Evaluation of Underwater Wireless Optical Communication Link with Pspice Simulator

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Abstract—**There is significant need for high rate communication between observing platforms in monitoring the ocean environment. Due to radio waves suffers high attenuation in water and acoustic communication systems are relatively low data rates, we demonstrated an optical communication system that is capable of supporting underwater wireless communication in a high data rate. In this paper, a new and simple analytical method based on general simulator Pspice is developed to evaluate the capacity of underwater optical links with the effects of scattering and absorption in realistic ocean water. The cost measure of bit error rate for Lighting Emitting Diodes (LEDs) links in underwater communication is presented.**

Keywords: underwater wireless optical link, Pspice simulation, bit-error rate

I. INTRODUCTION

Currently, oceangraphic studies frequently involve using large, expensive devices to observe the environmental phenomena at fixed location over a long period. Autonomous underwater vehicle (AUV) can provide a real time, remote control capability for these platforms by passing data and coordinating mission with "wireless" communication system[1]. Traditionally, acoustic methods have been substantial advantage in underwater communication. However, acoustic link suffer the limitation of providing sufficient bandwidth for large amounts of data[2]. Limited communication bandwidth presents a considerable challenge to underwater wireless application. A possible solution to this problem is offered by the introduction of optical communication which offers capacity of high data rates. High speed, high capacity, underwater, non-conductive optical communication system will enable wireless underwater communications between AUV and observatories. Recently, Lighting Emitting Diodes (LEDs) have been commercialized with high efficiency and high power. It provides the possibility of constructing underwater wireless communication with inexpensive and compact devices.

Implementing underwater optical link is dependent on the characteristic of ocean water. Optical wireless communication must contend with phenomena resulting from the interaction of the propagating light beam with the water medium, such as absorption and scattering of light in the ocean water[6]. It is important to minimize the effort of experiments during the system design by simulating the transmission characteristics of wireless optical system in underwater environment. Commercial simulation tools mainly developed for the application of optical free space communication. Therefore, it is required to develop simple method to validate the concept design of optical communication for underwater condition.

In this paper, we demonstrated the feasibility of underwater optical communication based on circuits simulation tool: Pspice. An analytical method of examining the property of LEDs transmission for underwater communication is firstly proposed by making use of electronic circuits simulation tool. We also evaluate the performance in term of bit error rate for LEDs wireless communication in different water conditions. The method proposed in this paper is useful to evaluate the expected performance characteristics given a characterization of operational environment and to determine optimum operational settings.

II. UNDERWATER OPTICAL LINK IMPLEMENTATION

The block diagram of the LED based underwater optical communication system is sown in Fig. 1. The hardware consists of transmitter and receiver. For the transmitter, the circuit consist of voltage regulator and LED driver[3]. The LED driver used in this study is shown in Fig.2.

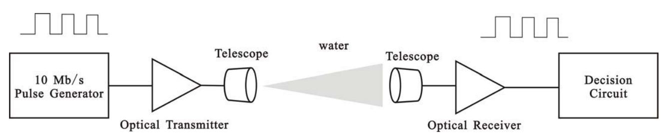


Figure 1. The setup for underwater optical communication system

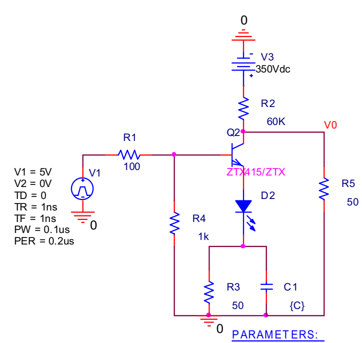


Figure 2. The LED Driver s

A. Transmitter model

The main consideration for underwater optical communication is optical wavelength and beam parameters. Seawater is composed of primarily H_2O which absorbs heavily the red spectrum and the dissolved salts also absorb light at specific wavelengths. However, there is a transmission widow around 400nm-500nm which is represented the blue-green region of the visible light spectrum.

Lumileds SuperFlux LEDs produced by Philips is adopted for transmitter system design. The two wavelengths products are considered for underwater applications, one is blue light (HPWN-MB00-00000), and the other is green light (HPWN-MG00-00000) [4]. Philips Lumileds series are presently the industry leader in high powered LEDs. The characteristics of Philips Lumileds series are as following:

1) Generally speaking LEDs intensity is about 100mcd. However SuperFlux LEDs Blue minimum intensity is 900mcd and Green minimum intensity is 2700mcd.

2) The temperature increase at the LED junction is about half that experienced by other LEDs when operated at equivalent power. A normal LED's brightness can be increased with an increased drive current. The extra flux will be exchanged for decreased reliability and lifetime. The Superflux LEDs, with almost 650% advantage in light intensity, still maintain their reliability.

