Transferring Audio Information via Light

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***Abstract*—This project investigates the conversion of audio signals into light-based signals for transmission over a distance and their subsequent reconversion back into audio signals. The system is designed using entirely analog components and consists of four primary subsystems: audio-receiving, light-emitting, light-sensitive, and audio-generating units. Two different approaches are explored in this study: one using a traditional electret microphone and the other employing an optical microphone system. Simulations and experimental implementations are conducted to analyze the performance and reliability of both systems. The results demonstrate the effectiveness of the proposed designs in transmitting audio information via light, highlighting the advantages and limitations of each approach.**

Keywords—Audio transmission, electret microphone, optical microphone, analog circuits, light communication.)

I. INTRODUCTION

The increasing demand for innovative audio transmission technologies has driven the exploration of novel methodologies. This project explores the concept of transmitting audio signals via light, employing both a conventional electret microphone and an optical microphone system. The system is fully analog, avoiding the use of digital controllers or microprocessors, to maintain simplicity and highlight the capabilities of analog circuitry.

The project comprises four subsystems:

- Audio-receiving subsystem: Converts incoming sound waves into electrical signals.
- Light-emitting subsystem: Modulates the electrical signal into light using a monochromatic light source.
- Light-sensitive subsystem: Detects and reconverts light signals into electrical signals.
- Audio-generating subsystem: Recovers the original audio signal from the electrical signal.

Two distinct implementations are developed:

- Electret Microphone Approach: Utilizes a traditional electret microphone for capturing sound.
- Optical Microphone Approach: Employs a photodetector to sense sound waves via light intensity variations.

This document details the design, simulation, and implementation of both systems, supported by experimental results and analysis.

II. DESCRIPTION OF THE ENTIRE SYSTEM

The designed system transmits audio signals using light as a medium. It consists of four main subsystems: the audio-receiving subsystem, the light-emitting subsystem, the light-sensitive subsystem, and the audio-generating subsystem. Two configurations are implemented: one using an electret microphone and the other employing an optical microphone. The detailed description of the system, based on the circuits and components used, is as follows:

A. Audio-Receiving Subsystem

The audio-receiving subsystem captures sound waves and converts them into electrical signals using different configurations:

Electret Microphone Configuration

Microphone Signal Processing:

- An electret microphone captures sound waves and converts them into a weak electrical signal.
- The microphone output is amplified using an LM358-based amplifier circuit, which enhances the signal for further processing.
- The circuit includes biasing resistors, capacitors for coupling and decoupling, and feedback resistors to set the gain of the operational amplifier.
- This ensures the signal is robust enough for input to the light-emitting subsystem.

Optical Microphone Configuration

This configuration uses two photodiodes, as detailed below:

First Photodiode and Current-to-Voltage Conversion:

- The optical microphone setup begins with a mirror diaphragm that modulates the intensity of light reaching the first photodiode as seen in Figure 1.
- A current-to-voltage converter circuit, transimpedance amplifier, processes the photocurrent generated by the first photodiode into a usable voltage signal. This stage is critical for capturing and amplifying the small current changes caused by light intensity variations.

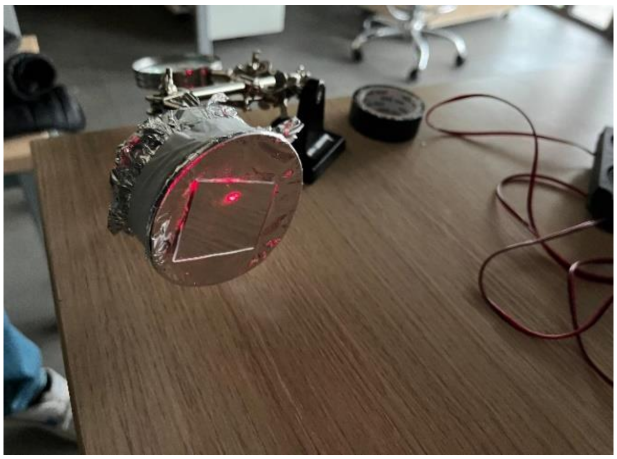

Figure 1 - Optical Microphone

Common Collector Stage

- The output voltage from the current-to-voltage converter is fed into a Common Collector (Emitter Follower) circuit.
- This stage provides high input impedance and low output impedance, ensuring the stability and compatibility of the signal for the subsequent light-emitting subsystem.

B. Light-Emitting Subsystem

The light-emitting subsystem modulates the light source in response to the processed audio signal.

Electret Microphone Light Modulation Circuit (Emitter Follower)

- Amplified audio signal is used to modulate the intensity of a laser diode.
- A transistor-based Light Modulation Circuit, emitter follower, adjusts the brightness of the laser diode based on the amplitude of the audio signal.

Key components include:

  - A NPN transistor as the modulation driver.
  - Resistors to limit current and set biasing conditions.
  - A coupling capacitor to transfer the AC signal while blocking DC components.

- The modulated light carries the audio information to the light-sensitive subsystem.

Optical Microphone Light Modulation Circuit (Emitter Follower)

- The processed signal from the common collector is sent to the light-emitting subsystem, which uses a laser diode as the light source.
- The Light Modulation Circuit modulates the intensity of the laser diode based on the amplitude of the input voltage signal.
- A transistor-based configuration, emitter follower, ensures precise control over the laser diode’s intensity to encode the audio information effectively.

C. Light-Sensitive Subsystem

The light-sensitive subsystem captures the modulated laser diode beam and converts it back into an electrical signal.

Electret Microphone Light-Sensitive Circuit (Transimpedance Amplifier)

- The modulated light signal is captured by a photodiode, which generates a photocurrent proportional to the light intensity.
- A current-to-voltage converter circuit, transimpedance amplifier, amplifies and converts the photocurrent into a voltage signal suitable for audio reproduction.
- Resistors and feedback components are used to set the amplification gain and minimize noise.
- Coupling capacitors are used to transfer the AC signal while blocking DC components.

Optical Microphone Light-Sensitive Circuit (Transimpedance Amplifier)

Second Photodiode

- The laser diode beam carrying the modulated audio signal is detected by a second photodiode in the light-sensitive subsystem.
- Similar to the first stage, the photodiode generates a photocurrent proportional to the laser diode's intensity variations.

Current-to-Voltage Converter (Transimpedance Amplifier)

- The photocurrent is converted into a voltage signal using another current-to-voltage converter circuit, transimpedance amplifier.
- Resistors and feedback components are used to set the amplification gain and minimize noise.
- This stage ensures that the signal is accurately recovered with minimal noise and distortion.

D. Audio-Generating Subsystem

Electret Microphone Audio Generating Circuit

Common Emitter Amplifier

- The recovered voltage signal is amplified using a Common Emitter Amplifier. This stage provides significant voltage gain to boost the audio signal.

Second Common Emitter Amplifier

- The amplified signal is further amplified using a common emitter amplifier with an emitter follower.

Speaker Output

- A Complementary Push-Pull Output Stage at the final stage ensures the signal has sufficient current gain and power to drive the speaker effectively.
- The complementary arrangement of NPN and PNP transistors minimizes crossover distortion while amplifying both the positive and negative halves of the signal.
- The amplified signal is fed to a speaker through a coupling capacitor, which filters out DC components, reproducing the transmitted sound with high fidelity.
- The combination of the driver and push-pull output stages ensures minimal distortion, efficient power delivery, and preservation of the original audio signal's quality.

Optical Audio Generating Circuit

Amplification with a Common Emitter Amplifier

- The recovered voltage signal is amplified using a Common Emitter Amplifier. This stage provides voltage gain necessary for audio signal recovery.

Complementary Push-Pull Output Stage

- The amplified signal is passed through a Complementary Push-Pull Output Stage to provide sufficient current gain and efficient power delivery to the speaker.
- The push-pull configuration consists of an NPN and a PNP transistor, working together to amplify both the positive and negative halves of the signal. This ensures minimal distortion and high-quality reproduction of the audio signal.
- The output signal is fed into the speaker through a coupling capacitor, reproducing the original audio transmitted via the laser diode.

