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Generation and Transmission of Solitons at 64Gbps using Multiplexing in Polarization and Wavelength Domains

Gouri V, Sreeni K G

Abstract : *The factors which impose an upper limit on data rates in high speed optical systems have been explored. A 64Gbps system has been designed and simulated using a combination of Wavelength Division Multiplexing (WDM) and Polarization Division Multiplexing (PDM) employing soliton(secant hyperbolic pulse) transmission. The possibility of Gordon Haus jitter and adjacent pulse interaction, which curtails performance of very high speed systems, has been ruled out by use of multiplexing in multiple domains. The Polarization Mode Dispersion (PMD) has also been evaded by limiting the data-rate of individual channels to 8 Gbps. This also permits use of components with relaxed specifications, when compared to single channel realizations. In this work a 64 Gbps WDM-PDM based system employing secant hyperbolic pulses at 8Gbps over a distance of 1000km has been simulated. It yields an average bit error rate of* 10^{-10}

Keywords**:** *Group-Velocity-Dispersion, Polarization-Division-Multiplexing, Secant-Hyperbolic-Pulse, Wavelength-Division-Multiplexing.*

I. INTRODUCTION

The demand for huge amounts of data among nation-wide and intercontinental destinations, is ever increasing. The need for high Quality of Service(QoS) and high speed data grows with increase in global population every day. However the requirement of economically viable systems of data transfer is growing rapidly due to the changing environment of the present day scenario. Spanning the gigantic geographical area in reliable communication or data transfer links at low cost is a present-day hotspot of research. In this context, it was decided to probe into the problem of utilizing the medium of data transfer to its maximum bandwidth. In this work the simulation of a high bit rate system design is being introduced.

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* Correspondence Author
Gouri V., Post Graduate, Microwave and Television Engineering at College of Engineering Thiruvananthapuram.
Email: gourivijayakumar7@gmail.com or gou1357101215@gmail.com
Sreeni K G is a fa faculty in Electronics and Communication Engineering at College of Engineering Thiruvananthapuram. dr.nvkr@gmail.com

Through this system which employs both multiplexing techniques and pulse shaping, the various possibilities of economically increasing data rate in future research are also highlighted.
The polarization mode dispersion which attacks channels of bit rate higher than 10
Gbps can be avoided by use of multiplexing low bit rate channels [1]. Pulse shaping can improve reliability and system error performance [2].
A combination of two
4-channel WDM, PDM of two orthogonal planes and secant hyperbolic pulse shaping has been employed in realizing a 64 Gbps system in this work.

A brief discussion of the organization of this paper is as follows. Section II deals with the design and generation strategy of secant hyperbolic pulses. Section III gives a description of the proposed system. In section IV a discussion of the results in the error analysis of the system is presented.

II. SECANT-HYPERBOLIC TRANSMISSION

Solitons(Secant hyperbolic pulses) are more resilient to dispersion than Gaussian pulses. Hence, employing secant hyperbolic pulses enables higher bit rates at low error rates. The structure and design of a typical secant hyperbolic generator are discussed in the sections below.

A. secant hyperbolic generator

Secant hyperbolic pulses are found to be more resilient to Group Velocity Dispersion and hence leads to minimum Inter Symbol Interference.

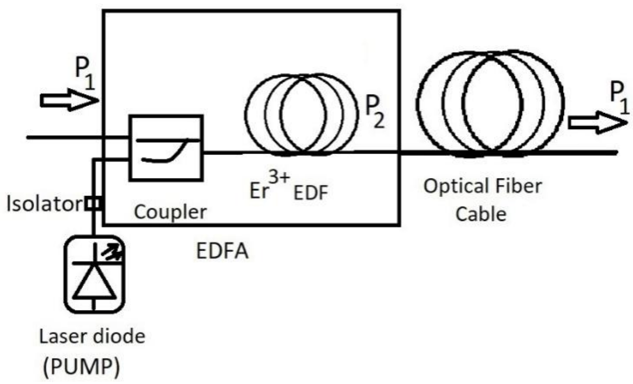

Figure 1: A simple secant hyperbolic generator

Transmission of secant hyperbolic pulses demands a periodic restoration to retain the shape of the pulse over the transmission distance. Need for periodic amplification hails from requirement for maintaining peak power and pulse width to sustain the pulse. Generation of secant hyperbolic pulses can be achieved by using Erbium Doped Fiber Amplifiers(EDFAs) with properly chosen parameters. In this work we designed a secant hyperbolic generator. The Fig. 1 shows the block schematic of a simple secant hyperbolic generator.

