PHOTOPHONE PROJECT

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***Abstract* - This report presents an optical wireless communication system employing an infrared LED for signal transmission and a photodiode for detection. The system integrates subsystems such as a microphone driver, Automatic Gain Control, filters, a summing amplifier, a power amplifier, and an RGB LED indicator for signal strength monitoring. Both theoretical analysis and practical testing demonstrate stable performance, accurate signal separation, and reliable audio reproduction. Results confirm the effectiveness of the design, offering a compact and robust platform suitable for diverse applications in optical communication.(**
Keywords: Wireless Communication, Optical Transmission, Audio Signal Processing, Electronic Circuits)

1.INTRODUCTION

In this report, the design and implementation of an optical wireless communication system, commonly known as a photophone, will be analyzed both theoretically and experimentally. The optical transmission system is composed of three main sections: the transmitter unit, which utilizes an infrared LED for signal transmission; the receiver unit, which employs a photodiode to detect the transmitted signals; and the indicator unit, which measures the signal strength and visually represents it using an RGB LED. The subsequent sections of this report will provide a detailed examination of each subsystem individually, discussing their design, functionality, and performance evaluation.

2. BACKGROUND INFORMATION

Optical Wireless Communication (OWC) involves the transmission and reception of information through visible, infrared, or ultraviolet light, without relying on physical wiring. The earliest wireless telephone, known as the photophone, was introduced by Alexander Graham Bell and operated by modulating a beam of light to carry speech. Building on this foundational work, the present report details the design of a modernized photophone in which analog electronics are used to modulate the transmitted light signal.

3. THEORETICAL WORK

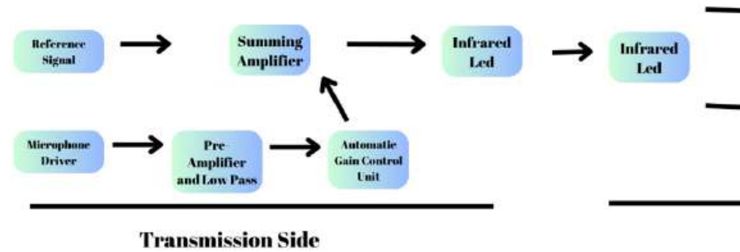


Fig.1. Block Diagram of Design

As shown in Figure-1, the project consists of multiple subsystems. The process begins with converting the audio signal from the microphone driver into an electrical signal. Since the voltage output from the microphone is relatively low, it is first passed through a preamplifier to amplify the signal to a usable level. To ensure that only the audio signal is processed, the output is then filtered using a low-pass filter, which eliminates unwanted high-frequency noise. The resulting signal is then fed into the Automatic Gain Control (AGC) unit.

The purpose of the AGC is to maintain a consistent output level despite sudden changes in the input signal, ensuring a more stable system. Next, the output from the AGC unit is combined with the reference signal, which is supplied by a signal generator. These two signals are summed in a summing amplifier, which produces a modulated output signal containing both the reference and audio signals.

The modulated signal is then processed through two separate paths:

- High-pass filtering: The high-frequency reference signal is extracted and sent to the indicator to visualize signal strength.
- Low-pass filtering: The audio signal is extracted and sent to the power amplifier, which amplifies it before driving the speaker, converting it back into sound.

These are the initial steps in our solution. In the future sections of the report, a more detailed explanation of the circuits used for each subsystem will be provided.

