BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 460 (January 2024)

Optoelectronics Laboratory

Final Project Report

Section: G1 Group: 04

Laser Audio Transmission:

A Study on the Laser Properties

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Academic Honesty Statement:

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

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1 Abstract

This project focuses on transmitting audio signals using a laser-based communication system. The audio signal is digitized using an ADC and modulated via Pulse Amplitude Modulation (PAM). A laser diode emits light corresponding to the modulated signal, which is received by a solar cell at the receiver end. The received signal is demodulated and converted back to an analog signal using a DAC, which is fed to a speaker for audio playback. Applications include secure wireless communication, data transmission in hazardous environments, military signaling, inter-building communication, and optical remote sensing. The implementation demonstrates the feasibility of optical audio transmission with minimal hardware and high fidelity.

2 Introduction

In this project "Laser Audio Transmission" we have done so far-

1. Firstly, sent a baseband amplified speech signal (PAM) to a laser (red, green, blue). Then laser emits light according to the variation of the speech signal. This light is detected by a 90mmx90mm, 5V, 200mA mini solar board and produces voltage fluctuation to PAM module as per the transmitted signal and the PAM module give output (actually demodulates) as same as the original input speech signal.
2. Then we have tried to apply digital ASK modulation instead of PAM. Flow of signal was:

   Speech → Electrical Signal →ADC → ASK→ Amplifier→ Light from Laser → Detector→ Demodulation (RC) →DAC→ LNA→ Again Speech Signal.
   Unfortunately, this scheme was not successful.
3. Measured noise with respect to wavelength λ.
4. Measured noise with respect to distance.
5. Measured noise with respect to input voltage.
6. Measured noise with respect to background radiation.
7. Measured noise with respect to transparent obstacle.

3 Design

3.1 Problem Formulation

The goal of this project is to design and implement a system that transmits audio signals wirelessly using laser technology. This involves converting an audio signal into a modulated light signal, transmitting it through a laser beam, and subsequently reconstructing the audio signal at the receiver with minimal distortion and high fidelity.

1. **Signal Modulation and Transmission:**
    - Convert audio signals into a format suitable for modulation with a laser beam.
    - Ensure efficient modulation techniques to encode audio signals onto the laser beam for wireless transmission.

2. **Signal Reception and Demodulation:**
    - Design a receiver capable of detecting the modulated laser beam and extracting the encoded audio signals.
    - Utilize solar panel or similar components to accurately demodulate the received signal.

3. **Quality and Fidelity:**
    - Minimize noise, interference, and loss during transmission.
    - Maintain high fidelity of the reconstructed audio signal at the receiver.

4. **Range and Power Optimization:**
    - Optimize the system to achieve a practical range of transmission.
    - Ensure power efficiency for the laser and receiver components.

    ✓ **Alignment and Stability:**
    - Maintaining precise alignment of the laser beam with the receiver is critical, especially for long-range transmission.
    - Mitigating the effects of environmental disturbances (e.g., vibrations, wind) on beam stability.

    ✓ **Noise and Interference:**
    External factors like ambient light, weather conditions, and physical obstructions may interfere with signal integrity.

    ✓ **System Power Requirements:**
    Balancing laser intensity to ensure sufficient signal strength while adhering to safety and power constraints.

    ✓ **Component Selection:**
    Selecting appropriate lasers, photodetectors, and amplifiers to ensure system compatibility and performance.

5. **System Requirements:**
    - **Transmitter Module:**
        1. Laser diode capable of modulating audio signals.
        2. Modulation circuit to convert audio signals into optical signals.

    - **Receiver Module:**
        1. Solar panel to capture the laser signal.

2. Amplifier and filtering circuits to process the received signal.
3. Speaker or audio playback system for output.

- **Communication Link:**
  1. A clear line of sight for the laser beam.
  2. Adequate safety measures to prevent exposure of laser beams to unintended targets (e.g., human eyes).
  3.

6. **Evaluation Metrics:**

   - **Signal-to-Noise Ratio (SNR):** Evaluate the clarity of the received audio signal.
   - **Transmission Range:** Determine the maximum distance achievable without significant signal loss.
   - **Audio Fidelity:** Measure the accuracy of the reconstructed audio signal compared to the original input.

3.2 Design Method

The design of our laser-based audio transmission system began with a thorough theoretical analysis to understand the principles of laser communication and define the system's requirements, such as range, signal quality, and environmental factors. We then selected key components, including the appropriate laser diode, photodetector, amplifiers, and filters, to ensure optimal performance. The hardware setup involved designing and assembling the transmitter and receiver circuits, along with integrating collimating optics to maintain beam stability. We carefully tested the system, aligning the components for stable communication and debugging any issues in the hardware and software.

After initial testing, we evaluated the system's performance by measuring laser properties such as intensity and divergence and testing the system under various environmental conditions. Optimization focused on fine-tuning the laser power and receiver sensitivity, incorporating filters to reduce noise, and ensuring energy efficiency for potential portable applications. Finally, we integrated all components, verified the system's reliability and stability, and documented the results, delivering a functional and efficient laser-based audio transmission system.

3.3 Circuit Diagram

Transmitter:

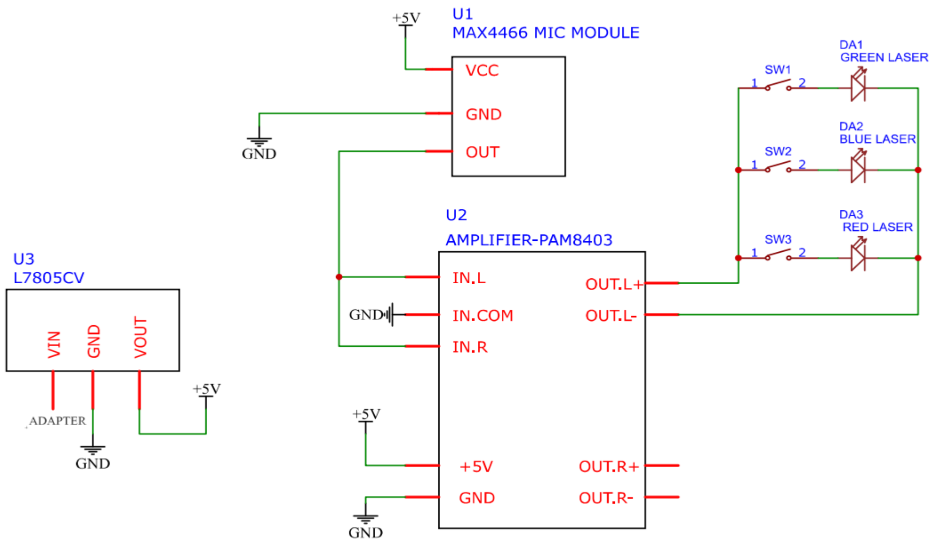

Figure 1 : Transmitter Section Circuit Diagram

Transmitter electronic circuit consists of L7805CV, MAX4466 mic, PAM8403 class D amplifier. There are three laser which are connected by switch with the output of the amplifier. This modulates the amplitude of the laser according to the intensity of the sound.

Receiver:

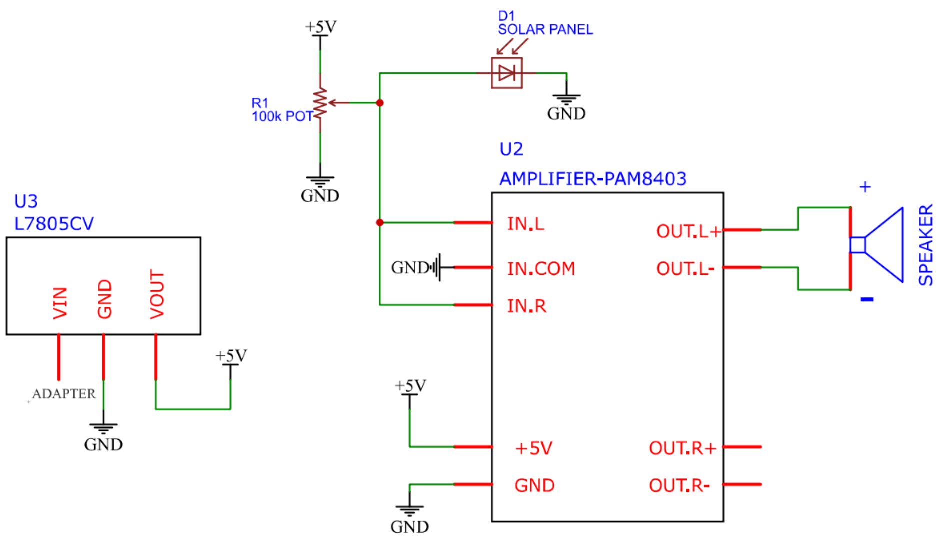

Figure 2 : Receiver Section Circuit Diagram

Receiver electronic circuit consists of L7805CV speaker and PAM8403 class D amplifier. The amplitude modulated light falls upon solar panel, as a consequence the voltage and current of solar panel varies. This signal gets modified by the PAM-8403 module and vibrates the speaker.

3.4 Full Source Code of Firmware

We have tried to utilize digital modulation scheme ASK (Amplitude shift keying) coded into Arduino Uno board for noise minimization. Full source code is given below:

```
//Transmitter code

/* Serial laser communicator, transmitter
 The circuit:
 * laser VCC pin to pin 6, - pin to ground
 * photodiode signal on pin 7, power pins as normal
 Note:
 * timer 2 used
 * For arduino uno or any board with ATMEL 328/168.. diecimila, duemilanove, lilypad, nano, mini...
 Author: Andrew R. from HobbyTransform (http://hobbytransform.com/)
 Written in 2016
*/
#include <HT_hamming_encoder.h>
#include <HT_light_modulator.h>
HT_PhotoTransmitter laser;

void setup(){
  laser.set_speed(25000);
  laser.begin();
  Serial.begin(9600);
}
//timer2 interrupt toggles LIGHT_SEND_PIN at
//determined speed to transmit each half bit
//via the manchester modulated signal.
ISR(TIMER2_COMPA_vect){
  // transmit message, if any
  laser.transmit();
}



void loop(){
  char incomingByte;
  uint16_t msg;
  incomingByte = Serial.read();
  if(incomingByte != -1){

Serial.print(incomingByte);
msg = hamming_byte_encoder(incomingByte);

    laser.manchester_modulate(msg);
    //delay(44);
  }
}
```

```
//Receiver code

/* Serial laser communicator, receiver

 The circuit:
 * laser VCC pin to pin 6, - pin to ground
 * photodiode signal on pin 7, power pins as normal
 Note:
 * timer 2 used
 * For arduino uno or any board with ATMEL 328/168.. diecimila, duemilanove, lilypad, nano, mini...

 Author: Andrew R. from HobbyTransform (http://hobbytransform.com/)
 Written in 2016
*/
#include <HT_hamming_encoder.h>
#include <HT_light_modulator.h>

HT_PhotoReceiver pdiode;

void setup(){

  pdiode.set_speed(25000);
  pdiode.begin();
  Serial.begin(9600);

}//end setup

//timer2 interrupts LIGHT_RECEIVE_PIN at determined speed to receive each half bit
//via the manchester modulated signal.
ISR(TIMER2_COMPA_vect){

  //receive message, if any
  pdiode.receive();

}

void loop(){

  //print and return most recently received byte, if any, only once
  pdiode.printByte();

}
```

3.5

Figure 3 : Source Code for ASK Modulation

Output of this ASK scheme:

Unfortunately, this code of ASK scheme can only transmit ASCII equivalent binary numbers. In other words, we need to two converters _ one at the transmitter (Binary to ASCII) and one at the receiver (ASCII to binary). These inclusions make the system unstable and noisy. That's why we've discarded this ASK modulation scheme. Rather we've used PAM modulation and amplification stated above already.

