International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802137

Underwater Data Transmission Using Li-Fi Communication System

Poongodi K.K.[1], Elakya R[2], Kiruthika C[3], Sivasini R[4], Rokeshuvaraj Nagarajan N[5]

AP/EEE, Paavai Engineering College, Namakkal, Tamil Nadu, India[1]

UG Student/EEE, Paavai Engineering College, Namakkal, Tamil Nadu, India[2]

UG Student/EEE, Paavai Engineering College, Namakkal, Tamil Nadu, India[3]

UG Student /EEE, Paavai Engineering College, Namakkal, Tamil Nadu, India[4]

Master of Science in Aerospace Engineering, Virginia Polytechnic and State University, Blackburg VA[5]

Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: Underwater communication remains a significant challenge due to the high attenuation of radio frequency (RF) signals and the limitations of acoustic communication, such as low data rates and high latency. This project presents the design and implementation of an underwater data transmission system based on Li-Fi (Light Fidelity) technology, which utilizes visible light as a medium for high-speed and secure data transfer in aquatic environments.

The proposed system consists of a transmitter and receiver unit built around Arduino microcontrollers. At the transmitting end, textual or audio data from a computer is processed and encoded into modulated optical signals using a laser source driven by a dedicated driver circuit. The intensity of the light is varied according to the input data, enabling efficient signal propagation through the water medium. At the receiving end, a photodiode or captures the transmitted optical signals and converts them into electrical signals. These signals are then decoded by the microcontroller to reconstruct the original data. The output is displayed in textual form on an LCD screen.

The system is evaluated based on parameters such as transmission distance, signal clarity, and environmental factors like water turbidity and light scattering. Experimental results demonstrate that Li-Fi-based communicationprovides a reliable and low-latency alternative for short-range underwater data transmission. Compared to traditional acoustic systems, the proposed method offers higher bandwidth and enhanced security due to its line-of-sight nature.

This work highlights the potential of Li-Fi technology in underwater applications such as marine research, environmental monitoring, offshore exploration, and defense communication systems. Future enhancements may include the integration of advanced modulation techniques, error correction algorithms, and improved optical components to increase transmission range and data rate.

KEYWORDS: Li-Fi, Underwater Communication, Arduino, Optical Transmission, LED Communication.

I. INTRODUCTION

Underwater communication plays a vital role in various domains such as marine research, environmental monitoring, offshore oil and gas exploration, disaster prevention, and defense operations. The ability to transmit data efficiently beneath the water surface is essential for real-time monitoring and control of underwater systems. However, establishing reliable communication in aquatic environments remains a significant challenge due to the unique physical properties of water.

Conventional communication technologies face serious limitations underwater. Radio frequency (RF) signals experience rapid attenuation in water, making them unsuitable for long-distance communication. On the other hand, acoustic communication is widely used but suffersfrom drawbacks such as low data rates, high latency, signal distortion, and susceptibility to environmental noise. These limitations restrict its effectiveness in applications that require high-speed and real-time data transmission.
To overcome these challenges, optical wireless communication has gained attention as a viable alternative. **Li-Fi**

(Light Fidelity) technology, which uses visible light for data transmission, offers advantages such as high bandwidth, low latency, energy efficiency, and enhanced security due to its line-of-sight nature.

In this project, an underwater data transmission system based on Li-Fi technology is designed and implemented using Arduino microcontrollers. The system architecture consists of a transmitter and receiver unit. At the transmitter side, input data in the form of text or audio is processed and converted into modulated optical signals using a light source and driver circuit. These signals travel through the water medium and are captured at the receiver using a photodiode or light sensor.

The received optical signals are converted back into electrical form and decoded by the microcontroller to reconstruct the original data. The output is displayed on an LCD for text communication system. The system demonstrates the practical implementation of Li-Fi technology for underwater data transfer.The primary objective of this work is to develop a cost-effective and efficient underwater communication system that demonstrates the feasibility of Li-Fi technology as an alternative to traditional methods. This project also aims to highlight the potential of optical communication in enabling faster, more secure, and reliable underwater data transmission.

