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BER Estimation for Laser Based Underwater Communication

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Abstract: Apart from land and air, sea has also become very important from defense strategic point of view and is required to be integrated with network centric communication. In future it may play a very important role in network centric warfare. Free space laser communications provide wide bandwidth and high security capabilities to unmanned aircraft systems in order to successfully accomplish intelligence, surveillance, target acquisition, and reconnaissance missions[l] Laser based communication is emerging as a most promising solution for underwater communication. Most of laser cannot penetrate through the sea due to be absorbed by the sea, but the blue-green laser (the wavelength is about 470 ~ 570*nm*) has the minimum energy fading in the sea, whose fading rate is about 0.155~0.5dB/m, this feature of blue-green laser in the sea is said the window effect[2]. Long-range links use directed laser beams to transmit data, and can be used for building-to-building, ground-to-aircraft, or ground-to-satellite communication [3]. Laser communication throws quite different challenges in water in respect to air. Laser attenuation in water is key bottleneck for underwater communication as attenuation in water is roughly 1000 times as in air. This exponential variation plays a very important role in determining the type of laser (CW or Q switched laser) and place a restriction on the use of CW laser for longer distance because of impractical sizes. Turbulences and variation in salt concentration in different part of a sea and in different seas imposes a dynamic challenge for underwater laser communication. Issues at sea-air interface for aerial platform to underwater communication also plays crucial role for establishing an uninterrupted communication link. All these issues throttle the effective baud rate of transmission.

I. Introduction

Transmission of data at lower bit error rate (BER) is foremost characteristic of a communication system. It is a very important parameter to be considered while modeling a communication system and specially communication channel as sources of error at transmitting and receiving end can be modeled and optimized more deterministically. ON-OFF Key (OOK) is the most common and simple (Implementation point of view) modulation technique for CW laser beam. It is perfect solution for laser communication in air. In water, laser attenuation is roughly 1000 times with respect to air so power requirement for underwater communication is huge and vary exponentially . Size of CW laser imposes a practical constraint for higher power. Q switched pulse laser is a ideal solution for high peak power requirement but imposes a constraint on modulation technique.. Other possible modulation technique pulse width modulation (PWM) varies the energy of the Q switched pulses and hence the overall communication path length degrades. In this paper we have calculated the bit error rates for different sources of error in the water channel for both OOK and PPM.

BER calculation: Attenuation of laser beam in water degrades its intensity drastically and it degrades signal amplitude at the detector output. Decision device will occasionally make error and consider symbol 1 as symbol 0. To determine the average probability of error, we first consider the two possible kind of error separately. Assume that symbol 0 was transmitted, corresponding to a level of 0 volts. The output signal y(t) then consists of noise alone, as shown by

$$Y(t) = n(t), \qquad \text{symbol 0 was sent}$$

When symbol 0 is transmitted, the random variable y_k is Gaussian-distributed with zero mean and variance σ^2 where y_k denote the sample value obtained by observing the sample function y(t) at time $t=t_k$ and Y_k denote the corresponding random variable Hence, the conditional probability density function of y_k given that symbol 0 was transmitted, equals

$$f_{Yk/0}(y_k/0) = \frac{1}{\sqrt{2\pi\sigma}} exp\left(-\frac{y_k^2}{2\sigma^2}\right)$$

Let P_{eo} denote the conditional probability of error, given that symbol 0 was transmitted. This probability is defined by the area under the $f_{Yk/0}(y_k/0)$ curve, from A/2 to ∞, which can be expressed as:

$$P_{eo} = \frac{1}{2} erfc\left(\frac{A}{2\sqrt{2\sigma}}\right)$$

The conditional probability density function of y_k given that symbol 1 was transmitted, can be expressed as

$$f_{Yk/1}(y_{k/1}) = \frac{1}{\sqrt{2\pi\sigma}} exp\left[-\frac{(y_k - A)^2}{2_{\sigma^2}}\right]$$

