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Underwater Optical Channel Analysis Using DPIM & PPM

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Abstract: In the present day scenario underwater optical communication techniques are poor in efficiency, error performance and system complexity. This happens because multiple scattering and absorption causes temporal spread of the beam pulse resulting in inter symbol interference (ISI) and degraded system error performance. In the light of this,we attempt to analyze an underwater optical communication channels for sea water by performing link budget analysis using various modulation techniques on each of them and conclude with the most effective design. Thus, out of the various modulation techniques used today for underwater communication we are going to compare the performance of digital pulse position modulation (DPPM) and digital pulse interval modulation (DPIM) and find the most suitable between them. All the operations will be simulated using MATLAB. The various real life applications include offshore oil industry, pollution monitoring in environmental systems, collection of scientific data recorded at ocean-bottom stations, disaster detection, national security and defense (intrusion detection and underwater surveillance), as well as for the discovery of new natural resources.

Key words: Digital pulse position modulation (DPPM) · Digital pulse interval modulation (DPIM) · Inter symbol interference (ISI) · Under water · Optical communication

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INTRODUCTION

Wireless communication under water has tremendous applications such as communication among divers, unmanned underwater vehicles (UUV), submarines,ships and underwater sensors. Some of these UUVs and sensors are deployed togather important data such as real-time videos and environmental and security data which may be time sensitive. Also, information on the remote control of these UUVs and submarines may be relayed through wireless communication [1]. Therefore, efficient and high speed communications are required for handling underwater data transmission of large amounts of data with as small a delay as possible. Traditionally, wireless underwater data communication employs acoustic waves. Because an acoustic wave has low loss in the water, its range of communication can be very long. However, it has several disadvantages. The acoustical communication channel has a narrow bandwidth; therefore, it can only handle a relatively low bit rate. Also, the acoustic wave speed in water is slow (1500 m/s), which results in latency in communication [2]. To accommodate a higher bit rate, a higher frequency has to be considered. A possible candidate is the optical frequency. It has been reported in a specific case that the range of communication can be up to 425 m. However, even this kind of range is enough for communication among UUVs and divers in scenarios such as search and rescue operations in a disaster in a concentrated area. In this case, realtime, high quality images are crucial. High rate data transmission among underwater nodes and the buoy is therefore necessary. Optical wireless communication is possible in water, especially in the blue/green light wavelengths because it suffers less attenuation in water compared to other colors. Compared to acoustic waves, it propagates faster in the water (2.255 × 108 m/s) and offers a larger bandwidth. However, an optical wave is subjected to more absorption and scattering than an acoustic wave. The effects of the scattering in water are twofold. First, it attenuates the transmitted signal reducing signal to noise ratio.Second, it creates the inter-symbol-interference (ISI) effect corrupting the signal waveform. Therefore, the characterization of light propagation through an underwater channel that includes the absorption and scattering effects is crucial to analyze the wireless optical

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communication in underwater environments [3]. In the present day scenario underwater optical communication techniques are poor in efficiency, error performance and system complexity. This happens because multiple scattering and absorption causes temporal spread of the beam pulse resulting in inter symbol interference (ISI) and degraded system error performance. In the light of this,we attempt to analyze different underwater optical communication channels, perform link budget analysis using various modulation techniques on each of them and conclude with the most effective design. Thus, out of the various modulation techniques used today for underwater communication we are going to compare the performance of digital pulse position modulation (DPPM) and digital pulse interval modulation (DPIM) and find the most suitable between them. All the operations will be simulated using MATLAB. The various real life applications include offshore oil industry, pollution monitoring in environmental systems, collection of scientific data recorded at ocean-bottom stations,disaster detection, national security and defense (intrusion detection and underwater surveillance), as well as for the discovery of new natural resources.Our basic methodof operation was threefold. Firstly, to design the link budget by implementing the various link budget equations. We analyzed the channel by constructing an underwater link budget which included the effects of scattering and absorption of realistic sea water. Secondly, to implement Digital Pulse Interval Modulation(DPIM) and generate various waveforms necessary for determining the effectiveness of the technique. Lastly, to implement Pulse Position Modulation(PPM) and generating the requisite waveforms [4]. Finally, we put forward an efficient and feasible underwater optical channel model by analyze the various aspects of the results obtained.