4. CIRCUIT DESIGNS,MATHEMATICAL COMPUTATIONS AND SIMULATION RESULTS

3.1. Receiver Side

A.1) Microphone Driver

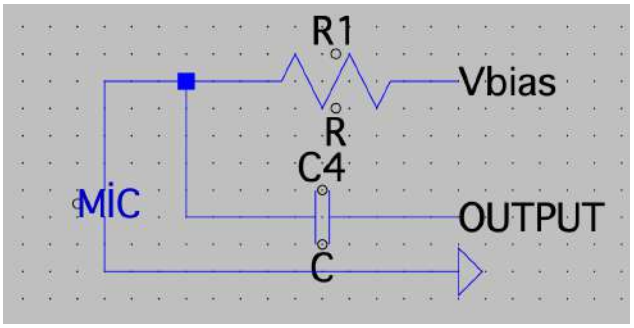


Fig. 2. : Circuit schematic of basic microphone driver

Figure 2 illustrates the fundamental RC circuit employed for an electret microphone. In such circuits, a resistor and a capacitor work together to shape the electrical signal produced by the microphone. The resistor sets the input impedance of the circuit, ensuring proper signal matching, while the capacitor blocks any unwanted DC components that may be present. These components collectively enhance the microphone's performance, ensuring consistent and accurate audio signal processing.

B.1) Low pass Filter

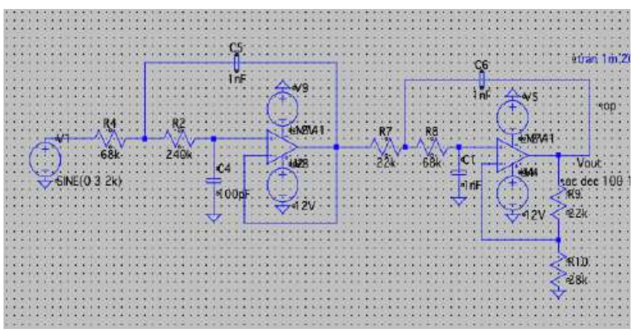


Fig. 3. : Low Pass Filter Circuit Schematic

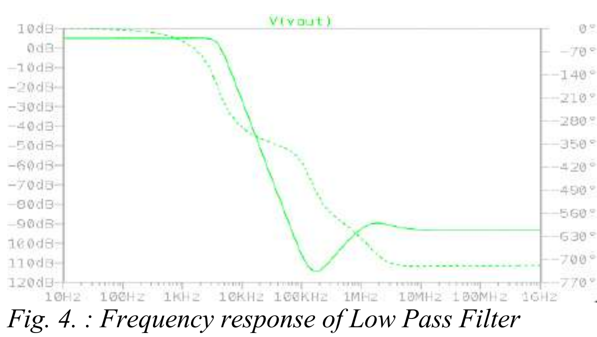


Fig. 4. : Frequency response of Low Pass Filter

To enhance the accuracy of our system by achieving a sharper cutoff frequency, we opted to implement a second-order, two-stage low-pass filter**.** During simulations with a single-stage design, we observed that frequency components close to the undesired reference signal frequency passed through with relatively high amplitudes. To address this issue, we designed a two-stage low-pass filter, as depicted in Figure-3.

By analyzing the frequency response of the constructed circuit, shown in Figure-4, we observed that the signal attenuation begins immediately after the desired 3.4 kHz cutoff frequency. Additionally, the response exhibits a much steeper roll-off, ensuring that higher frequencies are significantly attenuated, effectively minimizing their presence in the output signal.