Key Requirements for Effective Detection Effective detection in an underwater Li-Fi communication system depends on the reliable capture and processing of optical signals that are significantly weakened due to absorption and scattering in water. A sensitive optical receiver is essential, and in this system, a **photodiode is used as the detector**, converting incident light into

Communication through line-of-sight transmission. Several studies demonstrate the use of LEDs for transmitting data underwater achieving significantlyelectrical signals. Its large surface area allows better light collection under low-intensity conditions, but its slower response time limits high-speed data transmission, making proper system tuning important. Accurate alignment between the transmitter and receiver is critical because Li-Fi operates on a line-of-sight basis, and even slight misalignment can reduce signal strength drastically. Additionally, ambient light and environmental noise can interfere with detection, so optical shielding and basic filtering techniques are necessary to improve the signal-to-noise ratio. Since the output from the solar panel is relatively weak and may fluctuate, signal amplification and conditioning circuits are required before feeding it into the microcontroller for decoding. Efficient signal processing, including proper sampling and decoding methods, ensures accurate reconstruction of transmitted data. Factors such as water clarity, transmission distance, and system stability also influence detection performance. Overall, achieving effective detection requires a balance between hardware design, environmental considerations, and signal processing techniques to ensure reliable underwater communication.

II. LITERATURE SURVEY

Underwater communication has been extensively studied using three primary approaches: radio frequency (RF), acoustic, and optical communication. Early research indicates that RF communication is highly ineffective in underwater environments due to severe signal attenuation, limiting its use to extremely low frequencies and very short ranges. As a result, acoustic communication has traditionally been the dominant method for underwater data transmission. Studies on acoustic systems highlight their ability to achieve long-distance communication; however, they suffer from inherent drawbacks such as low data rates, high latency, multipath propagation, and susceptibility to environmental noise.

To overcome these limitations, recent research has focused on **underwater optical wireless communication (UOWC)**, particularly using visible light and laser-based systems. Li-Fi technology has emerged as a promising solution due to its capability to provide high bandwidth, low latencyhigher data rates compared to acoustic methods, especially in clear water conditions.Recent experimental works have investigated alternative receiver designs,including the use of solar panels as optical detectors. Photodiode for light collection and can improve signal reception under low-intensity conditions. However, studies indicate that their slower response time limits their effectiveness for high-speed data transmission, making them more suitable for low-data-rate applications.Despite these advancements, challenges such as light absorption, scattering in turbid water, alignment sensitivity, and environmental interference continue to affect system performance. Most existing systems also focus on either high-speed communication or long-distance transmission, with limited emphasis on low-cost and practical implementations.

In this context, the proposed work focuses on developing a cost-effective underwater Li-Fi communication system using Arduino-based architecture and a solar panel receiver. The system aims to balance simplicity, reliability, and

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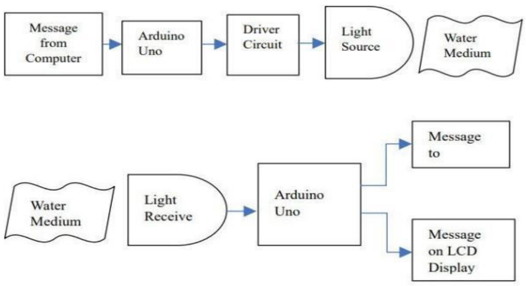
functionality by enabling text and audio transmission over short distances, while addressing practical challenges such as signal attenuation and noise. This approach contributes to the ongoing research in underwater optical communication by emphasizing accessibility and real-world feasibility.