Channel Modeling: Establishing a communication channel requires many prerequisites in order to a get an efficient and cost productive link. In order to evaluate the effectiveness of a given channel coding and processing technique before construction, some model of the channel must be developed that adequately describes the environment [5]. Such analysis reduces the cost of developing a complex system by reducing the amount of hardware that has to be developed for evaluation of performance. By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model may be developed that highlights the important characteristics of a given environment. This model is evaluated on basis of a the formulated link budget equation. Link budgets are a design tool to predict signal-to-noise ratio (SNR) at a receiver given system parameters such as transmit power and antenna gain and channel parameters such as propagation loss and interference. This predicted SNR is compared to a minimum required SNR to obtain a link margin.

$$Pr = Pt + Gt + Gr + Ls + Ln \tag{1}$$

Here,

Pr= Received Power, equivalent to SNR (all quantities in dB), Pt = Transmitted Power, Gt = Transmitting Antenna Gain, Gr = Receiving Antenna Gain, Ls = Free Space Path Loss, spreading and atmospheric attenuation, Ln = Noise Factor,

Link Budget Equation Looks like This:

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) - Losses (dB) (2)

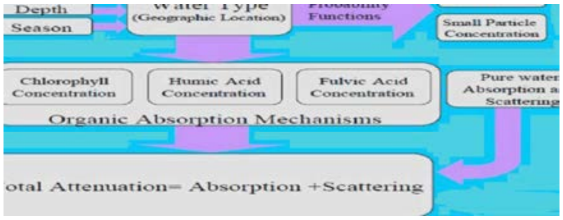


Fig. 1: Factors Affecting Link Budget

While mathematically analyzing an underwater channel, the power is exponentially decaying as function of the path length Lm and is formulated as:

$$P_R = P_T e^{-\alpha(\lambda)L_m} \tag{3}$$

PR: Received power

Lm: Path length through the lossy medium

PT: Initial transmitted power

α : total attenuation coefficient of the medium.

Underwater Absorption Model: Underwater, light is affected by:

- Depth
- Subject distance
- Weather and surface conditions.

The overall absorption of seawater can be written as the sum of each of the ocean's optical components multiplied by their concentration

$$a(\lambda) = \Sigma_{i=0} C_i a_i(\lambda) \tag{4}$$

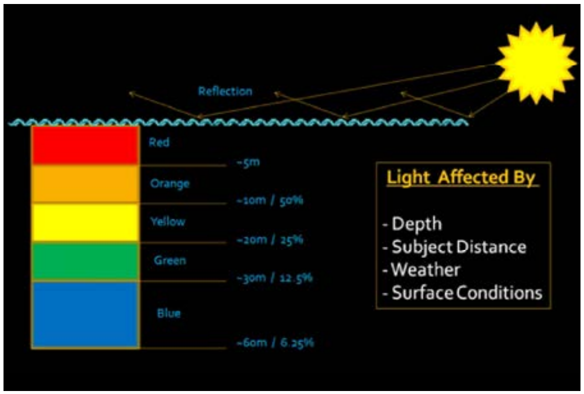


Fig. 2: Absorption Characteristics

The absorption coefficient a(λ) is given by:

$$a(\lambda)=aw(\lambda)+acl(\lambda)+af(\lambda)+ah(\lambda) \tag{5}$$

where,
aw(λ): Absorption coefficient of water as a function of wavelength
acl(λ): Absorption chlorophyll acid coefficient as a function of wavelength
af(λ): Fulvic acid absorption coefficient
ah(λ): Humic acid absorption coefficient.

