UNDERWATER AUDIO TRANSMISSION USING LI-FI TECHNOLOGY

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ABSTRACT

This paper presents a practical implementation of an underwater audio transmission system using Li-Fi technology. Traditional underwater communication systems using radio frequency and acoustic methods suffer from limited bandwidth, high latency, and significant signal attenuation in conductive water environments. In contrast, Li-Fi (Light Fidelity) is an emerging form of visible light communication that offers high-speed, low-latency transmission by modulating light intensity. The proposed system leverages this concept by modulating an analog audio signal onto a high-intensity LED or laser source, which emits visible light through a water column. Instead of using a photodiode, a solar panel is employed as the light receiver, capitalizing on its ability to generate voltage from incident light. The modulated light passes through clear water, and the solar panel captures the varying light intensity, converting it back into electrical signals. These signals are filtered and amplified using an LM386 audio amplifier circuit and fed to a speaker for audio playback. This setup was tested in a controlled environment using a water-filled plastic container to simulate the aquatic medium. The system demonstrated clear and intelligible audio transmission over a short range of approximately 30 centimeters. Factors such as water clarity, alignment accuracy, and ambient light interference were found to impact the performance. The use of a solar panel as a receiver simplified the circuit and reduced cost, making the system accessible for educational and prototype-level applications. The results suggest that Li-Fi can be a viable alternative for short-range underwater audio communication where conventional RF systems fail.

Keyword - *Li-Fi, Underwater Communication, Solar Panel, Audio Transmission, Visible Light Communication*

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1. INTRODUCTION

Underwater communication has long been a challenge due to the high attenuation of radio frequency (RF) signals and the limited bandwidth of acoustic waves. Traditional communication methods face limitations such as low data rates, high latency, and interference in water-based environments. As a result, researchers have explored alternative technologies such as optical wireless communication, specifically Li-Fi (Light Fidelity), which uses visible light to transmit data through modulation techniques.

In this project, a novel approach is adopted using Li-Fi for short-range underwater audio transmission. A microphone captures the analog audio signal, which is then amplified and modulated onto a high-intensity LED or laser diode. The light beam propagates through a column of water and is received on the other side by a solar panel acting as a photodetector. The varying intensity of light captured by the solar panel generates a corresponding voltage signal, which is then filtered and amplified for playback on a speaker.

This system was tested using distilled water in a transparent container to simulate a clean aquatic medium. The alignment between the light source and the solar panel was found to be critical to ensuring consistent signal quality. Additionally, environmental factors such as water clarity and external light interference were evaluated during testing.

As per Kaushal and Kaddoum, optical wireless communication has demonstrated significant promise in underwater environments due to its high data rate and low latency compared to acoustic systems [1]. It is reported that the absorption characteristics of water are lowest in the blue-green light spectrum, making it ideal for Li-Fi-based systems [2].

2. LITERATURE REVIEW

Several studies have explored the limitations of conventional underwater communication methods and the potential of optical technologies to address them. Traditional approaches such as acoustic communication offer long-range capability but suffer from low bandwidth, high latency, and multipath distortion. Similarly, radio frequency (RF) signals are heavily attenuated in water, especially saline environments, making them ineffective for most underwater applications.

In contrast, optical wireless communication using visible light has shown considerable promise in recent years. Researchers like Kaushal and Kaddoum [1] have highlighted the feasibility of underwater optical systems, noting their high data rate and low latency. Blue and green wavelengths, in particular, exhibit lower absorption in water, allowing for improved signal propagation. Doniec et al. [2] proposed a signal strength model to evaluate underwater optical performance, while Jaruwatanadilok [3] applied vector radiative transfer theory to assess channel reliability.

Recent advancements in Li-Fi technology, a subset of visible light communication (VLC), enable modulating data onto light emitted from LEDs or lasers. Most existing research has focused on digital data transfer using photodiodes or phototransistors. However, this project extends the application of Li-Fi by using **analog modulation of audio signals** and a **solar panel as the receiver**, offering a cost-effective alternative for basic underwater communication.