III. BLOCK DIAGRAM

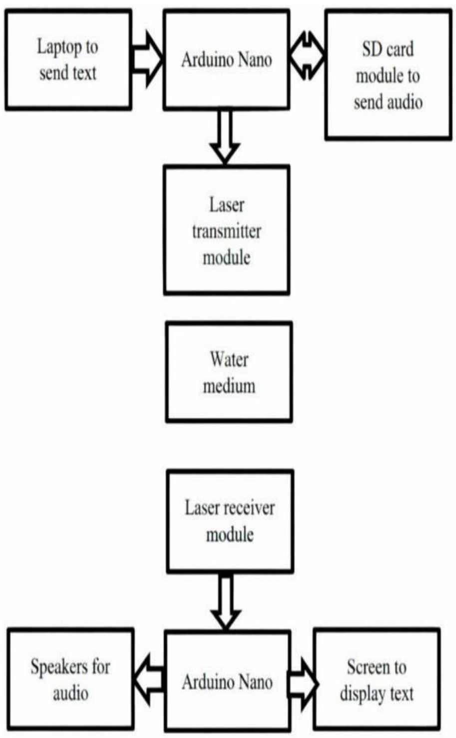
A. Transmitter

Fig 1. In the transmitter section, the input message from a computer or laptop is sent to the microcontroller such as Arduino Uno or Arduino Nano, where the data is converted into digital signals. These signals are passed to a driver circuit, which amplifies and modulates them to control the light source, such as an LED transmitter. The modulated light carries the encoded information and is transmitted through the water medium using visible light communication.



B. Receiver

The receiver section captures the transmitted optical signal from the water medium using a photodiode receiver module, converting light variations into electrical signals. These signals may be weak and affected by noise due to underwater attenuation, so they are conditioned and then fed into a microcontroller like an Arduino for decoding. The microcontroller processes and reconstructs the original transmitted data using programmed logic. Once recovered, the data is sent to output devices such as an LCD display for text , ensuring the information is accurately converted into a readable form, thereby completing the communication process.These signals may be weak and affected by noise due to underwater attenuation, so they are conditioned and then fed into a microcontroller like an Arduino for decoding.



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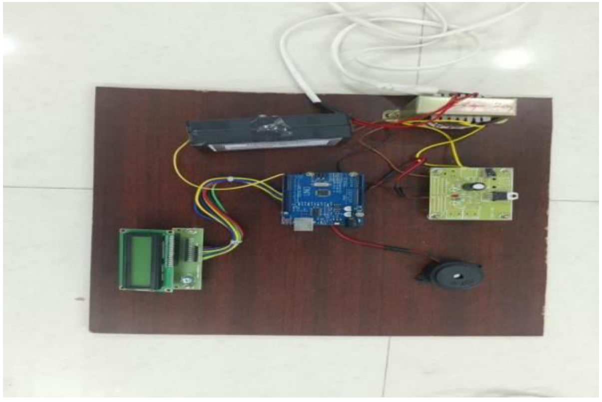
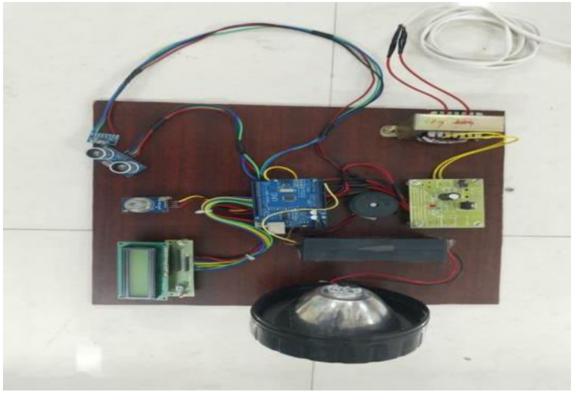
Functions of block:

1. **Power Supply Unit:**
Converts 12V input to a stable 5V supply for the Arduino and other components.
2. **Microcontroller (Arduino Uno):**
Processes, encodes, and decodes signals, and controls transmission and output operations.
3. **Input Module:**
Accepts text (via serial) or audio signals for transmission.
4. **Mode Selection:**
Switches between data and audio transmission modes.
5. **Laser Transmitter Module:**
Converts electrical signals into optical signals for transmission through water.
6. **Water Medium:**
Acts as the communication channel for light signal propagation.
7. **LED Receiver / Photodetector:**
Converts received optical signals back into electrical signals.
8. **Signal Conditioning:**
Amplifies and filters weak signals to improve quality.
9. **Output Module:**
Displays text on LCD and outputs audio through speaker.

Design and implementation of system





Software Requirements:

1. Embedded Programming & Communication: The system is developed using Arduino IDE with Embedded C, utilizing libraries for LCD, sensors, and serial communication. UART protocol is used fordebugging and data transmission, allowing real-time monitoring of system parameters through serial output.