In a secant hyperbolic link the peak power P_{oa} and pulse width T_0 is fixed and power at output of each repeater P_2 are kept same throughout the link. The pulse width is determined by data-rate and adjacent pulse interaction.

The actual pulse width is reduced to a factor of $1/5^{th}$ to reduce interaction between pulses. A forward pumped EDFA is designed for output power P_2 from received power P_1 as per design discussed in the section B (Design Aspects) below. The parameters like EDF length and Pump power are fixed as per [3] [5].

B. Design Aspects

The general design procedure for establishing the secant hyperbolic link is as follows.

(1) Set the bit rate, keeping in mind PMD occurs at data rates higher than 10 Gbps. If a data rate of 10 Gbps or higher is used the design would have to be enhanced to incorporate provision for PMD compensation.

(2) T_0 or pulse width is calculated as per requirements of Optisystem NRZ pulses and a factor of $1/n^{th}$ for compensating effects like jitter or inter-pulse interactions, where n is a constant. We get T_0 for our work as 50.5 ps.

(3) . Fix the type of fiber and assign coefficients , β_2 and γ as per standards or requirements and customize other factors like length. For example, a typical HNLF has γ= 10.68 W^{-1}/km, D = 0.08 ps/nm.km, and α = 0.1 dB/km, where β_2 in ps^2/km is given by[3] ,

$$\beta_2 = \frac{-D\ \lambda^2}{2\ \pi c} \qquad (1)$$

We used a fiber of $\gamma = 1\ W^{-1}$/km, D = 5.1 ps/nm.km, and α = 0.1 dB/km . γ in Optisystem is governed by the parameters- n_2, A_{eff} and wavelength used n_2 has the unit m^2/W and is given by [3],

$$n_2 = \frac{\gamma\ A_{eff}\ \lambda}{2\ \pi} \qquad (2)$$

(4) Power is adjusted at output of amplifier with respect to power of input pulsed signal by setting gain of amplifier such that output power in Watts is [4],

$$P_{oa} = N^2\ \frac{\beta_2}{\gamma\ T_0^2} \qquad (3)$$

(5) Inter-amplifier spacing is given by [4],

$$L_s = \left(\frac{1}{\alpha}\right) 10 \log_{10}\left(\frac{P_2}{P_1}\right) \qquad (4)$$

Where P_1 is the least power to sustain pulse shape and P_2 is power at output of first EDFA from which spacing is calculated to the next EDFA. They are given by [4],

$$P_1 = N_1^2\ \frac{\beta_2}{\gamma\ T_0^2} \qquad (5)$$

$$P_2 = N_2^2\ \frac{\beta_2}{\gamma\ T_0^2} \qquad (6)$$

Where , N_1 and N_2 are two constants in range,

$0.5 \leq N_1 < N_2 \leq 1.5$

These limits are chosen so as to combat dispersive wave radiation and ensure sustenance of pulse shape.

III. METHODS OF MULTIPLEXING

The Multiplexing part is made with the Optisystem components : 4X1 WDM MUX & DE-MUX , linear polarizers, polarization controllers, and, PBC & PBS cubes. A channel spacing of 100GHz was employed in the WDM system. Two orthogonal linear polarizations 90 ^{o} and 0^o were used and combined by a PBC and the whole system was converted to secant hyperbolic form. At receiver end, a PBS splits the beam into two orthogonal components to be de-multiplexed by WDM block and hence each channel is analyzed. The concepts of WDM and PDM are discussed in detail as follows.

A. Wavelength Division Multiplexing

There are different variants of WDM [6][7]. The commonly used are Coarse Wavelength Division Multiplexing and DWDM. Traditional WDM has evolved from THz range to 40-50 GHz in adjacent channel spacing. Coarse Wavelength Division Multiplexing has generally 13-20 nm channel spacing. DWDM on the other hand, has 0.4 nm channel spacing. The frequently used channel spacing in DWDM are 50GHz, 100GHz and 200GHz. Coarse Wavelength Division Multiplexing commercially available today supports eight channels and can be extended upto eighteen channels. This work comprises the multiplexing of two sets of four wavelengths each with two 4-WDM-muliplexers.

B. Polarization Division Multiplexing

To explain PDM a basic foundation of polarization is required. The plane of polarization is physically the plane of oscillation of Electric field intensity. When the magnitude with direction of vector Electric field intensity is plotted for a TEM wave traveling in positive z direction, the Electric field intensity is somewhere on the x-y plane. Generally natural EM waves are unpolarized. Therefore electric field peak can be anywhere on the x-y plane or does not have fixed direction of oscillation. In case of linearly polarized wave the electric field vector peaks along a line in the x-y plane and circularly polarized wave the electric field vector peaks occur along or traces a circle in the x-y plane. Similarly in elliptical polarization the oscillating electric field vector traces an ellipse in the x-y plane. One of the most common polarization components used in a PDM network [8] is the Polarization Beam Splitter/Polarization beam combiner cube. In this work the output of the two WDM-multiplexers are combined by a and output of the PBS/PBC cube cube is used to generate secant hyperbolic pulses.