C.1) Automatic Gain Control Unit

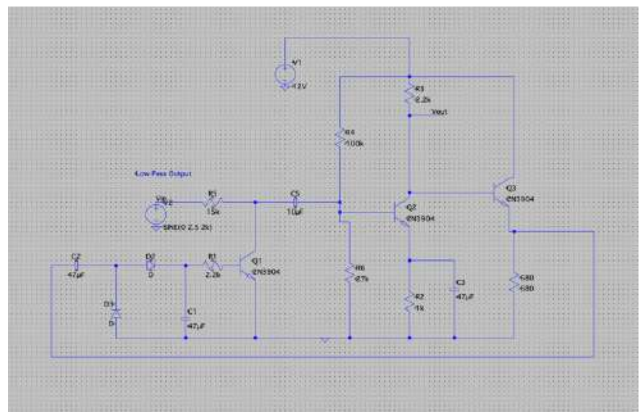


Fig. 5. : Circuit Schematic for AGC

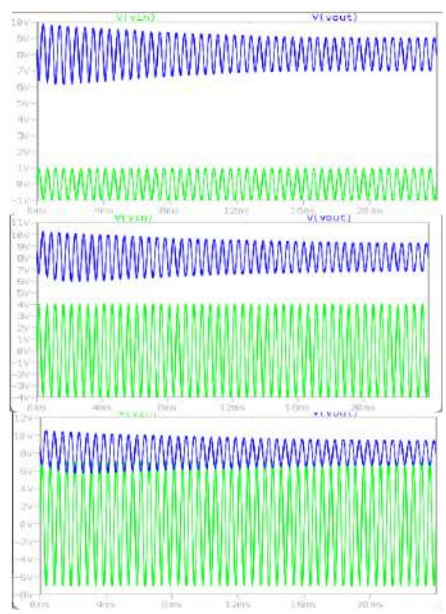


Fig. 6. : AGC output for 1V-4V-7V amplitude inputs respectively.

An Automatic Gain Control (AGC) circuit is an electronic system that automatically modifies the input signal's amplitude to sustain a stable output level. It continuously adjusts the gain to account for fluctuations in the input signal strength, ensuring the output stays within the desired operational range. In our project, we incorporated this system to protect the circuit from abrupt increases in input amplitude or higher-than-expected input levels, thereby preventing damage and mitigating undesirable input behavior that might otherwise affect subsequent stages. Specifically, we designed the circuit shown in Figure 5 to be placed before the summing amplifier in order to stabilize the microphone output. As illustrated in Figure 6, for various input voltages of 1 V, 4 V, and 7 V, the AGC behavior remains stable at approximately 2 V peak-to-peak. In this manner, higher input voltages are effectively limited, ensuring that different input levels yield a consistent output.

D.1) Summing Amplifier

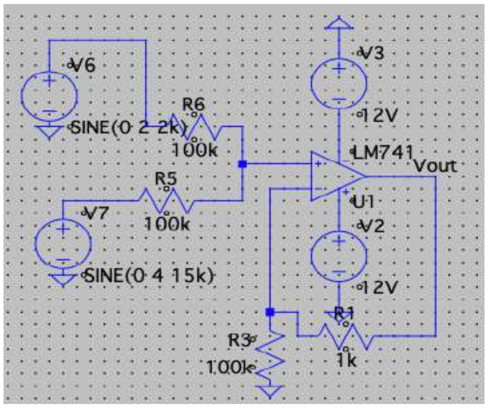


Fig. 7. : Summing Amplifier Circuit Schematic

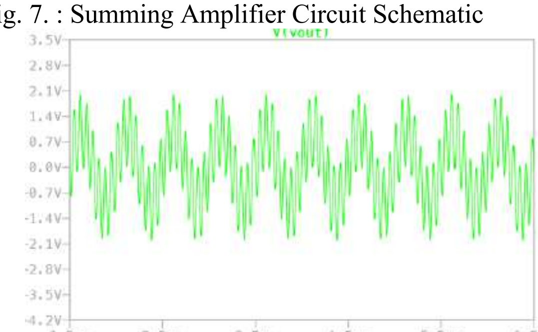


Fig.8. : Summing Amplifier Output Waveforms

In this project, we combine a reference signal with the microphone output, then transmit via an infrared LED. The summing amplifier is crucial for precisely merging both signals, ensuring the reference acts as a carrier while preserving audio content. Therefore, we designed the circuit depicted in Figure 7. By utilizing an operational amplifier, our goal is to superimpose the microphone signal—after it has passed through the AGC unit—onto the reference signal. As shown by Equation 1, the amplifier is configured for unity gain, ensuring that the microphone output is simply overlaid on the reference signal without additional amplification or attenuation.

$$Av = 1 + \frac{R1}{R3} \qquad (1)$$

3.2) Reciever Side

A.2) Transmission :

