# Influence of Inclination Angle on the Performance of Underwater Wireless Spatial/Spectral OCDMA System

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***Abstract*: In this paper, the influence of inclination angle on the bit error rate (BER) performance of underwater wireless spatial/spectral optical code division multiple access (OCDMA) system using two dimensional perfect difference codes (2D-PDCs) is analyzed. Here to calculate BER of the system, thermal noise, shot noise and phase-induce-intensity noise (PIIN) are taken. A 532nm wavelength LED is chosen as optical source and p-i-n photodiode is utilized as optical detector in the proposed system. The effect of inclination angle on the proposed system is investigated for different system parameters such as link distance, transmitter power, and beam divergence angle and data rate. From numerical results it is observed that best BER performance is achieved for narrower inclination angle in pure sea water channel among all water channels.**

***Keywords*: BER performance, 2D-OCDMA, UWO communication, water types, perfect difference code**

## 1. Introduction

In recent years, underwater wireless optical communication (UWOC) has been playing an important role for different applications such as ocean currents monitoring, weather forecasting, seismic monitoring, control surveillance systems, real-time monitoring, environmental research, climate condition recording, oceanography research, forecasting, transmission of data between ships etc. [1]-[6]. Currently, acoustic technology is the most widely used underwater wireless communication technique but it suffers from both low bandwidth and high latency [9]. Electromagnetic (EM) waves, in the radio frequency (RF) range, are a good option for underwater wireless communication when used for high data rate transfer in short distances. However, due to strong water attenuation, radio frequency-based communication technologies are rarely used for underwater wireless communication [1]-[5]. Optical wave provides less attenuation, higher data rate, higher bandwidth, smaller propagation delay, lower latency, less power losses and more energy efficiency [7].

However the implementation of UWOC is not easy and it faces some hindrance that is difficult to overcome. The main drawbacks of UWOC is the restricted link distance. The maximum attainable communication link distance is below 100 m only [8]-[9]. Optical signal while travelling through water medium faces many hindrances such as absorption, scattering and atmospheric turbulence which causes the change in direction of the optical beam, intensity loss of received optical power, spreading of optical beam, multipath interference etc. These effects are actually unavoidable in UWOC and greatly degrade communication quality [4]

Among many optical access technology, Optical Code Division Multiple Access (OCDMA) is experiencing much attention because of its many attractive features such as efficient bandwidth utilization, better security, improved spectral efficiency, and increased robustness [2], [6]. Since OCDMA allows many users to access the network at the same time with same frequency, it produces multi user interference (MUI). MUI is the primary performance degradation factor in OCDMA systems. Among many OCDMA techniques, two dimensional-OCDMA (2D-OCDMA) system with interference cancellation receiver is a popular technique to reduce the effect of multiuser interference (MUI). However, to mitigate the MUI, 2D-OCDMA system must be implemented with code sequence that possesses the property of fixed in-phase cross-correlation value [4]. The application of 2D Perfect Difference (2D-PD) codes will be beneficial as it has unity in- phase cross-correlation value [4]. It is also noted that 2D-PD codes with spatial/spectral transceiver structure can more effectively suppress the phase induced intensity noise (PIIN) and reduce the effect of MUI in OCDMA.

## 2. System description

The schematic block diagram of the underwater wireless 2D-OCDMA is shown in Fig. 1. A set of a combiner and a splitter is used to combine the signals from all transmitters and broadcast them to all receivers. Here, the user code sequence is addressed using 2D-perfect difference codes. Let us consider there are K number of users in the system. At the transmitter, the user binary data is modulated by an on-off keying (OOK) modulator using a broadband optical source. Then the modulated signal is fed to the combiner via a 2D-OCDMA encoder. The structure of the encoder can be fabricated by the Fiber Bragg Gratings (FBGs) array structure [3].