4 Hardware Design

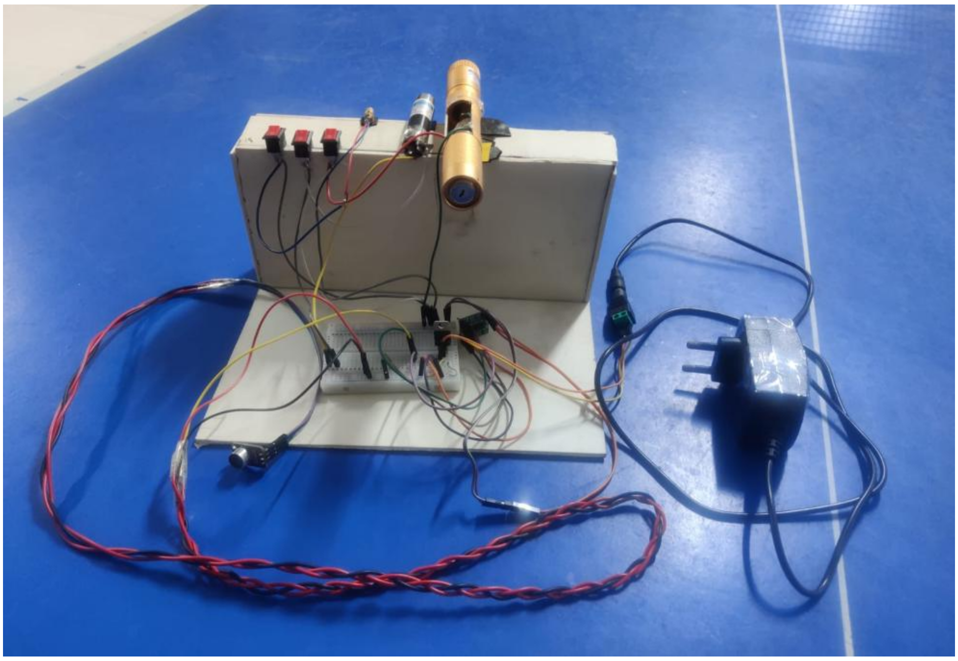

Figure 4: Transmitter Set-up of the Hardware Design

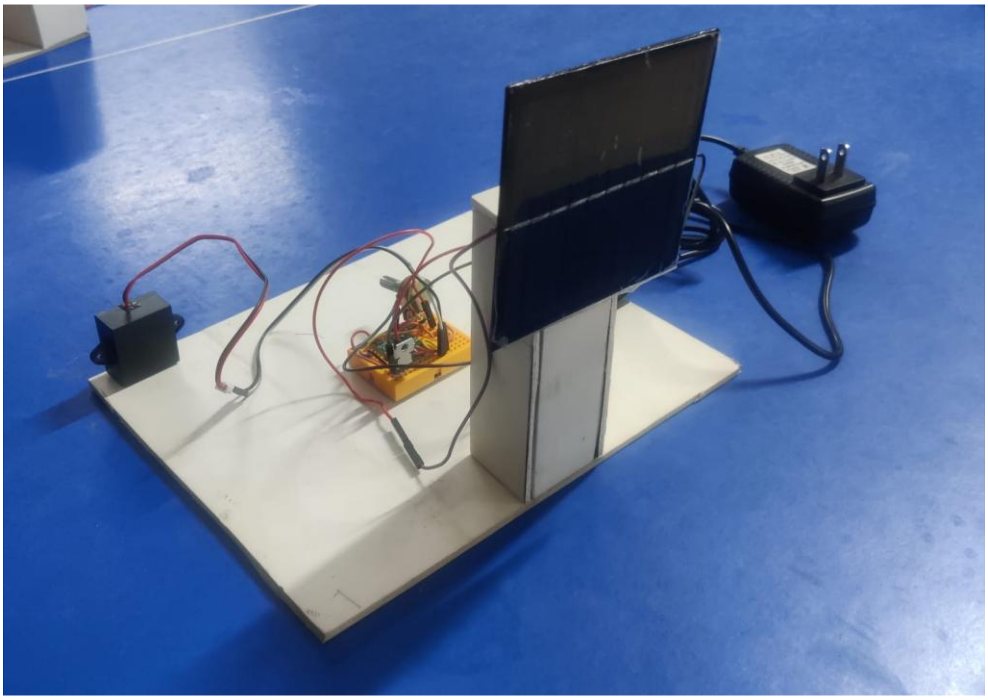

Figure 5 : Receiver Set-up of the Hardware Design

5 Components

Our system consists of two modules. One is transmitter and second is receiver. There is no physical connection between them. Both of them are mobile. The used modules are-

1. **Laser:**

Figure 6 : Laser Module

The characteristics of the used laser for this project are -

- **Output Rated Power:** Min 2.5mW, Typical 3.0mW, Max 5.0mW
- **Current Rating :** Min 10mA, Typical 20mA, Max 25mA
- **Working voltage:** Min 2.3VDC, Typical 4.5VDC, Max 8.0VDC
- **Wavelength: 650nm** (Red laser), 532**nm** (Green laser), 405**nm** (Blue laser).

2. **Solar panel:** The solar panel has been used in the project-

Figure: 7 Solar Panel Module

Solar Panel Specifications:

Rated Open Circuit Voltage: 6 V

Rated Maximum Power Voltage: 5V

Rated Short Circuit Current: 200mA

Rated Maximum Power: 1 W

Dimension: 90mm×90mmx3mm

Later we discovered that that beamwidth increases with increasing distance. A large solar panel may do better in longer distance.

3. MAX4466 Microphone Module

- **Working Voltage:** 2.4-5.5V
- **PSRR:** 112dB
- **CMRR:** 126dB

Figure 8 : Microphone Module

4. PAM8403 audio amplifier:

The PAM8403 is a 3W, class-D audio amplifier. It offers low THD+N, allowing it to achieve high-quality sound reproduction. The new filter less architecture allows the device to drive the speaker directly, requiring no low-pass output filters, thus saving system cost and PCB area. With the same numbers of external components, the efficiency of the PAM8403 is much better than that of Class-AB cousins. It can extend the battery life, which makes it well-suited for portable applications.

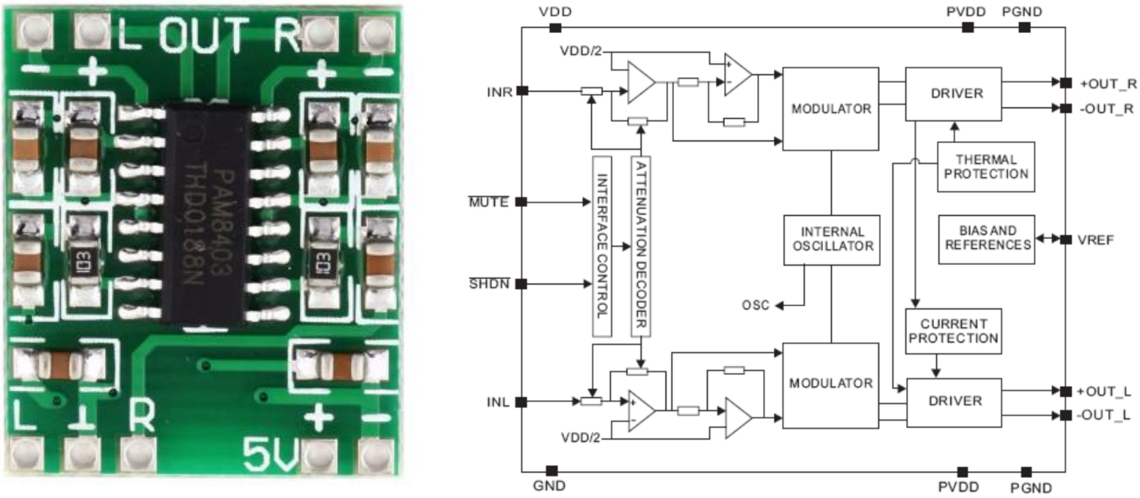

Figure 9: PAM Module and Schematics

Digital power amplifier is generally composed of several parts such as pulse generator, PWM circuit, switching amplifier and demodulator. The pulse generator generates a square wave signal with a duty cycle of 50%. The audio signal is input from the Vin terminal, and the pulse width modulation is performed on the square wave signal output by the pulse generator, so that the pulse width is proportional to the amplitude of the input audio signal. width modulated pulse signal. After the signal is amplified by the switching amplifier (the power tube works in the switch state), and then demodulated by the low-pass filter, the speaker can be driven to work. This is the basic working principle of the digital power amplifier.

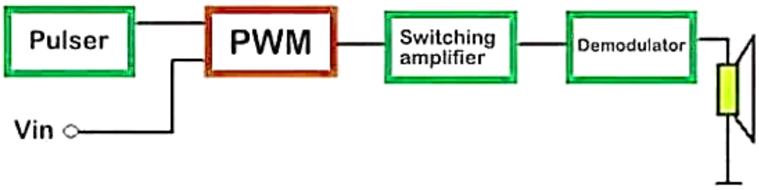

Figure 10 : Block Diagram of Digital Power Amplifier

5. L7805 Voltage Regulator:

L7805 is used to give constant 5V between VCC and GND. This was necessary as the maximum operating voltage of PAM is 5.5V.

Figure 11 : Voltage Regulator LM7805

6. **Mini Speaker**

- Internal Resistance : 8 Ω
- Rated Maximum Power: 3 W

Figure 12 : Speaker Module

7. **Potentiometer**
   - ❖ Maximum rating of the potentiometer : 100k

Figure 13: Potentiometer

6 Design Analysis and Optimization

6.1 Novelty

The novelty of this project lies in the integration of laser-based communication for audio signal transmission using minimal hardware while achieving high fidelity and practical implementation. Unlike traditional RF or optical communication systems, this project explores:

1. The design and implementation of a cost-effective receiver module utilizing a mini solar board for signal demodulation.
2. Systematic analysis and characterization of noise sources, including wavelength, distance, input voltage, background radiation, and transparent obstacles, to enhance system robustness.
3. Application-driven design targeting secure communication in hazardous environments and inter-building data transmission, addressing alignment and stability challenges through innovative approaches.
4. The demonstration of optical communication with simplified circuitry, making it accessible for educational and experimental purposes.