E. System Integration

The System with Electret Microphone

The entire system integrates these subsystems to perform the followings:

- The audio-receiving subsystem captures and amplifies the audio signal from the electret microphone using an LM358-based non-inverting amplifier.
- The light-emitting subsystem modulates the amplified signal into light using an LED, with its brightness varying based on the audio signal.
- The light-sensitive subsystem detects the modulated light and reconstructs the signal into a usable electrical form using a photodiode and current-to-voltage converter.
- The audio-generating subsystem uses a Complementary Push-Pull Output Stage to amplify the recovered signal and drive the speaker, providing efficient power delivery and high-fidelity sound reproduction.

The System with Optical Microphone

The entire system, Figure 2 and Figure 3, integrates these subsystems to perform the followings:

- The audio-receiving subsystem captures sound waves using a homemade optical microphone with a glass diaphragm and the first photodiode. The detected signal is converted into a voltage signal by a current-to-voltage converter and amplified for transmission.
- The light-emitting subsystem modulates the amplified signal into light using a laser diode, where the light intensity varies based on the audio signal.
- The light-sensitive subsystem detects the modulated laser diode light with a second photodiode and converts it back into an electrical signal using a current-to-voltage converter.
- The audio-generating subsystem uses a Complementary Push-Pull Output Stage to amplify the recovered signal and drive the speaker, ensuring efficient power delivery and clear sound reproduction.

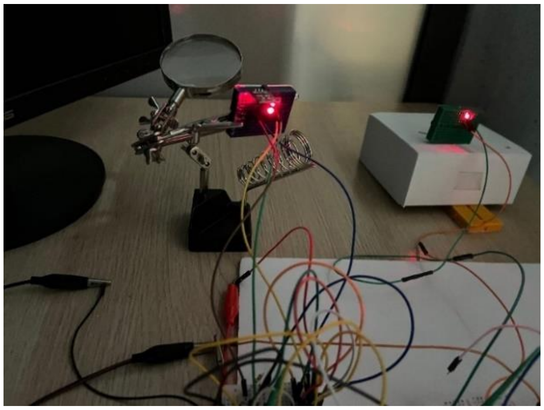

Figure 2 – The Whole Optical System

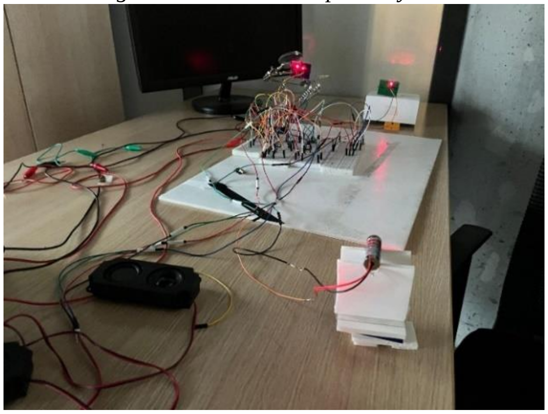

Figure 3 – The Whole Optical System

Models Used in the Simulation and the real system

Laser Diode Model:

- Represents the behavior of the laser diode used for light modulation.

2N3904 (NPN Transistor):

- Widely used for amplification and switching in various stages of the circuit. Multiple instances are used for different functions.

2N3906 (PNP Transistor):

- Used in the complementary push-pull output stage as the counterpart to the 2N3904 NPN transistors.

III. ELECTRET MICROPHONE CONFIGURATION

1. Microphone Circuit (Non-Inverting Amplifier)

The electret microphone captures sound waves and generates a weak electrical signal, amplified using an LM358 op-amp.

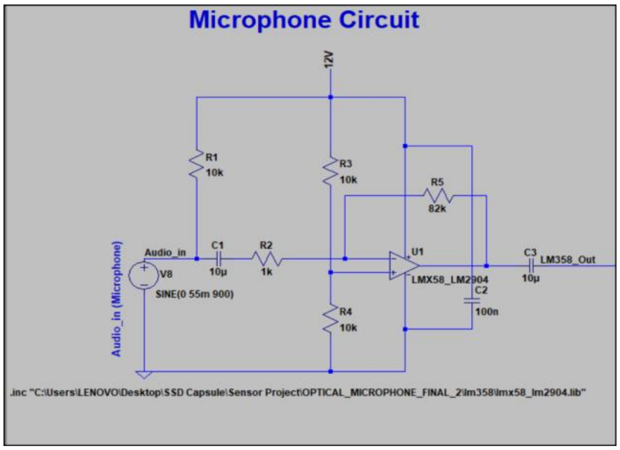

Figure 4 - Electret Microphone Circuit

Circuit Explanation

Microphone Biasing:

- A biasing resistor (R_2) provides the necessary voltage for the electret microphone to operate.

Signal Coupling:

- The AC audio signal is coupled via capacitor C_1 to block DC components before entering the amplifier.

Amplification:

- The Non-Inverting Amplifier Circuit using LM358 operational amplifier boosts the weak microphone signal. Feedback resistors set the amplifier's gain, ensuring a sufficiently strong output.

Key Observations:

- The amplified signal is robust enough for modulation in the light-emitting subsystem.

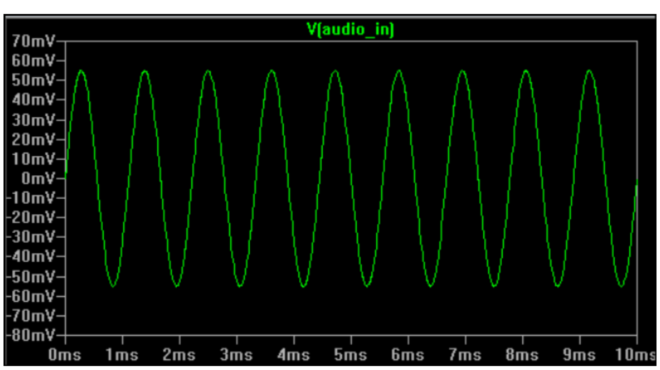

Figure 4.1 Electret Microphone Circuit Input

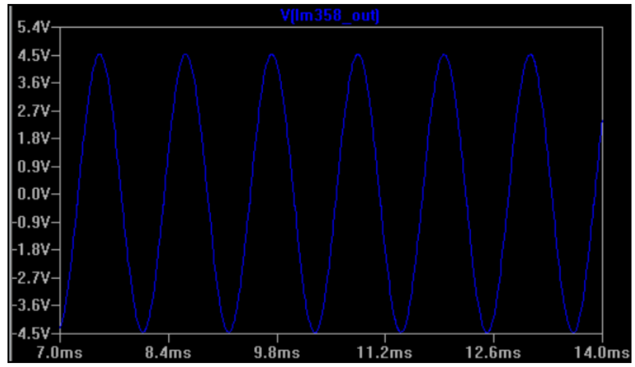

Figure 4.2 Electret Microphone Circuit Output

Input Signal (Figure 4.1):

- The input signal is a low-amplitude sine wave (~±55 mV), reflecting the raw audio signal from the electret microphone before amplification.

Output Signal (Figure 4.2):

- The output signal is a significantly amplified sine wave (~±4.5 V), demonstrating the effective gain provided by the LM358.
- The sine wave's shape is well-preserved, indicating minimal distortion and efficient operation of the amplifier.

2. Light Modulation Circuit (Emitter Follower)

This circuit uses a laser diode to modulate light intensity based on the amplified audio signal.

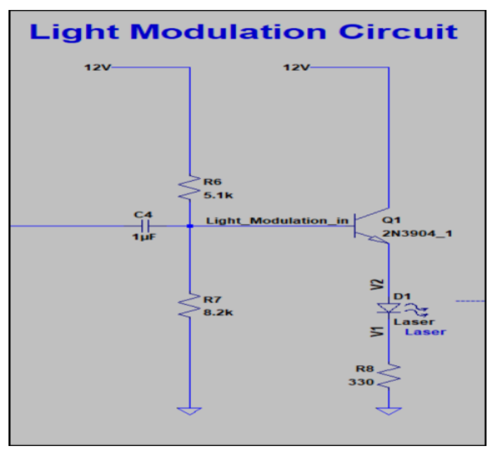

Figure 5 – Light Modulation Circuit

Circuit Explanation

Signal Input:

- The amplified signal from the microphone circuit is AC-coupled via a capacitor (C_4).