This literature forms the foundation of the current work, which emphasizes simplicity, affordability, and the practical viability of using Li-Fi for short-range underwater audio transmission.

3. SYSTEM DESIGN AND IMPLEMENTATION

The proposed underwater audio transmission system is designed using a simple analog modulation technique, enabling real-time communication through visible light. The system is divided into two major sections: the transmitter and the receiver, with a water medium between them.

The transmitter section consists of a condenser microphone that captures analog audio signals. These signals are fed into an LM386 audio amplifier, which boosts the signal strength. The amplified signal is used to modulate a high-brightness LED or laser diode, which emits light according to the amplitude variations of the audio signal. This modulated light is projected across a short underwater distance, typically between 10 to 30 centimetre's, through a container filled with distilled water.

The receiver section utilizes a solar panel as the light detector. When the modulated light reaches the panel, it converts the light intensity changes into small electrical signals. These signals are then passed through a filter circuit to remove noise and amplified again using another LM386 amplifier, restoring the original audio waveform. Finally, the output is played through a speaker.

To minimize distortion, proper alignment of the LED and solar panel was ensured. Water quality and light interference were considered during testing, with the best results obtained in clean, still water. The overall system design remains cost-effective and easy to implement using basic components while effectively demonstrating the feasibility of Li-Fi-based underwater communication.

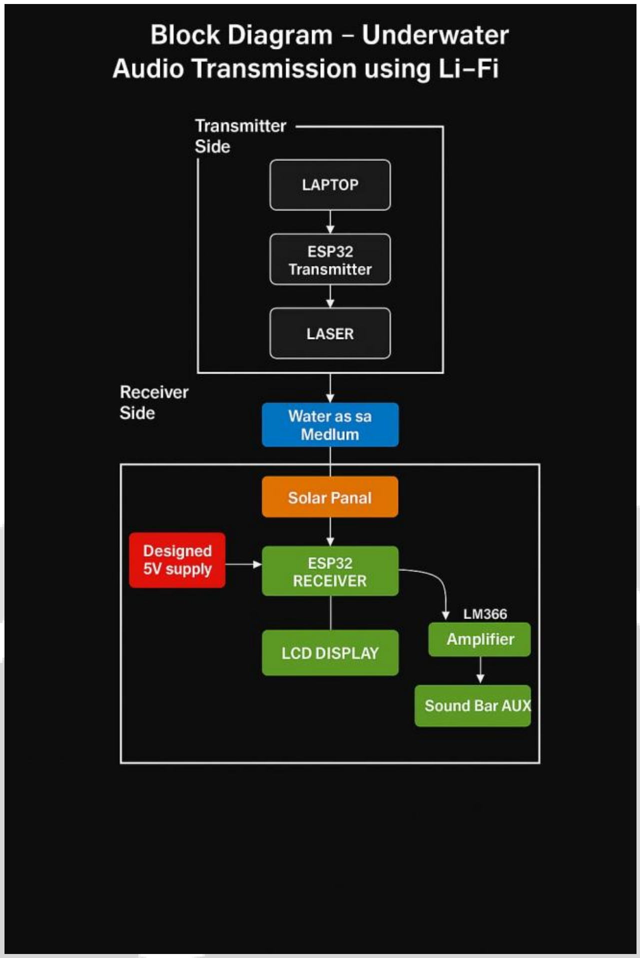


Fig.1. Block diagram

3.1 Transmitter Section

The transmitter section begins with an analog audio input captured using a microphone. The weak audio signal is amplified through an LM386 low-voltage audio amplifier, which boosts the signal strength to a level suitable for modulation. The output of the amplifier is connected to a high-brightness LED or laser diode. This component serves as the light source, converting the electrical signal into modulated visible light. The LED's light intensity changes in accordance with the amplitude of the audio signal, effectively encoding the information onto the light beam.