6.2 Design Optimization

In this project of 'Laser Audio Transmission' we've tested how noise can be improved in laser communication with respect to five major properties of laser.

1. Wavelength (λ).
2. Distance (d).
3. Input voltage (V).
4. Background radiation.
5. Transparent Obstacle.

With respect to these factors, we've optimized our design and came to the conclusions that.

a. Wavelength (λ) determines the energy of laser. But intensity depends on illuminated area of the beam of the laser. The smaller the area, the more intensity we have. So, smaller beam width corresponds to louder receiver sound. At the same time, we need to consider the responsivity of the photodetector as well to check which region of λ responds well.
b. For light we know $I \propto (1/d^2)$. But for laser, this relation may not be true. Because the laser beam is highly collimated and concentrated. We need to optimize how much distance we can cover for a considerable and tolerable amount of noise.
c. Input voltage of laser will be varied according to the variation of speech. We need to record the intensity variation/modulation of signal and determine the minimum amount of fluctuation needed to overcome noise.
d. We have tested the presence of three types of background noise condition___ daylight, artificial light, dark room to find out the best environment suited to laser operation.
e. We also need to check if our design can sustain any thin transparent barrier between transmitter and receiver such as cloud, rain, fog, fume and dust particles etc.

By testing all these conditions, we can conclude to best possible operating conditions with suitable surrounding and appropriate setup. These will be explained further.

6.3 Design Considerations

Designing a reliable laser-based audio transmission system requires addressing key factors:

- **Optical Link Stability:** Ensure precise alignment, minimize beam divergence with collimating optics, and mitigate environmental disturbances like wind and vibrations.
- **Noise Reduction:** Use shielding to block ambient light, high-quality circuitry to reduce electronic noise, and filters to suppress unwanted frequencies.
- **Power Management:** Optimize laser intensity for safety, maximize receiver sensitivity with efficient photodetectors, and minimize circuit power consumption.
- **Component Selection:** Choose reliable laser diodes, sensitive photodetectors, and low-noise amplifiers for efficient signal processing.
- **Safety:** Implement measures to prevent accidental laser exposure and protect components from damage.
- **Performance:** Balance laser power and receiver efficiency for the desired range while ensuring audio fidelity through efficient modulation techniques.
- **Cost and Scalability:** Use affordable, modular components adaptable for various applications and distances.

These considerations ensure robust performance, high fidelity, and cost-efficiency.

7 Investigation

To complete our project, we have done a group of hardware experiments emphasizing the knowledge what we have earned from the lab. We have investigated the laser property, built a circuit and used it for communication purposes.

7.1 Design of Experiment

We have done three basic experiments of laser and PV cell to collect data with the help of the knowledge of our sessional course. Special focus was on the property's verification of laser along with the PV cell.

7.1.1 Set of the Instrument for Light-Current (L-I) Characteristics of Laser

Figure 14: Digital Optical Power Meter Console (Thorlabs model PM100D)

Figure 15 : Silicon Photodiode Sensor (Thorlabs model S120VC)

To measure the L-I characteristics, we have used this module of Thorlabs- Thorlabs PM100D and Thorlabs S120VC. The sensor should be such a position that the light beam enters into to the sensor hole. To take data with respect to distance we moved the sensor module keeping the main circuit stagnant.

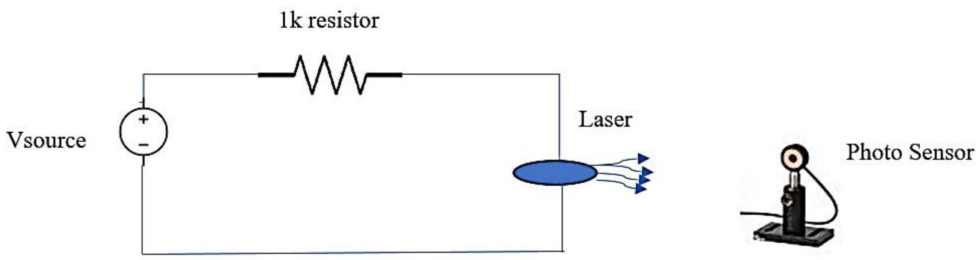

Figure 16: Set-up schematic for L-I

Thorlabs PM100D and S120VC instrument have been used to go through the experiment. We continuously varied the input voltage and measured the voltage across the 1k resistor. From here we got the current through the laser in mA range. To get the voltage across the laser , the measured voltage was subtracted from the input voltage. Simultaneously, the laser light power was also noted from Digital Optical Power Meter Console (Thorlabs model PM100D) which was sensed by Silicon Photodiode Sensor. Same procedure has been done for Blue , Green and Red colored laser.

7.1.2 Set-up of the Instrument for Spectral Characteristics analysis of Laser

Figure 17 : Set up for spectral analysis of the laser

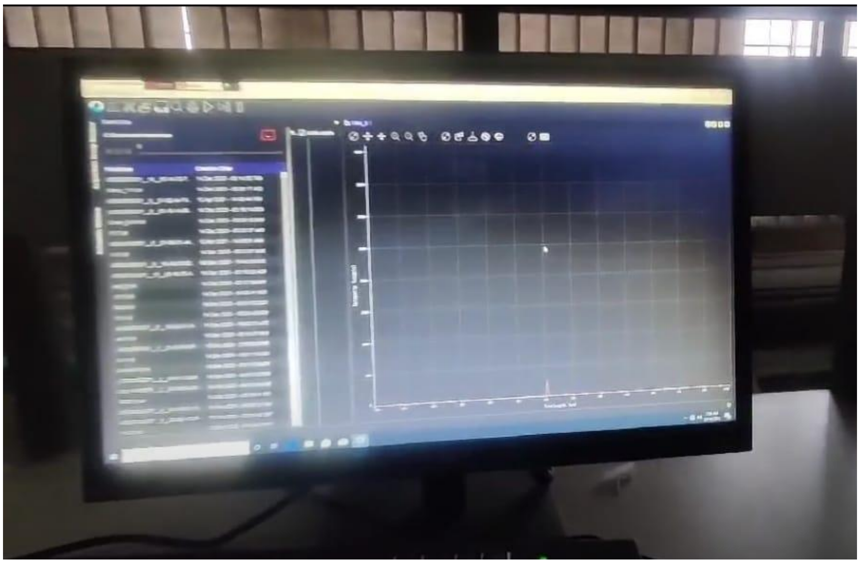

Figure 18: Output of the Spectral Characteristics of the laser

To do the analysis Optical Spectrometer (Red Tide USB650 Fiber Optic Spectrometer) was used. Spectrometer compatible optical fiber was connected with the spectrometer. Spectroscopy software (OceanviewTM) was run to display and collect the laser data. The same experiment has been done for Green and Red laser.

7.1.3 Set-up for I-V Characteristics of Solar Panels

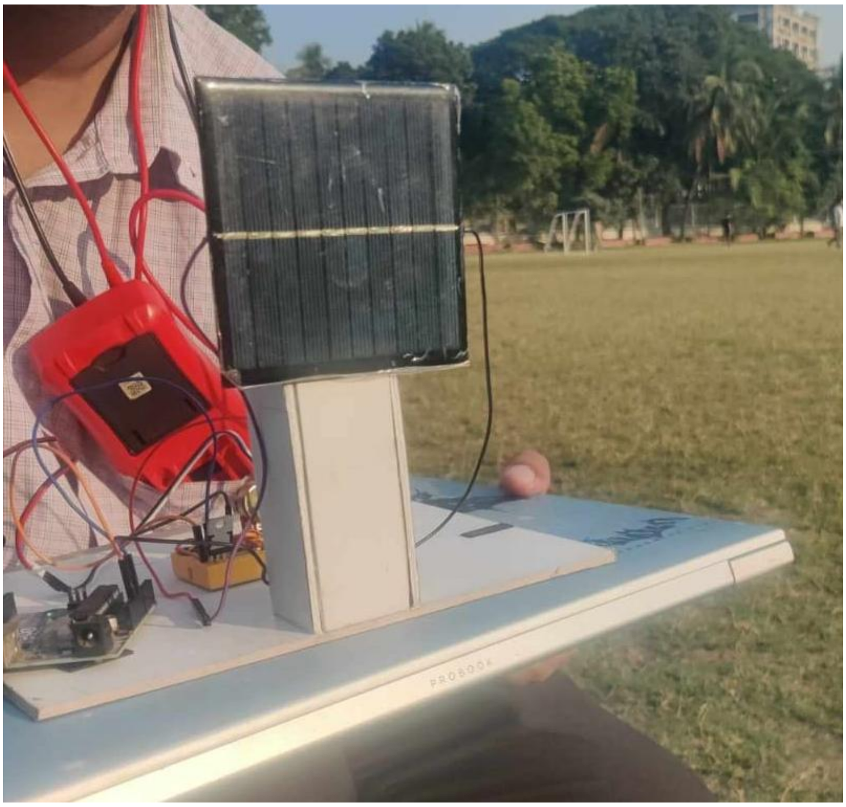

Figure 19 : Set-up for the I-V characteristics of solar

The experiment was done with the reference of the experiment that we have done in our **experiment 06 Titled "Measurement and Analysis of I-V Characteristics of Solar Panels and Cells".** To have the higher light intensity, we did the experiment on the open field with a high day light.