Light Modulation:

- The Emitter Follower Circuit uses an NPN transistor to modulate the laser diode current in response to the input signal, varying its brightness.

Current Limiting:

- Resistors are used to control the current through the laser diode, preventing overdriving and ensuring stability.

Key Observations:

- The modulated light intensity encodes the audio information for transmission.

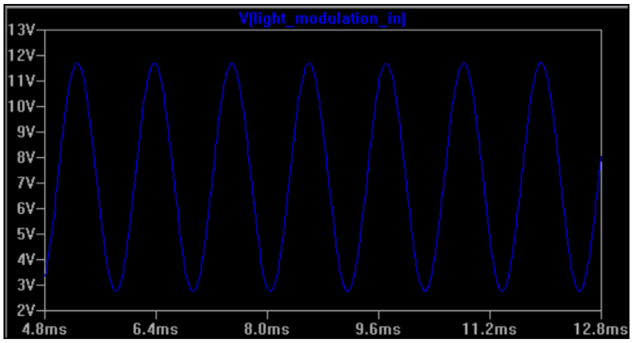

Figure 5.1 Light Modulation Circuit Input

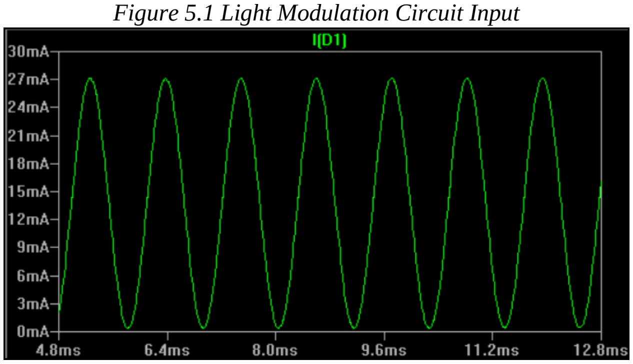

Figure 5.2 Light Modulation Circuit Laser Diode Current

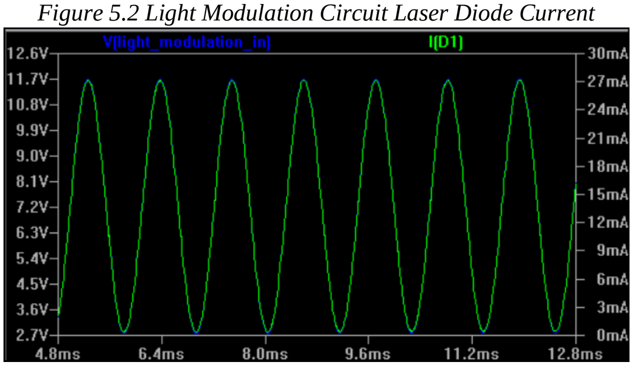

Figure 5.3 Combined Graph

Input Voltage to the Light Modulation Circuit (Figure 5.1):

- The input voltage signal is a clean sine wave ranging from approximately 2.5 V to 11.7 V.
- This represents the modulated signal provided to the laser diode driver circuit for converting the audio signal into light.

Laser Diode Current (Figure 5.2):

- The current through the laser diode (I_{D1}) closely follows the input voltage signal, ranging from 0 mA to approximately 27 mA.
- This indicates proper modulation of the laser diode, with the current varying directly with the input signal.

Combined Graph (Figure 5.3):

- The combined graph shows the input voltage and the laser diode current (I_{D1}) are in phase, demonstrating a linear response of the laser diode driver circuit.
- The laser diode accurately converts the input voltage into proportional light intensity variations, suitable for transmitting the audio signal

3. *Light-Sensitive Circuit (Current-to-Voltage Converter)*

The light-sensitive circuit captures the modulated light and converts it back into an electrical signal.

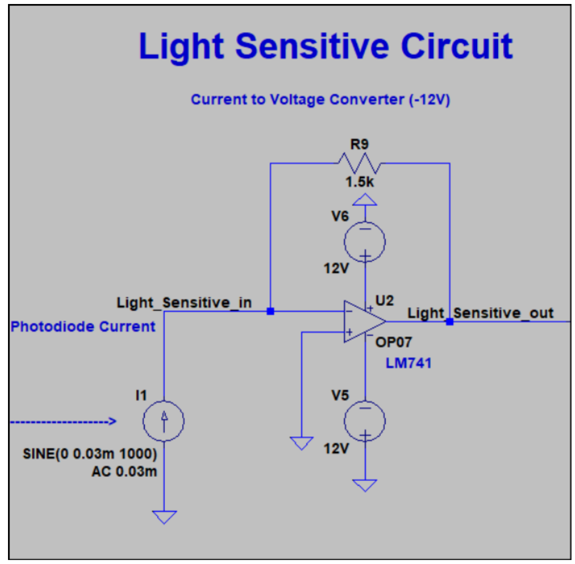

Figure 6 – Light Sensitive Circuit

Circuit Explanation

Photodiode Detection:

- The photodiode generates a current proportional to the light intensity received.

Current-to-Voltage Conversion:

- An operational amplifier-based, LM741, Current-to-Voltage Converter amplifies the photocurrent into a voltage signal suitable for further processing.

Key Observations:

- The output voltage accurately reflects the transmitted audio signal.

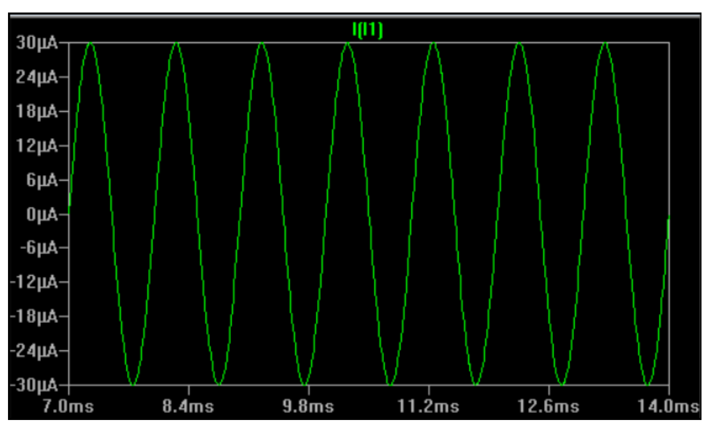

Figure 6.1 Light Sensitive Circuit Photodiode Current

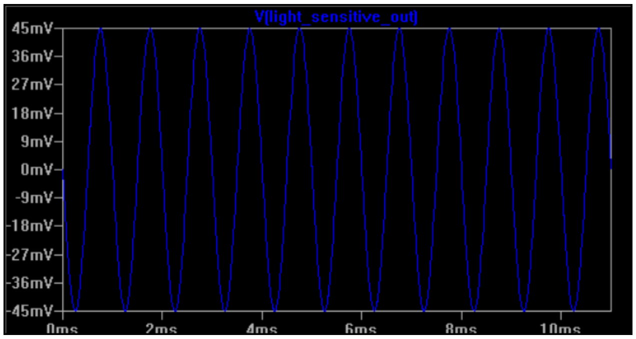

Figure 6.2 Light Sensitive Circuit Output

Photodiode Current (Figure 6.1):

- The current generated by the photodiode is a clean sinusoidal waveform with a peak amplitude of approximately ±30 µA.
- This indicates that the photodiode is successfully detecting variations in light intensity and converting them into a proportional electrical signal.