Let P_{e1} denote the conditional probability of error, given that symbol 1 was transmitted. This probability is defined by the area under the $f_{Yk/1}(y_{k/1})$ curve, from - ∞ to A/2. Assuming equally probable symbols and setting threshold midway between 0 and A, implies P_{e1}=P_{eo}.To determine the average probability of error in the receiver, we note that the two possible kinds of error considered above are mutually exclusive events in that if the receiver, at a particular sampling instant, chooses symbol I, then symbol 0 is excluded from appearing, and vice versa. Furthermore, P_{eo} and P_{e1} are conditional probabilities with P_{eo} assuming that a 0 was transmitted and P_{e1} assuming that a 1 was transmitted. Thus, assuming that the a priori probability of transmitting a 0 is P_o, and the a priori probability of transmitting a 1 is P_1, we find that the average probability of error P_e in the receiver is given by

$$P_e = P_o P_{eo} + P_1 P_{e1}$$

Since P_{e1}=P_{eo} and we have assumed that P_o=P_1, we obtain

$$P_e = P_{e1} = P_{eo}$$

Which is given as:

$$P_e = \frac{1}{2} erfc\left(\frac{1}{2}\sqrt{\frac{\gamma}{2}}\right)$$

Where γ is the signal to noise ratio.

The above calculation is for the case of on-off keying. Now we analyze the probability of error for a Pulse Position Modulation (PPM) system. The PPM generally is applied to higher data rate in the underwater laser communication. The PPM adopts optical pulse as the carrier which is controlled by the modulated signal. The pulse position is varied with the modulated signal, and the message is transmitted via this position variation. The efficiency of Pulse position modulation is higher than others modulations, especially in the underwater laser communication system and it are most optimized. *k*-PPM decreases the average power requirement at the cost of large bandwidth[4]. In terms of power efficiency if the *k* is greater than 2, PPM modulation exhibits a higher efficiency than OOK does. An increase in *k* causes an increase in the bandwidth requirement. The average number of bit errors per *k*-bit symbol is:

$$P_b = \frac{2^{k-1}}{2^k - 1} . P_m$$

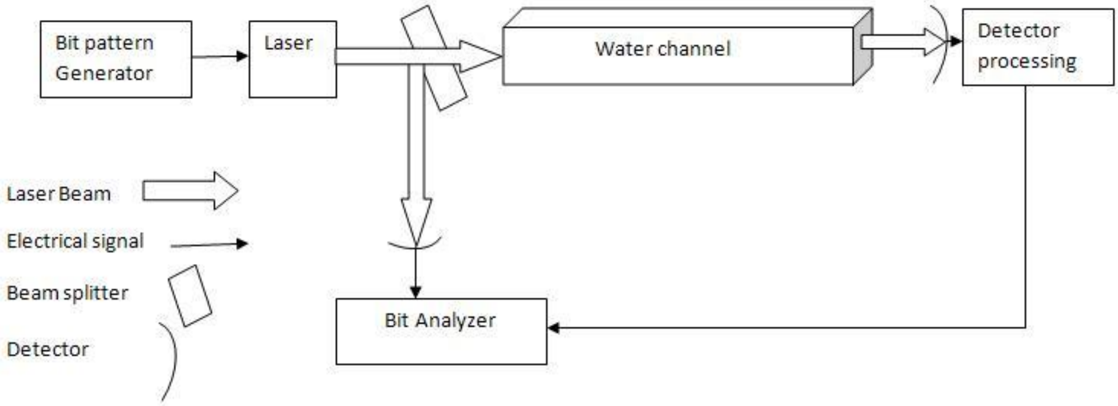
Where P_b is the average number of bit errors per *k* bit symbol and P_m is the bit error rate for a PPM system.

