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A High-Efficiency Diver-to-Diver Optical Communication System

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Abstract

As voice waves cannot propagate through water, divers need to find alternative ways to communicate with each other. Researchers have investigated different approaches to develop underwater communication systems. Designs differ in complexity, quality of voice signal, and cost. In this study, the transmission of a voice signal in a water medium via light-emitting diodes (LEDs) of different wavelengths was experimentally investigated. The scattering of different wavelengths was examined, revealing that light from LEDs with shorter wavelength exhibits less scattering. The maximum propagation distance that can be reached using a 460-nm LED is observed to be 33.3 m.

Keywords- *underwater communication; optical communication; visible light; LED communication*

I. INTRODUCTION

Underwater communication is extremely important nowadays for both civilian and military applications. One important application is diver-to-diver communication systems. Because the human voice cannot be heard in water, over the years, researchers have been designing and improving systems that allow divers to communicate with each other. Such systems vary in complexity, quality of the transmitted signal, cost, and the maximum distance over which the signal can be transmitted. To a diver, the highest priority system characteristics are reasonable cost and less weight. Systems that use acoustic signals [1-3] are valuable and useful for transmitting data underwater; however, they are not suitable for an application such as diver-to-diver voice communication because of their complexity and cost. Other systems use optical signals to transmit data in water [4-6]. The data rate of an optical system can reach 10 Gbps [3]; however, data processing, modulation, demodulation, and other processing takes place outside the medium, making these systems unsuitable for diver-to-diver communication.

Woodward and Sari transmitted speech by compressing it using linear predictive coding (LPC). Their system was based on digital signal processing, with one signal being processed in the demodulation process in [4] and a multipath signal in [5] with a transmission rate of 2.4 kbps. A communication system based on frequency modulation with a transmission distance of 2.7 m was designed using a laser beam [6]. Other communication systems have been mainly designed to transmit different types of data. Sendra et al. in [1] designed a hybrid communication system, achieving a data rate of 100 Mbps. The system was designed for cellular mobile communication networks via acoustic, wireless optical, and optical fiber channels and had a land-based data center that collects and analyzes all received data from different sources.

In coastal and harbor, the transmission of an optical signal with lower attenuation shifts to green. However, the available green LEDs in the market are not good. Jan and Peter in [7] show the promising results of using phosphor-converted green LEDs pumped by a blue LED. Another technique to enhance the transmission in water medium is using a freeform lens [8]. Using a blue LED array and freeform lens, 19 Mbps data rate has been transmitted for a distance of 8 m and attenuation of about 0.4 m^{-1}.

II. METHODOLOGY

As mentioned above, the most important features for a diver-to-diver underwater communication system are weight and cost. Besides these two features, the system must be capable of transmitting data for a few meters. In this study, light-emitting diodes (LEDs) with different visible wavelengths (460 nm (blue) and 520 nm (green) and optical power ratings (10, 20, and 30 W) have been investigated experimentally. The experiments were conducted in water with a turbidity of 2 NTU, a salinity of 900 mg/L, and electrical conductivity of 1427 µS/cm at room temperature. The system was designed to have a diver-compatible physical size and weight. The schematic diagram of the transmitter and the receiver is shown in Figure 1 and Figure 2, respectively. When the switch is closed, the LED is turned on, and speaking through the microphone, which has an amplifier, will modulate the output beam. Modulation of the LED causes it to turn on and off very quickly (beyond what the human eye can recognize). A collimating lens is attached to the LED to minimize the diverging angle because the LEDs have a wide emission pattern.

At the receiver, the modulated wave that is transmitted through the LED is received and demodulated by a photodiode. The photodiode converts the optical signal into an electrical signal. In this setup, a solar cell was used for this purpose. The signal demodulated by the solar cell runs the headphone at the receiver. Because the absorption coefficient and scattering of light depend on the wavelength of the light, two wavelengths have been investigated. Lightweight large-area photodetectors can be attached to the front and back of the diver to allow a large number of photons to be collected in both directions. The system is isolated from the water, and the microphone and the headphone are attached to the diver's helmet.

