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Underwater Wireless Optical Communication System Using Blue LEDs

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Abstract. We demonstrate a self-designed underwater wireless optical communication system using blue LEDs. The performance of the transmitter and receiver was experimentally investigated. Four different square wave signals (10 KHz, 100 KHz, 500 KHz and 1 MHz) were successfully transmitted via a short water channel at the first phase.

1. Introduction

Nowadays underwater wireless sensor networks (UWSNs) have played a more and more important role in underwater surveillance field. As the traditionally used underwater acoustic communication is limited in bandwidth and celerity, there is a growing need for real-time high-rate data, image, and even video transmission between the nodes of a UWSN. Underwater wireless optical communication turns out to be an appropriate solution thanks to its high-bandwidth, cost-effectiveness and low-energy consumption [1-2].

Light emitting diodes (LEDs), with low power consumption, high efficiency and long lifetime, are good light sources for indoor visible light communication systems [3]. But their great potential to be as the light source for underwater wireless optical communications has not been fully investigated. So in this paper we propose the underwater wireless optical communication system based on blue LEDs.

2. System Description

The experimental block diagram of an underwater wireless optical communication system based on blue LEDs is shown in figure 1. The signal in a sensor was uploaded into Memory-1 in a serial way. When Receiver-1 had received a sending request from Emitter-1, ARM-1 sends the signal in Memory-1 to Emitter-2, where the signal directly drives the blue LEDs via a bias-tee (BT).

After transmitting in an underwater optical communication channel, light was focused on Receiver-2 which consists of photoelectric detecting circuit, filter circuit, and amplifying circuit. After clock recovery and level decision, the signal was captured by ARM-2, uploaded into Memory-2, and further processed offline via MATLAB to calculate the BER.

Figure 2 shows the transmitter and the receiver of the underwater wireless optical communication system. Emitter-2, Receiver-2 and convex lens are placed in the front. The main control circuit is placed in the middle. Serial communication and power interface are placed at the end. The whole system can realize high-speed data collection, storage and processing.

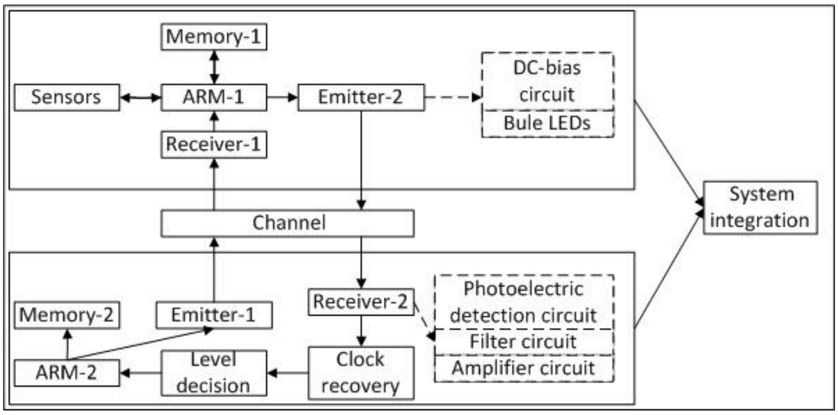


Figure 1. Experimental block diagram of an underwater wireless optical communication system based on blue LEDs.

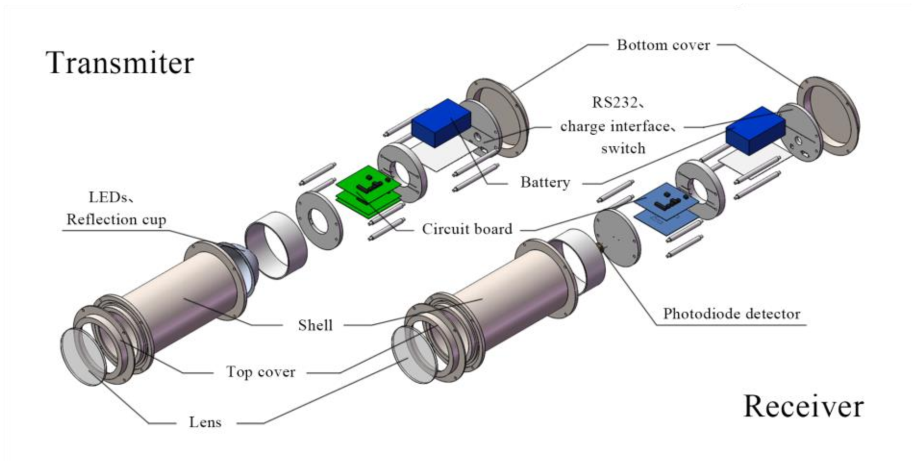
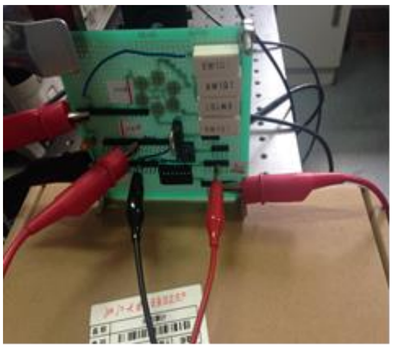


Figure 2. Structure of underwater wireless communication system.