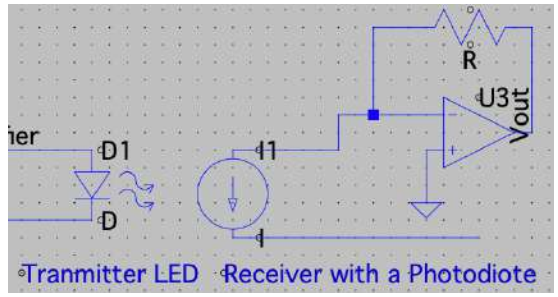


Figure-9: Optical transmission system

For the transmission stage, we opted to use an infrared (IR) LED in conjunction with a photodiode for signal reception. In this design, the microphone output and reference signal are first combined and then transmitted via the IR LED. The photodiode detects the incoming modulated signal and generates a photocurrent, which is subsequently converted to a voltage by an operational amplifier.

Fig.9. : Transmission Operation with Circuit Diagrams

B.2) Filters :

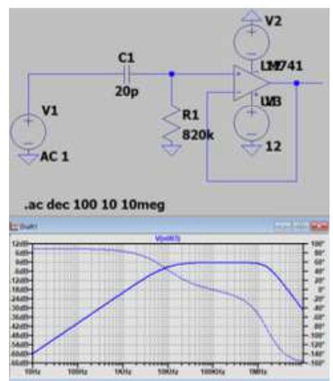


Fig. 10. : Designed high pass filter

Following the optical transmission, we designed a high-pass filter to effectively separate the reference signal from the combined audio output. This design choice was premised on the assumption that the reference signal would occupy a frequency band beyond 10 kHz, thus avoiding any overlap with the lower-frequency microphone output. By selecting an appropriate cutoff frequency, as illustrated in Figure 10, the undesired low-frequency components are attenuated, allowing for robust isolation of the reference signal. This separation is critical for subsequent processing, including driving an RGB LED indicator, where a clean high-frequency reference is essential.

Low frequency signalimiz için de Figure-3'de gösterilen filtreyi kullandık. Bu sayede sonrasında speaker a gönderebilmek için gelen ses sinyalimizi ayrıştırabiliriz.

C.2) RGB Led Comparator (Inducator)

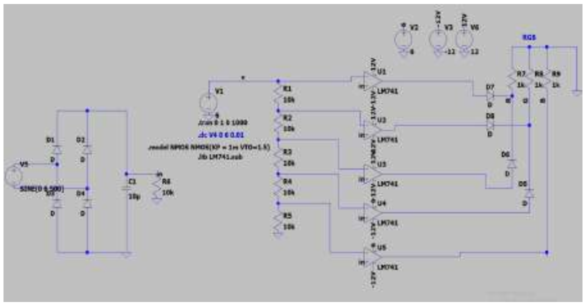


Fig.10. : Circuit Schematic of RGB Led comparator

The project involves designing a circuit where an RGB LED changes color based on the strength of an input signal. The circuit's functionality relies on a comparator network consisting of five operational amplifiers (op-amps) with a staircase configuration of reference voltages applied to their inverting inputs.

Since we are receiving signal which low frequency voice signal and reference signal is multiplexed, we need a high pass filter to get reference signal. After getting high frequency reference signal we amplified it to satisfy comparator voltage requirement. Then we need to convert our signal to DC voltage to compare its strength with reference DC voltage. We used a full bridge diode rectifier to convert our signal into DC voltage. This DC voltage is connected to non inverting inputs of the each opamp. When the signal strength is increased, opamps that have higher inverting reference voltage will give output and when signal strength is decreased, opamps that have higher inverting reference voltage will turned off and lower ones will give output.

We connected positive power input of the lower referenced 2 opamp to +6 voltage and outputs of them are connected to different legs of the RGB with a diode. Other opamps have +12 V positive power input, when signal strength is suitable to give output, opamps with higher positive power input will give output and via diodes lower ones could not give output to the RGB. Since opamps that have higher positive power input will give higher positive output when signal strength is enough, color of the RGB is changing and giving 5 different color output according to high frequency reference signal strength.