The absorption coefficient for sea water type, aw(λ), was interpolated from data surveyed with respect to water concentration of woc= 1 mg/m3 and water concentrations 0 ≤wc ≤ 15 mg/m3. It then became:

$$a_w(\lambda) = a_w^0(\lambda)\left[\frac{W_c}{W_c^0}\right]^{a_w^0} \tag{6}$$

For sea water aw0(λ) = 0.0405λ. As well as the absorption coefficient for chlorophyll, acl(λ), was interpolated with respect to a chlorophyll concentration of Cc0 = 1 mg/m3 and chlorophyll concentrations 0 ≤ Cc ≤ 12mg/m3. It then became:

$$a_{cl}(\lambda) = a_c^0(\lambda)\left[\frac{C_c}{C_c^0}\right]^{0.0602} \tag{7}$$

For ac0(λ) = 0.0602λ, next, the absorption coefficient of the yellow substance which is broken into two separate components: humic, ah(λ) and fulvic, af(λ) acid.

$$a_h(\lambda) = a_h^0\, C_h \exp(-k_h\, \lambda) \tag{8}$$

$$a_f(\lambda) = a_f^0\, C_f \exp(-k_f\, \lambda)$$

where kh= 0.01105/nm, ah0 =18.828 m2/mg is the specific absorption coefficient of humic acid, the first component of CDOM and kf= 0.0189/nm, af0 = 35.959 m2/mg is the specific absorption coefficient of fulvic acid, the second component of CDOM. Also, Ch and Cf are the concentration of humic acids and fulvic acids in mg/m3, respectively and can be expressed as follows:

$$C_f = 1.74098 C_c \exp\left[0.12327\left(\frac{C_c}{C_c^0}\right)\right]$$

$$C_h = 0.19334 C_c \exp\left[0.12343\left(\frac{C_c}{C_c^0}\right)\right] \tag{9}$$

Underwater Scattering Model: Scattering is a change of direction of electromagnetic energy and there are two reasons for its significance in a communication system.1. Firstly, it reduces the number of photons reaching the detector, therefore weakening the detected signal.2. The second reason is the temporal effects that can occur under water.

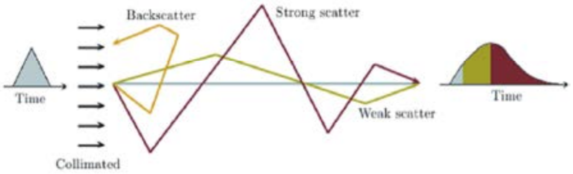


Fig. 3: Temporal Scattering

If a photon is scattered away and then later scattered back and detected, it has travelled a longer path than a photon moving a straight line. The longer path takes more time to travel and the time delay between receiving the two photons can cause inter-symbol interference if the bit rate of the system is not suitably lowered to accommodate for the temporal scattering. Scattering is largely independent of wavelength.

In fact, it is more dependent on particulates that are present, thus is dominant in particulate-rich coastal areas. Scattering also occurs in pure seawater and because of its refractive index changes which can be due to variations in flow, salinity and temperature.

The scattering coefficient, b(λ), which describes the loss of flux due to the redirection of photons by means of total scattering. The total scattering is a linear combination of the scattering coefficient of water, bw(λ), scattering from small particles, bs0 (λ) as a function of wavelength and concentration and scattering form large particle, bl0 (λ) as a function of wavelength and concentration.

Digital Pulse Interval Modulation (DPIM): DPIM is an anisochronous PTM technique in which data is encoded as a number of discrete time intervals, or slots, between adjacent pulses. The symbol length is variable and is determined by the information content of the symbol. In order to avoid symbols in which the time between adjacent pulses is zero, an additional guard slot may be added to each symbol immediately following the pulse [6-7]. Thus, a symbol which encodes M bits of data is represented by a pulse of constant power in one slot followed by k slots of zero power, where 1 < k < L and L = 2M.