2. Sensor Data Processing & Integration:
The software reads analog inputs from temperature and dust sensors, converting them into meaningful values (°C and µg/m³) using calibration formulas. It applies noise filtering and averaging for accuracy, integrates multi-sensor data, and continuously monitors conditions by comparing values with predefined thresholds.

3. Control Logic, Display & Testing:
The system uses conditional logic for decision making, triggering alerts like buzzer activation when thresholds are exceeded, while maintaining stability under normal conditions. The LCD dynamically displays real-time parameters such as temperature and dust levels. Simulation tools like Proteus are used to test circuit behavior and validate program logic before hardware implementation.

Hardware Requirements:

1. Microcontroller Unit (Arduino Uno)
The Arduino Uno acts as the central processing unit of the system, integrating all sensing, processing, and output operations. It continuously acquires data from multiple sensors including ultrasonic, gas, dust, and temperature sensors, and processes them in real time. The microcontroller operates at 5 V with a 16 MHz clock frequency and provides multiple input/output pins for interfacing, making it suitable for multi-sensor embedded systems.

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2. Power Supply Unit
The power supply unit consists of a transformer, rectifier, voltage regulator, and battery backup. It ensures a stable DC voltage (typically 5 V and 9–12 V) required for system operation. The regulated supply is critical for maintaining sensor accuracy and preventing fluctuations that could affect system reliability.

3. Display Module (16×2 LCD)
The 16x2 LCD Display is used to display real-time environmental parameters such as temperature, gas levels, dust concentration, and system alerts. It enhances user interaction by providing continuous visual feedback about system conditions.

4. Temperature Sensor
The LM35 Temperature Sensor is used to measure ambient temperature. It provides an analog output voltage linearly proportional to temperature (10 mV/°C). The sensor operates in the range of -55°C to 150°C and requires a supply voltage of around 5
V. It is directly interfaced with the analog input pins of the microcontroller for accurate environmental monitoring.

5. Dust Sensor
The GP2Y1010AU0F Dust Sensor is used to detect particulate matter (dust/smoke) in the environment. It operates using an infrared LED and photodiode to measure dust density based on light scattering. The output is an analog voltage proportional to dust concentration, typically in the range of 0–5 V, which is read by the microcontroller. This sensor is crucial for monitoring air quality and detecting pollution levels.

6. Ultrasonic Sensor
The Ultrasonic Sensor measures distance using ultrasonic waves. It is useful for obstacle detection or level sensing and operates within a range of 2 cm to 400 cm.

7. Buzzer
The buzzer provides audible alerts when sensor values exceed predefined thresholds, such as high temperature, or increased dust levels. It ensures immediate user attention during abnormal conditions.

Optical Source (LED / Lamp)
A high-intensity LED or lamp is used for Li-Fi–based optical transmission. It converts electrical signals into light signals for communication, especially in underwater environments.

Amplifier and Driver Circuit
Amplifier circuits enhance weak signals from sensors or optical receivers, ensuring reliable signal processing. Driver circuits control high-power devices such as lamps and buzzers safely.

IV. METHODOLOGY

The image outlines the methodology for an underwater communication system using Li-Fi (Light Fidelity) technology. Here's an explanation of each step:

1. System Input
The system begins by collecting input data from sensors or user inputs. These inputs represent environmental parameters or messages that need to be transmitted through the communication system.

2. Data Processing (Arduino)
The collected data is processed by the Arduino microcontroller, where it is formatted and prepared for transmission. This includes converting raw sensor data into a structured digital form suitable for encoding.

3. Data Security (Blockchain Module – Encryption & Generation)
To ensure secure communication, the processed data is encrypted using a blockchain-based module. This step generates a secure data block, protecting the information
from unauthorized access during transmission.

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4. Data Modulation and Transmission (Li-Fi Transmitter)
The encoded data is modulated into electrical signals and fed to the Li-Fi transmitter. The transmitter converts these signals into optical signals using a laser or LED light source, enabling high-speed data transmission.