D.2) Power Amplifier

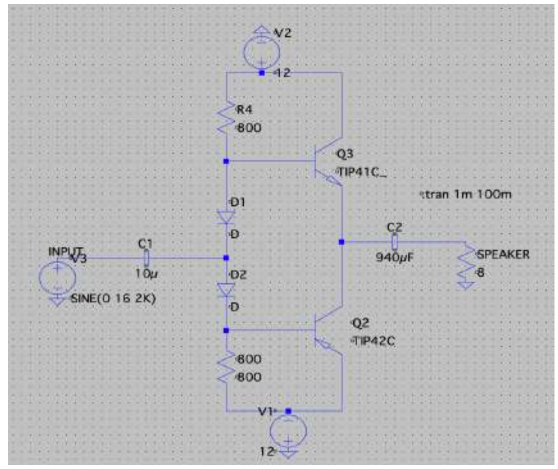


Fig.11. : Circuit Schematic for Power Amplifier Circuit

The power amplifier's primary function is to deliver sufficient current and voltage swing to drive the speaker. By boosting the low-frequency audio signal to an appropriate power level, it ensures clear and audible sound reproduction. Consequently, we designed the amplifier circuit depicted in Figure 11 to meet these requirements.

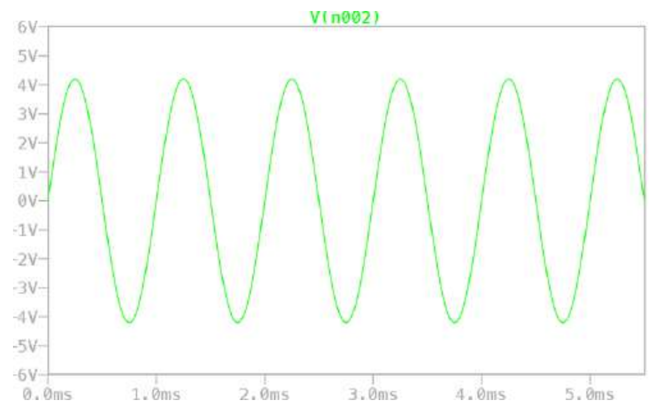


Fig.12. :Output wavefrom of power amplifier

$$P = \frac{\left(\frac{V}{\sqrt{2}}\right)^2}{R} \quad (2)$$

$$P = \frac{\left(\frac{4.2}{\sqrt{2}}\right)^2}{8} = 1.1\,W$$

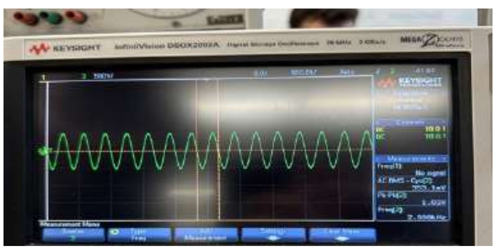
In order to achieve the desired power level of 1 W for an 8 Ω speaker, Equation 2 can be employed to determine the required voltage amplitude. As illustrated in Figure 12, our power amplifier delivers a 4.2 V peak-to-peak output signal, enabling the speaker to operate at the specified power.

5. COMPARISON OF THEORETICAL AND EXPERIMENTAL IMPLEMENTATION

In this section of the report, we will compare and analyze the theoretical and experimental results we obtained, as well as examine any discrepancies that may have arisen.

A) Low Pass Filter

Once we implemented our previously designed low-pass filter and applied inputs at various frequencies, the results obtained are shown below.



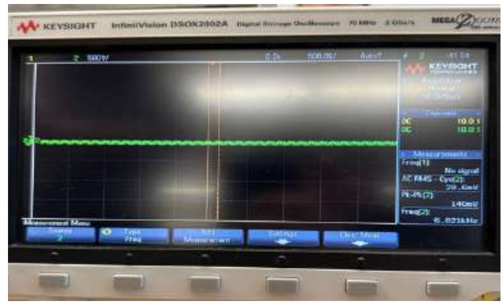
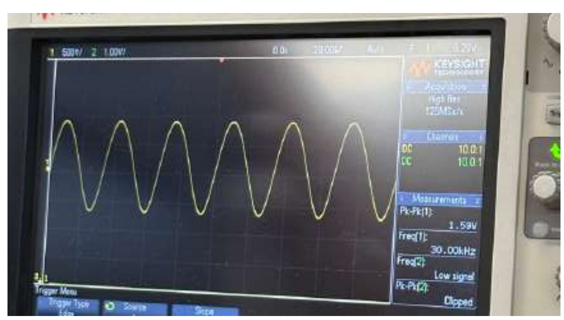