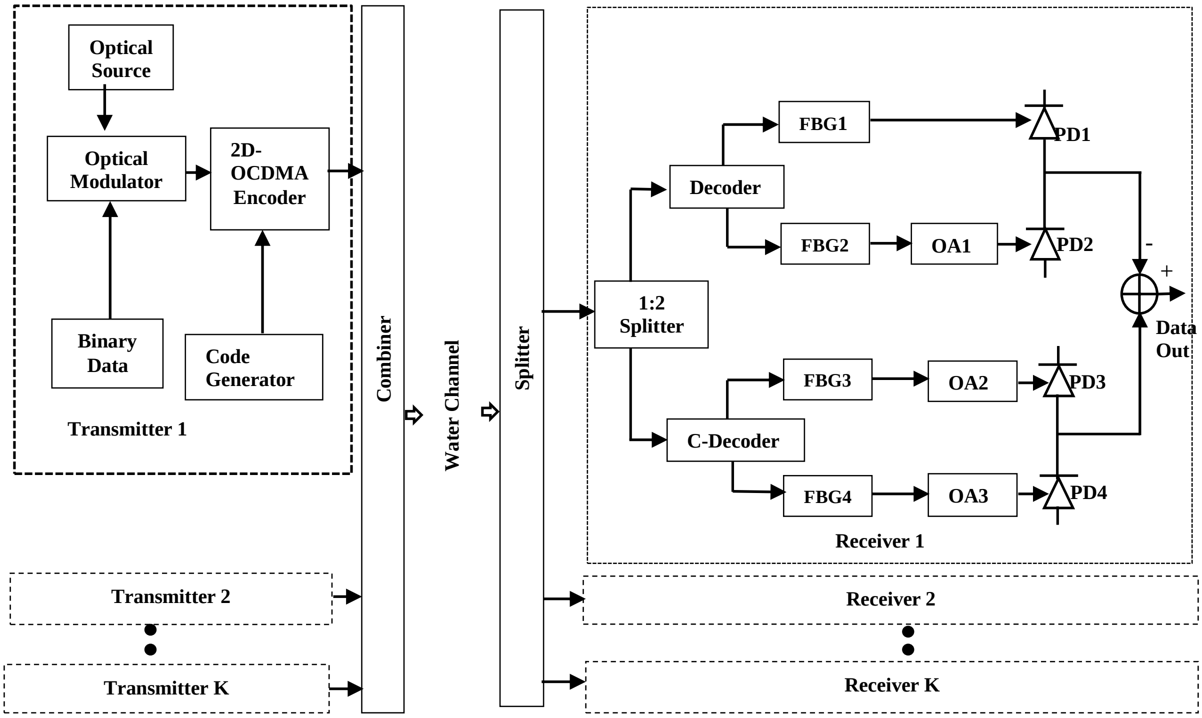


**Fig. 1 Block diagram of the proposed 2D-OCDMA UWOC system.**

## 3. System analysis

### 3.1 Underwater Link Design

In designing the UWOC system, the prior consideration is to comprehend the link budget equation. For the line of sight (LOS) link, the link budget equation is given by [1] and [2],

$$P_R = P_T \eta_T \eta_R \frac{A_R \cos(\varphi)}{2\pi d^2[1-\cos(\varphi_0)]} \exp\left[-c(\lambda)\frac{d}{\cos(\varphi)}\right] \quad (3.1)$$

Where $P_T$ is the transmitted optical power, $P_R$ is the received optical power by the receiver after a distance of $d$, $\varphi$ is the transmitter inclination angle from the axis connecting the transmitter-receiver pair, $A_R$ is the receiver aperture area, $\eta_T$ and $\eta_R$ are the optical efficiencies of the transmitter and the receiver, respectively, $d$ is the transmission distance, $\varphi_0$ is the transmission beam divergence angle. The total loss coefficient for an underwater optical channel $c(\lambda)$ is defined as [2-3], [4],

$$c(\lambda) = a(\lambda) + b(\lambda) \quad (3.2)$$

The attenuation coefficient is denoted as $c(\lambda)$ $m^{-1}$, where $\lambda$ is the source wavelength. If where $a(\lambda)$ and $b(\lambda)$ are the underwater optical absorption and scattering coefficient, respectively. $a(\lambda)$ depends on the dissolved impurities in water, chlorophyll concentration, transmission wavelength, and link distance; $b(\lambda)$ is dependent on chlorophyll concentration, wavelength, small and large water-soluble particles in water [6-9].

### 3.2 The Bit Error Rate Calculation

PIIN, thermal noise, and short noise are considered for the calculation of the BER of the system. The signal to noise ratio (SNR) can be calculated as:

$$SNR = \frac{I_r^2}{I_t^2} \quad (3.3)$$

Where $I_t$ is the total noise power affecting all the photodiodes and $I_r$ is total photocurrent of receiver. The photocurrent $I_r$ can be expressed as:

$$I_r = \frac{RP_{rec}w_1}{M} \quad (3.4)$$

where $P_{rec}$ is received optical power, $w_1$ is code weight of spectral code sequence, *M* is the code length of spectral code sequence, and $R$ is the of photodetector responsivity.

