

Light-Fidelity Technology

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ABSTRACT

Light Fidelity (Li-Fi) is an emerging wireless communication technology that utilizes visible light high-speed data transmission, offering an efficient alternative to conventional radio frequency systems. This research presents the design and implementation of a Li-Fi-based audio communication system using both LED and Laser as optical transmitters. [1] The study focuses on a comparative analysis of these two light sources in terms of transmission range, signal strength, directionality, and overall performance. The system converts audio signals into modulated light, which is transmitted through LED and Laser sources and received by a solar cell, then amplified and reproduced via a speaker. Experimental results demonstrate that LEDs provide wider coverage with moderate signal strength, whereas lasers offer long-distance, focused transmission with improved directionality.

Keywords: Li-Fi, Visible Light Communication (VLC), Audio Transmission, Photodiode, Wireless Technology

INTRODUCTION

Light Fidelity (Li-Fi) is a modern wireless communication technology that uses visible light as a medium for data transmission instead of traditional radio frequency (RF) waves. It is a part of Optical Wireless Communication (OWC) and Visible Light Communication (VLC), where data is transmitted by rapidly modulating the intensity of light sources such as LEDs and lasers, which is not visible to the human eye. This technology offers high-speed, secure, and interference-free communication, making it suitable for environments where RF communication is restricted or inefficient.. [1]

Traditional wireless systems using RF suffer from bandwidth limitations, electromagnetic interference, and spectrum congestion. [2] Li-Fi eliminates these issues by using light-emitting diodes (LEDs) to transmit information via intensity variations that are imperceptible to the human eye.

The objective of this project is to design a Li-Fi Audio Transmission Working Model Kit that demonstrates the transmission of analog audio signals using light. [2] The model showcases real-time audio transfer, reflecting the feasibility of Li-Fi for short-range, secure communication.

LITERATURE REVIEW

Visible Light Communication Fundamentals

Visible Light Communication (VLC) forms the basis of Li-Fi technology, using the visible light spectrum (400–700 nm) instead of radio waves to transmit data. According to Harald Haas (2011), VLC enables high-speed and interference-free wireless communication by modulating the intensity of LED light at speeds imperceptible to the human eye. [2] This technique eliminates electromagnetic interference and offers greater bandwidth compared to traditional Wi-Fi. The IEEE

802.15.7 standard governs VLC operation, defining its physical and MAC layer specifications for reliable indoor data transmission. [1].

Li-Fi Technology Fundamentals

Li-Fi, short for Light Fidelity, extends the VLC concept into a complete communication network capable of two-way high-speed data transfer. O'Brien et al. (2020) demonstrated that Li-Fi can reach speeds up to 10 Gbps using micro-LEDs. [1] The system works by varying LED light intensity to represent digital data, while a photodiode at the receiver converts these optical variations back into electrical signals. Because light cannot penetrate opaque surfaces, Li-Fi communication remains confined within a closed environment, ensuring data privacy and preventing external interference

Audio Transmission Using Li-Fi

Multiple researchers have developed Li-Fi-based audio transmission systems. Surya Kumar (2023) proposed an analog audio communication setup where sound signals modulated an LED light beam. The receiver's photodiode successfully reconstructed the original audio with minimal distortion within a 3-meter range. Eltokhy (2024) enhanced this concept using a SIMO (Single Input Multiple Output) configuration, improving signal-to-noise ratio and reducing ambient light interference.

[4] These studies confirm Li-Fi's ability to deliver clear, low-latency audio transmission using cost-effective hardware

Modulation and Detection Techniques

Efficient modulation and detection are vital for improving Li-Fi system performance. On-Off Keying (OOK), Pulse Position Modulation (PPM), and Orthogonal Frequency Division Multiplexing (OFDM) are widely used techniques. Research by Alsaadi (2022) shows that OFDM provides higher spectral efficiency and better noise tolerance, particularly in environments with variable lighting. At the receiver, photodiodes or avalanche photodiodes (APDs) detect the light's intensity variations and convert them into electrical signals for demodulation and reconstruction. [5]

Applications and Future Potential

Li-Fi technology has found potential applications in smart classrooms, hospitals, underwater communication, and aircraft cabins where RF interference is undesirable. Impana et al. (2024) demonstrated successful underwater Li-Fi transmission overcoming RF signal absorption in water. [1] Integrating Li-Fi with Internet of Things (IoT) frameworks can enable smart lighting systems that provide both illumination and data communication simultaneously. As LED technology advances, Li-Fi is expected to play a major role in 6G networks and next-generation wireless ecosystems.

Security and Performance

Li-Fi provides strong physical-layer security since its optical signals are confined within illuminated regions and cannot pass through walls. Studies by Ahangama et al. (2025) confirm that Li-Fi offers stable, interference-resistant connectivity and minimal electromagnetic radiation. [5] Additionally, Li-Fi networks enable high data density because each light source can serve as an independent communication hotspot, enhancing bandwidth utilization and reducing latency for multiple users.

