Modelling PM-BPSK Signals for Coherent Optical Transmission over Single-Mode Fiber

Navya Yelloji, Navnith Ravindran, Anand Kumar
Electrical and Electronics Engineering
BITS Pilani, Dubai Campus
Dubai, UAE
nnyelloji@gmail.com, akumar@dubai.bits-pilani.ac.in

Arun Bera, Vijay Mehra
iCoreTec
Bangalore, India
{arun, vijay} @icoretec.com

***Abstract*— Fiber optics has long been a successful mode of telecommunication due to its high transmission speed with very low losses compared to electrical cables. Using light to transmit data is much more efficient than electrical signals. Light polarized at a particular angle travels faster; this polarized light can then be modulated with the required data that needs to be transmitted using various modulation schemes. This report deals with the modeling of such a fiber optic network in Optiwave and studying the effects of transmission at high data rates on a single mode fiber. Using Optiwave a BPSK Signal has been modulated onto the carrier laser beam using Mach-Zehnder Interferometer modeled as a modulator. The Bit Error rate Q factor and Eye diagram has been analyzed for the best signal quality in three different cases of no polarization, linear polarization and circular polarization. The eye diagram provides details on best time to sample the signal, Signal to Noise Ratio and the transmission capacity of the system.**

Keywords-Single mode Fiber; Polarization Modulation; Phase Shift Keying; Eye Diagram; Bit Error Rate; Q Factor

I. INTRODUCTION

Fiber optic communication employs the method of using light as carrier wave for the information to be received and transmitted over longer distances at higher data transfer rates (or Bandwidths) with low losses through optical fibers which acts as a waveguide. Optical Fiber is made with glass (silica) or with plastics and is thinner than human hair (< 0.50 mm). Single mode Fiber's (SMF) use a single ray of light to transmit or receive information. Single Mode Fiber is preferred over Multi Mode Fiber for Long Haul Distances as they show narrow modal dispersion and also have higher bandwidths.

Glass fiber to transmit an optical signal was thought of by Alexander Graham Bell. The first steps in optical communications began in the 1960s and is developing with time gaining higher speeds and bandwidths. Various inventions like LASERs, low loss optical fibers, optical fiber amplifier, and in-fiber Bragg grating contributed to better optical communication networks. Also with advancement in semiconductors, it contributed to the electronic parts of the communication networks.

The following parameters impact optical communication over fiber: attenuation, upper limit on power to ensure linearity, polarization [3], dispersion (chromatic, modal and waveguide), and transmitter and receiver noise due to electronic components. Glass characteristics like wavelength dependent attenuation due to absorption and wavelength dependent transmission capacity affect the transmission [9]. Fiber modes and light modulation methods impact the overall performance of the system [10][11][7]. Effects can be categorized into Linear and Non Linear effects: Attenuation and Chromatic Dispersion come under Linear Effects whereas Brillouin diffusion, Raman diffusion, fluctuations of the refraction index comes under Non-linear Effects

In Fiber Optic Communication, the electrical information is passed through an encoder, which converts the signal into light pulses and then transmits it through the fiber. At the decoder, these received light pulses are then converted back into electrical signals. As the constellation size increases, the launch power for the laser beam also increases. The constellation sizes for BPSK, QPSK and 16 QAM (Quadrature Amplitude Modulation) are 2, 4 and 16 respectively. In denser constellations, noise is added due to Interference. And also, for denser constellations, there is a trade-off between Reach and Capacity. BPSK will have a longer reach using lower launch power and have a lower information carrying capacity, whereas on the other hand, 16 QAM will have a Larger Capacity for a smaller Reach which implies that the fiber length will be smaller too. In N-WDM (Nyquist – Wavelength Division Multiplexing) systems using PM – BPSK, QPSK and QAM Modulation schemes with Non Return to zero (NRZ Signal) using a Single mode fiber (SMF) with a 25 dB span Loss, it was found that PM – BPSK can reach 6480 km at a net capacity of 4Terra Bits/ sec whereas PM- 16 QAM reaches 270 km with a net capacity of 27 Terra Bits/ sec [15].The functioning of basic optical network is described in the following steps:

- A serial input in the form of electrical signals is fed into the modulator. The modulator encodes the data and feeds to the fiber for transmission. The type of digital modulations may be BPSK, QPSK, QAM, OFDM, Polarization Division Modulation, and Intensity Modulation.
- A light source usually LASERs or LEDs are powered by the modulator and the light is focused into the transmitting fiber.
- The light traverses through fiber optic cable. During the transmission the signal may experience Chromatic dispersion, polarization mode dispersion or loss of signal strength.