Current-to-Voltage Converter Output (Figure 6.2):

- The output voltage is a sinusoidal waveform with a peak amplitude of approximately ±45 mV.
- The current-to-voltage converter has effectively amplified the weak photocurrent into a usable voltage signal for further processing.
- The signal maintains its sinusoidal shape, showing minimal distortion introduced by the circuit.

4. *Audio-Generating Circuit (Common Emitter Amplifier and Complementary Push-Pull Output Stage)*

The recovered signal is amplified to drive a speaker.

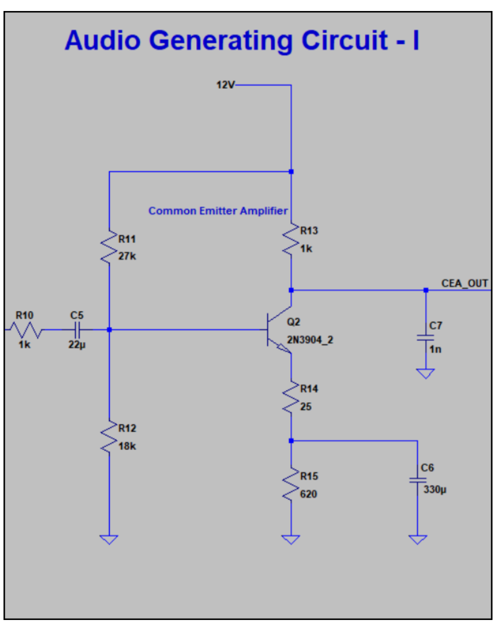

Figure 7 – Audio Generating Circuit – I (Part1)

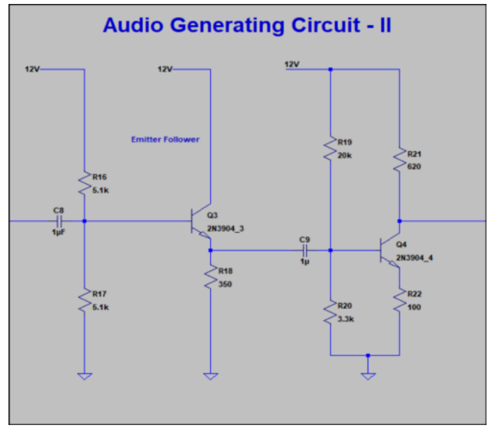

Figure 8 – Audio Generating Circuit – II (Part2)

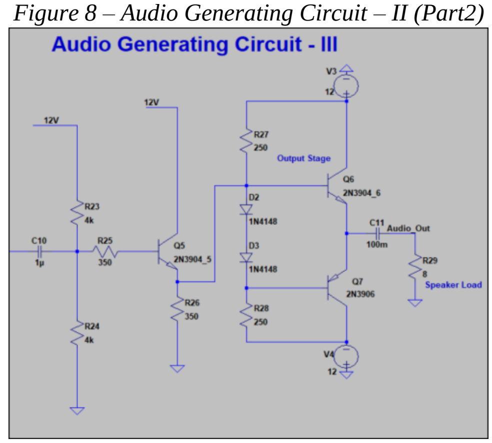

Figure 9 – Audio Generating Circuit – III (Part3)

Circuit Explanation

Common Emitter Amplifiers (Figure 7 and Figure 8):

- Q2 and Q4 provide voltage gain, amplifying the recovered signal from the light-sensitive circuit.

Complementary Push-Pull Output Stage (Figure 9):

- The push-pull stage includes Q_6 and Q_7 (PNP), which amplify both the positive and negative halves of the input signal.
- Diodes D_3 and D_4 (1N4148) provide thermal stability and prevent crossover distortion.

Decoupling:

- The signal is decoupled using capacitors to remove any DC offset.

Key Observations:

- The speaker reproduces the audio with excellent clarity, validating the system's performance.

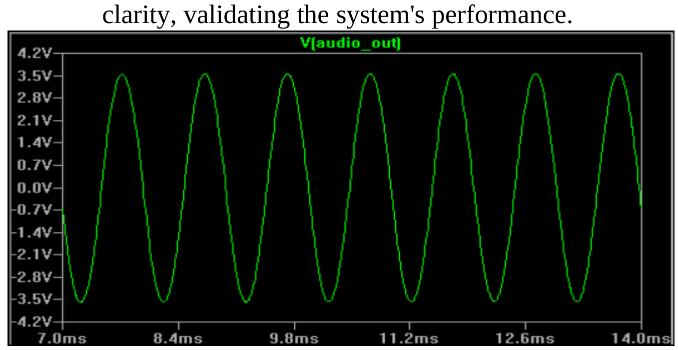

Figure 9.1 – Audio Generating Circuit Output

Audio Output Signal (Figure 9.1):

- The output voltage is a clean sinusoidal waveform with a peak amplitude of approximately 3.5 V.
- This indicates that the final stage of the circuit (the Complementary Push-Pull Output Stage) has successfully amplified the signal to a sufficient level to drive the speaker.

IV. *OPTICAL MICROPHONE CONFIGURATION*

The optical microphone configuration uses photodiodes and a laser diode to process and transmit audio signals via light. This section explains each subsystem and its role in detail.

1. *Optical Microphone Circuit*

The optical microphone begins with a mirror diaphragm that modulates light intensity, detected by the first photodiode.

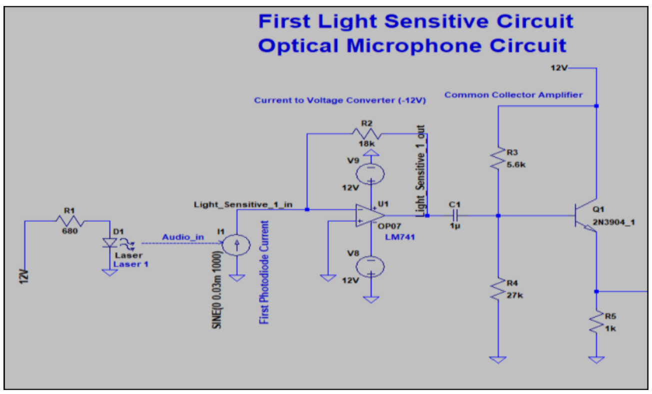

Figure 10 – First Light Sensitive Circuit

Circuit Explanation

Mirror Diaphragm and First Photodiode:

- The mirror diaphragm reacts to sound waves, causing changes in light intensity reaching the first photodiode.
- The first photodiode generates a photocurrent proportional to these intensity changes.

Current-to-Voltage Conversion:

- An operational amplifier-based, LM741, Current-to-Voltage Converter converts the weak photocurrent from the photodiode into a voltage signal.
- Feedback resistors set the gain of the circuit, ensuring a sufficient output signal.

Signal Preparation:

- The converted voltage signal passes through a Common Collector (Emitter Follower) circuit, which provides impedance matching and prepares the signal for the light modulation stage.

Key Observations:

- The output voltage from the first photodiode circuit mirrors the sound wave's intensity variations.
- The common collector ensures signal stability and efficient transfer to the next stage.