IV. PROPOSED SYSTEM

The details of our project we subdivided the description into three modules: Transmitter, Channel and Receiver. The WDM signals are combined by PDM and is transformed to secant hyperbolic pulses which is demultiplexed at receiver end and detected.

A. The Transmitter

The Fig. 2 shows one of the individual channels which are linearly polarized for Polarization Division Multiplexing and based for generation of secant hyperbolic pulse. It features simple amplitude modulation set up using MZM which is used to modulate the light from the laser source using a binary bit sequence carrying the information required, at 8Gbps. The bit sequence block containing information is converted to NRZ electrical form before supply to plates of MZM, through use of NRZ generator in Optisystem. The fiber used in the system is assigned with $\gamma = 1\ W^{-1}/km$ and $\beta_2 = 5.1 ps^2/km$, close to the typical standard values of commercially available fibers.

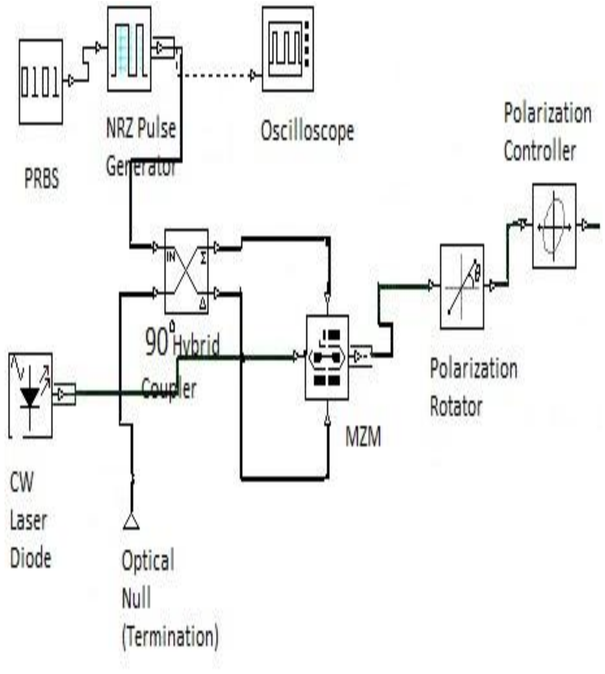

Figure 2: One of the multiplexed channels from transmitter end

The inter-amplifier spacing is to be kept much less than the dispersion length defined by[3],

$$L_D = \frac{T_0^2}{\beta_2} >> L_S \quad (7)$$

B. The Channel

The channel for 64 Gbps WDM-PDM secant hyperbolic system is similar to that of a typical secant hyperbolic link.The EDFA block can be visualized as a single subsystem complete with pump and EDF and functions based on various program code in Optisystem software. The EDFA is used to boost the signal to get the required power for secant hyperbolic pulse generation. The EDFA gain are adjusted so that throughout inter-amplifier distance the power remains

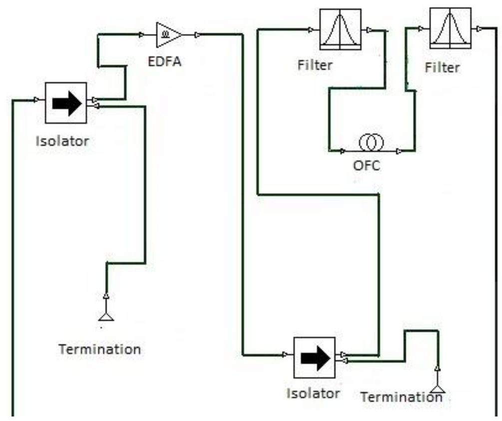

Figure 3: A segment of the channel

within the safe range for efficient secant hyperbolic transmission. The power requirement is equal to that of 8 Gbps secant hyperbolic link. Filters can be used for eliminating unwanted signals and noise. The Fig.3 shows the channel suited for secant hyperbolic transmission, which we have used in our project. The reason for the choice of fiber length is described in generalized design procedure. Filters are used to ensure reduction in unwanted noise and pump signals from EDFA. In Fig. 4 the WDM multiplexers are shown collecting the signals from eight channels similar to the previously shown 8Gbps channel in Fig. 2.