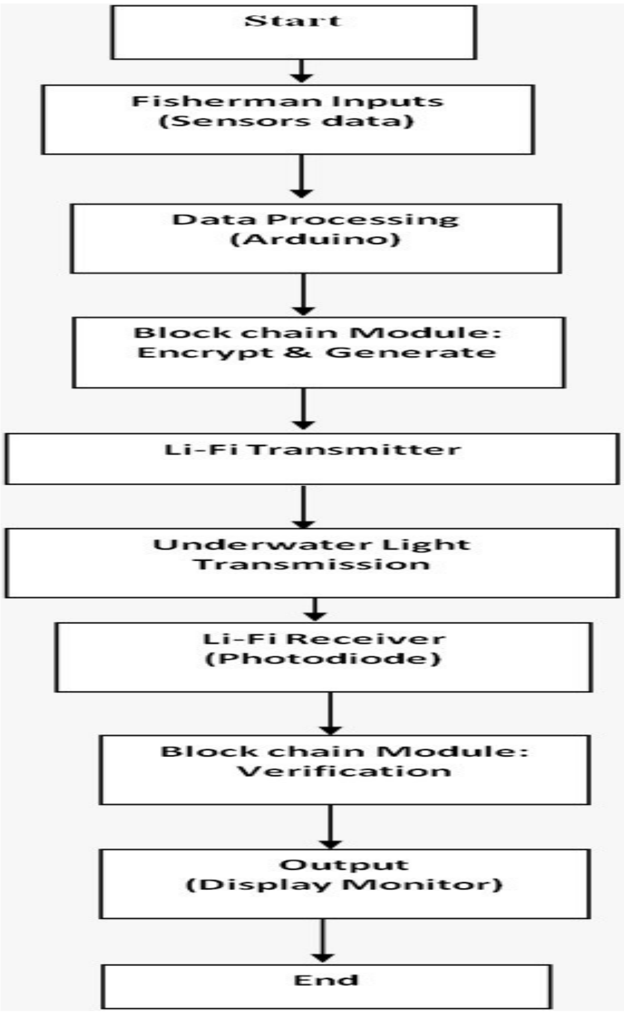
5. Transmission Medium (Underwater Light Propagation)
The optical signals travel through water, which acts as the communication medium. The system utilizes visible light for transmission, considering factors like absorption, scattering, and attenuation in the underwater environment.

6. Data Reception (Li-Fi Receiver – Photodiode)
At the receiver end, a photodiode detects the incoming light signals and converts them back into electrical signals. These signals represent the transmitted data in its received form.

7. Data Verification (Blockchain Module) The received data is passed through a blockchain verification process to ensure integrity and authenticity. This step confirms that the data has not been altered during transmission.

8. Output Display
After verification, the decoded data is displayed on an output device such as a display monitor. The system may also provide audio output depending on the type of transmitted data.

9. System Completion
The communication process concludes once the transmitted information is accurately received, verified, and displayed, completing the underwater Li-Fi communication cycle.



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V. RESULTS

Utilizing **Li-Fi (Light Fidelity)** technology for underwater communication offers a revolutionary alternative to traditional methods like acoustic communication. By employing light waves for data transmission, Li-Fi delivers superior bandwidth and faster data transfer rates.

Followings are the results:

1. The proposed underwater Li-Fi communication system utilizing an LED as the transmitter and a photodiode as the receiver was successfully implemented and tested for transmitting text through a water medium. The system demonstrated stable performance over short distances, with transmitted data being accurately received, decoded, and displayed on an LCD screen.

2. The use of an LED as the transmitter introduced both advantages and limitations. The wider beam angle of the LED reduced strict alignment requirements compared to laser-based systems, making the setup easier to implement. However, the lower intensity and diffused nature of LED light resulted in reduced transmission range and signal strength, limiting the system's overall performance.

3. The Photodiode used as the receiver provided a larger detection surface, which improved the ability to capture incoming light signals, especially under low-intensity conditions. However, its slower response time restricted the system's capability to handle high-frequency signals, thereby limiting the achievable data rate. As a result, the system performed best under low-frequency modulation conditions.

4. Signal quality analysis revealed that proper alignment between the transmitter and receiver still played a significant role in maintaining stable communication. While the LED's wider beam allowed some flexibility, misalignment still caused noticeable signal loss.