978-1-4799-2578-0/13 $31.00 © 2013 IEEE
DOI 10.1109/EMS.2013.118

- At the receiving side the light signal is fed to a detector like a photodiode and is converted to electrical signal.
- The received signal is then fed to an amplifier and followed by a detector; the detector then identifies the signal and its corresponding time frame. Once the signal gets decoded, the signal stream is reconstructed.

In many contexts light can be taken to behave like quantum particles called "photons". Light may be regarded on as waves when studying transmission or propagation. It can also be taken as a particle when we study its interactions with matter. In the optical communication networks, the best way of regarding light is to treat it as an electromagnetic wave. Electromagnetic waves are similar to radio waves except that they have a smaller wavelength. Electromagnetic waves have orthogonal electrical fields and magnetic fields. The axes can be oriented arbitrarily and this orientation is called polarization.

II. Modulation Schemes

In polarization multiplexing, optical signals are transmitted through fibers using polarization of light [3][4][12][13] through which the capacity of the channel can be increased. Angle of rotation of light acts an identifier of the signal, which means even if the information is carried using same wavelength, due to polarization the signals can be differentiated at the ends of the fiber.

In Intensity Modulation, The power of the incoming signal is varied and then transmitted into the optical fiber. At both ends, transmitter and receiver, the amplitude of the signal can be measured and mapped (Power is proportional to the square of the amplitude). Phase-shift keying (PSK) is a digital modulation scheme that conveys data by modulating the phase of the message signal with respect to the carrier wave. It uses finite number of different symbols to represent the digital data to be conveyed. Each phase encodes equal number of bits in different patterns to represent distinct phases. When the received information is passed through a demodulator, each phase is mapped to its symbol, and that is how the original data is obtained.

In Wavelength Division Multiplexing, multiple signals are multiplexed on laser beams at different wavelengths onto a single fiber. With this technique, bidirectional/duplex communication is possible using a SMF. WDM can multiply the effective bandwidth of fiber optic communication using optical amplifiers such as EDFA (Erbium Doped Fiber Amplifiers). For a long-haul fiber Amplifiers are placed periodically at repeated intervals to boost signal power. Each amplifier stage adds amplified spontaneous emission (ASE) noise and degrades the OSNR. In the presence of High OSNR, the Q values are more reliable. Frequency Division Multiplexing (FDM) and Wavelength Division Multiplexing essentially explain the same concept. In FDM, a carrier is identified by it frequency whereas in WDM, a carrier is identified by its Wavelength.

Optical amplifiers directly amplify light without the need for converting to electrical medium. EDFA is a class of optical amplifiers which uses Erbium Doped Silica Fiber. When Erbium is excited with light of wavelengths either 980nm or 1480nm (called pump wavelengths), it stays in a quasi-stable intermediate state before decaying to ground state to emit light between 1525 nm to 1565nm. EDFA has a carrier lifetime in the order of milliseconds which implies for large data transfer rate, there will be less interference. It is also polarization insensitive and has high saturation power. [16]

III. Simulations

Two optical models are designed with linear polarization of 45 degrees and Circular polarization of 45 degrees using Optiwave software which is the emerging leader in the development of innovative software tools for the design, simulation, and optimization of components, links, systems and networks for the dynamically growing fields in photonics nanotechnology, optoelectronics, optical networks and other