In each PPM symbol, the empty slots following a pulse are essentially redundant and it is this redundancy which is removed when adopting digital pulse interval modulation (DPIM). In DPIM, information is encoded by varying the number of empty slots between adjacent pulses. As with PPM, DPIM maps each block of M"log2¸ input bits to one of¸ possible symbols. Unlike¸ PPM however, symbol durations are variable and determined by the information content of each particular symbol. In order to avoid symbols, which have no slots between adjacent pulses, a guard slot may be added to each symbol immediately following the pulse. Thus, each symbol consists of a pulse of constant power with duration) one slot, followed by k slots of zero power, where, 1 < k < L. This may be expressed as,

$$SDPIM(t) = P,\ nTs < t < (n+1)Ts \qquad (10)$$
$$0,\ (n+1)Ts < t < (n+k+1)Ts$$

where, Ts= Slot Duration

The minimum and maximum symbol duration are 2Ts and (L+1)Ts respectively. In ¸L-PPM each symbol has a "fixed duty cycle of 1/L¸, whereas in ¸L-DPIM symbols have a variable duty cycle, the average of which is higher than 1/L¸. Consequently, for a "fixed value of L, DPIM has a higher average power requirement compared with PPM.The minimum and maximum symbol lengths are 2Ts and (L + 1)Ts, respectively, where Ts is the slot duration. For a given value of M, the duty cycle of PPM symbols remains fixed, unlike DPIM symbols which vary since the symbol length varies. Thus, a DPIM encoded pulse stream has a higher average optical power than a pulse stream encoded using PPM since, on average, the symbol length is shorter. Figure 2b shows the average optical power of DPIM and PPM, normalized to OOK, versus the number of bits per symbol. For M=4, DPIM has an average power ~ 6.8 dB lower than OOK but ~ 2.2 dB higher than PPM.

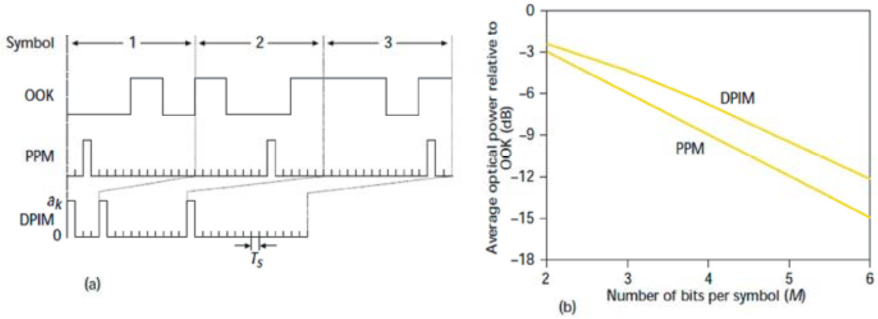
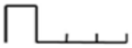


Fig. 4: Comparison between modulation techniques

Digital pulse interval modulation (DPIM) scheme is a modified version of the Pulse Position Modulation (PPM), it displays a higher transmission capacity by eliminating all the unused time slots from within each symbol and give build in symbol synchronization ability. Therefore DPIM requires no symbol synchronization since each symbol is initiated with a pulse. In DPIM, instead of coding the data sequence by the location of the position of a pulse in a fixed frame width, the data sequence is coded such that it is represented by the time interval between the previous and the present pulse[8].

Table 1: DPIM /PPM signals

Source data	*4-DPIM 1GS*	*4-PPM*
00		
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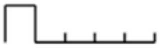
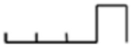
11		

DPIM signal can be written as,

$$x(t) = \Sigma k=-\infty^{\infty 8}\ a\square\ [t-Ts(2k+\Sigma m=-\infty^{k-1}\ Sm)] \qquad (11)$$

where, □= unit- energy rectangular pulse of duration ‘T/(M+1)’ and amplitude ‘a’.

For the DPIM, we have defined a frame as the interval from the end of the previous pulse to the end of the present pulse so it can be seen that, if an error occurs such that a pulse is missed or a non-existing one is detected, then the PIM data stream will be resynchronized on the detection of the next pulse, this error will produce two erroneous DPIM intervals, since each PIM pulse is used to define an end or start.