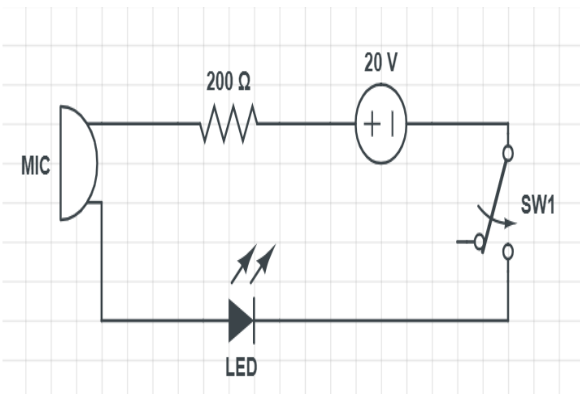


Figure 1 Transmitter schematic diagram

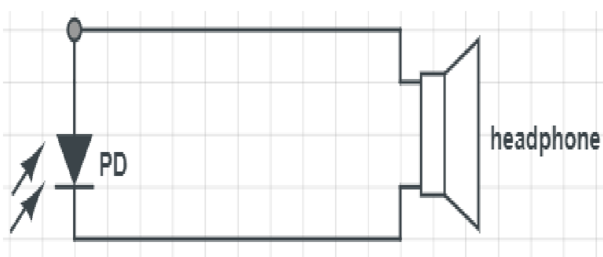


Figure 2 Receiver schematic diagram

III. RESULTS AND DISCUSSION

A. LEDs without a Collimating Lens

First, LEDs with a wide-angle emission pattern were investigated with no lens. Figure 3 shows the solar cell's voltages being illuminated by different LEDs concerning the distance between the transmitter and the receiver. Figure 3(A) shows the results using 10-W LEDs with wavelengths of 460 nm (blue) and 520 nm (green). The results indicate that the signal can be transmitted for 6.15 and 5.85 m using the blue and green LEDs. At these distances, the voice signal can be heard clearly.

Similarly, Figure 3 (B) shows the results using 20-W LEDs. It shows that the signal can be transmitted for 6.72 m for the blue LED and 6.41 m for the green LED. For 30-W LEDs, the results are shown in Figure 3(C). It shows that the signal can be transmitted for 8.8 and 6.5 m for the blue and green LEDs.

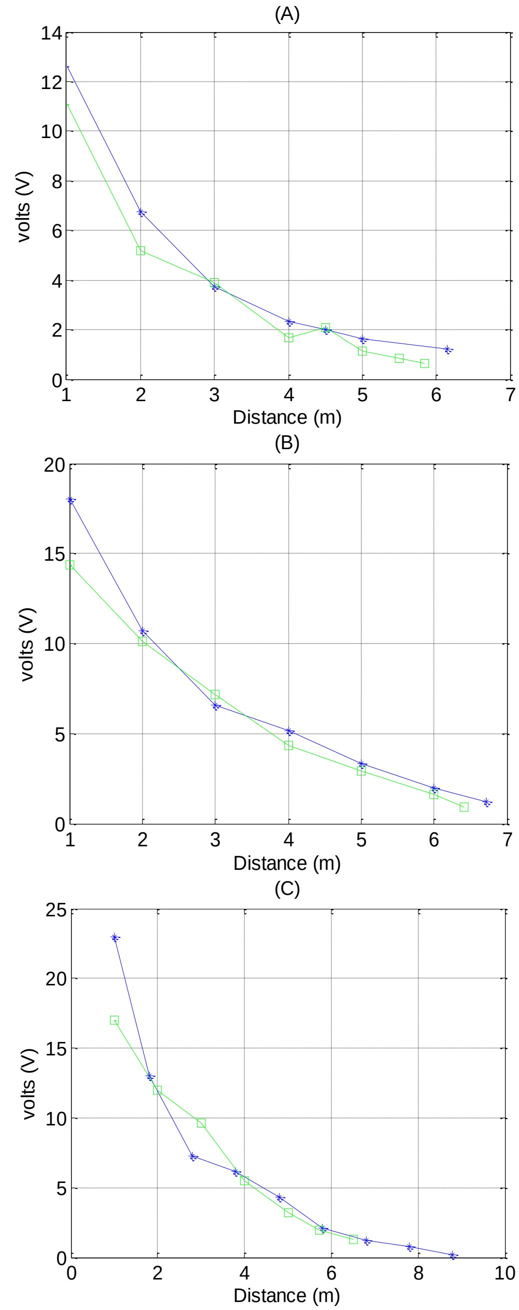
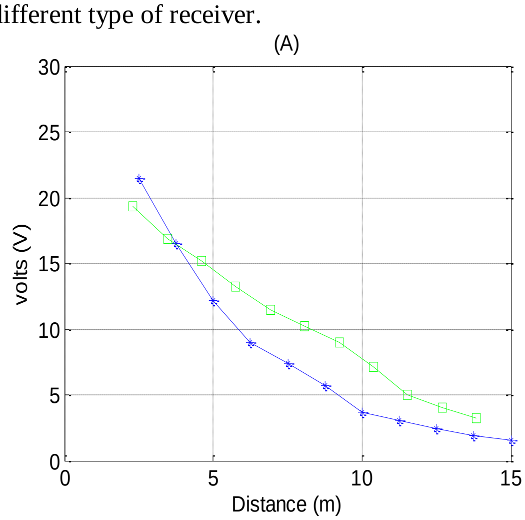