3) In an optical communications system the ability to collimate a beam is very important. Superflux LEDs's low profile package can be easily coupled with reflectors or lenses to efficiently distribute light and provide the desired lit appearance. They have optimized the design such that the image is not distorted, in addition to taking special care forming a good lens with the epoxy. When focused, the illuminated LED die can be seen very clearly with minimal distortion.

B. Water medium model

The light is generated from transmitter circuit are transmitted via water to the receiver. General speaking, an optical signal is attenuated in water by two processes, absorption and scattering. Absorption occurred as photon energies are lost due to thermal processes. Scattering losses occur when the interaction with particulates causes photons to scatter out of the main bean path. It is often more convenient to represent these losses together as the total attenuation α, which is defined as:

$$\alpha = \gamma + \beta \tag{1}$$

where γ is absorption coefficients and β is scattering coefficients. Attenuation coefficients α is changed with wavelength and water. Table 1 shows green representative absorption, scattering, and attenuation coefficients for various water types [6].

In the model of the underwater transmission link, the attenuation of the signal light is realized by a controlled voltage source. The background light is simulated by an additive direct voltage proportional to the background radiation power[5], which is defined as following:

$$P_r = p_0 e^{-\alpha d} + p_b = Ap_0 + p_b \tag{2}$$

Where P_0 is optical source power, d is transmitting distance and P_b is background light power.

TABLE I. INHERENT OPTICAL PROPERTIES OF VARIOUS WATER TYPES

water type	γ（m-1）	β(m-1)	α(m-1)
pure sea water	0.0405	0.0025	0.043
clean ocean	0.114	0.037	0.151
coastal ocean	0.179	0.219	0.298

The model of transmitter link based on Pspice LED is shown in Fig.3.

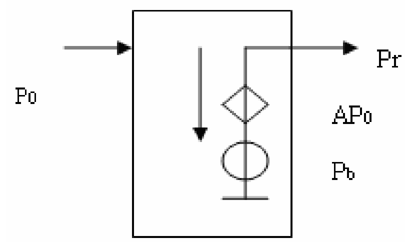


Figure 3. Model for the transmission link

C. Receiver model

Receiver circuits comprise electro-optic examination (photodiode), Amplifier and equalizer. For electro-optic examination purposes, the following aspects about photodiode should be considered: (1) Peak sensitivity wavelength; (2) High spectral response; (3) High response speed, when incidence light signal is modulated by high frequency, photodiode can respond quickly; (4) Low noise. Photodiode is an important components in the receiver circuits. Hamamatsu Photonics G5645 with (λp=470nm) and S5627-01(λp=540nm) are adopted in receiver circuits.

NE592 is used as receiver amplifier. The light receiver noise mainly includes the amplifier noise, the photo-electricity detector quantum noise and the photorectifier multiplication noise. During the simulation, all noises are equivalent as amplifier's fronthand[5]. It is necessary to build macro model for the receiver in the simulation to equivalent the circuit modeled by some controlled sources. After equivalent macro model established, the circuit becomes a simpler perspicuity and it makes the simulation feasible.

D. The decision circuit

In order to calculate the error rate of wireless communication system condition, the output-terminal of receiver should connect to a decision circuit which is used to decide signal level (1 or 0). The threshold voltage is defined as *D*. If *Vout* is bigger than the threshold voltage *D*, the output is set as "1". When *Vout* is less than the threshold voltage *D*, the output is set as "0". The threshold voltage D is determined as following:

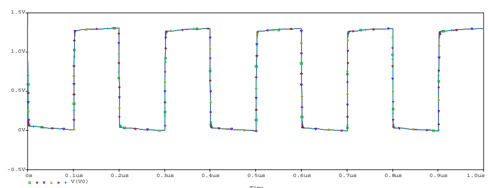
$$\frac{D - V_{0,\max}}{\sigma_0} = \frac{V_{1,\min} - D}{\sigma_1} \tag{3}$$

Where $V_{0,max}$ is at the decision for the max. of logical "0". $V_{1,min}$ is at the decision for the min. of logical "1", σ_0 is the standard deviation of the decision variable for a transmitted logical "0"at the sampling instant, σ_1 is the standard deviation of the decision variable for a transmitted logical "1" at the sampling instant. By making use of function S(x) in Pspice simulator, we can obtain $\sigma_0$and σ_1.

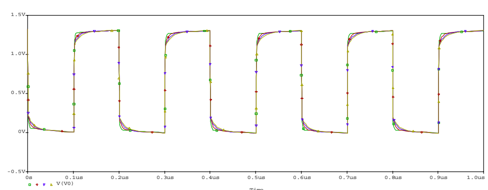
III. SIMULATION RESULT

After the optical transmitter, the signal attenuation underwater and the optical receiver, are simulated, we combined the tree modules for system level simulation[7]. Input signal is set as 10M Hz square-waveform and the simulation results are given as follows.