A symbol is composed of a pulse of one slot duration followed by a series of empty slots, the number of which is dependent on the decimal value of the M-bit data stream to be encoded. Consequently, the minimum and maximum symbol durations are Ts and LTs respectively, where Ts is slot duration. In order to provide some immunity to the effects of Inter Symbol Interference (ISI), a guard band consisting of one or more empty slots can be added to each symbol independently following the pulse. Clearly,adding a guard slot (GS) changes the maximum and minimum symbol durations to 2Ts and (L+1)Ts respectively. DPIM can be used to achieve either higher bandwidth efficiency or power efficiency compared to PPM by varying the value of L.For a fixed average bit rate and fixed available bandwidth, improved average power efficiency can be when using higher bit resolution (i.e. higher M) compared to PPM.The mapping of source data to transmitted symbols for 4-DPIM with no guard slot (NGS) and with a guard band consisting of one slot (1GS)

Observation and Results:

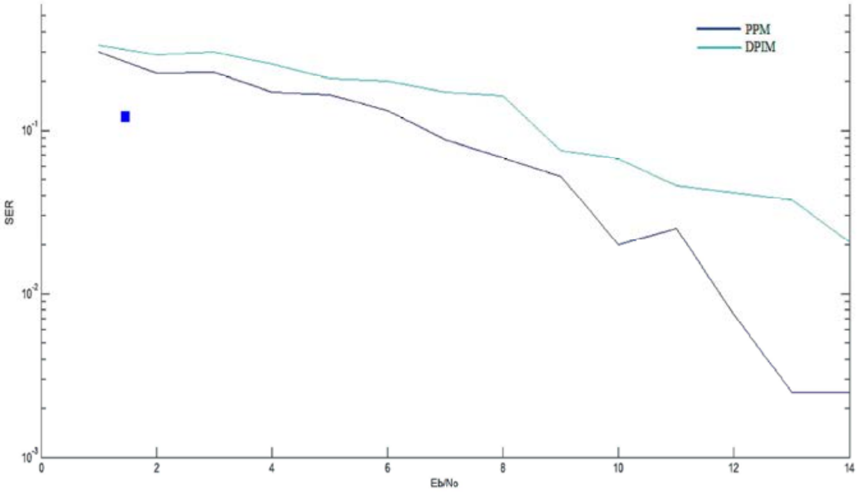


Fig. 5: SER vs Eb/N0 (M=2)

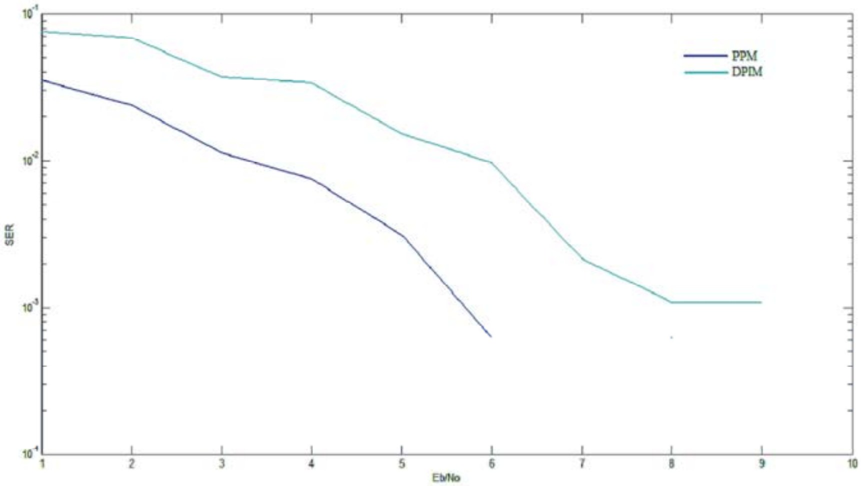


Fig. 6: SER vs Eb/N0 (M=4)

From the two curves shown above, it can be easily concluded that in case of Digital Pulse Interval Modulation (DPIM) the SER is less as compared to the SER demonstrated by PPM for the same values of M.