If the variance due to PIIN, shot noise and thermal noise are $I_{PIIN}^2$ , $I_{Shot}^2$ and $I_{Thermal}^2$, respectively, then $I_t^2$ can be illustrated as [2],

$$I_t^2 = I_{PIIN}^2 + I_{Shot}^2 + I_{Thermal}^2 \quad (3.5$$

In the case of 2D-perfect difference code, the PIIN can be expressed as:

$$I_{PIIN}^2 = \frac{R^2 B_e P_{rec}^2}{2M\Delta f w_2^2 w_1 (MN-1)^2}\left\{(w_1 w_2 (MN-1) + w_2 (U-1)(M-1))^2 + \frac{w_2^2 (U-1)^2 (M-1)^2}{(w_1-1)^2}\right\} \quad (3.6)$$

Where $B_e$ is receiver electrical bandwidth, $\Delta f$ is source bandwidth, $w_2$ is code weight of spatial code sequence and *N* is the code length of spatial code sequence.

As the thermal noise is highly dependent on receiver noise temperature, it can be represented as:

$$I_{Thermal}^2 = \frac{4K_b T_m B_e}{R_{Load}} \quad (3.7)$$

Where $K_b$ is Boltzmann constant, $R_{Load}$ is receiver load resistance and $T_m$ is the noise temperature of receiver.

The shot noise can be written as:

$$I_{Shot}^2 = \frac{eB_e P_{rec} R}{w_2 M}\left\{w_1 w_2 + \frac{2w_1(U-1)(N-1)}{(MN-1)} + \frac{2w_2(U-1)(M-1)}{(MN-1)} + \frac{4(U-1)(M-1)(N-1)}{(MN-1)}\right\} \quad (3.8)$$

The SNR at the receiver can be expressed as:

$$SNR = \frac{I_r^2}{I_{PIIN}^2 + I_{Shot}^2 + I_{Thermal}^2} \quad (3.9)$$

The BER of the system can be expressed as:

$$BER = \frac{1}{2} erfc\left(\sqrt{SNR/8}\right) \quad (3.10)$$

**4. Results and discussion**

In this section, the BER performance of UWOCDMA system for various water types has been presented. The system parameters are following: the transmission wavelength $(\lambda)$ = 532nm, data rate $(D_r)$ =0.5GHz , the transmitter optical efficiency $(\eta_t)$ = 0.9, receiver optical efficiency $(\eta_r)$ = 0.9, LED beam divergence angle $(\theta_0) = 40^o$, transmitter inclination angle $(\theta)$ =$15^o$, receiver capture area $(A_r)$ = 0.01m$^2$, electron charge $(e) = 1.6\times 10^{-19} C$, Boltzmann constant $(k_b)$ = $1.38\times10^{-23}$J/K and temperature $(T)$ = 298K, Photo detector responsivity $(R)$ =0.85, receiver load resistance $R_{load}$ = 100Ω, electrical bandwidth $(B_e)$= 250MHz, total number of simultaneous user $(U)$ =50, transmitter power $(P_t)$ =30dBm are considered. The code weight of spectral and spatial code sequence is 6 and 3 respectively.