7.1.4 Noise Vs Wavelength, Distance, Background Radiation and Medium

Figure 20 : Set-up for noise measurement for (Water + Glass) medium

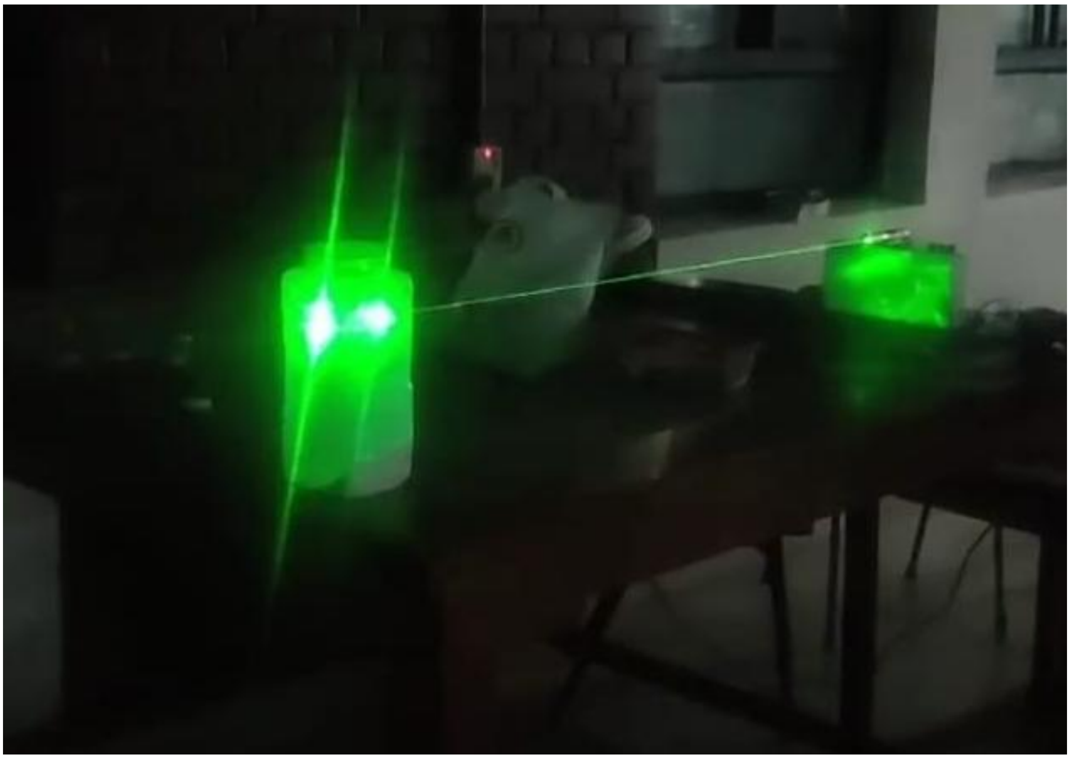

Figure 21 : Set up for noise measurement for (Plastic+ Air) medium

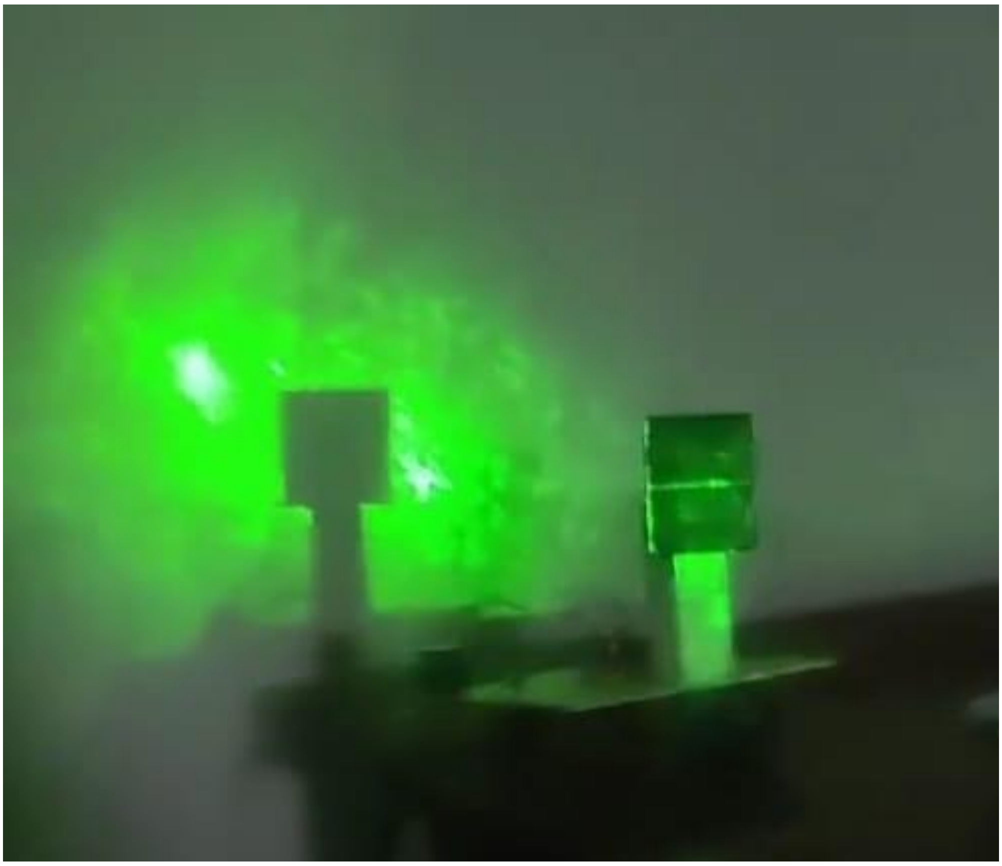

Figure 22 : Receiving set-up for (Plastic+ Air) medium

We have done this experiment to investigate the effect of different medium on noise performance and the receiving signal. Normally the experiment has been done on Air medium, to investigate the effect we have done on (Water+ Glass) and (Plastic + Air) . With the presence of this medium the receiving signal got some extra bit noise but the signal was reconstructed with audible range.

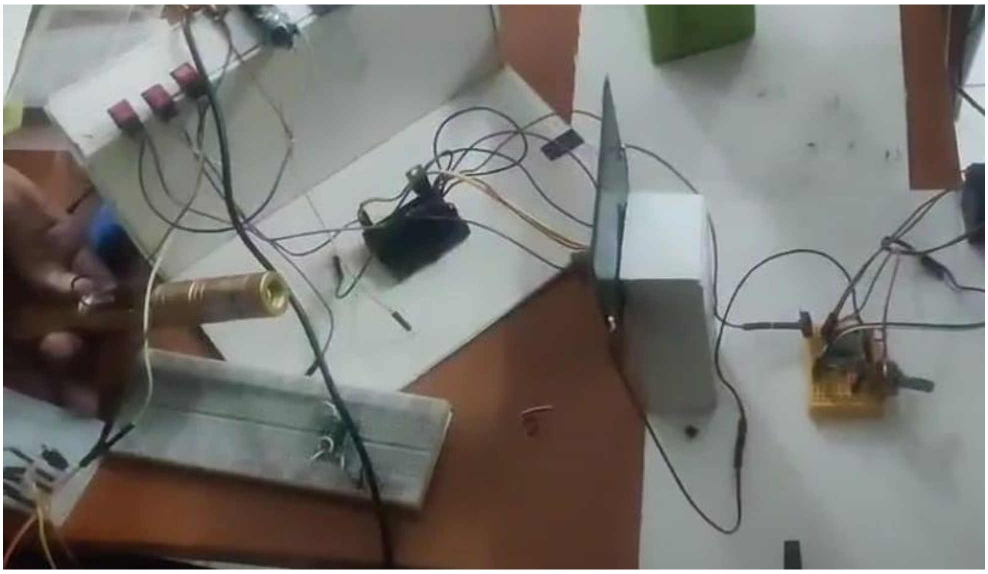

Figure 23 : Set-up for data collection on Day light

Figure 24: Set-up for data collection on Dark room on the Receiving side

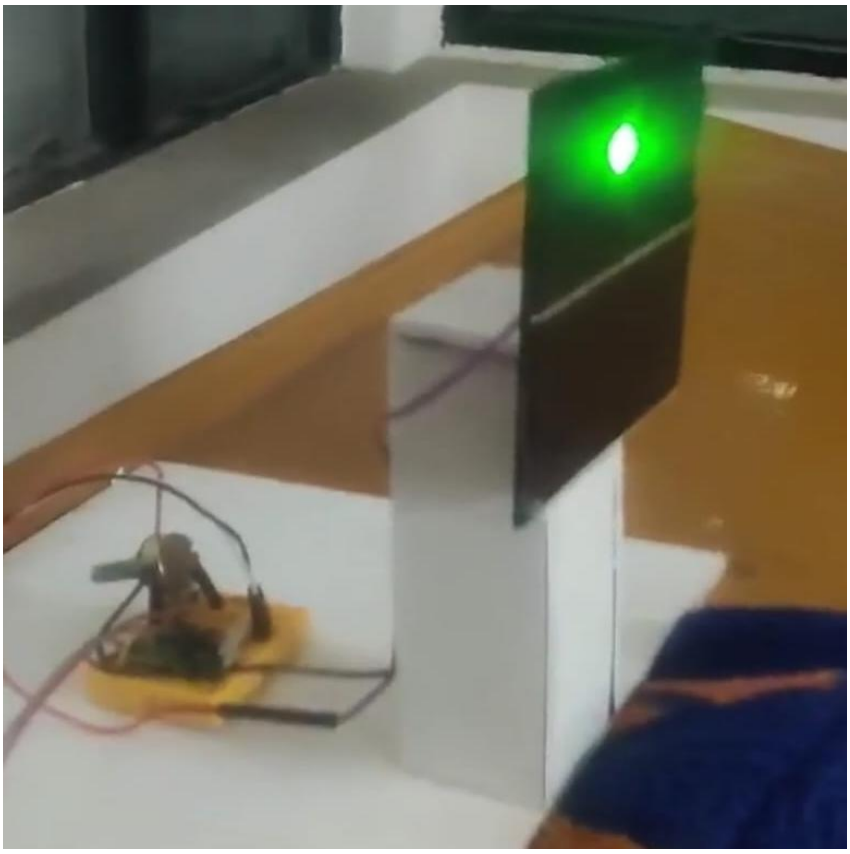

Figure 25: Set-up for data collection on Artificial lamp light

To collect data on daylight, artificial light and dark room , we have made our set-up above mentioned procedure.

7.2 Data Collection

We have collected data on each of the set-up mentioned above. We have collected data by physically on lab and on field simultaneously.