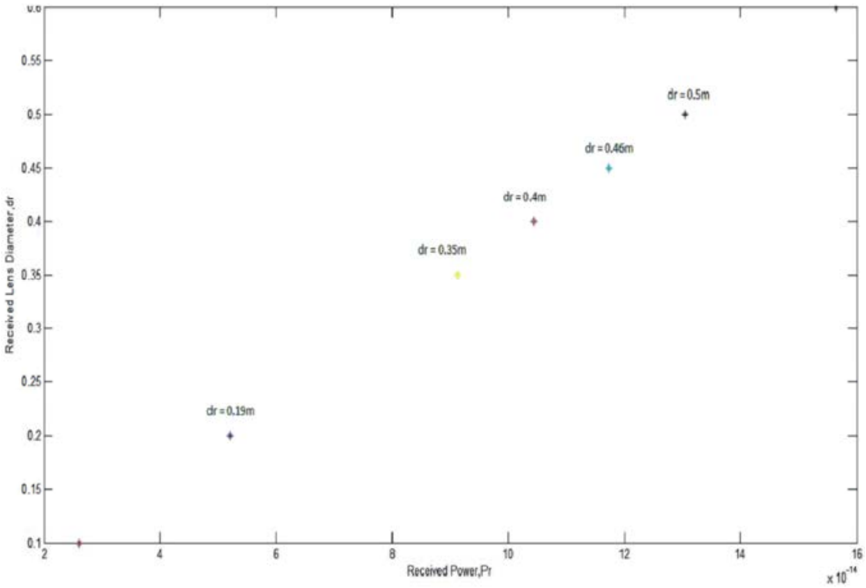


Fig. 7: Receiver Lens Diameter (dr) in meters vs Received Power (Pr)

The received power has a direct relationship with the diameter of the receiver lens (dr). As the diameter of the receiver lens increases, the received power increases along with it. This occurs because an increased aperture area of the lens results in a greater collection of energy.

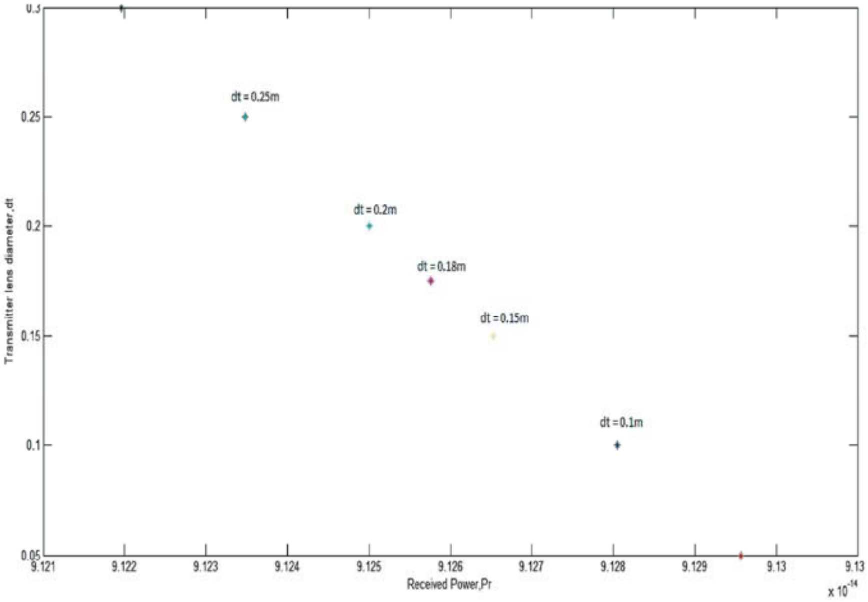


Fig. 8: Transmitter Lens Diameter (dt) in metres vs Received Power (Pr)

As the diameter of the transmitting lens increases, the received power goes on decreasing. Thus, suggesting that the received power is inversely proportional to the transmitter lens aperture area.