The effects of capacitor C_1 for transmitter circuit is shown in Fig. 4. Fig.4 (a) shows that the change of C_1 has a little influence on output signal when C_1 is changed from 0pF to 50pF. Fig. 4(b) shows the result when C_1 is increased from 50pF to 350pF. It is sowed that the if the value of C1 is higher than 50pF, it could deform the output signal. Thus, the capacity of less than 50pF is applied in our experiment design.



(a) Output signal when C1 is changed from 0pF to 50pF



(b) Output signal when C1 is changed from 50pF to 350pF

Figure 4. Transmitter circuit simulation

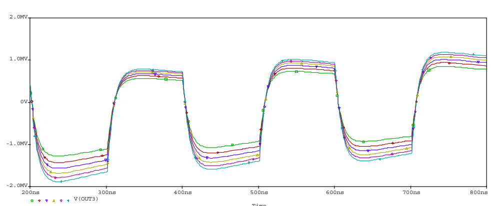
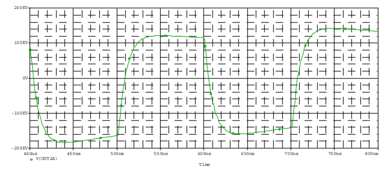


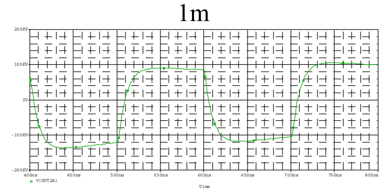
Figure 5. Receiver circuit simulation

Receiver circuit simulation results are shown in Fig.5. It is shown that parameter variation of the receiver circuit only has impact on voltage amplitude.

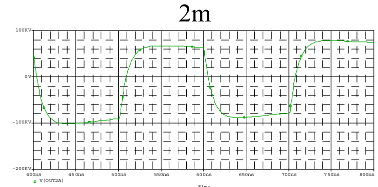
The different transmitting ranges are evaluated for coastal ocean. Fig. 6 shows the received signal waveform at different distance between 1 m, 2m, 3m and 3.5m respectively. It is demonstrated that the optical wireless communication system offer superior characteristics in a blue and green windows.



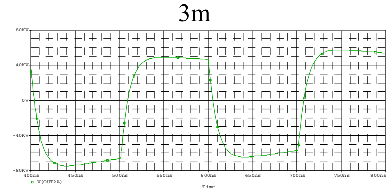
1m



2m



3m



3.5m

Figure 6. Simulation results for different distance of underwater optical wireless communication

IV. IMPACT ON BIT-ERROR RATE

The performance of underwater optical wireless communication is evaluated in term of bit error rate (BER). The BER of optical link will vary in proportion to the range in a given environment. The acceptable BER of optical communication is 10^{-6}. The resulting performance is usually evaluated using the Q parameter:

$$Q = \frac{V_{0,\max} - D}{\sigma_0} = \frac{V_{1,\min} - D}{\sigma_1} \tag{4}$$

The BER for different range may be derived from a Gaussian approximation and can be estimated as following[8]:

$$Pe = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{5}$$

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Where *erfc(a)* is the function that can be expressed as $erfc(a)=\frac{2}{\sqrt{\pi}}\int_a^\infty e^{-t^2}dt$. The formula (5) can be written as:

$$Pe=\frac{1}{2\pi}\frac{\exp(-\frac{Q^2}{2})}{Q} \quad (6)$$

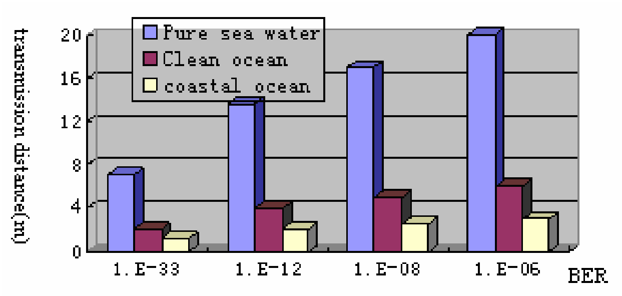

Figure 7. Bit error rate at different range and water condition

Fig. 7 shows a comparison of BER and transmission range with different sea water conditions. It is shown the maximum distance with acceptable BER is around 20 meters for the pure sea water. For coastal ocean, the communication range is reduced approximately 3.5 meters.

V. CONCLUSION

We have presented a method for the simulation of underwater optical wireless communication system with circuit design simulator of Pspice. It is demonstrated that the LED emitters can be successfully used for high speed optical communication in underwater applications. A fast simulation approach for BER calculation of underwater transmission systems has been developed. By using Pspice simulator, the channel behavior can be simply modeled as voltage source. The bit-error rate (BER) is used to estimate the system performance. The simulation results indicate that optical communication system based on LED technology is suitable for underwater applications and the maximum communication distance is approximately around 3 meters in coastal water and 6 meters in clean ocean. It is shown that the proposed method could easily be incorporated into many different applications, such as underwater laser communication and laser diode links.

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