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THE REALIZATION OF UNDERWATER ELECTRIC CURRENT FIELD COMMUNICATION SYSTEMS

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Abstract. *Communication is one of the most important basic capabilities for the underwater robots. This paper presents a small, flexible underwater communication system. It solves the problem that the optical and acoustic methods would not work normally in complex underwater environment. Firstly, a theoretical model is presented to explain how the several important factors affect the underwater electric current communication system. Secondly, we give a detailed presentation of the communication system, which focuses on the charge and discharge circuit and the comparison circuit, to facilitate the detection of the communication state. Finally, the bit error rate (BER) is adopted to evaluate the performance characteristic of this underwater communication system. This communication system, which mainly focuses on the detection of the communication state, can make significant contribution to the multiple underwater robots underwater communication system.*
Keywords: Electric current field, Underwater electric current field communication system, Underwater robot, BER

1. **Introduction.** It is similar to the terrestrial and aerial robots that communication is one of the most important basic capabilities for the underwater robots. In the underwater domain we are faced with the fact that any realistic communications system must be wireless, such as electromagnetic, optical or acoustic. Cables, even for shallow water operations are heavy, constraining divers' movements and creating additional hazards [1]. Acoustic wave communication is one of the most widely used methods for underwater robots. However, it is easily affected by various external factors which causes highly communication error rate [2]. Although optical communication possesses high information carrying capacity, it is easily affected by seawater, suspended solids, plankton, etc. So optical communication is restricted by the work environment. Due to the electromagnetic wave decays seriously in the water, it is impractical for radio communication to expand the range of communication by increasing transmission power [3,4]. In nature, electric fish can generate electric fields which can communication with others and keep away from barrier by transmitting electric signals [5]. This method by electric current in fish is called electric current communication. The study on electric current communication

recorded began in the early 1970s. Article [6] is the most representative because Momma and Tsuchiya analyzed the principle of electric current communication and obtained the approximate theoretical model. It was not until recent years that the underwater electric current communication was researched again [7-10]. J. Joe and S. H. Toh verified the feasibility of the underwater electric communication through experiment [7]. And this method is not affected by the murkiness of the underwater condition [9].

In this paper, we have developed a small, flexible underwater communication system on the basis of previous research. One of the contributions of this paper is that the hardware principle of the communication system is expounded in detail. Another contribution of this paper is that the charge and discharge circuit and the comparison are designed to facilitate the detection of the communication state. Also, some other methods are adopted to ensure the integrity of the communication messages. At last, the BER is adopted to evaluate the performance characteristic of the communication system.

This paper is organized in 5 sections including the introduction. Section 2 presents some factors which impact the underwater communication system. Section 3 presents some design details of the communication system which include the transmitting and receiving principle. Also, some experiment results to evaluate the performance characteristic of this communication system are in Section 4. Section 5 summarized this paper.

2. **Several Important Factors of the Communication System.** Generally speaking, one must take the influence of conduction current and displacement current into account when the electric field changes over time. Here J_d is the displacement current and J_c is the conduction current. In order to construct the quasi-static current field, the relationship between J_d and J_c should be described as:

$$\frac{J_d}{J_c} = \tau\omega << 1 \tag{1}$$

The relaxation time of seawater is $\tau = 1.77 * 10^{-10}s$, and ω is the angular frequency. So the displacement current in the seawater can be neglected up to several hundred MHz. The electric dipole field is shown in Figure 1 when I_0 is applied.

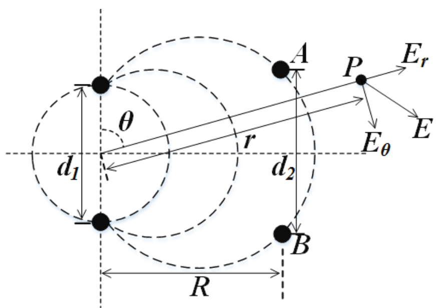

FIGURE 1. Electric dipole field when current I_0 is applied

From Figure 1, we can acknowledge the principle of the electric dipole field when the electric current I_0 is applied. Here the strength of electric field formed by electric current at point P can be described as,

$$E = E_r + E_\theta \tag{2}$$

$$E_r = \frac{I_0 d_1 \cos\theta}{2\pi\sigma r^3} \tag{3}$$

$$E_\theta = \frac{I_0 d_1 \sin\theta}{4\pi\sigma r^3} \tag{4}$$

where r is the distance between point P and the transmitting electrodes, and θ is the angle in polar coordinates. When the angle $\theta = \pi/2$, the strength of electric field E can be shown as,

$$E = E_\theta = \frac{I_0 d_1}{4\pi\sigma r^3} \tag{5}$$

Here the difference of potential between point A and B is written as,

$$V_{AB} = \int_0^{d_2} E_\theta ds = \frac{I_0 d_1 d_2}{4\pi\sigma R^3} \tag{6}$$

From Formula (6) we can figure out how the several factors impact this communication system. We acknowledge that the strength of electric current I_0, the distance of transmitting electrodes d_1, the distance of receiving electrodes d_2 and the electric constant σ can contribute to the effective range of the communication system.