3.2 Transmission Medium

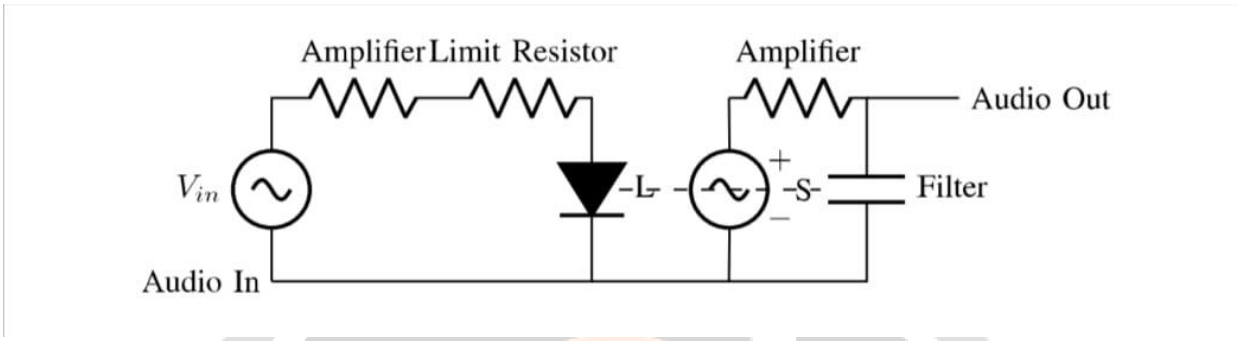
A transparent water-filled plastic container serves as the underwater medium. The modulated light travels through the water column, carrying the audio signal in the form of light intensity variations. The transmission distance is kept between 10–30 cm to minimize loss due to scattering and absorption. The system performs best in clear, still water, as turbidity and movement can cause signal degradation.

3.3 Receiver Section

At the receiving end, a solar panel is positioned directly in line with the LED or laser beam. As the modulated light hits the solar panel, it converts the variations in light intensity into corresponding electrical signals. The raw output is filtered to eliminate noise and amplified again using an LM386 amplifier to restore the audio waveform. This signal is finally passed to a speaker, allowing real-time playback of the transmitted audio.

Proper alignment between the transmitter and receiver is essential for optimal performance. Additional measures such as shielding the receiver from ambient light and collimating the light beam were considered to improve signal fidelity.

Fig.2 Circuit Diagram



4. METHODOLOGY

The methodology adopted for the underwater audio transmission system focused on the development, alignment, and calibration of the transmitter and receiver modules. The approach was divided into several key phases: circuit design, component selection, prototype assembly, and performance testing.

4.1 Circuit Design and Assembly

The transmitter circuit was designed using a condenser microphone, followed by an LM386 audio amplifier. The amplified signal was connected to a high-power LED, chosen for its ability to emit bright, focused light. In some experimental setups, a laser diode was used to increase directional accuracy. The circuit was built on a breadboard for testing and later soldered onto a PCB for stability.
The receiver circuit used a solar panel to capture light signals. Since the panel's voltage output varies with light intensity, its signal was routed through a passive filter to eliminate noise, and then passed into a second LM386 amplifier to boost the audio signal for speaker output.

4.2 Alignment and Calibration

The transmitter and receiver were aligned within a transparent water container to maintain direct line-of-sight. Distance was kept between 10–30 cm. Calibration involved ensuring that the light beam was centered on the solar panel, and gain control on the amplifier was tuned for maximum clarity without distortion.

4.3 Testing Conditions

The setup was tested in controlled indoor conditions. Tests were conducted under different lighting scenarios—dark room, natural light, and with additional ambient light. Performance parameters such as clarity, volume, and range were evaluated for each condition.
This methodology ensured a repeatable and measurable approach to verify the feasibility of using visible light for underwater audio communication.