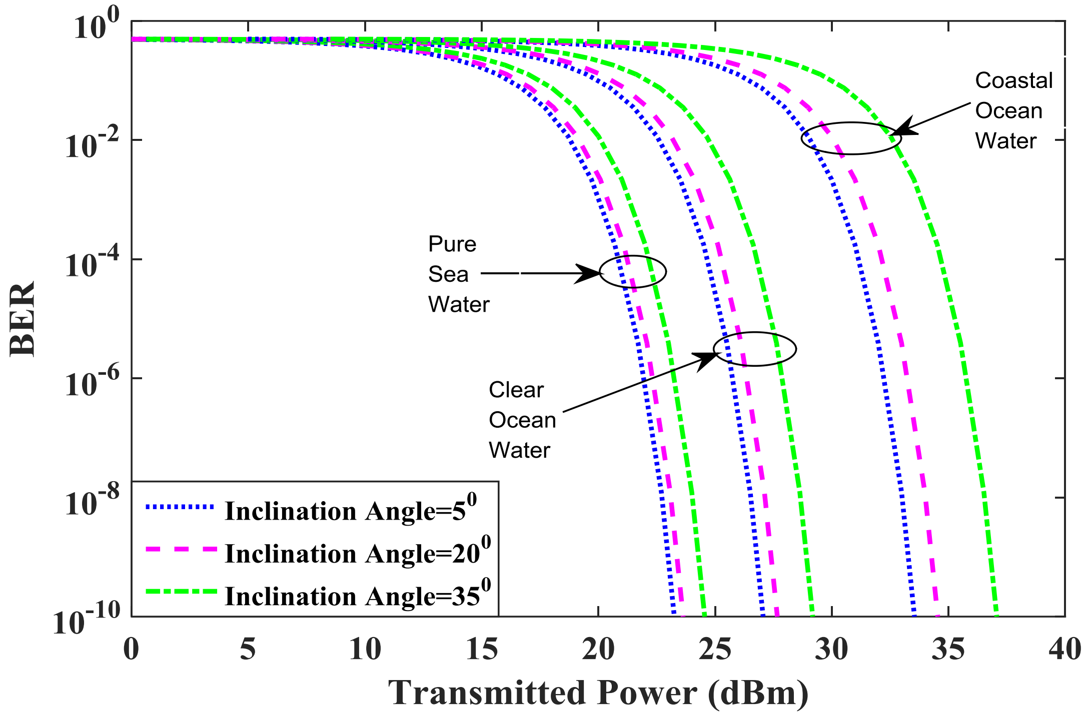


Fig. 2: BER versus transmitted power at different incident angle for different water.

Figure 2 shows the plot of BER versus transmitted power for various types of water with different inclination angle. The performance is observed for inclination angle of 5°, 20° and 35°.In pure seawater, the value of BER 10-8 is achieved at 22.8 dBm, 23.10 dBm, and 24.05 dBm transmitted power when the inclination angle is 5°, 20° and 35° respectively. For same BER in clear ocean water 26.55 dBm, 27.15 dBm, and 28.65 dBm transmitter power at the inclination angle is 5°, 20° and 35° respectively. And in coastal ocean water at same BER, transmitted powers are 33 dBm, 34 dBm and 36.60 dBm for same inclination angles respectively. It is clear that when the inclination angle decreases, the BER performance of the system improves. And it is also proved that the BER performance is very poor in coastal ocean water due to present large number of impurities whereas the BER performance is best in pure sea water.