3. **The Presentation of the Communication System.** The operating principle of the communication system is shown in Figure 2.

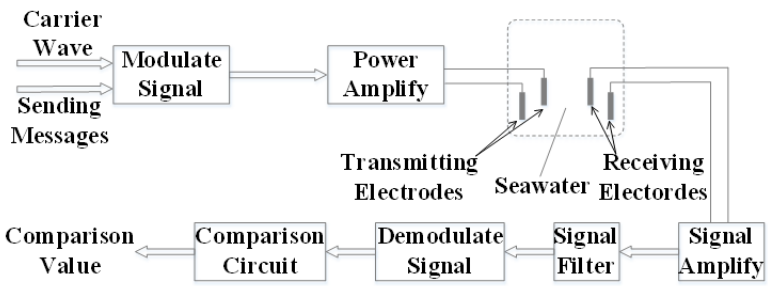

FIGURE 2. The operating principle of the communication system

From Figure 2 we can acquire the operating principle of the communication system which contains transmitter part and receiver part. In order to satisfy the requirements of information transmission and considering the possibility of technical implementation, we adopt one kind of digital modulation mode named binary amplitude shift keying (2ASK) in transmitter. The auxiliary controller generates the carrier wave and modulates the UART data which is transmitted in binary. In order to ensure the integrity of the transmitting messages, we use the timer of the auxiliary controller to generate the carrier wave like 50KHz, 40KHz and 50KHz. The operating principle of transmitting messages is shown in Figure 3.

It is well known that the center operation frequency of the transformer is 40KHz. So the controller is adopted to generate the carrier wave which is used to modulate the transmitting messages by 40KHz frequency. Then, the 50KHz carrier wave is adopted to modulate the messages to ensure the integrity of the transmitting messages. At last, the modulated signal would be transmitted by a pair of transmitting electrodes in the water.

We know that the transmitting power affects the range of communication system through the theoretical model above. So we use the transformer to amplify the transmitting power in power amplify part. The signal from the transmitting electrodes in the water can be picked up through a pair of receiving electrodes. We should amplify the signal first to confirm it can be identified in the receiving circuit. The band filter circuit is used to filter some kinds of noise which is amplified by the amplify circuit. Then, use two small chips named the phase-locked loop (PLL) to initially demodulate the signal. From the transmitting electrodes we can acknowledge that the useful message is modulated by 40KHz. So the output signal of the PLL which locks 40KHz is directly imported into the UART of the controller.

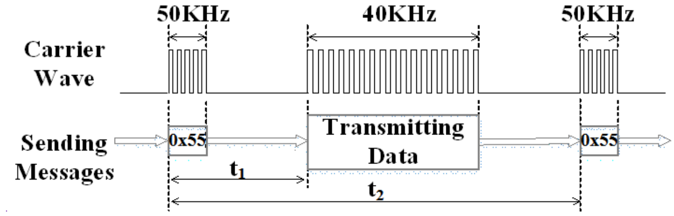

FIGURE 3. The operating principle of transmitting messages

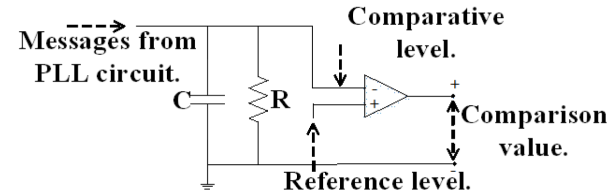

FIGURE 4. The comparison circuit of the receiving board

In order to identify the work model of the underwater communication system, we adopt a comparison circuit which is consisted of a small charge and discharge circuit to generate the comparative level. The comparison circuit is shown in Figure 4.

From Figure 4 we can acquire that the charge and discharge circuit is consisted of an RC circuit which can be charged by the messages which were initially demodulated by the PLL circuit. Then, we use an operational amplifier to form a comparator to identify the change voltage of the comparative level. If the comparative level is higher than the reference level, the comparison value would be low level and vice versa. The comparison value would be high level when there is no message. The comparison value will form a falling edge which can be captured by the controller when the carrier wave changes from close to open. From Figure 3 we can acquire that three falling edges would be detected at the beginning of sending messages. And we can acquire the time of each falling edge, like t_1 and t_2. If t_1 and t_2 can be limited within a reasonable range, we can ensure the integrity of the receiving messages.

4. **Experiments and Results.** Some parameters, like t_1, t_2 and reference level, will be calculated to confirm the underwater communication system can work normally. The reference level should be firstly obtained through series of experiments. So we measure the voltage of charge and discharge circuit by the digital multimeter at the time of whole data frame is sending.