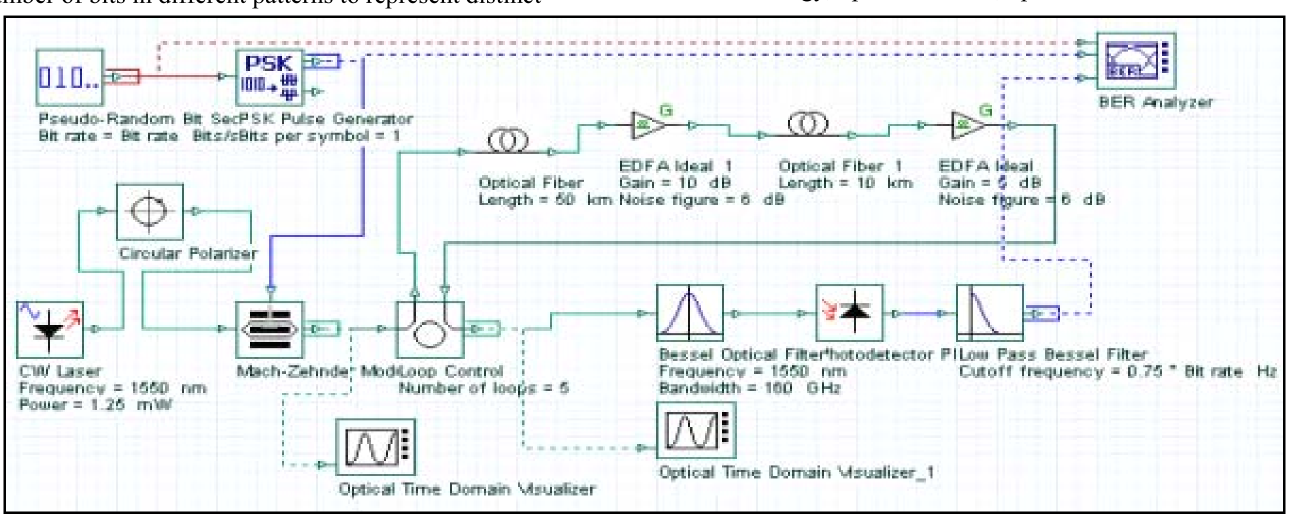

Fig 1 Optiwave Fiber Optic Model with Circular Polarization at 45 degrees

photonic applications. An eye diagram gives an idea of the ability of the system, as to how much data it can handle. The measurements are conducted in time domain and it shows the effect of distortion in the wave and gives Bit error rate. The received signal can be sampled at its best in the widest opening of the eye diagram and correspondingly gives the highest Q factor for the BER and the lowest error probability. When the eye opening is large, it's the ideal time to sample the signal with little to no error. The opening of eye also gives the noise level, the signal to noise ratio at the sampling point. The upper area shows the amount of distortion that is set by the signal to noise ratio. [13].

Continuous Wave laser at a wavelength of 1550nm and a power rating of 1.25 mW is used as a carrier beam onto which data is modulated in BPSK format .The laser input is given with Linear Polarizer and Circular Polarizer. Fig 1 shows the block diagram of the system with circular polarizer. The PSK pulse generator is programmed to give 1 bit per symbol with a 180 degree phase shift. The modulator is modeled using a Mach Zehnder interferometer. Mach Zehnder interferometer splits the carrier into two beams of equal intensity using a splitter and then passing it through a waveguide where electrodes around it manipulate the phase of the carrier beams depending on the applied potential. These are then recombined at the other end. When there is a 180 degree phase shift between the signals, the resultant intensity is zero. Depending on the extent of overlap the intensity varies and thus producing a modulated optical signal. This optical signal is then transmitted onto a glass optical fiber. EDFA's are placed along the fiber to amplify the signal strength. The optical signal at the receiving end is weak in signal strength, and hence again amplified. This amplified signal is viewed on the optical time domain visualizer in the visualizer library in Optiwave.