Figure 3 Generated volts by the solar cell which illuminated by a LED with wavelength 460 nm (Blue line) and 520 nm (Green line) with a power of 10 W (A), 20 W (B), and 30 W (C).

B. LEDs with a Collimating Lens

The prior results were obtained with LEDs used to transmit a voice signal but with no lens. This can help if the desired range for transmission is only a few meters and the LED is used to illuminate a large area. However, if the signal has to be transmitted for a longer distance, a lens can be attached to the LED to decrease the divergence angle, and then the light can propagate for a long distance in the water. Experiments with the same LEDs and optical powers were conducted using a collimating lens. The results shown in Figure 4 indicate that the signal can be transmitted for 15 and 13.85 m for the 10-W blue and green LEDs, respectively. For the 20-W LEDs, the signal can be transmitted for 22.5 m with the blue LED and 17.95 m with the green LED, as shown in Figure 4 (B). For the 30-W LED, the signal can be transmitted for 33.33 and 30 m for the blue and green LEDs, respectively, as shown in Figure 4 (C). The polycrystalline solar panels used have a limitation whereby they cannot generate more than 25 V, which means that the generated voltage reaches saturation as the LED comes closer to the panel, as shown in Figure 4 (B) and Figure 4(C). In general, the green light has higher power than the blue light at closer distances; however, its power decreases faster as it propagates through the water. This phenomenon occurs because water molecules scatter light in a manner that is inversely proportional to its wavelength. As a result, a signal can be transmitted over a greater distance with a blue LED than with a green one. Another noticeable result is that the receiver needs a higher optical power for the green LED than for the blue one to convert the optical signal into an electrical signal. For instance, for the 30-W LEDs, the signal can be transmitted for 33.3 m with 0.25 V generated by the solar panel, whereas, at 33.33 m, the green light generates more than 0.25 V, but the signal is weaker, and the sound cannot be heard clearly. This situation can be remedied by using a different type of receiver.



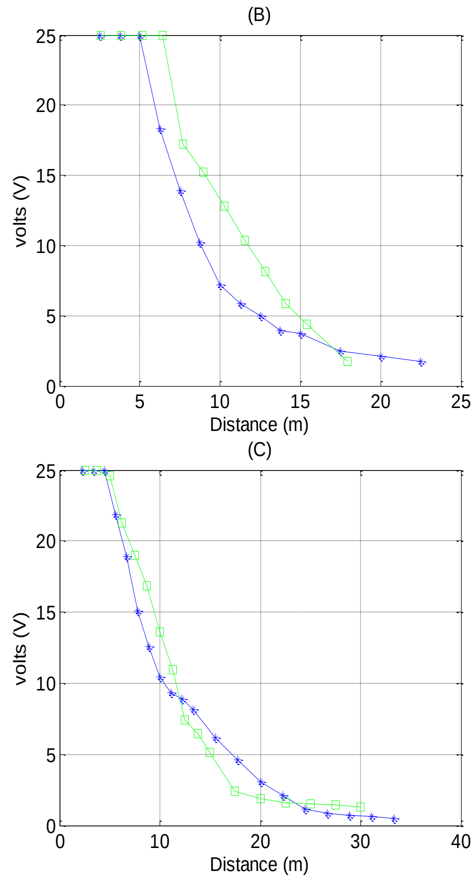


Figure 4 Generated volts by the solar cell, which illuminated by a LED with a collimated lens with wavelength 460 nm (Blue line) and 520 nm (Green line) with a power of 10 W (A), 20 W (B), and 30 W (C).