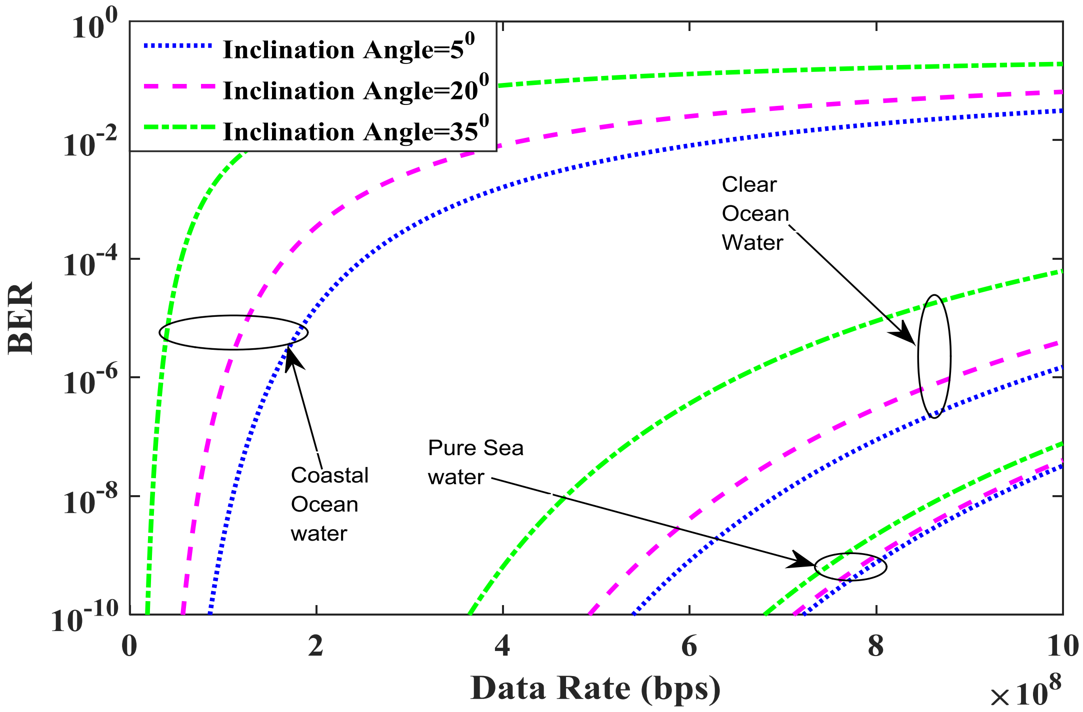


**Fig. 3: BER versus Data rate at different incident angle for different water.**

Figure 3 shows the BER versus data rate of the underwater wireless optical communication system. Where data rate $9.274\times10^8$ bps, $9.142\times10^8$ bps, and $8.74\times10^8$ bps for inclination angle of 5°, 20° and 35°respectively in pure seawater when the BER is $10^{-8}$. In clear ocean water, $6.93\times10^8$ bps, $6.328\times10^8$ bps and $4.676\times10^8$ bps data rate for same BER value at inclination angle of 5°,20° and 35°respectively. And coastal ocean water, data rate $1.103\times10^8$ bps, $7.311\times10^8$ bps, and $2.433\times10^8$ bps for same BER value at inclination angle of 5°,20° and 35°respectively. The above value shows that, data rate increases for lower inclination angle at same value of BER. And data rate will be maximum for only pure seawater.

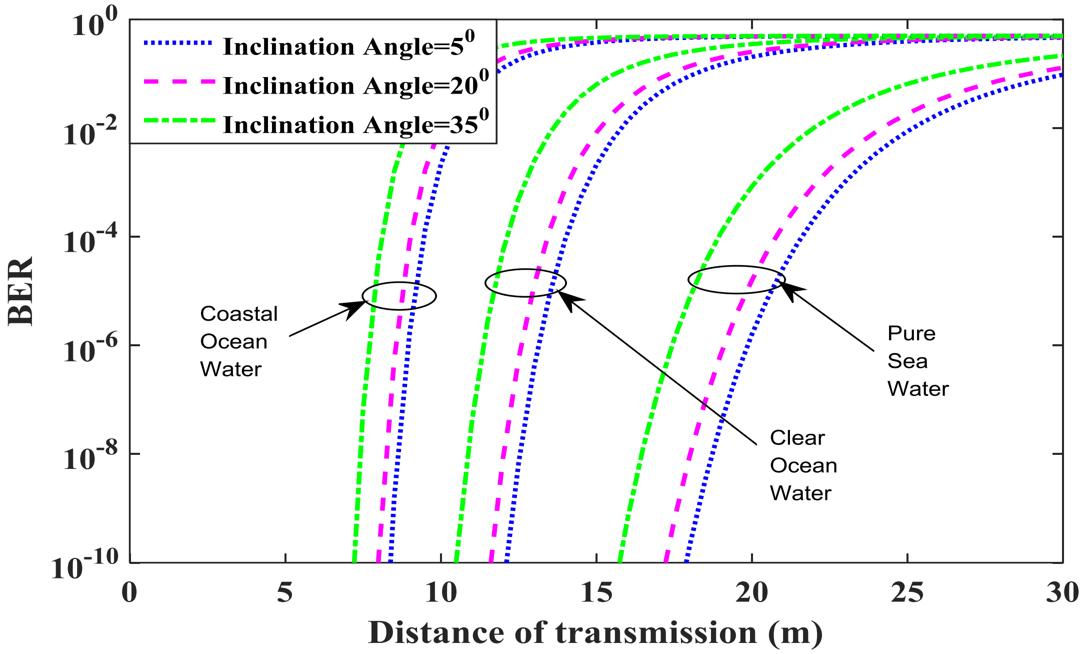


Fig. 4: BER versus transmission distance curve at different incident angle for different water.