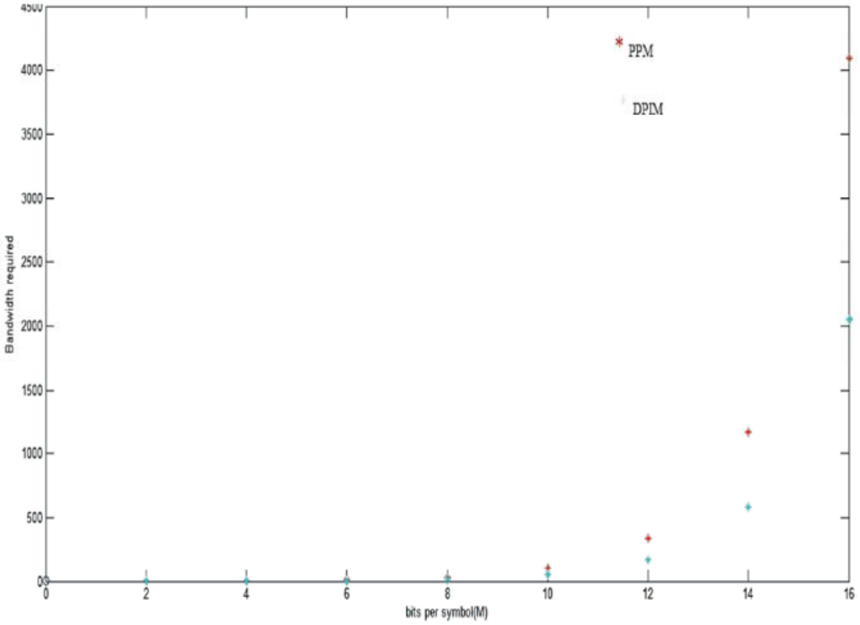


Fig. 9: Bandwidth Required in GHz vs Bits Per Symbol (M)

As the bandwidth required increases proportionally with the number of bits per symbol. This increase is generally more for Pulse Position Modulation (PPM) as compared to Digital Pulse Interval Modulation(DPIM) which clearly signifies that DPIM is more bandwidth efficient. This is mainly because the bandwidth requirement for DPIM is lesser for a particular wavelength as compared to that of PPM at the same wavelength.

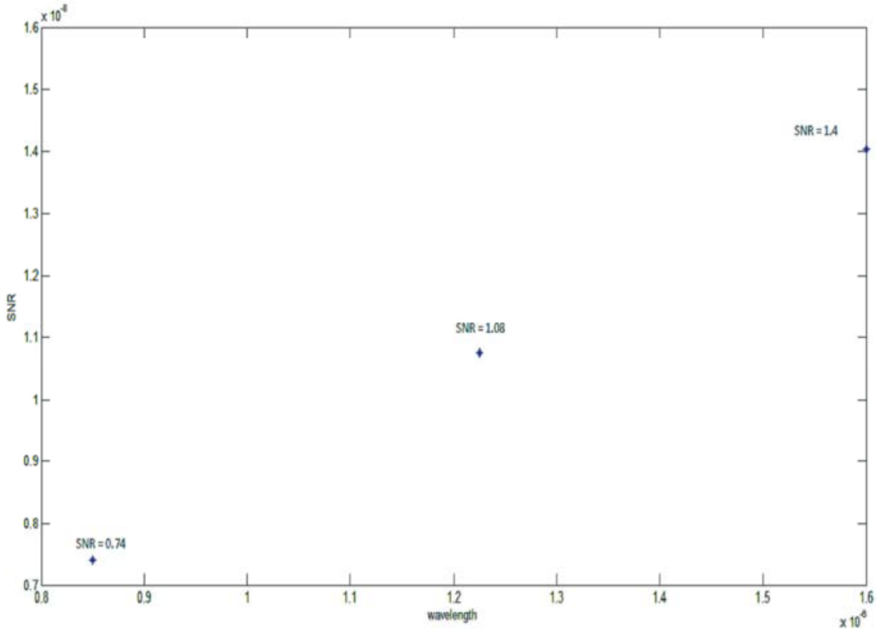


Fig. 9: Signal to Noise Ratio vs Wavelength (um)

The Signal to Noise Ratio (SNR) goes on increasing with increasing wavelength. This occurs mainly because the received power goes on increasing with increasing wavelength.