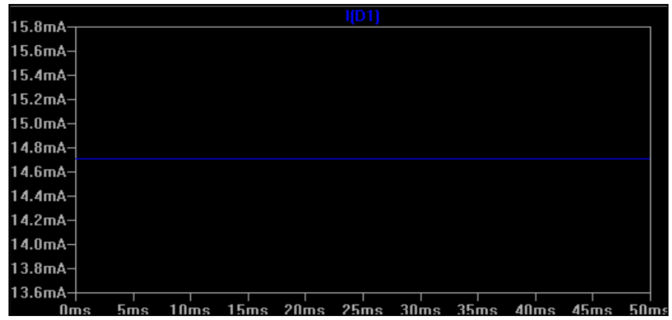

Figure 10.1 First Laser Diode Current

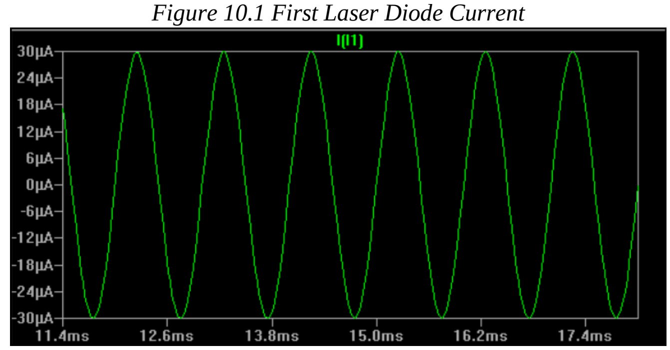

Figure 10.2 First Light Sensitive Circuit Photodiode Current

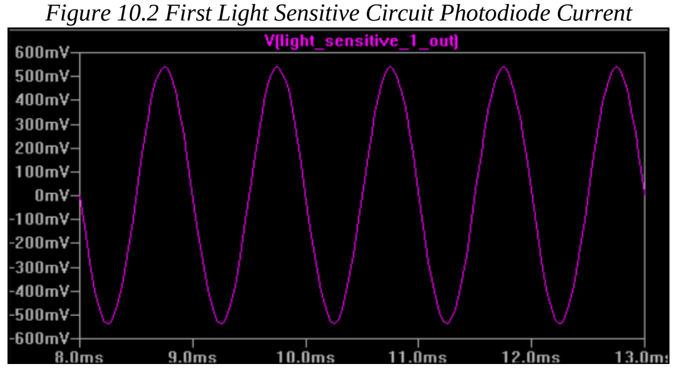

Figure 10.3 First Light Sensitive Circuit Output

Laser Diode Current (Figure 10.1):

- The laser diode current is steady at approximately 14.7 mA, indicating a constant bias current.
- The stable current ensures consistent laser diode operation, necessary for effective light modulation.

First Photodiode Current (Figure 10.2):

- The photodiode current is a sinusoidal waveform with a peak amplitude of approximately ±30 µA.
- This demonstrates the photodiode's response to the modulated laser diode light, successfully converting variations in light intensity into a proportional electrical signal.

First Light-Sensitive Circuit Output (Figure 10.3):

- The output voltage is a sinusoidal waveform with a peak amplitude of approximately ±540 mV.
- The current-to-voltage converter effectively amplifies the weak photodiode current into a usable voltage signal for further processing.
- The clean waveform indicates minimal distortion and effective signal preservation.

2. *Light Modulation Circuit*

The Light Modulation circuit translates the prepared voltage signal into modulated light using a laser diode.

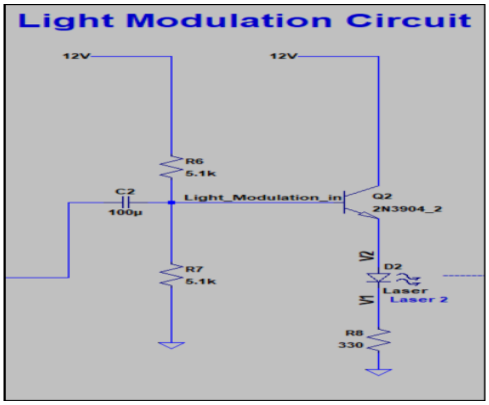

Figure 11 – Light Modulation Circuit

Circuit Explanation

Signal Coupling:

- The voltage signal from the first photodiode circuit is AC-coupled to block DC components.

Light Modulation:

- The Light Modulation Circuit uses an NPN transistor to modulate the current through the laser diode based on the input signal amplitude, creating a light signal that encodes the audio information.
- Resistors ensure proper biasing and current limitation for stable operation.

Key Observations:

- The laser diode beam intensity directly corresponds to the audio signal amplitude.
- This stage effectively converts electrical signals into optical signals for transmission.

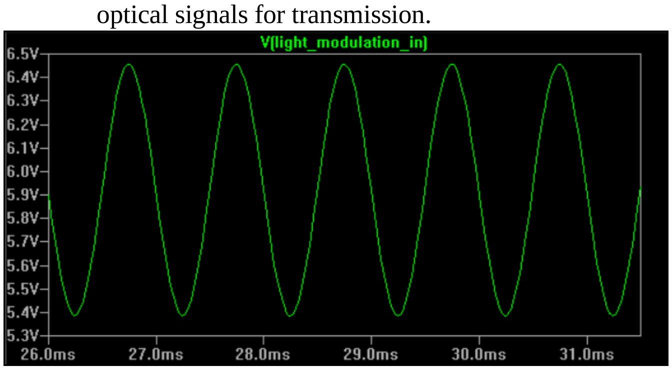

Figure 11.1 Light Modulation Circuit Input

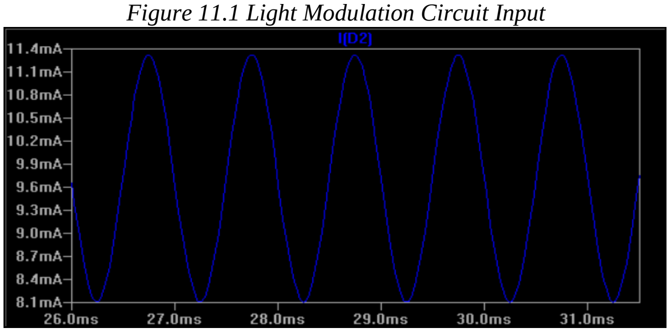

Figure 11.2 Light Modulation Circuit Laser Diode Current

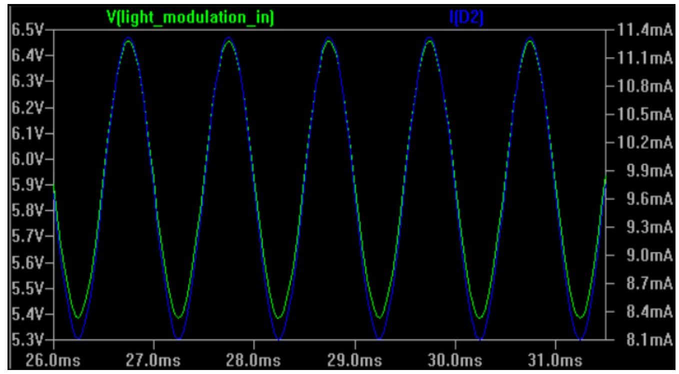

Figure 11.3 Combined Graph

Input Voltage to Light Modulation Circuit (Figure 11.1):

- The input voltage is a clean sinusoidal waveform ranging from approximately 5.4 V to 6.4 V.
- This signal represents the modulated audio input provided to the laser diode driver circuit.

Laser Diode Current (Figure 11.2):

- The current through the laser diode is a sinusoidal waveform ranging from approximately 8.1 mA to 11.4 mA.
- This indicates proper modulation of the laser diode current, closely following the input voltage.

Combined Graph (Figure 11.3):

- The combined graph shows the input voltage and the laser diode current (are in phase, demonstrating a direct and linear relationship between the two.
- This confirms that the laser diode effectively translates the input signal into proportional light intensity variations without distortion.

3. *Second Light-Sensitive Circuit (Current-to-Voltage Converter)*

The transmitted laser beam is detected by the second photodiode, converting the light back into an electrical signal.

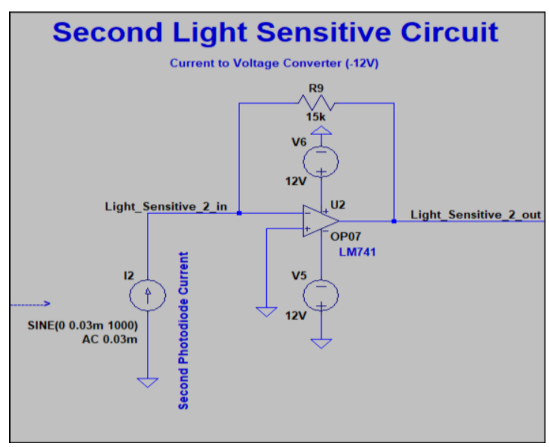

Figure 12 – Second Light Sensitive Circuit

Circuit Explanation

Light Detection:

- The second photodiode detects changes in light intensity and generates a weak photocurrent.