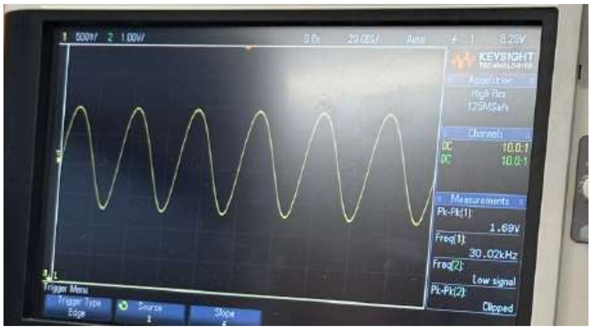
Fig. 13 : Results at different frequencies for 1kHz ,3 kHz

When evaluating signals beyond 6.6 kHz, the filter's gain progressively diminished as expected. Although the simulation confirmed the precise cutoff frequency originally targeted, experimental measurements indicated a slightly earlier cutoff. Nevertheless, at both critical points in the circuit—before the AGC stage and prior to the power transistors—the microphone output was successfully confined to the low-frequency band as intended. Overall, our theoretical calculations closely aligned with the practical results observed during testing.

B) Automatic Gain Controller

We designed our AGC to maintain an approximately 2 V peak-to-peak output, even under high input levels. To verify this behavior, we subjected it to various input amplitude levels, and the corresponding experimental results are presented below.





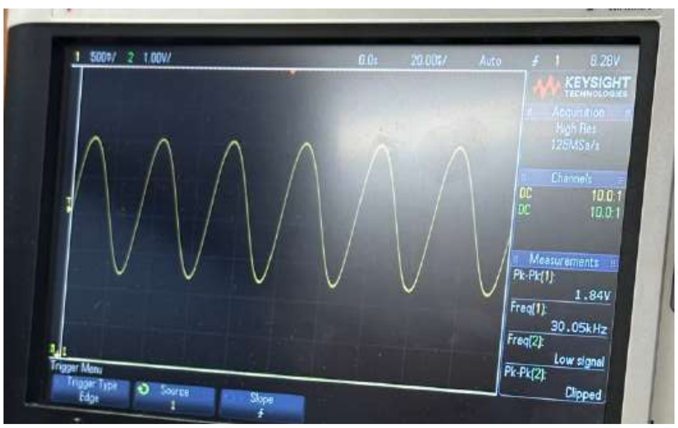


Fig. 14 : AGC output for different voltage values.

When we directly applied a signal to the AGC and varied the input voltage to 2 V, 4 V, and 6 V, we observed that as the input increased threefold, the gain decreased proportionally. Consequently, the change in output amplitude remained minimal. This outcome confirms that our experimental results align with the theoretical design. In particular, the theoretical design consistently provides a 2 V peak-to-peak output.

C) Summing Amplifier Output.

Before transmission, we used a summing amplifier to combine the reference signal with the microphone output.

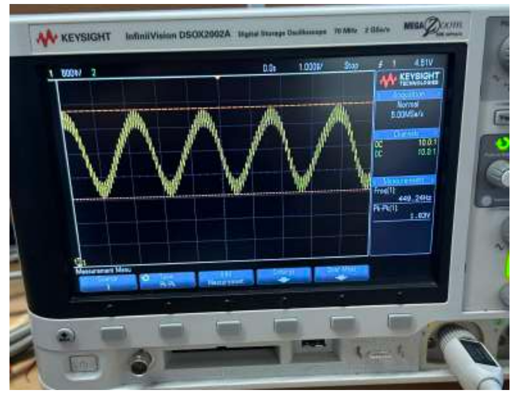


Fig. 15 : Summing Amplifier Output Waveform.