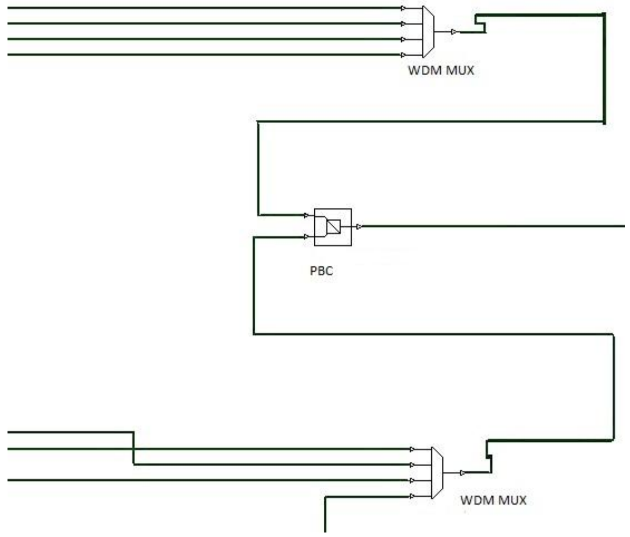

Figure 4: Transmitter end and inlet to channel

The WDM channels have a spacing of 100 GHz between the individual channels, as per the standard value in traditional WDM systems. The two WDM outputs are of mutually orthogonal polarizations. The two outputs are passed through a PBC cube to form a single beam of orthogonal polarization multiplexed signal. This is generally a mixture of secant hyperbolic pulses of different polarizations and frequencies. No two secant hyperbolic pulses of same frequency has same polarization plane.

C. The Reciever

The eight 8GBbps channels are retrieved after demultiplexing at the receiver side. The signals are analyzed for BER using Optisystem BER analyzers. Fig. 5 shows a part of receiver for the proposed model. The 3-R regenerator is a device used to compare the original signal with final received signal in Optisystem, to evaluate BER. The three inputs to BER analyzer are bit sequence (binary), NRZ pulses(original signal) and received signal.

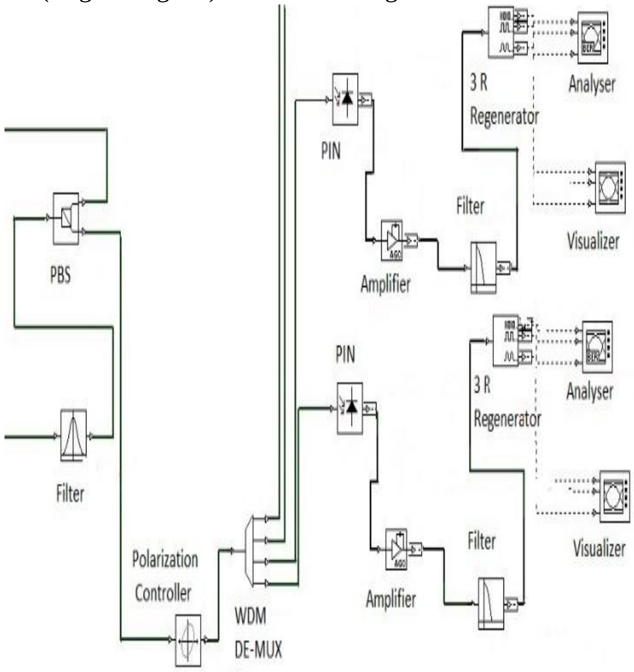

Figure 5: A Part of the Receiver

PIN detectors are used to detect the received signal and convert it to electrical form for analysis. A low pass filter is used to remove noise from 8Gbps signals.

V. RESULTS AND DISCUSSION

The results are presented in three sections. One being comparison of relative performance of a typical secant hyperbolic system with Gaussian pulse in absence of multiplexing, and the others being the effect of multiplexing and performance of overall systems. These are analyzed with the BER/Eye diagrams of individual channels.

Secant Hyperbolic versus Gaussian Pulse Transmission

The secant hyperbolic pulse link for a distance 280 km at bit rate 8 Gbps was simulated and similar Gaussian pulse link for a distance 225 km at bit rate 8 Gbps was simulated.