II. Lab setup for BER analysis

Transmitter: 200mW frequency double ND-YAG green laser operating at 532nm
Water channel: Water tank of path length 10 m
Data transfer rate: 10 Kbps
Detector: Silicon PIN photodiode
Mode: Duplex(full/half)/Chat mode
File type: Text file and Binary file

To estimate the BER, four sources of error are considered in the above setup as follow:

1. Effect of channel attenuation on BER
2. Effect of channel turbulence on BER
3. Effect of ambient noise on BER
4. Effect of laser ON-OFF stabilization rate on BER



1. Effect of channel attenuation on BER: Channel attenuation plays very crucial role in determining the BER of a laser based communication system. Attenuation of laser beam propagation varies exponentially. Keeping other factors constant (K), Attenuation (α) is the only variable. Laser propagation equation can be expressed as

$$P_r = P_t . e^{-\alpha x}$$

Where P_r is received power, P_t is transmitted power and x is the path length. Attenuation is most important factor for deciding the power requirement of a communication channel. Attenuation factor α of water is 1000 times of the air implies huge laser power requirement for underwater communication. Unit of attenuation constant of beam of light is m^{-1} and used for finding laser attenuation underwater. It is not dependent on wavelength and is approximately equal to 0.02 m^{-1} in clear water [5]. To analyze the effect of α in the above setup, attenuation of water is varied by adding NaCl in various concentrations and keeping other sources of errors inactive. Transmitted laser power is kept constant and intensity modulated by a bit pattern generator. Received power and bit pattern generated at the detector are compared with transmitted laser beam to analyze the attenuation factor and BER. Results are present in the table below:

	OOK	PPM
Types of water	Av. BER(per 1Mb)	
RO water	< 1	<0.5
Tap water	< 1.5	<0.75
Salt water1	< 1.5-2.0	<1
Salt water2	< 2.5	<1.5

2. Effect of intrachannel turbulence on BER: Sea waves may contribute to BER. Disturbance at sea surface plays very crucial role in aerial platform to underwater communication. Waves at sea surface changes the incident angle of incoming aerial laser beam dynamically. This effect leads to the beam dancing at receiver. Maximum deviation of beam from normal may be 10.6°(paper reference). In present experiment only intra-water disturbances are simulated using water churning motor placed at interval of 1.5m.Without churning and with churning (RPM) average BER remains less 1 bit/Mb.

	OOK	PPM
Turbulence	Av. BER(per 1Mb)	
No churn	< 1	<0.5
With churn	< 1	<0.5

3. Effect of ambient light on BER: Ambient light at the detector may lead to the receiver decision error. Probability of discrimination between '1' and '0' decreases with increase in ambient light level. Ambient light effect may be diminished by using very sharp laser line filters but fabrication of very narrow laser line width (nm) filter is a great challenge worldwide Receiver should be very robust to handle the effect of ambient noise. In the above setup BER is calculated under different light condition and keeping other error sources inactive. Results are presented in the table below:

	OOK	PPM
Light intensity	Av. BER(per 1Mb)	
No light	< 1	<0.5
100W bulb	1-2	0.5-1

4. Effect of laser ON-OFF stabilization rate on BER: Here we have used Nd-Yag laser rated 30 KHz TTL modulation. it was observed that up to 10 KHz the laser works smoothly but after 10 KHz it starts missing pulses. Due to these missed pulses there is an increase in the bit error rate.

	OOK	PPM
frequency	Av. BER(per 1Mb)	
10 KHz<	< 1	<0.5
10KHz to 15 KHz	< 2.5	<1
>15 KHz	< 3.0-4.0	<1.5-2

III. Conclusion

As the salt content of water increases the bit error rate increases. Churning of water has no considerable effect on the bit error rate. As the frequency of the laser is increased beyond 10 kHz the bit error rate increases significantly. When the source of ambient light is brought very near to the receiver the BER increases drastically and all the information content is lost. PPM modulation technique offers less BER as compared to OOK and provides an improved overall performance.

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