7.2.1 Data Collection for L-I Characteristics

For Blue Laser,

Output Light Power (μW)	**Voltage Across Laser (V)**	**Current Through Laser (uA)**
0.01	0	0
0.019	0.4913	8.7
0.019	0.989	11
0.019	1.4847	15.3
0.019	1.9842	15.8
0.019	2.3052	34.8
0.019	2.4858	114.2
0.32	2.6	200
0.017	2.7	260.3
1.6	2.74	300
2.3	2.7461	353.9
3.58	2.792	408
5.68	2.8261	473.9
9.51	2.8673	532.7
11.58	2.8679	733
22.8	2.8986	971.4
24	2.9675	1032.5
53	2.988	1220
80.5	2.9936	1263.8
102	3.02	1280
600	3.08	1320
1100	3.15	1350
2500	3.21	1390
4200	3.27	1430
4400	3.35	1450
5700	3.5	1500

Figure 26 : Data table of L-I Characteristics for Blue Laser

For Green Laser,

Output Light Power (µW)	Voltage Across Laser (V)	Current Through Laser (mA)
0.047	0	0
0.044	0.9956	0.0044
0.125	1.55	0.16
7.3	2.13	0.51
17.6	2.33	0.67
236	2.52	0.98
375	2.62	1.08
453	2.67	1.13
671	2.69	1.21
840	2.76	1.24
1060	2.78	1.35
1460	2.82	1.46
1920	2.84	1.55
2600	2.86	1.6
2890	2.88	1.65
3010	2.905	1.66
3100	2.953	1.67
3350	2.992	1.73
4550	3.095	1.81
5300	3.154	1.87
9100	3.251	2.05

Figure 27 : Data table of L-I characteristics for Green Laser

For Red Laser,

Output Light Power (µW)	Voltage Across Laser (V)	Current Through Laser (mA)
1.52	0	0
1.52	0.3	0
1.52	0.7	0
0.227	1.1	0
0.246	1.6531	0.0469
0.356	1.7581	0.1419
0.482	1.7682	0.2218
0.682	1.7774	0.3326
0.829	1.7923	0.4077
0.951	1.8318	0.4682
1.142	1.8393	0.5607
1.286	1.8425	0.6275
1.55	1.8573	0.7427
1.85	1.8659	0.8741
2.214	1.8795	1.0205
2.31	1.939	1.061
2.64	1.9467	1.1433
2.91	1.9568	1.2432
3.26	1.9662	1.3638

Output Light Power (µW)	Voltage Across Laser (V)	Current Through Laser (mA)
3.52	1.9746	1.454
3.78	1.9758	1.542
4.38	1.9794	1.606
4.54	1.9861	1.7439
4.82	2.0053	1.7947
5.14	2.0138	1.882
5.32	2.0155	1.9845
5.79	2.0227	2.0573
6.14	2.0368	2.1832
6.2	2.0512	2.2888
6.2	2.093	2.307
6.664	2.0532	2.4468
6.77	2.1214	2.4786
7.194	2.1305	2.5995
7.64	2.1728	2.7272
7.97	2.1798	2.8202
8.01	2.1877	2.8323
8.71	2.1856	3.0144
9.147	2.1893	3.2207
10.264	2.1938	3.4362
11.194	2.2014	3.5986
11.59	2.2253	3.7747
12.19	2.2739	3.9261
12.96	2.2898	4.1102
13.834	2.2828	4.3172
14.9	2.3473	4.5527
16.44	2.3536	4.8464
17.5	2.4161	5.0839
19.49	2.435	5.465
21.4	2.46	5.84
24.4	2.528	6.372
26.8	2.621	6.779
31	2.626	7.374
34.5	2.749	8.151
41.2	2.844	8.756
59.2	2.9	9.567
107.5	2.983	10.317
621	3.059	11.241
1260	3.167	12.333
1920	3.288	13.712
2580	3.46	15.54

Figure 28 : Data Table of L-I characteristics for Red Laser

At first , we have measured the voltage across the 1k resistor , it will be the current through the laser in mA range and to have the voltage across the laser subtracted the voltage of 1K resistor from the input voltage.

7.2.2 Data Collection for Spectral Analysis

Green		Red	
λ (Lambda)	**Intensity**	**Lambda**	**Intensity**
517	10.17	**640**	70.02
518	9.02	**641**	84.13
519	9.18	**642**	135.14
520	11.77	**643**	135.85
521	15.71	**644**	137.99
522	15.8	**645**	152.05
523	13.17	**646**	193.11
524	13.37	**647**	240.12
525	14.17	**648**	260.72
526	16.53	**649**	307.06
527	32.62	**650**	359.51
528	26.28	**651**	548.05
529	28.51	**652**	914.99
530	72.52	**653**	1759.37
531	**2119.74**	**654**	**3988.95**
532	***4018.16***	**655**	**4014.02**
533	**2602.45**	**656**	**4013.95**
534	122.59	**657**	**4014.02**
535	41.28	**658**	4003.1
536	23.96	**659**	969.75
537	17.32	**660**	532.89
538	10.16	**661**	419.21
539	11.48	**662**	357.29
540	9.02	**663**	295.2
541	9.25	**664**	252.28
542	7.17	**665**	217.82
543	5.96	**666**	201.47
544	7.14	**667**	166.05
545	7.09	**668**	139.05
546	7.2	**669**	108.61
547	6.56	**670**	100.91

Figure 29 : Data table of Spectral Analysis for Green and Red Laser

This data have been collected with oceanviewTm software. The data shows that the green laser has its maximum intensity at 532nm which is exactly what was mentioned in the datasheet but the red one has pick at 655nm which is 3nm greater than the datasheet value of 652nm.

7.2.3 Data Collection for I-V Characteristics of Solar Cell

Voltage (V)	Current (I)
0	-220
0.5	-219
1	-218.08
1.5	-218.33
2	-218
2.5	-218
3	-217.99
3.5	-217.99
4	-217.56
4.5	-212.78
5	-200.09
5.1	-186.22
5.2	-170
5.3	-142.07
5.4	-124.19
5.5	-95.031
5.6	-81.98
5.7	-71.071
5.8	-57.025
5.9	-29
6	-0.002

Figure 30 : Data table of I-V Characteristics of Solar cell

7.2.4 Data Collection for Noise Vs Wavelength, Background radiation, Output Voltage vs Medium and Light Power Vs Distance

Noise Vs Background Radiation

Light Condition	Noise Power (uW)
Daylight	852
Artificial Light	762
Dark	710

Figure 31: Data table of Noise vs Background Radiation

Light Power Vs Distance

Blue		Green	
Distance (m)	**Light Power (uW)**	**Distance (m)**	**Light Power (uW)**
0	1186	0	1500
0.4572	1154	0.4572	1472
0.9144	1142.9	0.9144	1435
1.3716	1136	1.3716	1418
1.8288	1116	1.8288	1410
2.286	1113.2	2.286	1400
2.7432	1100	2.7432	1381
2.7432	1100	3.2004	1377
2.7432	1100	3.6576	1369
		4.1148	1354
		4.572	1296
		5.0292	1284
		5.4864	1283

Figure 32 : Data table of Light Power vs Distance

This data has been collected in the lab varying the light sensor keeping the circuit stagnant.

Output Voltage Vs Medium

Medium (Lamp ligt)	Vin (with sound) (mV)	Vin (without sound) (mV)	Signal Voltage		Vout (No operation) (V)	Vout (with laser) (V)	Only Laser Signal output Voltage (mV)	Vout (with sound) (V)	Output Signal Power (mV)
Air	90	11	79		1.77	2.04	270	2.08	40
Plastic	117	16	101		1.56	1.82	260	1.845	25
Glass + Water	117	16	101		1.56	2.3	740	2.32	20

Figure 33 : Output Voltage vs Medium for 530nm Green Laser on Artificial Lamp Light

Medium	Vin (with sound) (mV)	Vin (without sound) (mV)	Signal Voltage (mV)		Vout (with sound) (V)	Vout (without sound) (V)	Output Voltage (mV)
Air (Sunlight)	**20**	**10**	**10**		**2.58**	**2.52**	**60**
Plastic (Sunlight)	**20**	**11**	**9**		**2.55**	**2.52**	**30**

Figure 34 : Output voltage vs Medium for 652nm Red Laser on Sunlight

This Output voltage data has been collected by three steps. First, Vin with sound and without sound has been recorded. From this, approximate signal voltage can be calculated. On receiver side, firstly the PV voltage without any operation normal condition the output voltage was recorded. Then with the presence of normal nonmedullated laser light and at last with presence of the modulated signal pulse the output voltage was recorded.

7.3 Result and Analysis

7.3.1 Laser L-I, I-V and P-V output

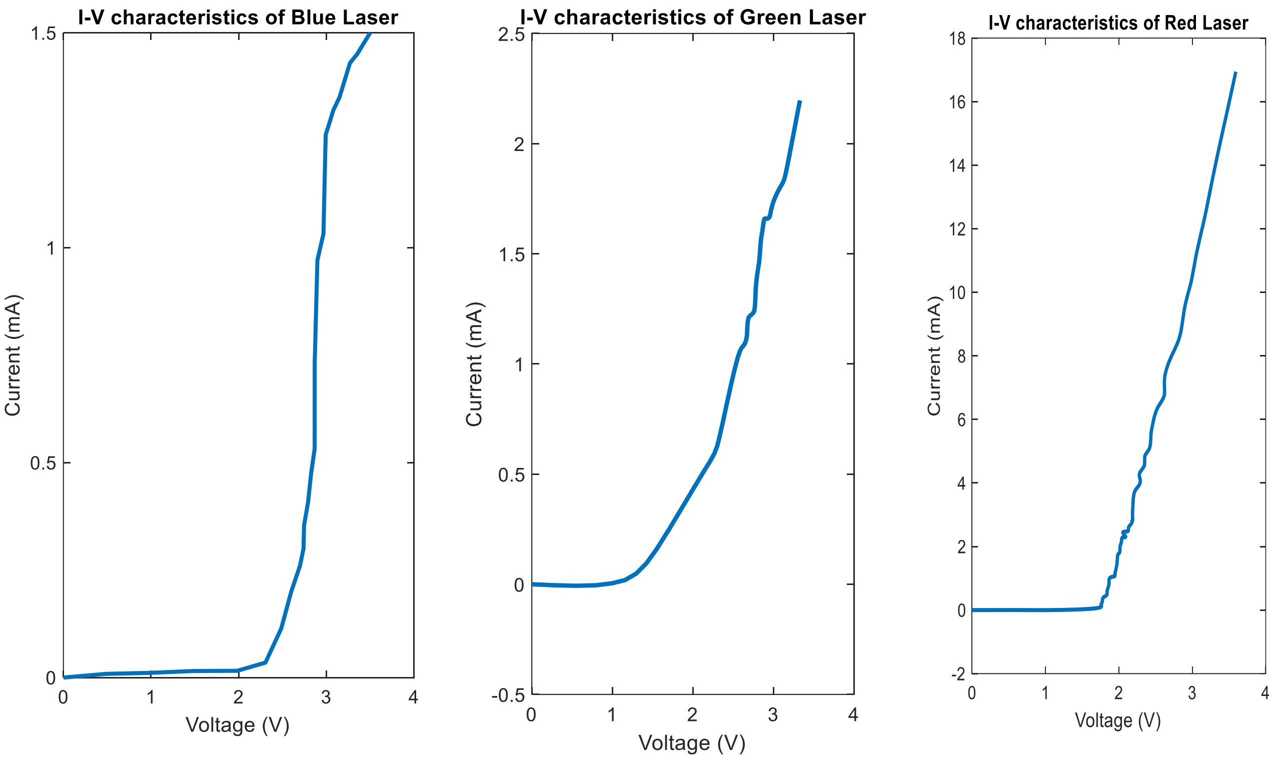

Figure 35 : I-V Characteristics of Blue , Green and Red Laser accordingly Left to Right

From the I-V graph, there is indication that the current changes drastically for all the laser. There is a certain voltage across the laser after which the laser start on . The current is going upward and the graph are not exactly exponential but there is a trend to be exponential.