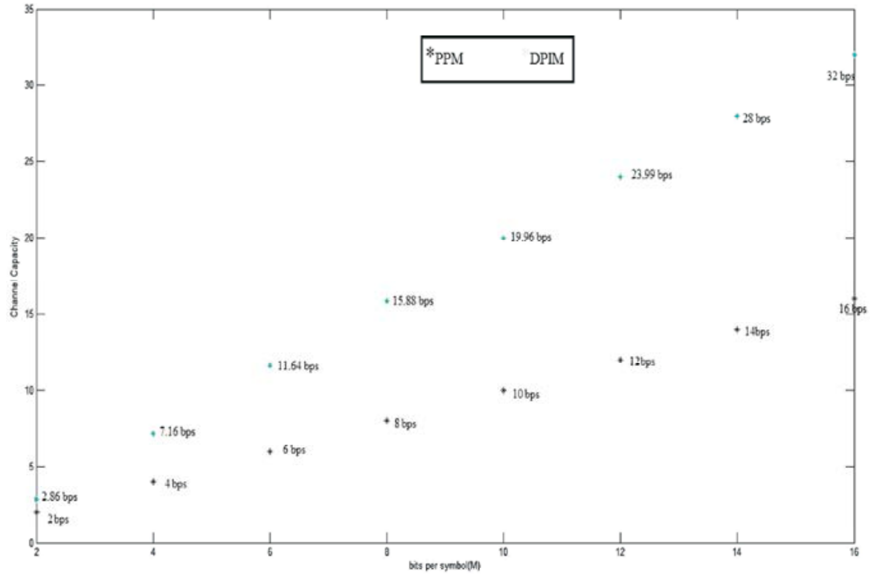


Fig. 10: Channel Capacity vs Bits per Symbol (M)

The channel capacity for both, DPIM and PPM, increases with an increase in the number of bits per symbol (M). However, in case of DPIM the channel capacity is much greater for a particular value of the number of bits per symbol (M) as compared to that shown by PPM.

These observations lead to an important conclusion that in case of error performance, PPM is less erroneous and has lesser noise compared to DPIM. But DPIM has a greater channel capacity and much greater bandwidth efficiency for the same set of values of number of bits per symbol (M) compared to PPM. Thus, if the application requires a transmission of a sensitive data with a high level of received signal strength then it is desirable to use Pulse Position Modulation (PPM) and if the application requires a greater bandwidth and greater channel efficiency then it is desirable to employ Digital Pulse Interval Modulation (DPIM).

CONCLUSION

From the various graphs it can be observed that the received power has a direct relationship with the diameter of the receiver lens (dr). As the diameter of the receiver lens increases, the received power increases along with it. This probably occurs because of the increased area of aperture of the lens which results in a greater collection of energy.

However, the received power is inversely proportional to the transmitter lens aperture area.

It can also be observed that the bandwidth required increases with an increase in the number of bits per symbol. This increase is generally more for Pulse Position Modulation (PPM) as compared to Digital Pulse Interval Modulation (DPIM) which clearly signifies that DPIM is more bandwidth efficient. This is mainly because the bandwidth requirement for DPIM is lesser for a particular wavelength as compared to that of PPM at the same wavelength.

It can also be discerned that the channel capacity of DPIM and PPM both increase with an increase in the number of bits per symbol (M). However, in case of DPIM the channel capacity is much greater for a particular value of the number of bits per symbol (M) as compared to that shown by PPM.

The Signal to Noise Ratio (SNR) goes on increasing with increasing wavelength. This occurs mainly because the received power goes on increasing with increasing wavelength. Another critical observation is the plot of Symbol Error Rate (SER) against various values of Bits per Symbol (M). From the curves, it can be easily concluded that in case of Digital Pulse Interval Modulation (DPIM) the SER is less as compared to the SER demonstrated by PPM for the same values of M.

This leads to the most important conclusion that in case of error performance, PPM is less erroneous and has lesser noise compared to DPIM. But DPIM has a greater channel capacity and much greater bandwidth efficiency for the same set of values of number of bits per symbol (M) compared to PPM.

Hence we arrive at the conclusion that,

- If the application requires transmission of sensitive data with a high level of received signal strength then it is desirable to use Pulse Position Modulation (PPM).
- If the application requires a greater bandwidth and greater channel efficiency then it is desirable to employ Digital Pulse Interval Modulation (DPIM).

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