C. Out-of-Sight Communication

One desired characteristic of using LEDs is that data can be transmitted even if the receiver and transmitter are out of sight of each other. As light propagates through the water, some of the photons get absorbed, and others are scattered. These scattered photons carry the same information as carried by the non-scattered photons. Therefore, data can be transmitted even when the LED is not pointing directly at the receiver. Figure 5(A), 5(B), and 5(C) show the produced voltages concerning the lateral angle of a blue LED (blue line) and green LED (green line) with powers of 10, 20, and 30 W, respectively. The results were obtained at distances of 7 m for the 10-W LED, 10 m for the 20-W LED, and 15 m for the 30-W LED. The results demonstrate that, even when an LED is directed away from the receiver, some photons are still received, and an electric field is generated. For all types of LEDs, sound can be heard clearly up to 45°. Beyond that angle, sound can still be heard with less clearness up to 60°.

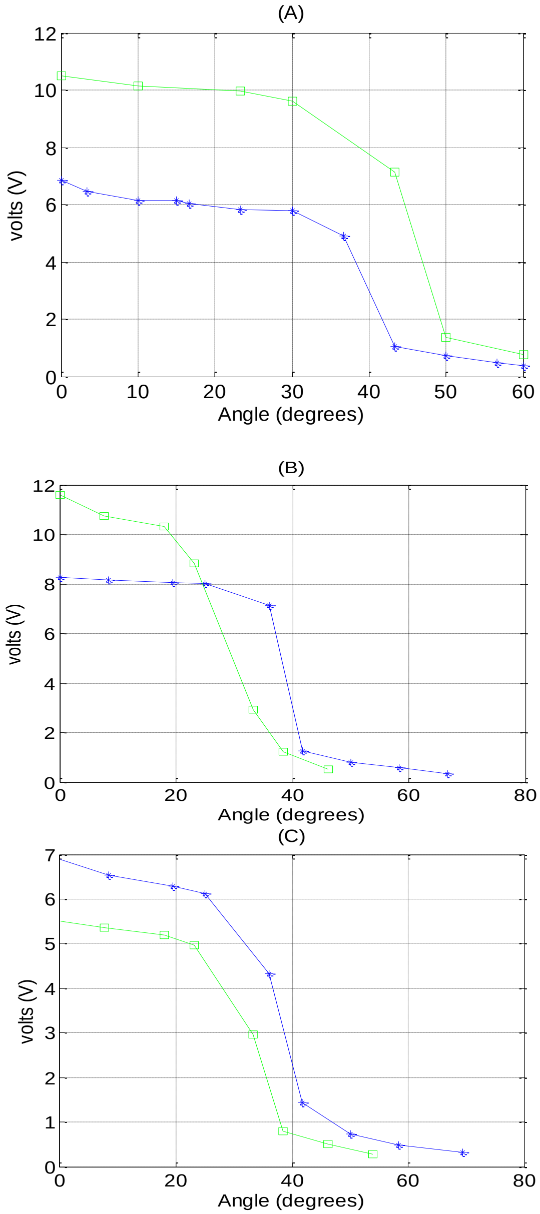


Figure 5 Generated volts by the solar cell which illuminated by a LED with a collimated lens with a lateral move for a wavelength of 460 nm (Blue line) and 520 nm (Green line) with a power of 10 W (A), 20 W (B), and 30 W (C)

IV. CONCLUSION AND FUTURE WORK

In this article, a cost-effective, lightweight, and high-quality underwater optical communication system has been proposed. In the designed system, an LED that the diver uses for lighting is also used to transmit data. The experimental results show that data can be transmitted over 30 m through the water. The results also demonstrated that data could be transmitted with a receiver being out of sight from the transmitter by up to 60°. The system can be improved by using a more directional LED. as the LED becomes more directional, fewer photons get lost, and therefore less power is consumed.

For future work, high directional, lower power LEDs will be investigated. Lasers at different wavelengths will be studied, and the results will be compared with LEDs.

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