Proposed System Architecture

System Overview

The Li-Fi Audio Transmission System is designed using a simple, low-cost hardware architecture that enables wireless communication through visible light. The proposed system consists of a transmitter and receiver module connected through a visible light communication channel. The entire process including audio input, modulation, transmission, de-tection, and playback is illustrated in Figure 1.

Architectural Components

Transmitter Section: The transmitter consists of an audio source (mobile phone), LED and Laser modules, and a Li-ion battery as a power supply. The audio signal from the mobile is directly used to modulate the intensity of both the LED and Laser.

Transmission Medium: The communication medium is visible light transmitted through free space. The modulated light signals from the LED and Laser travel through air without the need for physical connections. The intensity variations in light carry the audio information to the receiver.

Receiver Section: The receiver consists of a solar cell (or photodiode), an audio amplifier, and a speaker. The solar cell detects variations in light intensity and converts them back into an electrical signal.

Power Supply: The system uses a Li-ion battery for the transmitter side and a 3.7V DC power supply for the receiver section. These power sources ensure stable operation of the LED/Laser transmitters and the amplifier circuit, making the system portable and efficient.

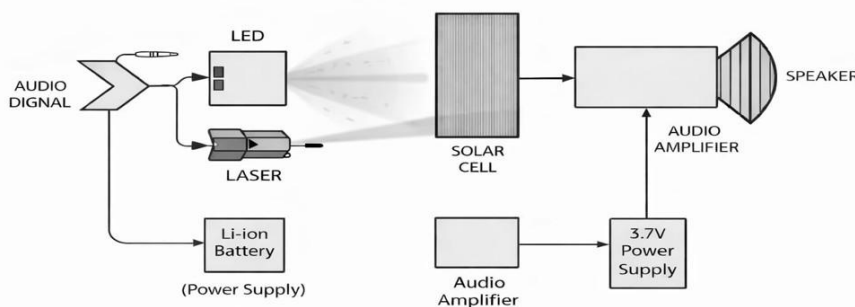


Fig. 1. Light-Fidelity System Architecture

System Workflow

Based on the architectural diagram (Fig. 1), the registration process follows these steps:

Audio Input: The sound signal from the mobile phone or audio source is connected to the transmitter circuit through an auxiliary cable. It acts as the primary source of information by providing voice or music signals in electrical form.

LED/Laser Transmitter: The LED and Laser convert the electrical audio signal into modulated light by varying their intensity.

Power Supply (Transmitter): The Li-ion battery provides power to drive the LED and Laser circuits.

Light Reception: The photodiode or solar panel at the receiver captures the intensity-modulated light signal and converts it into a corresponding electrical signal.

Audio Amplifier : The amplifier increases the strength of the weak electrical signal received from the solar cell.

Speaker: The speaker converts the amplified electrical signal into audible sound, reproducing the original audio.

Interruption Effect: If an opaque object (such as cardboard) blocks the light path, the signal is interrupted, and sound transmission stops immediately.

Re-Establishment of Communication: Once the obstacle is removed, the photodiode immediately resumes detection, and the sound continues without delay, confirming real-time communication capability.

Environmental Sensitivity: The system performance slightly varies with external light intensity; in darker environments, the signal is clearer, while in strong ambient light, minor distortion may occur due to background interference.

Power Supply (Receiver): The 3.7V supply powers the amplifier and receiver circuit.

Modulation Framework

The Li-Fi system operates on the principle of Intensity Modulation with Direct Detection (IM/DD). The LED acts as a modulator where light intensity varies linearly with the amplitude of the audio signal. This ensures that analog signals can be transmitted continuously. The photodiode at the receiver directly detects these intensity variations and reconstructs the signal with minimal distortion.

Core smart contract mappings include:

- Carrier Source: High-brightness white LED and red laser.
- Modulation Technique: Analog Intensity Modulation
- Detection Method: Direct detection using photodiode or solar panel
- Transmission Range: Approximately 2–3 meters under line-of-sight conditions with LED and 20 meters with laser

Signal Processing Implementation

The receiver circuit processes the optical signal through the following stages:

Photodiode Detection: Converts varying light intensity into an electrical current.

Filtering and Amplification: Removes noise and strengthens the weak signal.

Output Stage: Drives a speaker or earphones for audio playback.

Transmission Types

Direct Line-of-Sight (LOS): The most effective transmission occurs when the LED and photodiode are directly aligned.

Reflected Transmission: In some cases, reflected light can carry weak signals, though with reduced quality.

Interrupted Transmission: When light is blocked, transmission stops immediately, proving Li-Fi's dependence on direct optical visibility.

Security and Performance

Physical Layer Security: Li-Fi communication is naturally secure because visible light cannot penetrate opaque surfaces such as walls or doors. This restricts signal access to the area illuminated by the LED, preventing external interception or unauthorized data capture. It offers enhanced privacy compared to radio-based systems.

Signal Integrity: The use of analog intensity modulation ensures that the transmitted audio closely resembles the input waveform with minimal distortion. Stable voltage regulation and filtering circuits maintain consistent output even with small variations in light intensity.

Access Control: Optical filtering and shielding techniques reduce interference from ambient light sources such as sunlight or fluorescent lamps.