5. EXPERIMENTAL SETUP AND CALIBRATION

The experimental setup was constructed to test the performance of the underwater audio transmission system in a controlled environment. The main objective was to ensure that the light beam carrying the audio signal effectively reached the receiver through a water medium and that the audio signal could be recovered with acceptable clarity.

5.1 Setup Description

The system was implemented using two distinct modules: the transmitter and the receiver, placed opposite each other inside a transparent plastic container filled with distilled water. The container simulated the underwater environment. The **transmitter circuit**, comprising a microphone, an LM386 amplifier, and a high-brightness white LED, was mounted at one end of the container. On the opposite side, a **solar panel** served as the light receiver.
To reduce signal scattering and reflection, the container was cleaned and filled with still water. The water column length was varied between **10 cm to 30 cm** to analyze the effect of distance on signal quality.

5.2 Calibration Procedures

The **LED or laser** was carefully aligned to ensure its light beam directly struck the center of the solar panel. During initial trials, ambient light was minimized using black cloth around the setup to reduce interference. The gain control of the LM386 amplifier at the receiver end was adjusted to improve audio clarity without introducing significant noise or distortion.
A **signal generator** was also used in place of the microphone during calibration, producing known sine wave tones (e.g., 1 kHz) to help fine-tune the amplifier and evaluate waveform fidelity via an oscilloscope.

5.3 Observations

The system worked effectively for distances up to 30 cm. Clean, still water ensured better light transmission, while any turbidity or misalignment resulted in noticeable degradation in signal clarity. Environmental lighting, especially from fluorescent sources, occasionally introduced noise, which was mitigated by shielding the receiver.

6. RESULTS

The performance of the underwater audio transmission system was evaluated based on multiple experiments conducted in a controlled environment. Various parameters such as distance, clarity, stability, and environmental influence were analyzed during testing.

6.1 Audio Transmission Quality

The system successfully transmitted audio signals through distilled water over short distances ranging from 10 cm to 30 cm. Within this range, the audio output was clear and intelligible, with minimal distortion. At distances beyond 30 cm, the signal quality significantly degraded due to reduced light intensity and dispersion in water. Proper alignment of the LED and solar panel was critical in maintaining signal quality.

6.2 Environmental Effects

Tests revealed that water clarity played a significant role in system performance. In clean, still water, transmission was strong and consistent. However, when impurities such as salt, dust, or air bubbles were introduced, the received signal became noisy and weak. The presence of ambient light sources (especially fluorescent lighting) also interfered with the solar panel’s response, producing background noise. Shielding the receiver area improved signal reception in these conditions.

6.3 Comparison with Air Medium

For comparison, the same setup was tested in open air (without water between the LED and the solar panel). The clarity and volume were significantly better, confirming that the water medium introduces attenuation and refraction. However, even in water, the system maintained acceptable audio quality for short distances, making it suitable for specific low-range underwater applications.

6.4 Tabulated Results

Below is a summary of observed performance at different conditions:

Medium	Distance (cm)	Audio Clarity
Air	50	Excellent
Water	10–20	Clear and Loud
Water	30	Moderate Clarity
Water	>30	Weak or Unstable

Table -1 Conditions

These results confirm the feasibility of using visible light for short-range underwater analog audio transmission.

7. DISCUSSION

The results of the underwater audio transmission system reveal both the potential and the limitations of using Li-Fi technology in submerged environments. The system demonstrated effective short-range communication, particularly within 30 cm, using simple and inexpensive components. This validates the use of visible light as a medium for underwater audio communication, especially in controlled conditions.

One notable innovation in this project was the use of a solar panel as the receiver instead of a traditional photodiode. While photodiodes are commonly used for their high-speed response and sensitivity, solar panels offer a larger surface area and higher voltage output, simplifying the signal amplification process. This trade-off between bandwidth and signal strength was acceptable for low-frequency analog audio transmission, which does not demand high data rates.