Laser	Start on Voltage
Blue	2.4 V
Green	1.5 V
Red	1.8V

Figure 36 : Start-on Voltage of the different Laser

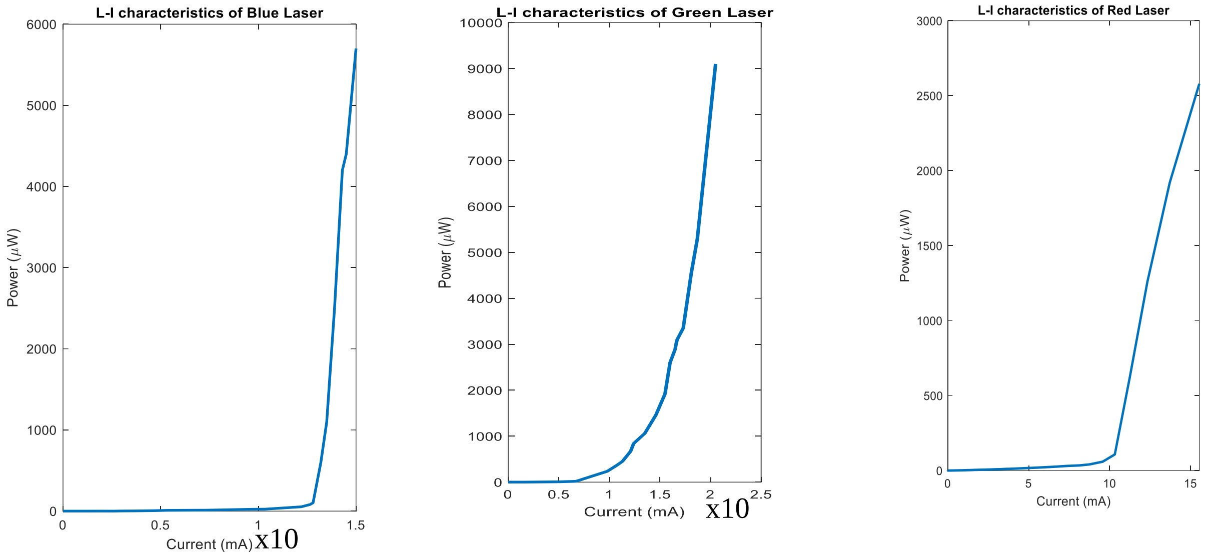

Figure 37 : L-I Characteristics of Blue, Green and Red Laser accordingly Left to Right

The L-I characteristics graph shows that there is a sharp rise in light intensity with the increase of current through the laser. The blue one shows the more sharpness than the two others. The green one has the lowest current requirement and the blue one has the highest.

Laser	Cut in current (mA)
Blue	13
Green	7
Red	8

Figure 38 : Cut-in current for different laser

Note : For green and blue laser, x axis should be multiplied by 10 because of the printing mistake.

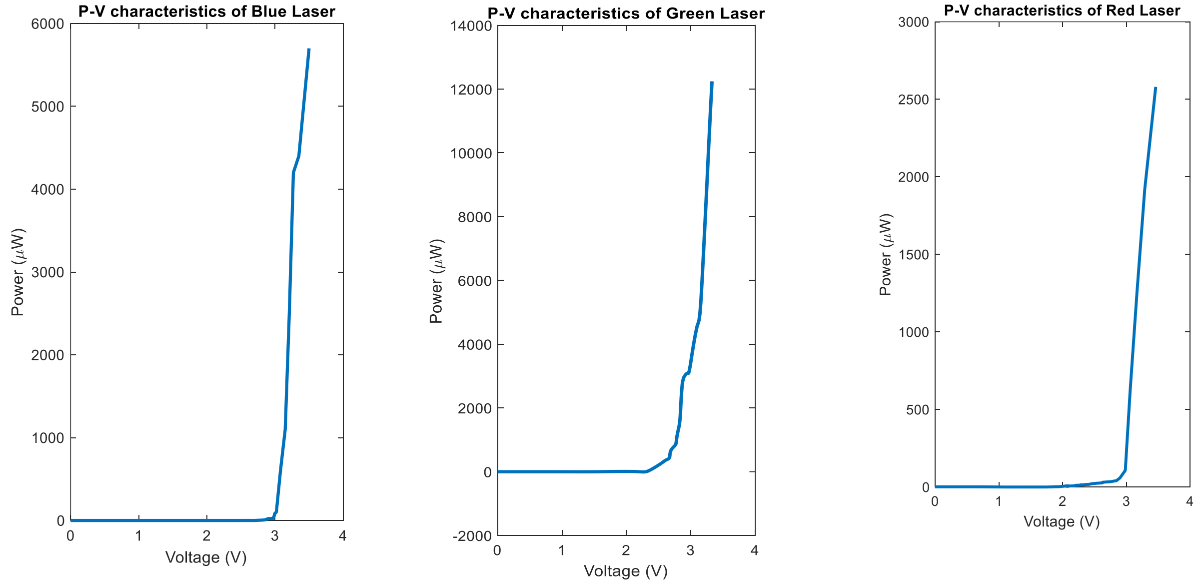

Figure 39 : P- V Characteristics of Blue, Green and Red Laser accordingly Left to Right

7.3.2 Spectral Characteristics Output

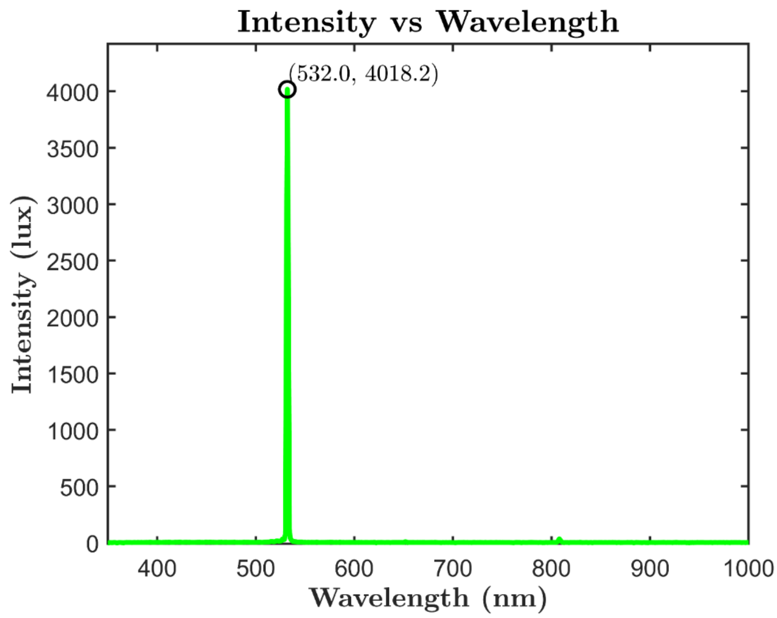

Figure 40 : Intensity vs Wavelength for the Green Laser

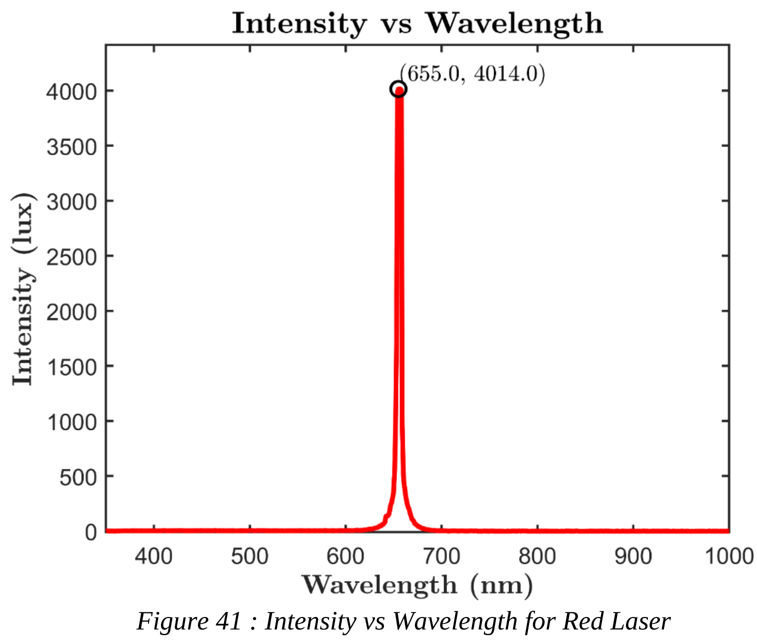

Figure 41 : Intensity vs Wavelength for Red Laser

From the graph we notice that the pick intensity for green laser and red laser is at 532nm and 655nm simultaneously. The green one matches with the datasheet but red one shows 3nm greater value. Both curve fits to highest intensity of around 4K. May be it is the limit of the machine.

7.3.3 Solar I-V Characteristics output

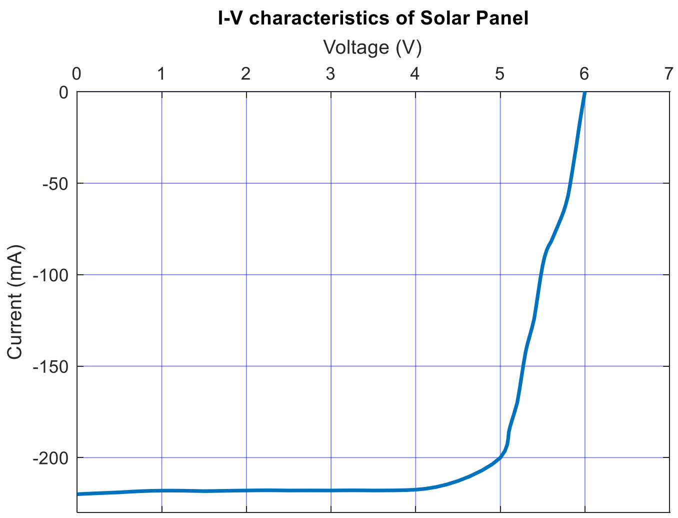

Figure 42 : I-V Characteristics of Solar Panel

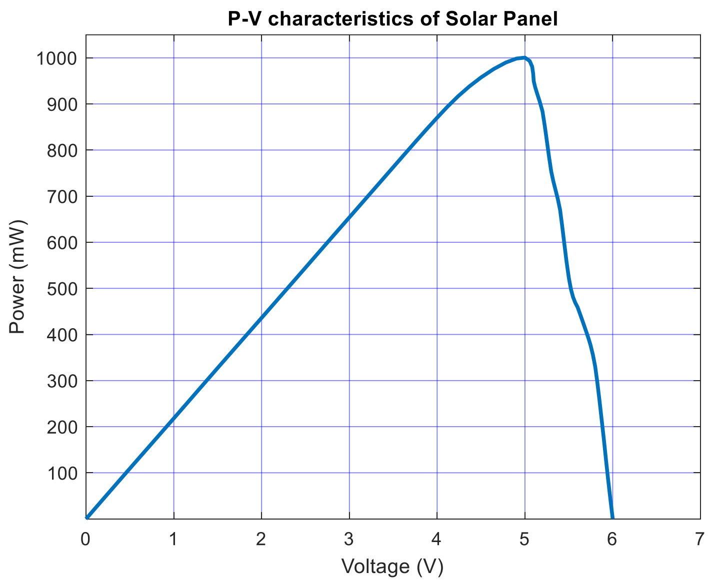

Figure 43 : P-V Characteristics of Solar Panel

Parameter	Experiment data	Datasheet data
Voc	5.97	6
Isc	230	250
Vm	5	5
Im	200	200
Pm	1W	1W
FF	0.728	
Efficiency	0.145	