The performance of data transmission using secant hyperbolic and gaussian pulses are compared. A bit rate of 8 Gbps was chosen for each channel. The eye diagrams in Figures 8 and 6 show the performance of secant hyperbolic pulse transmission far exceeds the gaussian pulse transmission. It has been found that the gaussian pulse

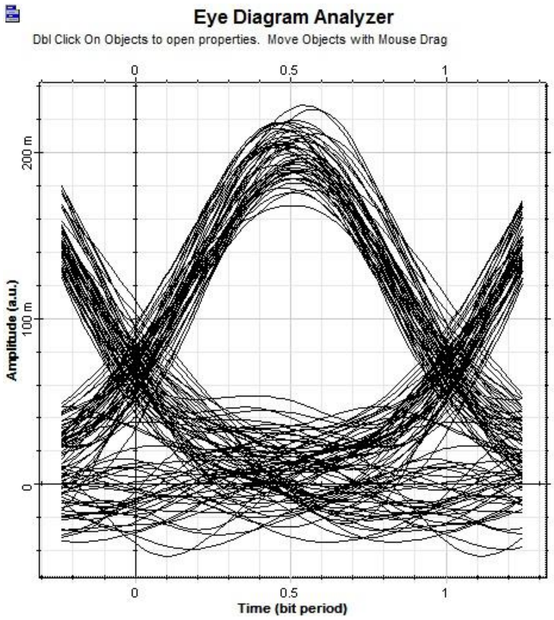

Figure 6: Eye Pattern of 225km Gaussian Link

transmission sustain performance satisfactorily upto 225 km. while secant hyperbolic pulse transmission is successful for over 280 km with good BER performance.

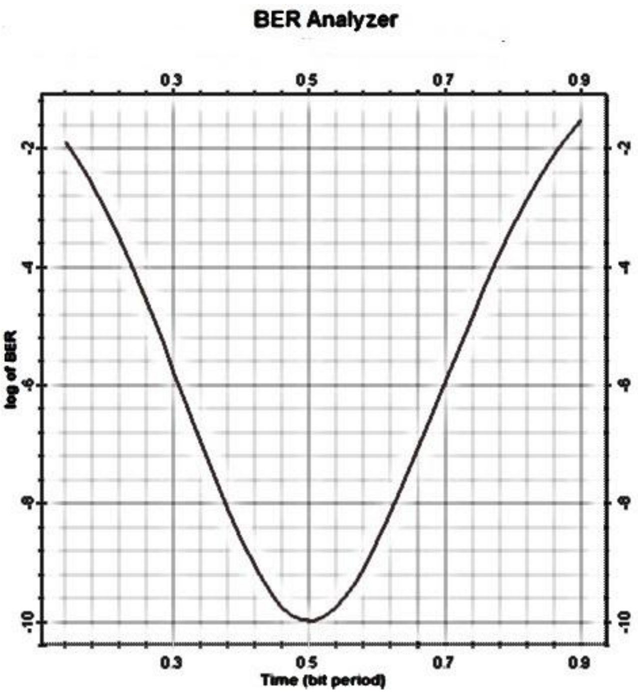

Figure 7: BER curve of 225 km Gaussian Link

A better BER can be achieved in case of proper design of secant hyperbolic link with appropriate choice of parameters and fixing of sampling instant. Here the BER, as seen from Fig. 9 is in the 10^{-20} to 10^{-25} range for secant hyperbolic link while BER, as seen from Fig. 7 is in the 10^{-8} to 10^{-9} range for gaussian link.

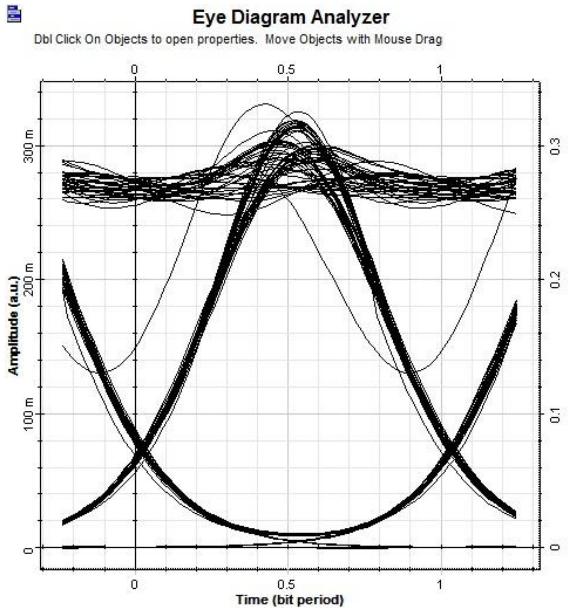

Figure 8: Eye Pattern of 280 km Secant hyperbolic Link

The Figures 5 and 6 shows results of the Gaussian link while Figures 8 and 9 shows results of the Secant hyperbolic link. The Figures 6 and 8 show the corresponding eye-patterns, and, 7 and 9 show the corresponding $\log_{10}$(BER) vs normalised sampling instant curves. As seen from these results the BER of the secant hyperbolic link is very low as compared to the Gaussian BER.