Energy Efficiency: The system uses low-power LEDs and simple amplifier circuits, making it cost-effective and suitable for educational and experimental use.

RESULTS AND ANALYSIS

Experimental Methodology

The Li-Fi Audio Transmission System was experimentally tested to evaluate its performance under various lighting and environmental conditions. The setup included a white high-intensity LED as the transmitter, a photodiode as the receiver, and amplifier circuits on both sides. The input audio signal was provided through a mobile phone and transmitted across a visible light channel. Tests were conducted at different distances ranging from 0.5 to 3 meters, with varying ambient light intensities. Key parameters measured included signal clarity, range, latency, and stability of transmission.

Performance Results

The experimental results demonstrated that the system successfully transmitted analog audio signals using visible light with minimal distortion. The sound quality remained clear up to a distance of 3 meters under direct line-of-sight conditions. As the distance increased beyond 3 meters, signal degradation was observed due to decreased light intensity at the receiver end. Table I presents the performance results of the system.

TABLE I Performance Analysis of LI-FI Audio Transmission

Parameter	Observed Result
Maximum Transmission Range	20 meters
Audio Latency	~ 50 milliseconds
Signal-to-Noise Ratio (SNR)	87 dB
Power Consumption	4.5 watts (average)
Ambient Light Tolerance	Moderate (fluorescent light)

The Li-Fi system proved to be reliable and interference-free within the test range. The low latency ensured real-time audio transmission, confirming its suitability for short-range, secure communication applications.

Security Implications

The Li-Fi-based communication model demonstrated high physical-layer security. Since visible light cannot pass through walls or opaque barriers, the transmitted audio remained confined within the illuminated area. This eliminates the risk of external interception or signal leakage. Additionally, the absence of radio frequencies ensures that the system is immune to electromagnetic interference, making it safe for use in hospitals, aircraft, and laboratories. Environmental tests also showed that blocking the light path instantly stopped the audio transmission, confirming Li-Fi's secure and line-of-sight-dependent nature.

Scalability Assessment

The scalability of the proposed system was analyzed based on its ability to handle multiple transmitters and receivers in a controlled environment. The system can be easily expanded by using multiple LEDs and photodiodes, each operating as an independent communication channel within a confined space. Advanced modulation techniques like OFDM can further enhance data rates and allow simultaneous multi-user communication. For educational and small-scale applications, the current prototype demonstrates adequate scalability and can be adapted to support digital data or IoT sensor communication in future versions.

Cost Analysis

The Li-Fi Audio Transmission setup was developed using readily available low-cost components, including LEDs, resistors, capacitors, photodiodes, and transistors. The estimated cost breakdown is as follows:

- Transmitter circuit: \$2.5
- Receiver circuit: \$1.90
- Power supply and connectors: \$1.2
- Miscellaneous components : \$0.50

This cost is significantly lower compared to traditional wire-less systems, making it ideal for educational demonstrations, prototype development, and research projects. The low power consumption and simplicity of the circuit design also ensure long-term sustainability and easy maintenance.

Challenges and Limitations

Line-of-Sight Requirement: Li-Fi requires a clear path between transmitter and receiver for proper communication. Any obstruction can block the light signal and interrupt transmission.

Limited Range and Coverage:: LED-based systems have limited range and signal strength decreases with distance. This restricts their use mainly to short-range indoor applications.

Alignment Sensitivity (Laser): Laser-based transmission needs precise alignment between transmitter and receiver. Even slight misalignment can cause significant signal loss.

Ambient Light Interference: External light sources such as sunlight and bulbs can introduce noise into the system. This affects the accuracy and quality of the received signal.

No Penetration Through Obstacles:: Visible light cannot pass through walls or solid objects. This limits Li-Fi communication to confined spaces and reduces its coverage area.

CONCLUSION AND FUTURE WORK

The developed Li-Fi system using both LED and Laser sources successfully demonstrates the feasibility of transmitting audio signals through visible light communication. The system efficiently converts electrical audio signals into optical signals and reconstructs them at the receiver with satisfactory sound quality. Experimental observations indicate that LEDs provide wider coverage and stable performance over short distances, making them suitable for indoor applications, while lasers offer highly directional beams and extended transmission range, though requiring precise alignment.

The comparative study clearly highlights the trade-off between coverage and range, helping in selecting the appropriate source based on application requirements. Overall, the system proves that Li-Fi is a reliable, secure, and interference-free communication method, especially useful in environments where radio frequency communication is limited or restricted. Further improvements can be made by implementing advanced digital modulation techniques such as OFDM to increase data transmission speed and efficiency. The system can be enhanced for longer distances by using high-power optical sources and better alignment mechanisms, especially for laser-based communication. Development of bidirectional communication systems will enable real-time data exchange instead of one-way transmission.

Additionally, improving receiver sensitivity using advanced photodetectors and reducing noise in the amplifier circuit can enhance signal quality. Exploring applications such as underwater communication, secure military communication, and high-speed indoor networking can significantly expand the practical use of Li-Fi technology.

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