The discussion also highlights the sensitivity of Li-Fi systems to water quality, alignment, and ambient lighting. Even slight deviations in the alignment between the LED and the solar panel drastically impacted performance. The water’s clarity played a major role in signal strength, with clean, still water producing the best results. Real-world underwater environments may present challenges such as turbidity, motion, and variable lighting, all of which can degrade signal quality.

To further improve the system’s reliability, future designs could implement digital modulation techniques such as PWM or FSK, along with digital signal processing (DSP) to filter noise more effectively. Additionally, the use of collimating lenses or reflectors could enhance light focusing and range.
In summary, this project proves that a low-cost, analog Li-Fi system using LEDs and solar panels can effectively transmit audio signals through water, provided environmental factors are managed and proper calibration is maintained.

8. CONCLUSION

This paper presented a cost-effective and practical approach for short-range underwater audio transmission using Li-Fi technology. By leveraging visible light communication and utilizing an LED or laser diode for transmission and a solar panel for reception, the system successfully demonstrated analog signal propagation through a water medium.
The experimental results validated that clear audio communication could be maintained over distances up to 30 centimeters in clean, controlled water conditions. The use of an LM386 amplifier on both transmitter and receiver sides enabled the audio signals to be effectively modulated and demodulated without the need for complex digital circuits. The substitution of a photodiode with a solar panel further simplified the design and enhanced the system’s voltage output, though at the cost of reduced bandwidth.
Although environmental factors such as water clarity, ambient light, and alignment significantly influenced system performance, appropriate calibration and shielding helped mitigate these challenges. The successful implementation of this system emphasizes the potential of Li-Fi as a viable solution for low-cost, low-range underwater communication.

This work can serve as a foundational step toward more advanced designs using digital modulation, optical beam collimation, and real-world deployment in underwater sensor networks, diver communications, and robotic platforms. The simplicity of the system also makes it an excellent educational tool to introduce students to optical communication principles and practical electronics**.**

9. ACKNOWLEDGMENT

We would like to express our heartfelt gratitude to all those who contributed to the successful completion of our project titled “Underwater Audio and Data Transmission Using Li-Fi.” First and foremost, we sincerely thank our respected guide, Prof. Rahul Bansode, for his valuable guidance, encouragement, and consistent support throughout the duration of this work.
We also extend our appreciation to the faculty members and technical staff of the Department of Electronics and Telecommunication Engineering, Sharadchandra Pawar College of Engineering, Pune, for providing the necessary facilities and a supportive environment for experimentation and development.
We are thankful to our classmates and peers for their insightful feedback, moral support, and active participation in discussions that helped refine our design and implementation. Finally, we are deeply grateful to our families for their unwavering motivation and support throughout this journey.

10. FUTURE ENHANCEMENT

Although the proposed system performed well under controlled laboratory conditions, several areas offer opportunities for improvement and advancement.

- Digital Modulation Techniques: Implementing digital modulation methods like Pulse Width Modulation (PWM), Frequency Shift Keying (FSK), or Amplitude Shift Keying (ASK) can increase signal robustness and reduce interference.
- Signal Processing: Incorporating Digital Signal Processing (DSP) techniques can enhance noise filtering and improve the overall audio quality under variable lighting and water conditions.
- Optical Components: Using collimating lenses or reflectors can help focus the LED or laser beam, allowing for longer-range underwater transmission.
- Dynamic Calibration: Adaptive systems that auto-tune gain and alignment based on environmental conditions would make the system more practical in real-world underwater applications.
- Two-way Communication: Enhancing the design to support bidirectional audio transmission can open up applications in underwater robotics and diver communication.
- Wireless Video Transmission: With more powerful optical components, the system could be upgraded to support compressed video transmission for underwater monitoring.

These improvements could significantly increase the reliability and usability of Li-Fi systems in submerged environments.

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