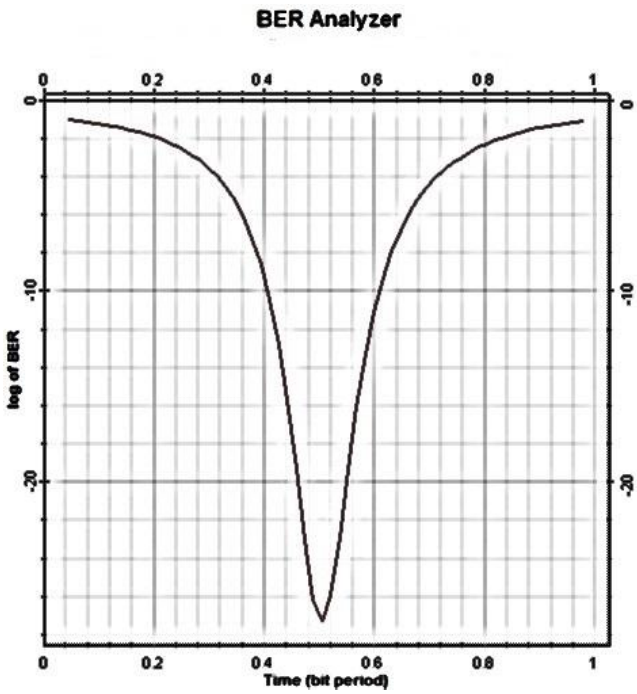

Figure 9: BER curve of 280 km Secant hyperbolic Link

For good performance in eye pattern the distance has been chosen to be lesser in Gaussian as compared to secant hyperbolic.

B. Overall system performance

The 64 Gbps system results are given in Figures 10 to 14 for 1000km.

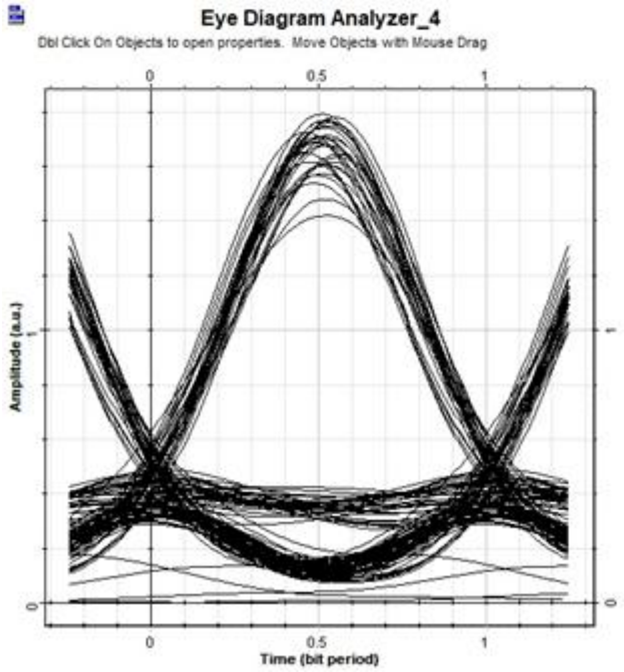

Figure 10: Eye Pattern of one of the 90° Channels

Only two results each from the two PD-Multiplexed WDM sub-channels are shown because every such channel has relatively shown similar performance. An average BER of 10^{-10} was observed. The BER and an eyepatterns corresponding to this is shown in Figures 10 to 13. This system combines performance characteristics of both pulse shaping and multiplexing whereby a large bitrate is achieved.