Figure 4 shows that BER versus transmission distance of c. The BER increases with the transmission distance. In pure seawater, the value of $10^{-8}$ BER is obtained at 19m, 18.5m and 16.5m for inclination angle of 5°, 20° and 25° respectively. In clear ocean water, the transmission distance between the sides are12.7m, 12.2m and 11m respectively. And in coastal ocean water they are 8.6m, 8.2m and 7.5m respectively for same inclination angle that is mentioned before. From the above information it is clear that as the impurity of water tends to increase the desired amount of BER is obtained at a much lower link distance and Large distance is obtained at lower value of inclination angle of the underwater wireless optical communication system

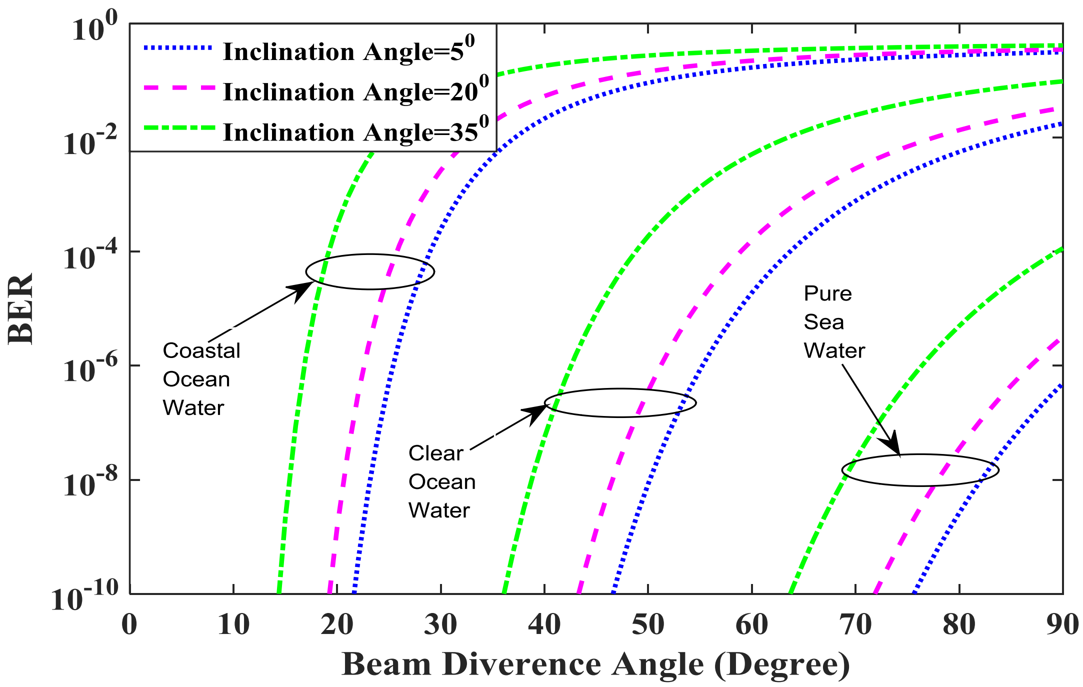


**Fig. 5: BER versus Beam Divergence angle at different incident angle for different water.**

Figure 5 shows that the BER versus beam divergence angle of the underwater wireless optical communication system. In pure sea water, beam divergence angle of 83˚, 78˚ and 69˚ is allowed to achieve a BER of $10^{-8}$ at the inclination angle of 5°, 20° and 35° respectively. In clear ocean water 51°, 47° and 39° of beam divergence angle can be taken at same BER and for same inclination angles given above. But in coastal ocean water at same inclination angles and at same BER of $10^{-8}$ the beam divergence angles are as follows 23.7˚, 20.8˚ and 15.8˚. From above value, it can be marked that the BER performance with respect to beam divergence angle develops with the decreasing inclination angle. So, it is verified that better BER performance is achieved in pure sea water with lower inclination angle.

## 5. Conclusion

In this paper, the impact of inclination angle on BER performance of an underwater wireless spectral/spatial OCDMA system using 2D-PDCs is analyzed. Here, different types of sea water are considered for the investigation of BER. In this system, shot noise, thermal noise and PIIN are taken into account. The transmission wavelength is selected as 532nm due to lower attenuation in yellow-green region. The BER performance is observed for different system parameters such as link distance, transmitter power, data rate and beam divergence angle with various inclination angle. It is found that the BER performance greatly dependent on inclination angle. Lower inclination angle gives better performance due to the fact that it allows limited coverage area of the signal and restricted orientation of transmitter-receiver pair. After analyzing all the results, it is noticed that best BER performance in pure sea water channel but the worst BER performance is achieved in coastal ocean water due to large number of impurities.

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