Figure 44 : Data table of PV experiment output

7.3.4 Noise Vs Wavelength Characteristics

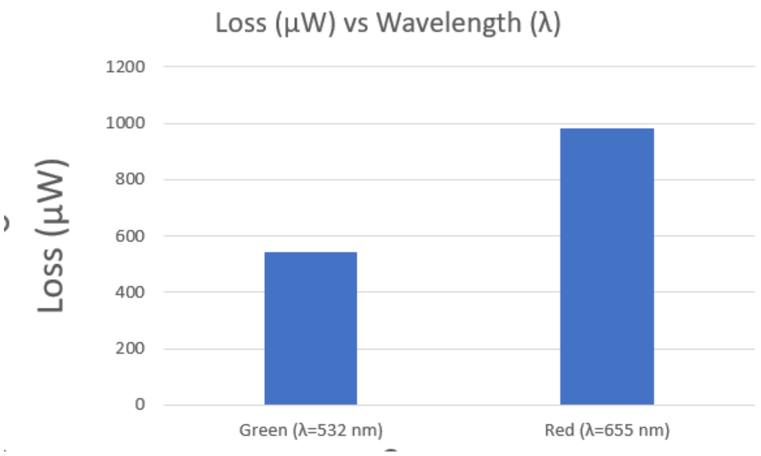

Figure 45: Loss vs Wavelength (approximate)

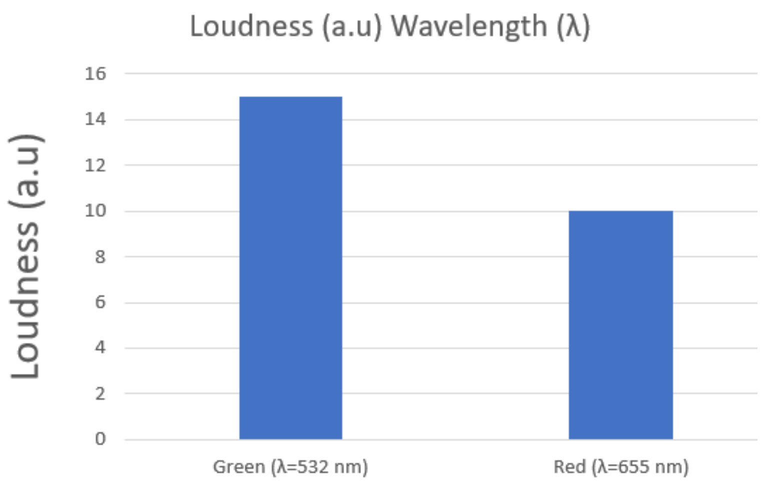

Figure 46 : Loud vs Wavelength (approximate)

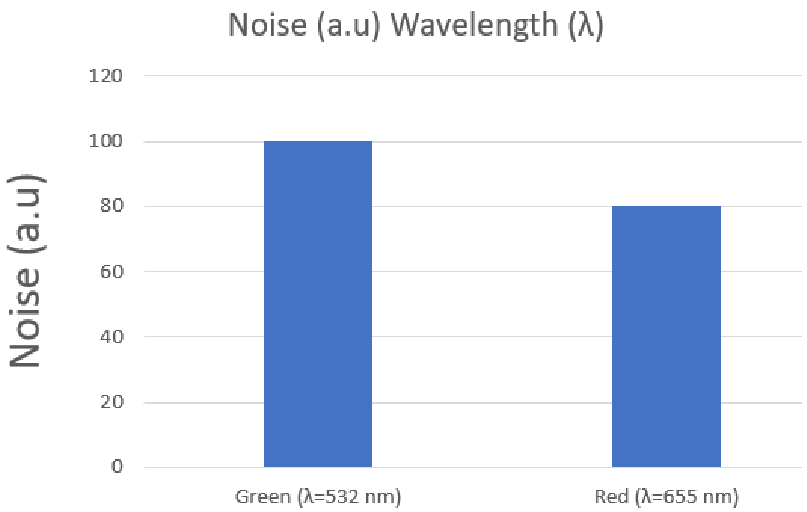

Figure 47 : Noise vs Wavelength (approximate)

7.3.5 Loss Vs Distance Characteristics

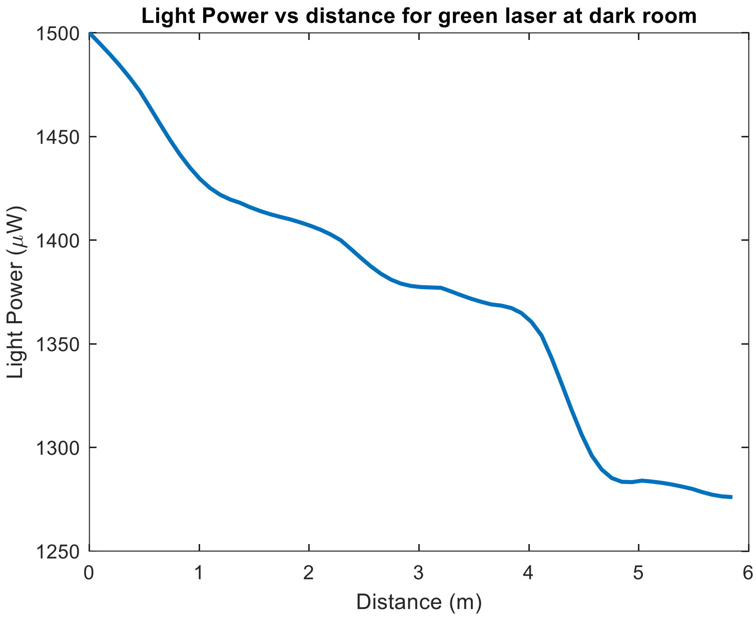

Figure 48 : Light Power vs Distance for Green Laser at Dark Room

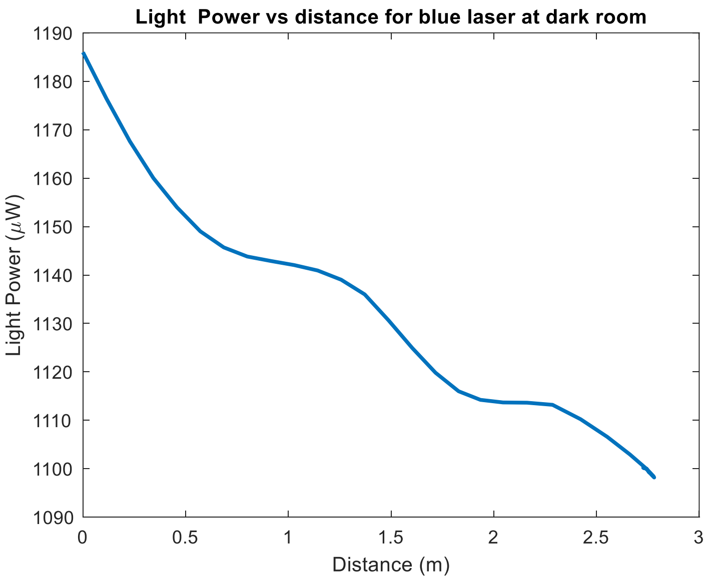

Figure 49 : Light Power vs Distance for Blue Laser at Dark Room

The light power vs distance graph indicates that as the distance increases the light power decreases. Both light show the same pattern of decreasing behavior. Red light shows low decreasing rate than the green one.

7.3.6 Loss Vs background radiation Characteristics

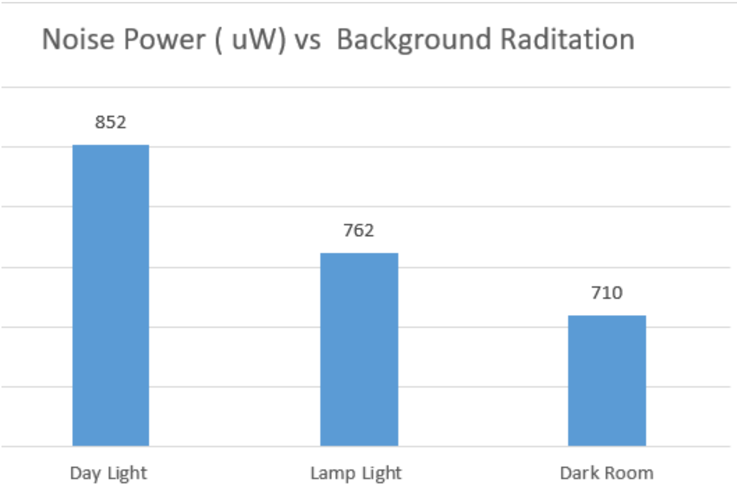

Figure 50: Noise power vs Background Radiation

It is indication from the graph that the dark room has the lowest noise power compare with the lamp light or daylight. Also the laser shows the best behavior in the dark among these medium.