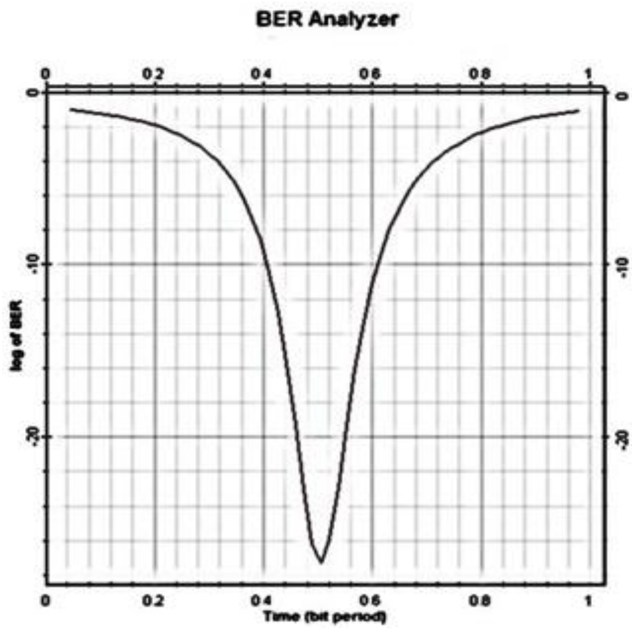

Figure 11: BER curve of One of the 90° Channels

The second window(centered about 1550nm) in optical communication bands was used in this thesis work. A 64 Gbps system employing eight channels making use of multiplexing in wavelength and polarization domains was designed. Four wavelengths starting from 193.1 THz to

Table – I: Design Parameters of Secant hyperbolic Link

Symbol	Value	Units	Description
α	0.1	dB/km	Attenuation coefficient
β	5.1	ps^2/km	Dispersion coefficient
γ	1	W^{-1}/km	Nonlinearity coefficient
P_0	2	mW	Fundamental pulse power for sustaining sech shape
T_0	50.5	ps	n times the actual pulse width where n < 1
N_1	0.65	-	Constant defining power requirement at output of fiber channel
N_2	1.17	-	Constant defining power requirement at output of amplifier

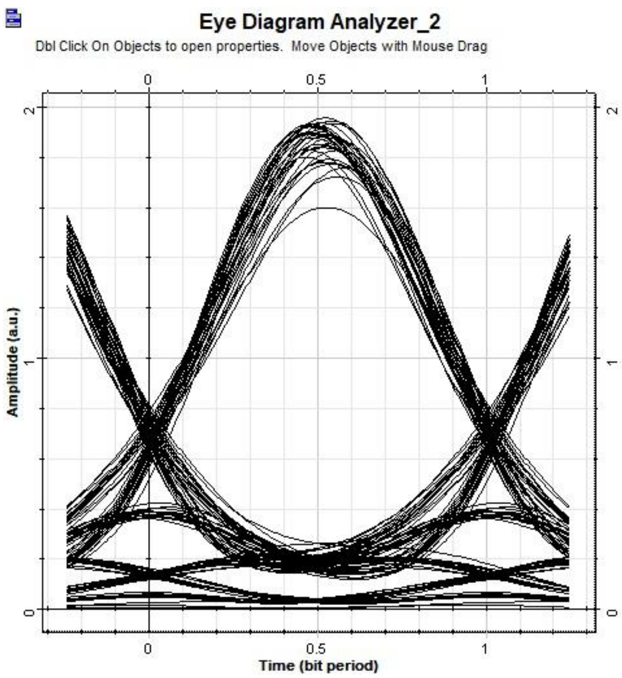

Figure 12: Eye Pattern of One of the 0^o Channels

193.4 THz has been generated in pairs to carry eight digital message signals and combined after assigning two different(orthogonal) polarizations to be transmitted over secant hyperbolic link. Line width of each laser source used is 10 GHz. The link and pulse parameters were selected so as to cancel out effects of GVD and SPM. This results in a secant hyperbolic pulse envelope which is deemed to have self

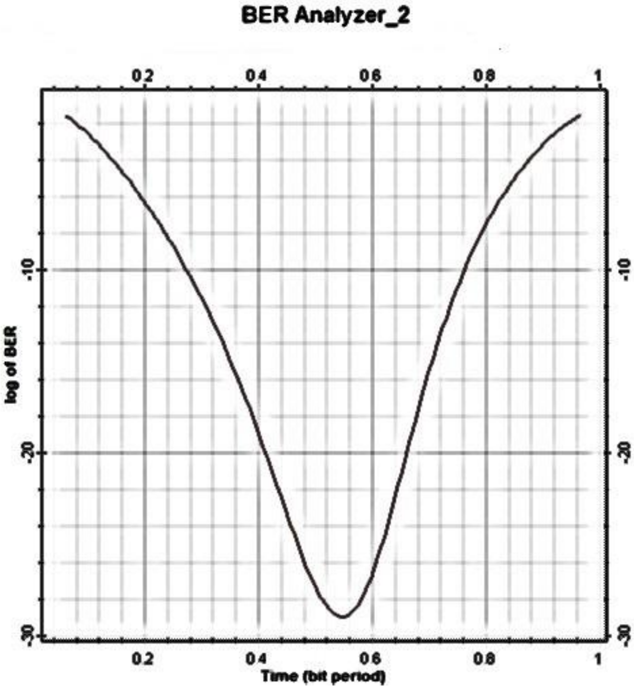

Figure 13: BER curve of one of the 0^o Channels

sustenance throughout the transmission. Table I shows list of parameters and the chosen values with units. The adjacent pulse interaction is avoided by selection of pulse width as a small fraction of bit period. Effect of PMD was avoided as individual channel bitrate was less than 10 Gbps. The