The transmitter and the receiver have a similar structure, but with different circuits. As shown in figure 3 and figure 4, the transmitter includes reverse amplification circuit, driving circuit and bias circuit. The receiver consists of transimpedance amplifier circuit, follower, amplifier circuit, comparing circuit and limiting circuit.


(a)

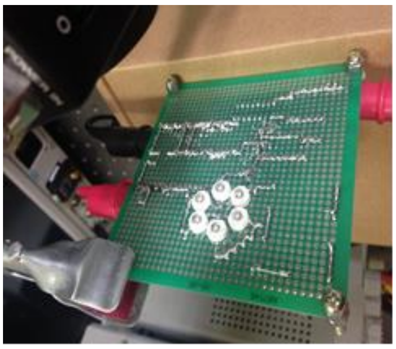

(b)

Figure 3. Circuits of transmitter.

In figure 3, reverse amplification circuit is to transform the voltage level from low voltage level to high voltage level, which can improve load capacity, and its input-signal value is limited from 0V to

5V. The driving circuit is used to drive LEDs for optical signal generation. The bias circuit makes LEDs operate in the linear region. Supply voltages of these three circuits were 5V, 12V and 16V, respectively.

In figure 4, a silicon PIN photodiode with a detection diameter of 10mm is used to detect the optical signal, and its response spectrum ranges from 300 to 1100 nm. The transimpedance amplifier circuit transforms the current signal to voltage signal. Follower is used to decrease output impedance and signal loss. Between the follower circuit and amplifier circuit, we used a blocking capacitor to remove the direct-current part of signal. In order to satisfy the processor's requirement of input signal, a comparing circuit was designed to transform analog signal to transistor-transistor logic (TTL) signal and a limiting circuit was designed to restrict the peak-to-peak voltage below 3.3 V_{pp}. Supply voltages of these circuits were 4.5V, positive 6V, negative 6V and 2.9V, respectively.

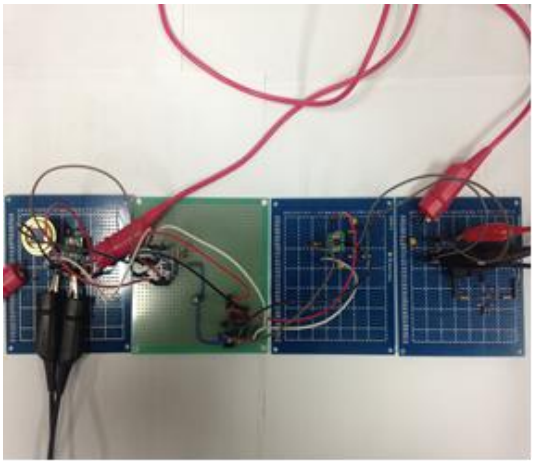
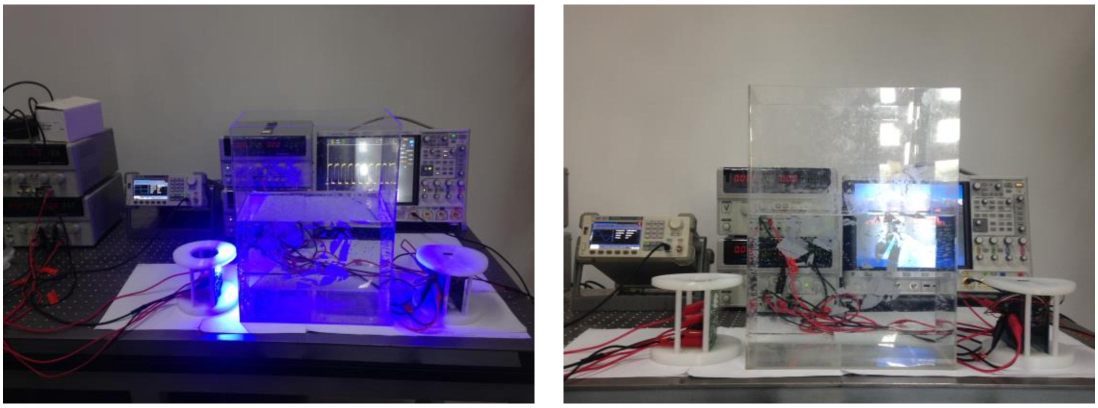


Figure 4. Circuits of receiver.