5 The experimental results showed that the received signal strength decreased progressively with increasing transmission distance. This behavior is consistent with the exponential attenuation model of light in water, where absorption and scattering significantly reduce signal intensity. The system performed effectively within a limited range, beyond which the signal became too weak for accurate detection and decoding.

6 Water quality was found to be a critical factor influencing system performance. In clear water conditions, the LED signal maintained sufficient strength, enabling reliable communication. However, in turbid or impure water, increased scattering and absorption caused rapid signal degradation, leading to reduced clarity and occasional data loss. This demonstrates the sensitivity of optical communication systems to environmental conditions.

5. The system's performance was also influenced by power supply stability. Variations in the input power to the LED caused fluctuations in light intensity, directly affecting the received signal. Similarly, instability in the receiver circuitry introduced noise and impacted decoding accuracy. Ensuring a regulated and stable power supply improved consistency and reduced transmission errors.

6. Overall, the results confirm that the proposed LED-based underwater Li-Fi system is a cost-effective and practical solution for short-range communication. While it offers advantages such as simplicity, low cost, and case of implementation, its performance is limited by factors such as environmental conditions, transmission distance, and hardware constraints. Future improvements can focus on enhancing optical power, optimizing modulation techniques, and improving receiver design to achieve better data rates and extended communication range.

Key Advantages of Li-Fi:

Enhanced Data Rates: Through the use of light waves, Li-Fi significantly outperforms conventional techniques such as acoustic and radio frequency (RF) communication in terms of data transfer speeds.

Improved Security: Light signals do not penetrate through solid or opaque objects, making Li-Fi communication inherently secure against eavesdropping or external interference, unlike RF communication.

Reduced Latency: Light waves travel faster than sound waves or radio waves, ensuring minimal delays during data transmission. This makes Li-Fi particularly suited for applications such as live video streaming or teleoperations.

Energy Efficiency: By leveraging existing lighting infrastructure, Li-Fi reduces the energy required for communication. This is particularly advantageous in environments where LED lights are already installed, leading to reduced power consumption.

Potential Applications of Li-Fi in Underwater Environments:

1. **Underwater Sensor Networks**: Li-Fi enables efficient data transmission in underwater sensor networks, which can be deployed for activities like marine exploration, environmental monitoring, and security surveillance.

2. **Autonomous Underwater Vehicles (AUVs)**: Communication between AUVs and remote-control stations is streamlined by Li-Fi, ensuring high reliability, low latency, and robust data rates.

3. **Underwater Robotics**: The high bandwidth offered by Li-Fi facilitates seamless interaction between underwater robots and control systems. This is essential for tasks such as inspection, maintenance, and complex underwater operations.

4. **Wi-Fi vs. Li-Fi:** A Brief Comparison While **Wi-Fi** (Wireless Fidelity) uses radio waves to facilitate wireless data exchange, **Li-Fi** relies on visible light communication (VLC). This fundamental difference gives Li-Fi advantages in speed, security, and efficiency, making it particularly effective in specialized settings like underwater communication systems.

As advancements in this field continue, the development of robust and efficient Li-Fi-enabled underwater communication networks holds immense promise for enhancing various underwater activities. These include scientific investigations, marine resource management, and exploratory missions beneath the ocean's surface.

VI. CONCLUSION

The implementation of **Li-Fi technology** for underwater communication offers an innovative solution to overcome the limitations of conventional methods used in subaquatic environments. Utilizing light waves rather than electromagnetic waves for data transmission, Li-Fi provides distinct benefits, including higher data transfer speeds, reduced latency, and immunity to electromagnetic interference.

VII. ACKNOWLEDGMENT

Every accomplishment is a result of collective effort, and this project is no exception. We sincerely extend our gratitude to all individuals who played a vital role in transforming this project from an idea into reality.

We are deeply thankful to **Assistant Prof. K.K. Poongodi** for her invaluable guidance and unwavering supervision throughout this journey.

We are equally thankful to our parents and friends for their continuous inspiration and moral support, which has been a driving force throughout this endeavour.

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