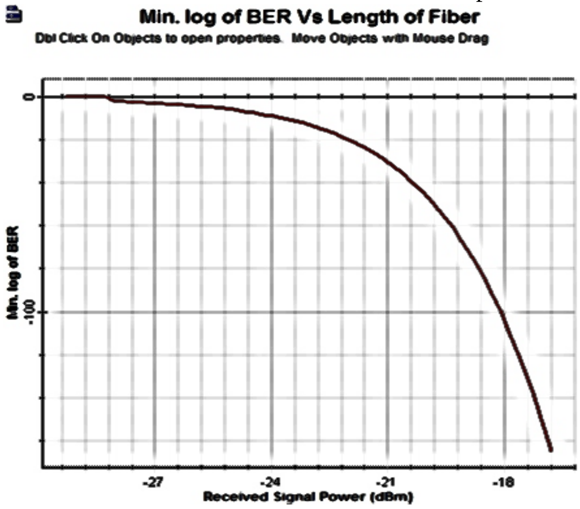

Figure 14: BER curve of 280 km Secant hyperbolic Link

dispersive wave radiation is minimized by selection of order of secant hyperbolic pulse(constant defining limits of power in link) to be nearly 1.1.(less than 1.5). Effect of Gordon Haus Jitter was neglected owing to the fact that it becomes significant in links of pulses with width in femtosecond range. Overall system performance were evaluated using BER curves and eye diagrams . Typical eye diagrams available in channel 1 in polarization mode of 90^o and another one in channel 8 in polarization mode of 0^o are shown an discussed for 1000 km. Fig. 14 shows the Bit Error Rate (log_{10}(BER)) vs Signal to Noise Ratio(SNR) of the proposed system. Entire design and simulation may be repeated considering a higher data rate and incorporating of analysis and compensation methods for PMD and Gordon Haus jitter.

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VI. CONCLUSION

The demand for high speed with minimum error rate and, at the same time, with lesser expense is growing rapidly as time progresses. A 64Gbps system comprising of WDM-PDM multiplexing and employing secant hyperbolic transmission has been designed and simulated. The data rate, above 10Gbps has negligible effect of PMD due to use of 8Gbps sub-channels that are multiplexed to 64Gbps. The use of secant hyperbolic pulses over traditional Gaussian pulses has been examined and the simulated results show the advantage of secant hyperbolic pulse over Gaussian pulse, in that secant hyperbolic has lesser BER over longer distance of cable length. Proper design strategy can be applied on the basis of available material resources to yield economic benefit with optimized performance. Overall performance of proposed 64Gbps system has been analyzed and its design has been found a promising strategy for future work. In this project an average BER of 10^{-10} has been achieved over a distance of 1000 km which forms a base for the possibility of such links of better performance to be used in near future.
By use of interleaving and appropriate coding techniques one can transmit data from multiple sources and achieve high bit-rates with less effects of phenomena like PMD. There are also modulation schemes like OFDM that can if incorporated with multiplexing fetch higher grades of performance in terms of BER. In this project analysis of effects due to Gordon Haus jitter and Dispersive wave radiation have not been considered. This could be an opportunity for future work. There is a visible trade-off between power used and price of manufacture of EDFA in secant hyperbolic transmission. As seen from this project, by the proper selection of available fiber, and hence its parameters, we can optimize the link to benefit economically. Fiber cables are required to span globally thousands of kilometers. Hence optimization becomes a smart choice. Furthermore considering stability of secant hyperbolic links with Automatic gain controlled EDFAs we can enhance the span of network over longer distances.

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AUTHORS PROFILE

Gouri V is a Post Graduate student at College of Engineering Trivandrum, Kerala, under the A.P.J.Abdul Kalam University, in Microwave and Television Engineering in the term of 2018-2020. She received her BTech degree in Applied Electronics and Instrumentation Engineering at College of Engineering Trivandrum under University of Kerala, in year 2017. Her research interests include Optical Communication Systems, Radio over Fiber System and Instrumentation Engineering .

Sreeni K G is a faculty of College of Engineering Trivandrum located in Thiruvananthapuram, Kerala, in the Electronics and Communication Engineering Department. He received his PhD degree from IIT Bombay in the year 2013. His research interests include Computational Haptics, Image processing, Computer graphics(OpenGL) and Signal processing in Optical Communication Systems.