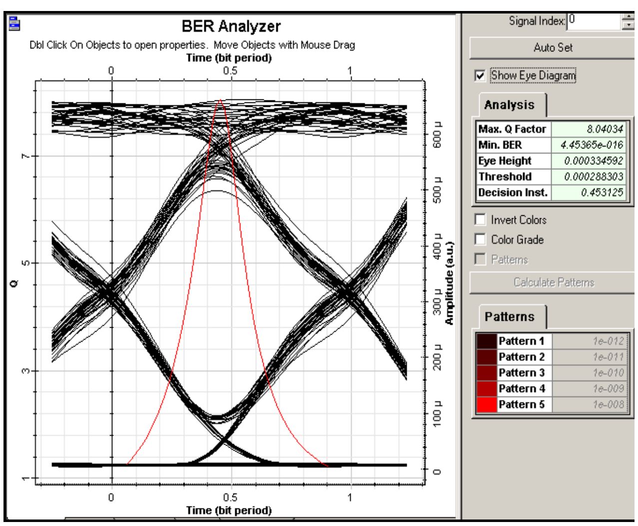

Fig 2 Output BER Q Factor and eye diagram for Linear Polarization at 45 degrees

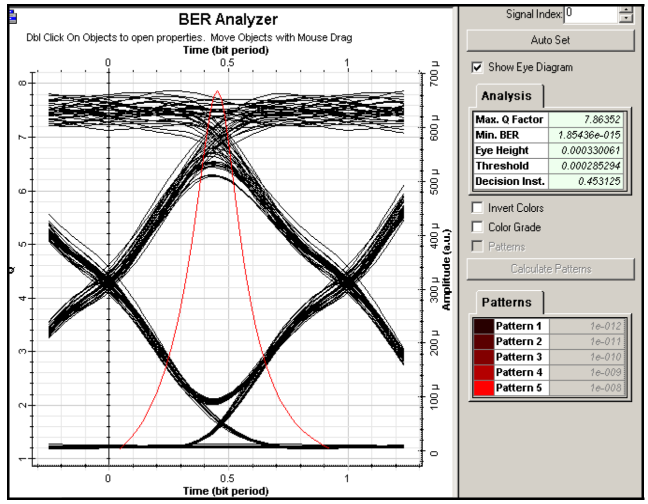

Fig 3 Output BER Q Factor and eye diagram for Circular Polarization at 45 degrees

After the signal amplification, it is passed onto a Bessel optical filter and then a photodiode detects the optical signal pulses and converts them to electrical signals. The photodiode is modeled such that it only triggers when a certain threshold is attained. This reduces further noise in the resulting signal. The final signal is passed through a low pass Bessel filter. The signal obtained after filtering is the final output. The final output is compared to the actual input using a Bit Error rate analyzer tool. BER analyzer gives us the Q factor of the signal, Minimum Bit error rate. The Q factor of the signal is the representation of the best time period in which the signal can be sampled without an error. At the peak of the Q factor, the signal can be sampled with the least error.

Fig 2 is the plot of eye diagram with the BER Q factor for linear polarization. Here the BER Q factor has a single peak at about 0.45 time in the bit period. The maximum Q factor obtained for this system is 8.04034. The eye diagram has a narrower opening and hence the Q factor peaks at the point of maximum opening. Fig 3 is the plot of eye diagram with the BER Q factor for circular polarization. In this system, the eye opening is similar to that of linear polarization. The BER Q factor peaks at time period of 0.45 with a peak value of 7.86352. For the case with no polarization, the observed maximum Q Factor was 23.6434. The Q factor has two peaks at the time period of 0.49 and 0.61 for a bit period.

IV. CONCLUSION

The Fiber optic communication network has been studied in detail with the two polarizations and modulation techniques. The final model has been made in Optiwave software. The eye diagram studied for different polarizations. The system modeled takes in a BPSK signal and then transmits it over a fiber with the set in parameters of the transmission network. At the receiver end, the output was observed and the Eye Diagram was plotted. The eye diagram gives the best time period to capture a specific data bit. In real implementation of the system, there are effects of polarization mode dispersion, chromatic dispersion and other influences which have not been considered in this model. The SMF chosen is also a simple model without considering the linear and non linear effects. The BER Q factor has two peaks for the system with no polarization which gives more time for the signal to be sampled. But in the cases of polarization, the sampling has to be done at a particular time for best signal quality. If the peak is missed, then the signal may not be reliable.

A. Discussion

Utilizing the concepts of Polarization Modulation, Wavelength Division Multiplexing, Intensity modulation a theoretical model is proposed, in order to effectively increase the bandwidth. The theoretical model has modulation schemes on three different levels i.e., Intensity Modulation, Wavelength Multiplexing and Polarization Modulation. The proposed design only implements polarization modulation scheme. Brief description of the mechanism is specified in the following.

- Level -1: Intensity Modulation: Source signals will be transmitted at different power levels.
- Level -2: Wavelength Multiplexing: At a corresponding power, signals with different wavelengths will be transmitted.
- Level -3: Polarization Modulation: Each wavelength signal's angle of rotation will be modified.

For example, as shown in Fig 4, two wavelengths are modified on 2 Intensity Levels and 3 Polarization levels, which results in 12 unique channels. The channel capacity of a two wavelength channel with no modulation schemes would have been 2. By incorporating intensity modulation and polarization modulation schemes, the channel capacity is now 12.