The experiments results can be shown in Figure 5. From Figure 5, in order to ensure the crest cannot drop to the reference level when transmitting any messages, the voltage of reference level is confirmed as 1V. And the comparison level of two complete data

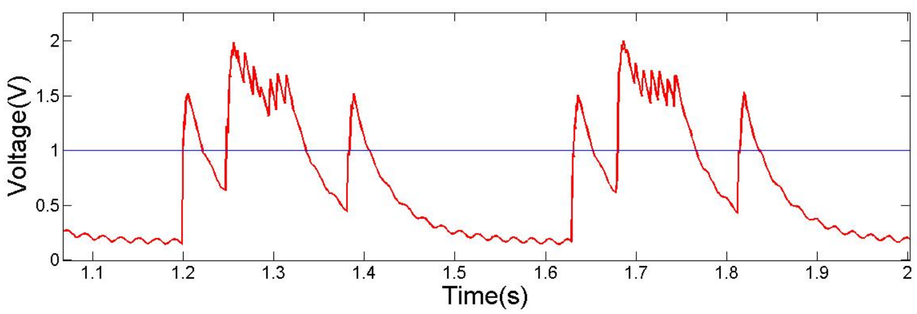

FIGURE 5. The voltage of charge and discharge circuit

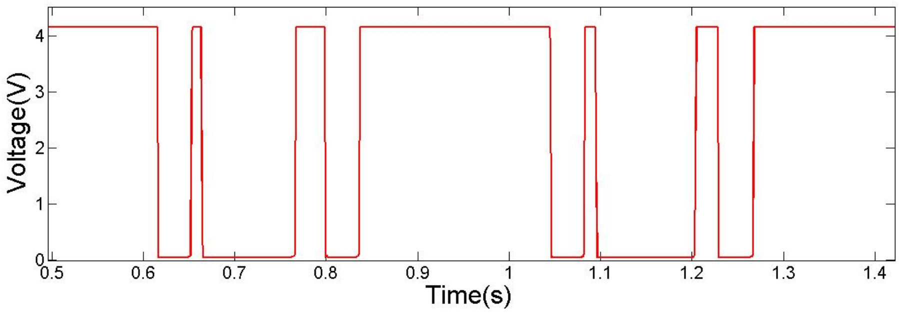

Figure 6. The voltage of comparison level

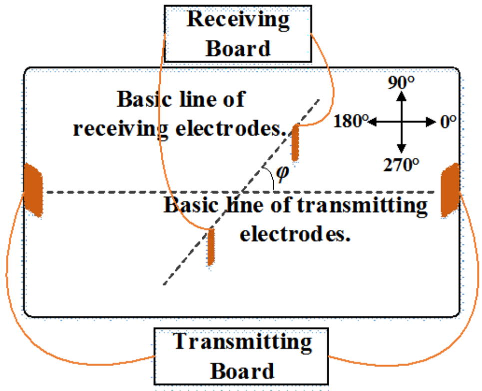

Figure 7. The schematic of the underwater communication experiments

frames is shown in Figure 6. It is obvious that each data frame processes three high levels and three low levels. The high level means the circuit receives messages from the transmitting electrodes and the voltage of charge and discharge circuit is higher than the voltage of reference level. We can easily acquire the reasonable range of time t_1 and t_2 to confirm the integrity of the receiving messages. Then, the BER is adopted to evaluate the performance of the developed underwater communication system through experiments.

An external transmitting device is used to transmit messages to a pair of transmitting electrodes in the water. Then, the receiving board receives the UART data which would be recorded by the online system. Finally, the performance of the underwater communication system can be evaluated by the BER.

As show in Figure 7, the transmitting electrodes are placed at the two sides of the water tank whose depth of water is 100cm. The basic line of transmitting electrodes is defined from 0° to 180°. The angle difference φ is defined as the basic line between transmitting electrodes and receiving electrodes. The BER of different positions can be shown in Table 1.

We can acquire that there are four special orientation in the experiments from Table 1. The BER is 0 when the orientation is 0° or 180°. In this situation, the difference of

Table 1. The BER of different positions

φ	BER	φ	BER	φ	BER
0°	0	120°	0.18%	240°	0.18%
30°	0.04%	150°	0.07%	270°	100%
60°	0.16%	180°	0	300°	0.18%
90°	100%	210°	0.05%	330°	0.08%

potential between a pair of receiving electrodes is the most sensitive in the electric current field. The BER is 100% when the orientation is 90° or 270°. Because the receiving electrodes are on the equipotential line of the electric current field, it is quite hard to detect the difference of potential between the electrodes. We can also draw an interesting conclusion that the magnitude of BER is approximately kept symmetry around the four special orientations.

5. **Conclusions.** In this paper, we have developed a small and flexible underwater communication system. We used a theoretical model to present the principle of the underwater electric current communication firstly. We give a brief presentation of the communication system which focuses on the signal modulation in the transmitting part. In the receiving part, the acquirement of the reference level is explained in detail in the voltage measurement of charge and discharge circuit. Some important parameters like t_1 and t_2, are given the detailed explanation through the experiments above. At last, the BER is adopted to evaluate the performance characteristic of the communication system.

In later work, much further research will be done to the communication system to maintain it can successfully transplant to several underwater robots. The communication system can provide strongly technical support to the formation of multiple underwater robots.

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