The resulting output waveform can be observed in Figure 15. Upon inspection, it becomes apparent that the waveform closely aligns with both our theoretical calculations and simulation results.

D) Transmission

Initially, we faced difficulties in transmitting our signal. To ensure the photodiode and infrared LED could easily align and establish a reliable link, we incorporated a tubular enclosure into the design. This enabled a direct line of sight and improved signal reception. With these three elements in place, our transmission path was successfully completed, yielding results consistent with our proposed solution.

E) RGB Indicator :

After completing the circuit up to the RGB indicator and separating the high-frequency reference signal via the high-pass filter, we routed this signal through a rectifier, enabling the RGB LED to reflect the signal quality. Consequently, the indicator produces five distinct colors, yielding experimental outcomes closely matching our theoretical expectations.

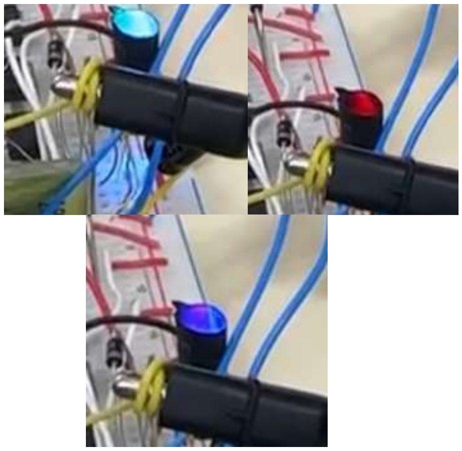


Fig. 15 : 3 different colours output at Indıcator

6) CONCLUSION

In conclusion, the proposed optical wireless communication system (photophone) effectively demonstrates the core principles of infrared-based audio transmission. By combining careful subsystem design—including low-pass and high-pass filtering, Automatic Gain Control, and summing amplification—the system manages to transmit audio with minimal distortion while maintaining a stable output level.

On the transmission side, the infrared LED and photodiode pair proved capable of delivering consistent, noise-reduced signals, particularly when placed within a confined channel to optimize line-of-sight reception. The power amplifier provided sufficient voltage swing to drive a speaker at the desired power level, ensuring clear audio output.

Furthermore, the RGB LED indicator offers a tangible, real-time method for monitoring signal strength, utilizing a comparator network and rectifier to map the reference signal amplitude to distinct color outputs. Experimental tests reveal that the final implementation closely matches the theoretical and simulated models, highlighting the robustness of the design choices. Future work could focus on extending the system's range, optimizing power consumption, and exploring alternative optical frequencies to enhance versatility. Overall, the project successfully meets its objectives and offers a solid foundation for advanced optical communication research and applications.

7) REFERENCES:

[1] Alegre Pérez, J. P., Pueyo, S. C., & López, B. C. (2011). *Automatic gain control*. https://doi.org/10.1007/978-1-4614-0167-4

[2] Cadence PCB Solutions (2022, October 13). *How IR led voltage drop effects led performance and life cycle*. Cadence. Retrieved from https://resources.pcb.cadence.com/blog/2019-how-ir-led-voltage-drop-effects-led-performance-and-life-cycle

[3] *Automatic gain control microphone preamp*. Electronic Circuits. (n.d.). Retrieved January 25, 2023, from http://www.electronicecircuits.com/electronic-circuits/automatic-gain-control-microphone-preamp

[4] Storr, W. (2022, August 2). *Class AB amplifier design and class AB biasing*. Basic Electronics Tutorials. Retrieved January 25, 2023, from https://www.electronics-tutorials.ws/amplifier/class-ab-amplifier.html

[5] Nadaf, I., & Joshna. (2018, September 10). *What is a peak detector? definition, circuit working and applications of Peak Detector*. Electronics Coach. Retrieved from https://electronicscoach.com/peak-detector.html