Current-to-Voltage Conversion:

- An operational amplifier-based, LM741, Current-to-Voltage Converter amplifies and converts the photocurrent into a usable voltage signal.
- Feedback resistors and capacitors suppress noise and set the circuit's gain.

Key Observations:

- The recovered signal closely resembles the original audio signal.
- The second light-sensitive circuit ensures minimal distortion and high fidelity.

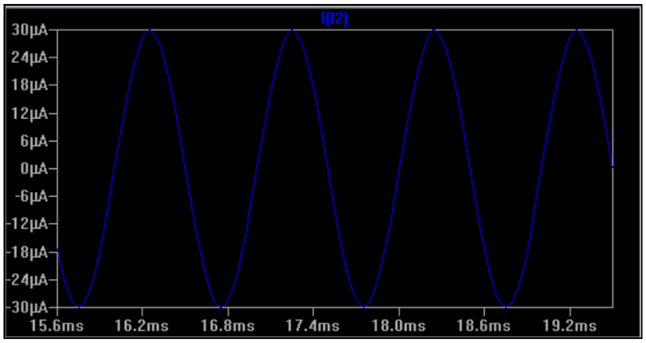

Figure 12.1 – Second Light Sensitive Circuit Photodiode Current

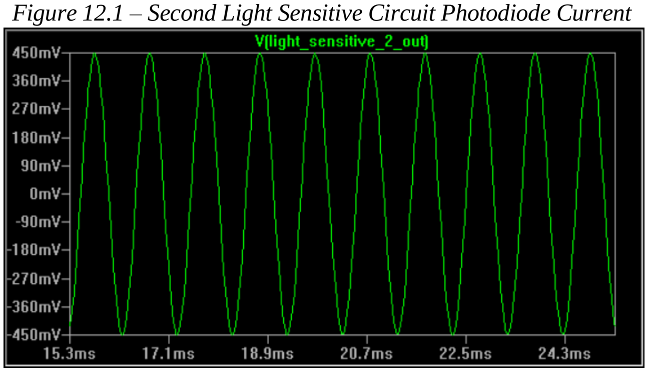

Figure 12.2 – Second Light Sensitive Circuit Output

Second Photodiode Current (Figure 12.1):

- The photodiode current is a clean sinusoidal waveform with a peak amplitude of approximately ±30 µA.
- This shows that the second photodiode effectively detects light intensity variations from the modulated laser diode and converts them into a proportional current signal.
- The phase and amplitude are consistent with the expected behavior of the photodiode.

Second Light-Sensitive Circuit Output (Figure 12.2):

- The output voltage is a sinusoidal waveform with a peak amplitude of approximately ±450 mV.
- The current-to-voltage converter in the second light-sensitive circuit effectively amplifies the weak photodiode current to a usable voltage level.
- The waveform remains clean and distortion-free, indicating precise signal handling and minimal loss in this stage.

4. *Optical Audio-Generating Circuit (Common Emitter Amplifier and Complementary Push-Pull Output Stage)*

The recovered voltage signal is amplified to drive a speaker for sound output.

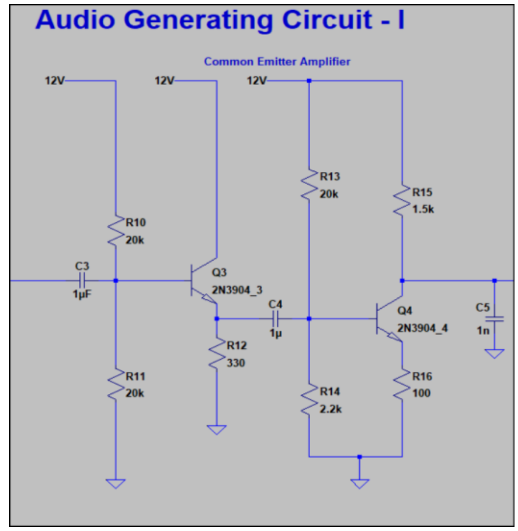

Figure 13 – Audio Generating Circuit – I (Part1)

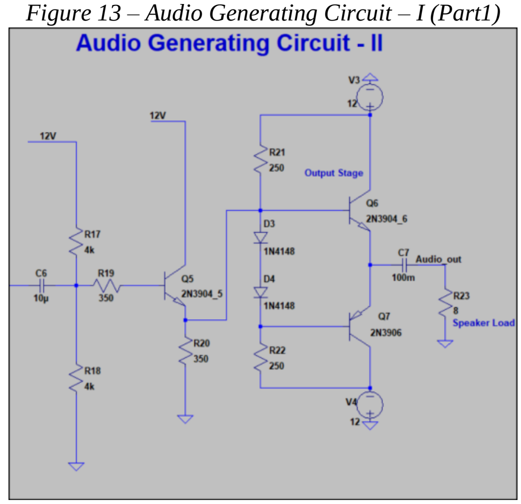

Figure 14 – Audio Generating Circuit – II (Part2)

Circuit Explanation

Common Emitter Amplifier (Figure 13):

- Q4 is configured as a Common Emitter Amplifier, providing voltage gain to amplify the recovered signal.
- This stage increases the signal's strength for driving the following stage.

Complementary Push-Pull Output Stage (Figure 14):

- The push-pull stage includes Q_6 and Q_7 (PNP), which amplify both the positive and negative halves of the input signal.
- Diodes D_3 and D_4 (1N4148) provide thermal stability and prevent crossover distortion.

Decoupling:

- The signal is decoupled using capacitors to remove any DC offset.

Speaker Output:

- A coupling capacitor ensures only the AC signal reaches the speaker, reproducing the transmitted sound accurately.

Key Observations:

- The combination of the Common Emitter Amplifier and the Complementary Push-Pull Output Stage provides sufficient gain and drive capability for the speaker.
- The Common Emitter Amplifier delivers voltage gain, while the Complementary Push-Pull Output Stage ensures efficient current gain and power delivery, making it suitable for driving low-impedance loads like speakers.
- The audio signal is reconstructed with high fidelity.

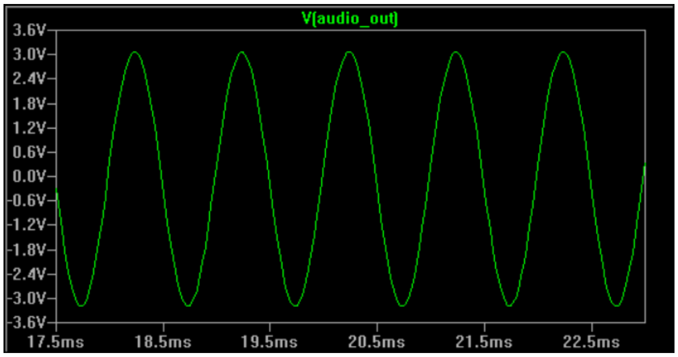

Figure 14.1 – Audio Generating Circuit Output

Audio Generating Circuit Output (Figure 14.1):

- The output voltage is a clean sinusoidal waveform with a peak amplitude of approximately 3.1 V.
- The waveform maintains its shape without noticeable distortion, indicating that the Complementary Push-Pull Output Stage has effectively amplified the signal to a level suitable for driving the speaker.
- This result confirms that the circuit successfully reproduces the audio signal with high fidelity and minimal power loss, ensuring clear sound output.

V. *CALCULATIONS*

Electret Microphone Configuration

1.1 *Microphone Circuit (Non-Inverting Amplifier)*

Circuit Role:

Amplifies the weak output signal of the electret microphone.

Gain Resistors (R_2, R_5):

R_2 = 1 kΩ

R_5 = 82 kΩ

Gain Calculation:

$$A_v = 1 + \frac{R_5}{R_2} = 1 + \frac{82}{1} = 83$$

1.2 *Light Modulation Circuit*

Circuit Role:

Modulates light intensity based on the amplified signal.

