation observed in the red LED is smaller compared to the blue and green LEDs in Fig.5. This can be attributed to the varying responsiveness of the LEDs at different flux levels. At higher flux densities, the LDR's sensitivity to flux changes diminishes. As a result, when the current is higher in the blue and green LEDs, the deviations in the graphs are more pronounced than in the red LED.

V. CONCLUSION & FUTURE WORK

The designed hardware setup plots the L-I curves of three different LEDs quite well. By mapping the LDR current to the LED current and using a previously measured L-I curve from the PM100D optical power meter, reliable calibration curves have been created. The calibration curves of the three LEDs follow a clear and consistent pattern. Although the LDR used in the setup is not perfect and does not capture the full light power emitted by the LED, the method still provides fairly accurate results Fig 5. This curve helps to estimate the light output of the LED with reasonable accuracy. While the results show a slight difference from the actual power measured by the PM100D, the deviation is expected due to the limitations of the LDR. Overall, the calibration offers a low-cost, effective way to measure LED performance. This approach can be easily replicated for different types of LEDs in future experiments. The existing configuration can be expanded to accommodate wavelength-resolved and colorimetric measurements through the use of advanced optical sensors, which are not part of the current framework. Moreover, modifying the system for high-power, UV, or IR LEDs presents an ongoing chance to expand its applicability.

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