If three levels of Modulations are performed, unique signals of the same wavelength can be transmitted in a SMF. This approach is very efficient on increasing the bandwidth, but has some short comings which are the following:

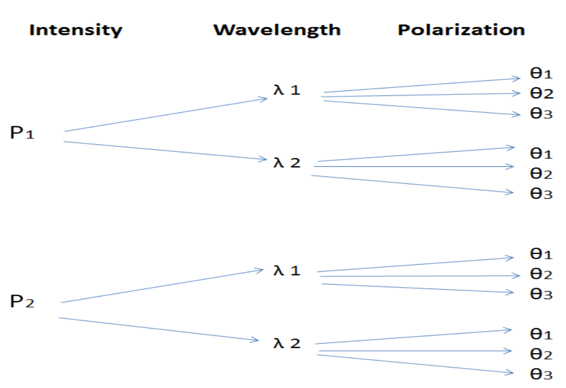

Fig 4. Modulation Schemes at different Levels

- Launch Power of the signal is important. If the signal strength is weak, the signal may be lost over transmission. For a Stronger signal power, if when operated with battery, then the optical system's complexity will increase. A range for optimum operation must be defined. Otherwise, an ideal fiber length must be defined.
- For polarization, suppose the angles of rotations are chosen to be symmetrical, i.e. at a mutual angular difference of 120 degrees then identification will be difficult.
- Employing 3 forms of modulation schemes will improve the capacity, but the complexity of the system will dramatically increase. Each signal has to be identified and mapped on 3 levels, i.e. Power, Wavelength, and polarization, which means three different detectors, must be used on both ends.
- Effects of Dispersion on Wavelength have not been considered.

B. Future Work

The design proposed is in its basic form employing only polarization modulation at 45 degrees. Progress will be subsequently made by adopting the different modulation schemes, different modulation format (e.g.: QPSK, QAM), while taking into account the effects dispersions, linear and non linear effects on the SMF [14].

ACKNOWLEDGMENT

This research was done as part of Navnith's dissertation for his Master's in Microelectronics and Navya's capstone project at BITS Pilani, Dubai Campus. The research was done in collaboration with iCoreTec, Bangalore, India.

REFERENCES

[1] Allard, Frederick, C. (1989) , Fiber Optics Handbook for Engineers and Scientists: McGraw-Hill, New York.

[2] Hoss, Robert J. (1990) , Fiber Optic Communications Design Handbook: Prentice Hall, Englewood Cliffs, New Jersey 07632.

[3] J. P. Gordon and H. Kogelnik, "PMD fundamentals: Polarization mode dispersion in optical fibers," PNAS, Vol. 97, No. 9, pp. 4541-4550, April 2000.

[4] S. Yao, "Polarization in Fiber Systems: Squeezing Out More Bandwidth", The Photonics Handbook, Laurin Publishing, 2003, p. 1.

[5] Agarwal, G.P. "Nonlinear fiber optics: Its history and recent progress", J. Opt. Soc. Am. B 28, A1-A10 (2011).

[6] Marcel Urban, François Couchot, Xavier Sarazin, Arache Djannati-Atai. The quantum vacuum as the origin of the speed of light. The European Physical Journal D, 2013

[7] Sudakshina, K. (2010). Analog and Digital Communications. Pearson Education India. pp. 163–184. ISBN 978-81-317-3187-1.

[8] Monolithically integrated asymmetric Mach-Zehnder interferometer as a 20 Gbit/s all-optical add/drop multiplexer for OTDM systems: Electronics Letters, Vol 32, No 3, February 1996.

[9] Peter Atkins and Julio de Paula, "Elements of Physical Chemistry", Freeman & Company, W. H., 2009.

[10] Thyagrajan K. and Ghatak, A.., "Fiber Optic Essentials", John Wiley & Sons, 2007.

[11] Saleh, B.E.A and Teich, M.C. "Fundamentals of Photonics", Wiley, 2007.

[12] Born, M. and Wolf, E. "Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light", Cambridge University Press, 1999.

[13] Ravindran, N. "Modelling PM-BPSK Signals for Coherent Optical Transmission over Single-Mode Fiber", M.E. Dissertaion Report, BITS Pilani, Dubai Campus, 2013.

[14] Pranav R.K., Kumar, A., Bera, A. and Mehra, V. "Modelling PM-BPSK Signals for Coherent Optical Transmission over Single-Mode Fiber", WASET Dubai Conference, 2013.

[15] Bosco, G. Dipt. di Elettron., Politec. di Torino, Torino, Italy Curri, V. ; Carena, A. ; Poggiolini, P. ; Forghieri, F., "On the Performance of Nyquist-WDM Terabit Superchannels Based on PM-BPSK, PM-QPSK, PM-8QAM or PM-16QAM Subcarriers", Lightwave Technology, Journal of (Volume:29 , Issue: 1)

[16] Wysocki, Mazurczyk, V, "Polarization dependent gain in erbium-doped fiber amplifiers: computer model and approximate formulas", Lightwave Technology, Journal of (Volume:14 , Issue: 4)