Gain Calculation:

The light modulation stage uses an Emitter Follower circuit, which has a voltage gain of approximately 1. It provides current gain, ensuring sufficient drive for the laser diode.

Current Through Laser Diode:

Laser Diode Current (I_{LASER}):

$$I_{LASER} = \frac{V_{in} - V_{BE}}{R_B + (1 + \beta_F)R_E} = 301 \times \frac{7.3 - 0.7}{3144 + (301) \times 330}$$

$$I_{LASER} \approx 19.3\ mA$$

1.3 *Current-to-Voltage Converter Circuit*

Circuit Role:

Converts the small current produced by the photodiode into a voltage signal using an LM741 operational amplifier.

Key Parameters:

Feedback Resistor (R_9): 1.5 kΩ

Photodiode Current (I_{pd}): 0.06 mA (typical for normal light intensity)

Gain Calculation:

The gain of a current-to-voltage converter is determined by the feedback resistor:

$$V_{out} = I_{pd} \times R_f$$

$$V_{out} = (0.06 \times 10^{-3}) \times (1.5 \times 10^{3}) = 90\ mV$$

1.4 *Audio-Generating Circuit (Speaker Amplifier)*

Common Emitter Amplifier:

The first stage amplifies the recovered voltage signal for the speaker.

Circuit Parameters of the Second Common Emitter Amplifier:

Collector Resistance (R_C): 620 Ω

Emitter Resistance (R_E): 100 Ω

Voltage Gain Calculation of the First Common Emitter Amplifier:

Calculated with the help of the small signal analysis:

$$A_v \approx 18$$

Voltage Gain Calculation of the Second Common Emitter Amplifier:

$$A_v = -\frac{R_C}{R_E} = -\frac{620}{100} \approx 6.2$$

Frequency Response:

Based on the frequency response formulas below:

$$f_{low} = \frac{1}{2\pi \times R \times C}$$

f_{low} is found as:

$$f_{low} \approx 45\ Hz$$

$$f_{high} = \frac{1}{2\pi \times R \times C}$$

f_{high} is found as:

$$f_{high} \approx 1.1\ MHz$$

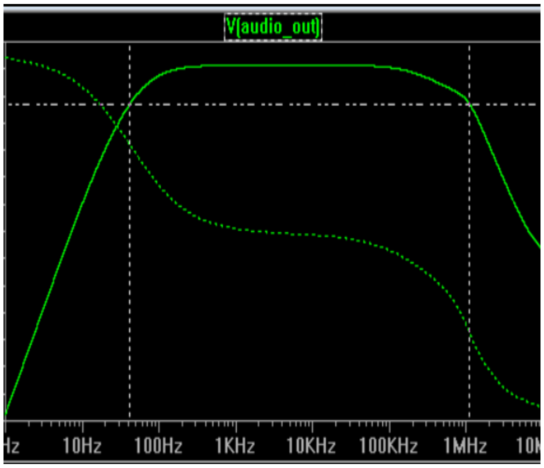

Figure 15 – Frequency Response of The Electret Configuration

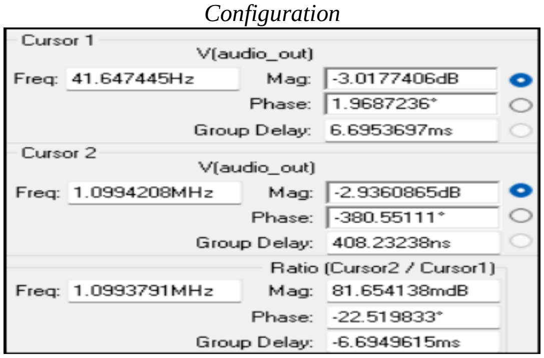

Figure 16 – Frequency Response Values of The Electret Configuration

Flat Range:

The system exhibits a flat frequency response between approximately 100 Hz and 100 kHz, suitable for audio applications.

Lower Cutoff:

The -3 dB point is observed at approximately 41.65 Hz, indicating the lower cutoff frequency.

Upper Cutoff:

The high-frequency -3 dB point occurs around 1.1 MHz, showcasing excellent bandwidth for audio and extended-frequency signals.

Key Data:

- 41.65 Hz: Magnitude = -3.02 dB, Group Delay = 6.695 ms.
- 1.1 MHz: Magnitude = -2.93 dB, Group Delay = 408.23 ns.

Complementary Push-Pull Output Stage:

The Complementary Push-Pull Output Stage provides current gain and efficiently drives the speaker, ensuring adequate power delivery and minimal distortion for clear audio reproduction.

Speaker Impedance:

Assuming an 8 Ω speaker, the Complementary Push-Pull Output Stage ensures sufficient current gain to drive the speaker efficiently. The configuration minimizes power loss while delivering clear and distortion-free audio to the low-impedance load.

Optical Microphone Configuration

1.5 First Current-to-Voltage Converter Circuit

Circuit Role:

Converts the small current produced by the photodiode into a voltage signal using an LM741 operational amplifier.

Key Parameters:

Feedback Resistor (R_2): 18 kΩ

Photodiode Current (I_{pd}): 0.06 mA (typical for normal light intensity)

Gain Calculation:

The gain of a current-to-voltage converter is determined by the feedback resistor:

$$V_{out} = I_{pd} \times R_f$$

$$V_{out} = (0.06 \times 10^{-3}) \times (18 \times 10^{3}) = 1.08\, V$$

1.6 Light Modulation Circuit

Circuit Role:

Modulates light intensity based on the amplified signal.

Gain Calculation:

The light modulation stage uses an Emitter Follower circuit, which has a voltage gain of approximately 1. It provides current gain, ensuring sufficient drive for the laser diode.

Current Through Laser Diode:

Laser Diode Current (I_{Laser}):

$$I_{Laser} = 301 \times \frac{6 - 0.7}{5100 + (301) \times 330} \approx 15.2\, mA$$

1.7 Second Current-to-Voltage Converter Circuit

Circuit Role:

Converts the small current produced by the photodiode into a voltage signal using an LM741 operational amplifier.

Key Parameters:

Feedback Resistor (R_9): 15 kΩ

Photodiode Current (I_{pd}): 0.06 mA (typical for normal light intensity)

Gain Calculation:

The gain of a current-to-voltage converter is determined by the feedback resistor:

$$V_{out} = I_{pd} \times R_f$$

$$V_{out} = (0.06 \times 10^{-3}) \times (15 \times 10^{3}) = 900\, mV$$

1.8 Optical Audio-Generating Circuit

Common Emitter Amplifier:

This stage amplifies the voltage recovered from the second photodiode.

Circuit Parameters:

Collector Resistance (R_C): 1.5 kΩ

Emitter Resistance (R_E): 100 Ω

Voltage Gain Calculation:

$$A_v = -\frac{R_C}{R_E} = -\frac{1500}{100} \approx 15$$

Frequency Response:

Based on the frequency response formula below:

$$f_{low} = \frac{1}{2\pi \times R \times C}$$

f_{low} is found as:

$$f_{low} \approx 25\ Hz$$

$$f_{high} = \frac{1}{2\pi \times R \times C}$$

f_{high} is found as:

$$f_{high} \approx 1.1\ MHz$$

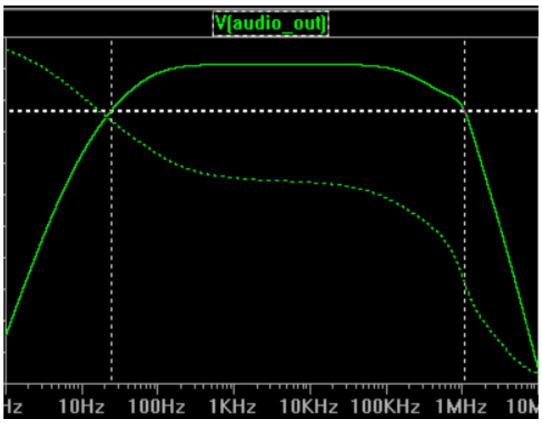

Figure 17 – Frequency Response of The Optical Configuration

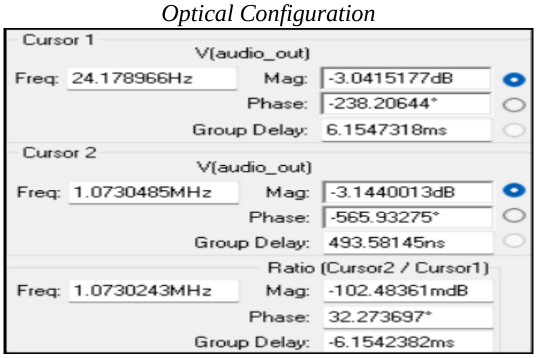

Figure 18 – Frequency Response Values of The Optical Configuration

Flat Range:

The system exhibits a relatively flat frequency response between approximately 100 Hz and 100 kHz, suitable for audio applications.