7.3.7 Noise Vs Medium Characteristics

Medium	**Light**	**Input signal voltage**	**Output Signal Voltage**	**Signal Gain**
Air	lamp light	79	40	0.506329
	Sunlight	10	60	6
Plastic	lamp light	101	25	0.247525
	Sunlight	9	30	3.333333
Glass+water	lamp light	101	20	0.19802
	Sunlight	10	18	1.8

Figure 51 : Input, Output and Signal Gain for different medium and Light source

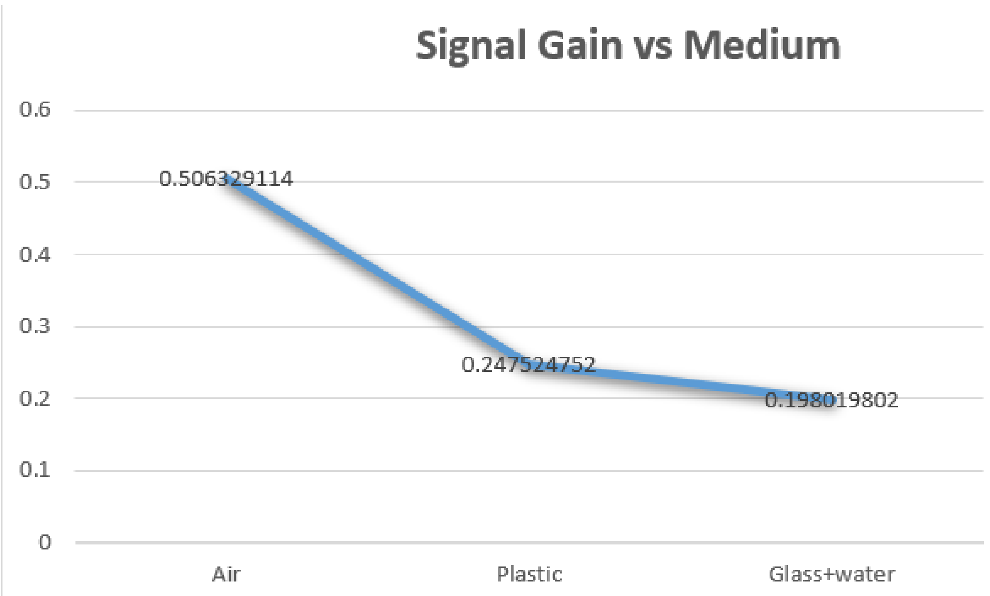

Figure 52 : Signal Gain vs Medium of Green Laser on Artificial Lamp Light at fixed Distance

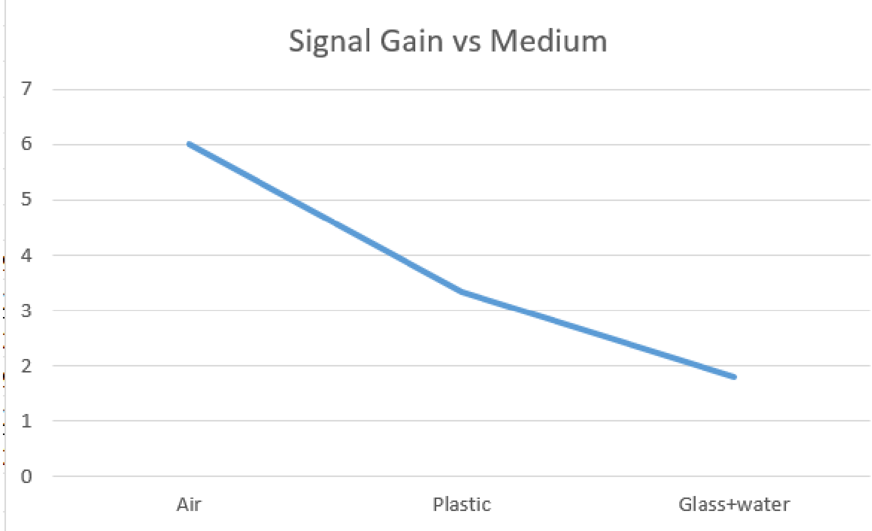

Figure 53 : Signal Gain vs Medium of Red Laser on Sunlight at fixed Distance

The graphs show that the output signal gain decreases with the presence of the medium other than Air. Both light shows the same pattern of decreasing behavior. On the second case the effect of sunlight was not excluded that's why the gain value such on. But the pattern is correct.

7.4 Interpretation and Conclusion on Data

8 Limitations of Tools

1. Purple laser (λ=405 nm) could not work because our mV range speech sound could not fulfil the requirement of laser threshold voltage (V_{th}) and could not supply threshold current (J_{th}). That's why it did not work.
2. During measurement of laser characteristics, the S120VC power head might be misaligned sometimes. This could lead to errors in measurements.
3. Optical energy and power meter (PM100D) reading fluctuates frequently due to machinery errors. This error could give rise to some random errors.
4. Solar cell I-V curve for different intensities were approximated due to limitation of appropriate amount of sunlight.
5. PAM (Pulse Amplitude Modulation) scheme was used in stead of ASK (Amplitude Shift Keying).

9 Sustainability Evaluation

The attributes that support design sustainability:

1. **Low-Cost Design:**
    - The modules and components used in this design, such as the PAM8403 amplifier and MAX4466 microphone module, are inexpensive and readily available.

- By using low-cost materials, the overall production cost is minimized, making the design affordable and accessible for various applications, including DIY projects, educational purposes, and low-budget commercial systems.

2. **Low Power Requirement:**
   - All the modules in the system are optimized for energy efficiency and operate on minimal power, typically requiring only a 5V supply.
   - The PAM8403 amplifier, being a Class-D amplifier, consumes significantly less power while delivering effective output, making it suitable for energy-conscious applications.
   - The laser diode and microphone module also draw minimal current, ensuring that the overall system has low energy demands.
   - Low power consumption enables the design to run on batteries or renewable energy sources, enhancing its environmental sustainability while reducing operational costs.
   -

By incorporating these two key attributes—**low cost** and **low power consumption**—the design achieves both economic and environmental sustainability, making it practical, efficient, and eco-friendly.

10 Reflection on Individual and Team work

Functioning effectively as an individual and as a member or leader in diverse teams and multi-disciplinary settings is essential for the success of the Laser Audio Transmission (LAT) project. As an individual, team member, or leader, effective communication skills are critical to convey ideas, share insights, and collaborate with colleagues from diverse backgrounds. Clear and open communication fosters a collaborative environment where team members can leverage their unique skills and perspectives.

In multi-disciplinary settings, where expertise from various engineering domains may be required, the ability to integrate insights from different disciplines becomes crucial. Engineers working on the LAT project must be adaptable, willing to learn from others, and capable of applying their expertise in a cross-functional context. Leadership skills are valuable for guiding the team, setting priorities, and ensuring that everyone is aligned with the project's objectives.

Understanding the strengths and weaknesses of team members allows for effective delegation and utilization of skills. Embracing diversity in thought and background enriches the problem-solving process, leading to innovative solutions for the complex challenges associated with LAT design. Team members who function well individually and collaboratively contribute to a dynamic and high-performing project environment.
By fostering an inclusive and collaborative culture, the LAT project benefits from the collective intelligence and diverse perspectives of its team members, ultimately enhancing the project's overall success and the quality of the engineered solution.

10.1 Individual Contribution of Each Member

Individual IDs	Contribution
1906070	Theoretical analysis, topic selection, data collection, plotting, result analysis, report writing, coding, cost management.
1906076	Circuit building, testing, debugging, design modification, report writing, leadership and editing.
1906077	Component selection, plan of work making, hardware set up building, testing, debugging, presentation slide building.
1906080	Graphical analysis, result analysis, proof reading, hardware modification, set up building, ppt editing, shouldering.

Figure 54 : Individual contribution of each member

10.2 Mode of Team Work

Our team work was distributed as:

- ✓ Theoretical study and topic selection
- ✓ Hardware setup and implementation.
- ✓ Testing and debugging.
- ✓ Component selection and purchasing.
- ✓ Group discussion and modification.
- ✓ Laser property measurement.
- ✓ Laser communication checking at different environment with respect to different factors,
- ✓ Report Writing.
- ✓ Slide making.
- ✓ Proposal presentation and final presentation delivery.

Although all the works were distributed equally, there were also individual work distribution as given below:

1906070: Theoretical analysis, coding, cost handling.

1906076: Design, modification and leading the team.

1906077: Debugging, testing and overall co-ordination.

1906080: Hardware management, result analysis and proof reading.

10.3 Logbook of Project Implementation

Week	Milestone Achieved	Individual Role	Comments
Week 4	Project Assign	-------------------	-----------------------------
Week 5	Initial team discussion, distribution of tasks	All members	Finalized roles and timeline.
Week 6	Theoretical study	1906070,1906076	Conducted literature review.
Week 7	Component selection and purchasing	1906070, 1906077	Components identified and procured.
Week 8	Hardware setup and alignment of laser communication	1906076,1906080	Ensured proper alignment for stable transmission.
Week 9	Testing and debugging	1906070,1906076, 1906077	Resolved initial issues in hardware performance.
Week 10	Laser property measurement and environmental tests	1906070,1906080	Measured beam divergence and stability factors.
Week11	Communication testing in varied environments	1906076, 1906077, 1906080	Verified signal reliability under different conditions.
Week12	Report writing and slide preparation.	All members	Finalized documentation and presentation slides.
Week13	Presentation and final delivery	All members	Delivered final presentation with all team inputs

Figure 55 : Logbook of the project

11 Summary

Our project focused on designing and implementing a **laser-based audio transmission system** that leverages laser communication technology to transmit audio signals wirelessly. The system was developed to ensure high fidelity, reliability, and scalability under diverse environmental conditions.

The project was executed in distinct phases, starting with a theoretical study and component selection, followed by hardware setup, testing, and debugging. Key considerations included optimizing optical link stability, mitigating noise, and ensuring efficient power management. Critical tasks such as laser property measurement and testing under varied environmental factors were conducted to validate the system’s performance.

Our team worked collaboratively, with distributed roles ensuring smooth progress. Significant achievements include achieving stable laser communication over a defined range, verifying the system’s functionality in different lighting conditions, and fine-tuning components for optimal performance. The final deliverables included a comprehensive report, presentation slides, and a functional prototype demonstrating reliable audio transmission via laser technology. This project highlights the potential of laser-based communication systems in modern applications, offering a cost-effective, modular, and high-performance solution.

12 YouTube Link of All videos (Abu)

13 Cost Analysis

Name	Unit	Price
Solar Panel	1	500
Laser Diode	3	900
PAM8403 audio amplifier	2	280
Speaker	1	50
L7805 Voltage Regulator	2	40
Audio Jack	1	50
Breadboard	2	100
Jumper Wire	20	40
Resistors, Potentiometer	-	100
TOTAL		2060

Figure 56 : Cost analysis of the project

14 Future Work

This project can be further extended in so many ways:

1. Blue, yellow, orange, IR laser can also be integrated and find the best wavelength region for optimum operation.
2. All the limitations of tools can be mitigated if high quality laboratory setup is used.
3. Better modulation and demodulation scheme can be used to improve the overall SNR.
4. The whole setup should be more compact and integrated for better user flexibility.
5. Detector responsivity can also be improved for desired range of operation.

15 Conclusion

The successful implementation of our **laser-based audio transmission system** demonstrates the potential of optical communication for reliable and high-fidelity signal transmission. Through systematic design, testing, and optimization, we were able to address critical challenges such as alignment, noise reduction, and environmental disturbances. The final system achieved stable performance across varying conditions, proving its feasibility for practical applications.

This project provided valuable insights into the integration of optical components, power management, and modulation techniques. It also highlighted the importance of teamwork and strategic task distribution in tackling complex engineering problems.

Overall, the project serves as a strong foundation for further exploration of laser communication systems, including enhancements for longer-range communication, improved robustness, and scalability for diverse use cases.

16 References

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