3. Experiment and Discussions

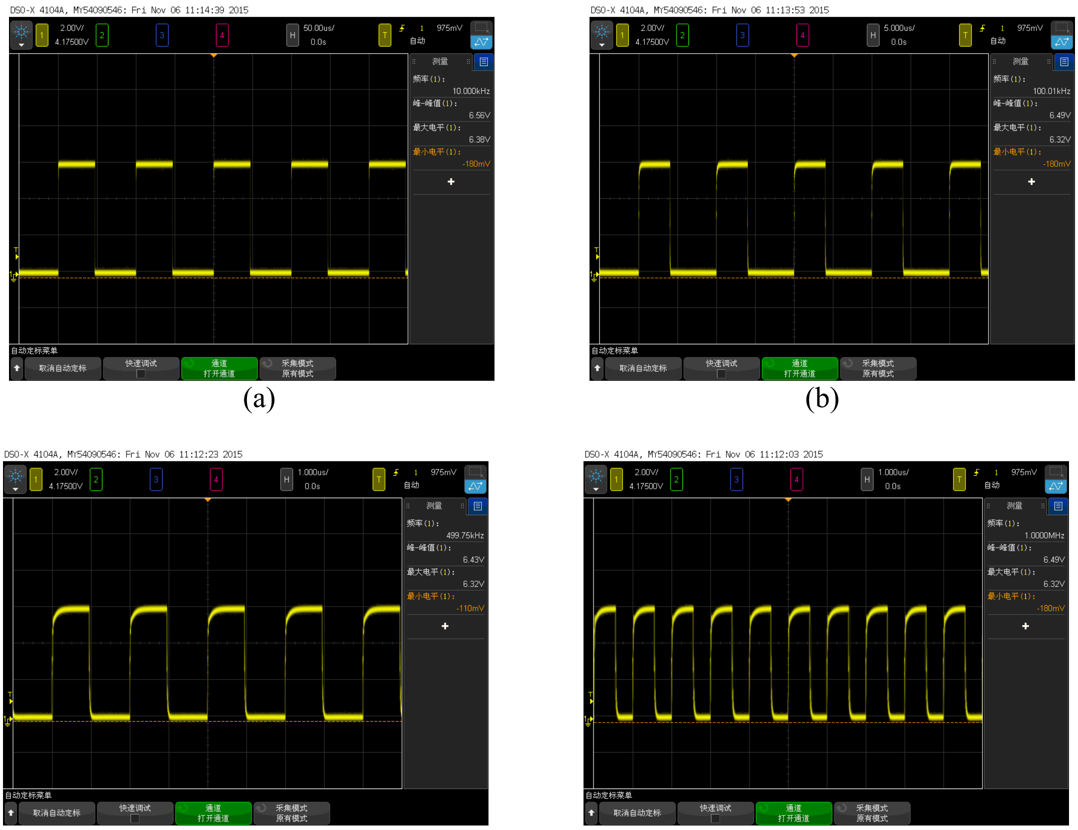
Figure 5 illustrates the experimental setup using an arbitrary waveform generator (AWG) to generate electrical signal at the transmitter side and a digital storage oscilloscope (DSO) to display the received signal waveforms at the receiver side.



(a) (b)

Figure 5. Experimental setup of an underwater wireless optical communication system based on blue LEDs.

We conducted several experiments to assess the feasibility of using two self-designed circuit board as the transmitter and receiver in a wireless optical communication system described above. In the experiments, we used four different square wave signals of 10 KHz, 100 KHz, 500 KHz and 1 MHz as the transmitted radio frequency (RF) signals, which was used to drive the transmitter. The amplitude of the driving signal is 6 V_{pp}. After being emitted from Emitter-2, the light was transmitted in the free space and focused on Receiver-2. Then the signal waveforms were processed by the receiver circuits, and ultimately displayed on the DSO. Figure 6 shows the waveforms of the received signals with four different frequencies. The clock recovery and data storage will be done in the subsequent experiments.



(a) (b) (c) (d)

Figure 6. The waveforms of the received signals with five transmission rates (a) 10 KHz, (b) 100 KHz, (c) 500 KHz, (d) 1 MHz.

From the figure 6, we can see that when the signal frequencies were 10 KHz and 100 KHz, the signals can be well recovered. However, when the signal frequency is increased to 1 MHz, the signal was deformed. It is due to that the detection area of Photodiode is too large, which results in a too large input capacitance. At high frequencies, the total input capacitance can severely limit the available bandwidth from the circuit or cause unstable dynamic response. There are two main methods to solve the problem. One is to decrease the detection area of the photodiode, but the received optical energy will decrease. The other is to employ an additional buffer amplifier to actively charge and discharge the input capacitance as required. Compared to the first method, the latter one not only can receive more energy, but also the overall bandwidth of the circuit will be increased.

4. Conclusions and Future Work

In the current work, we demonstrate a self-designed underwater wireless optical communication system using blue LEDs. The performance of the transmitter and receiver was experimentally investigated.

Further work on circuit optimization, adding data storage system, manufacturing product prototype, testing in an underwater environment as well as improving the transmission distance and bit rate would be carried out.

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Acknowledgments

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