Lower Cutoff:

The -3 dB point is observed at approximately 24.18 Hz, indicating the lower cutoff frequency.

Upper Cutoff:

The high-frequency -3 dB point is located around 1.07 MHz, showcasing a wide bandwidth that extends well beyond typical audio ranges.

Key Data:

- 24.18 Hz: Magnitude = -3.04 dB, Group Delay = 6.15 ms.
- 1.07 MHz: Magnitude = -3.14 dB, Group Delay = 493.58 ns.

VI. PERFORMANCE AND VERIFICATION

Electret Microphone Configuration

The electret microphone configuration uses commercially optimized components, such as the electret microphone and LM358 amplifier, resulting in higher signal fidelity and lower noise compared to the optical configuration.

Performance Metrics

Signal Fidelity:

- The electret microphone provides clean, accurate audio signals with minimal distortion.
- The LM358-based non-inverting amplifier ensures robust signal amplification, maintaining the fidelity of the input audio.

Noise Performance:

- The electret microphone exhibits lower noise compared to the optical microphone, with effective filtering in the amplifier stage.
- Noise caused by electromagnetic interference is minimal and does not significantly affect the signal quality.

Frequency Response:

- The system effectively transmits frequencies in the range from nearly 41.65 Hz to 1.1 MHz, smooth response, with slight attenuation beyond 1.1 MHz.
- The laser diode and photodiode contribute to minor roll-off at higher frequencies but maintain a smoother response compared to the optical configuration.

Verification

Simulation Results:

- Microphone Circuit: The simulated gain of the LM358 amplifier matches design expectations, with a clean, amplified output.
- Light Modulation: The modulated light intensity corresponds proportionally to the input audio signal, confirmed by simulated waveforms.
- Photodiode Circuit: The recovered signal from the photodiode accurately represents the input waveform, with minimal distortion.

Real-World Testing:

- A 1 kHz sine wave was fed into the microphone circuit, and the audio signal was transmitted via the laser diode.
- At the receiving end, the photodiode captured the modulated light, and the audio signal was reproduced with high fidelity.

Observations:

- High accuracy in signal reproduction, with minimal noise.
- Stable performance across varying environmental conditions.

Optical Microphone Configuration

The optical microphone configuration uses homemade components, such as a mirror diaphragm and photodiodes, to process and transmit audio signals. This introduces challenges related to accuracy, noise, and stability.

Performance Metrics

Signal Fidelity:

- The homemade optical microphone introduces distortions due to its non-optimized components (e.g., mirror diaphragm and photodiodes).
- The laser diode modulates the signal effectively while noise and signal loss are reasonable during detection and recovery.
- Recovered signals show reduced fidelity, especially at higher amplitudes.

Noise Performance:

- The system exhibits some noise due to:
    - Variability in the optical microphone's homemade diaphragm response.
    - Ambient light interference despite the laser diode's monochromatic nature.
- Noise filtering is partially effective but does not eliminate all unwanted variations.

Frequency Response:

- The optical system supports frequencies in the typical audio range (From nearly 24.18 Hz to 1.07 MHz, smooth response) but suffers from attenuation at high frequencies.
- Frequency response analysis shows irregularities caused by the sensitivity limitations of the homemade photodiodes and current-to-voltage converter circuit.

Verification

Simulation Results:

- Light Modulation: The simulated modulated current through the laser diode corresponds linearly to the input voltage signal.
- Recovered Signal: The output signal from the second photodiode exhibits distortions and noise, reducing overall fidelity compared to the original input.

Real-World Testing:

- The light was transmitted over a distance of 50 cm, and the audio signal was recovered with reasonable noise and distortion.
- Ambient light interference and the diaphragm’s nonlinearity introduced some additional noise in real-world conditions.

Observations:

- Good accuracy in reproducing audio signals.
- Reasonable noise levels, making the system suitable for precise applications.

VII. CONCLUSION

1. Electret Microphone Configuration

The electret microphone configuration provided a reliable and efficient method for transmitting audio signals via light. The use of commercially optimized components resulted in a system with high fidelity, low noise, and robust performance.

Metric	***Optical Microphone Configuration***	***Electret Microphone Configuration***
Signal Fidelity	*Moderate accuracy, reasonable distortion*	*Moderate accuracy, reasonable distortion*
Noise Performance	*Reasonable noise due to homemade diaphragm and photodiode*	*Low noise due to optimized components*
Frequency Response	*From nearly* 24.18 *Hz to* 1.07 *MHz, smooth response*	*From nearly* 41.65 *Hz to* 1.1 *MHz, smooth response*
Real-World Testing	*Good accuracy and reasonable noise over 50 cm*	*Accurate reproduction with minimal noise over 50 cm*

Key Takeaways:

- The electret microphone captured audio signals accurately, and the LM358 amplifier provided sufficient gain for signal processing.
- The light modulation circuit effectively transmitted the signal via light, and the photodiode circuit reliably recovered the signal at the receiving end.
- The system exhibited minimal noise and a broad frequency response from nearly 41.65 Hz to 1.1 MHz, making it suitable for general audio applications.
- Real-world testing confirmed its stability and performance, even in moderately noisy environments.

Conclusion:

The electret microphone configuration proved to be a practical and effective solution for audio transmission over light. Its advantages include:

- High fidelity and minimal signal distortion.
- Low noise levels, even in non-ideal environments.
- A broad frequency response, capable of handling most audio applications.

This configuration is well-suited for practical use and demonstrates the benefits of using commercially available components in a light-based audio transmission system.

2. Optical Microphone Configuration

The optical microphone configuration showcased the potential of using light as a medium for audio signal transmission. However, the system's performance was constrained by the limitations of homemade components and the challenges of optical signal processing.

Key Takeaways:

- The optical microphone was able to detect sound waves and modulate the intensity of a laser diode beam to transmit the signal.
- Significant noise and distortion were introduced due to:
  - The homemade mirror diaphragm's nonlinearity.
  - Sensitivity and noise susceptibility of photodiodes.
  - Ambient light interference during testing.
- The system's frequency response was limited to 1.07 MHz, which restricted its ability to handle higher frequencies effectively.
- The recovered audio was recognizable but lacked clarity, with noticeable amplitude loss and distortion.

Conclusion:

While the optical microphone configuration demonstrated basic functionality, its practical use is limited due to high noise levels, reduced fidelity, and a narrow frequency response. To improve the system, the followings are recommended:

- Use professional-grade photodiodes with higher sensitivity and lower noise.
- Implement a more refined optical diaphragm for better light modulation.
- Add shielding and filtering to minimize ambient light interference.

This configuration serves as a proof of concept and highlights the challenges of implementing a homemade optical audio transmission system.

Overall Summary

The Optical Microphone Configuration highlights the potential for innovation in audio transmission using light, but its performance is limited by the constraints of homemade components. The Electret Microphone Configuration, on the other hand, is a more robust and reliable solution, making it the preferred choice for practical applications. Both systems provide valuable insights into the challenges and possibilities of light-based audio transmission.

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[3] B. Cordell, *Designing Audio Power Amplifiers*, New York: McGraw-Hill, 2011, ISBN: 978-0-07-164024-4.