“Performance of Dispersion effects in OCDMA systems and Timing Jitter with Fiber Type”

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In

ELECTRONICS & COMMUNICATION ENGINEERING

Submitted by

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CERTIFICATE

I, Jyotisna Rishi, hereby certify that the work which is being presented in this thesis entitled "**Performance of Dispersion effects in OCDMA systems and Timing Jitter with Fiber Type** " by me in partial fulfillment of the requirements for the award of degree of **Master of Engineering in Electronics & Communication from Thapar University (Deemed University), Patiala,** is an authentic record of my own work carried out under the supervision of **Dr.R.S. Kaler(Professor).**

The matter presented in this thesis has not been submitted in any other University/ Institute for the award of Master of Engineering.

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ABSTRACT

The aim of the thesis is to study dispersion effects in OCDMA systems and to study the timing jitter with type of fiber.

The first objective of the thesis is to analysis the effect of dispersion of fiber on the performance of OCDMA system and to find the limitations imposed by dispersion on number of user and length of transmission. It has been observed that in the bit error rate performance curve the error is decreased when the number of subscriber is increased side by side the optical power is reduced when the users is added. Here for the user sequence is the m sequence.

An OCDMA system is simulated with no dispersion, dispersion and dispersion compensation in order to analyze the effects of dispersion. Various graphs have been taken to evaluate the impact of fiber chromatic dispersion on the bit-error-rate (BER) and the Q factor. Eye diagrams have been taken at different stages in OCDMA system in order to study the effect of dispersion. Received signal is also measured in all the cases.

The second objective of the thesis is to study different types of fibers with timing jitter. The simulation effort for 10 Gb/s optical communication system is done to select the fiber from the standard fibers available from some reputed fiber sources. The comparison on the basis of measured bit error rate (BER), Q-value, timing jitter and eye diagrams has been taken and presented. It was found that dispersion shifted normal & anomalous fibers give best performance among the fibers considered, second best performance is given by Corning LEAF fibers.

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ABBREVIATIONS

FO-CDMA	Fiber-Optic Code Division Multiple Access
OCDMA	Optical Code Division Multiple Access
MW-CDMA	Multiwavelength Code Division Multiple Access
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
WDMA	Wavelength Division Multiple Access
CDMA	Code Division Multiple Access
SPR	Single Pulse Per Row
T/S SPR	Temporal/Spatial Single Pulse Per Row
OOC	Orthogonal Orthogonal Codes
PS	Prime Sequence
BER	Bit Error Rate
MAI	Multiple Access Interference
QOS	Quality of Service

Nomenclature

NRZ	Non Return to Zero

BER	Bit Error Rate
DCF	Dispersion compensating fiber
SMF	Single Mode Fiber

CHAPTER 1

Introduction

1.1. Background

Earlier optical fibers have been used for point to point communication at a very high speed. Often the optical fiber offers much higher speed than the speed of electronic signal processing at both ends of the fiber. So to be able to take the full advantage of the speed in optical fibers one of the basics concepts in fiber optic communication is the idea of allowing several users to transmit data simultaneously over the communication channel. This is called multiple access. There are several techniques to provide multiple access and one of them is fiber optic-code division multiple access (FO-CDMA). In FO-CDMA each user is assigned one or more binary signature sequence, so called code words. The data to be send is mapped onto the code words and the different users code words are mixed together and send over the channel. At the receiver end a decoder, which is individual for each user, compares the incoming sequence with stored copies of the code words to be able to extract the information bits.

Fiber optics is a particularly popular technology for local area networks. In addition, telephone companies are steadily replacing traditional telephone lines with fiber optic cables. In the future, almost all communications will employ fiber optics. Multi- access techniques are required to meet the demand for high speed, large capacity communications in optical networks, which allow multiple users to share the fiber bandwidth. Multiple access schemes available for optical LAN’S include Time division multiple access (TDMA); Wavelength-division multiple access (WDMA); and Code-division multiple access (CDMA).

1.2 History

Early History (Before 1980)

During the 1970s when laser target designation was maturing, there were development efforts in pulse repetition rate codes, preferred by the U.S. Navy, and pulse interval modulation (PIM) codes, preferred by the U.S. Air Force. Today we recognize these as classes of PSO codes. These applications established the foundations on which the codes for OCDMA could be developed. These are also known as Optical Orthogonal Codes (OOC).

1980-1984

This timeframe produced some of the keystone papers in the area of PSOs/OOCs. This period produced a paper that was influential later in comparing the bandwidth efficiency of linear and 2D (matrix) codes of the same cardinality.

1985-1989

Research on fiber optic networks and OCDMA in particular began in earnest during this era. This era produced papers that emboldened a new generation to develop OCDMA codes, systems, and techniques. These papers demonstrated that encoders and decoders could be implemented with fiber optic tapped delay lines so that encoding and code correlation could be carried out all-optically. These papers used prime sequence codes that are not ideal OOCs and this triggered interest in developing better codes.

1990-1994

In this period, there was development of coherent spectral OCDMA as well as programmable pulse shaping of femto second pulses by means of liquid crystal phase modulators and the first programmable liquid crystal phase and amplitude modulator. A detailed analysis and simulation of coherent spectral OCDMA communication using the Weiner-Heritage configuration, including potential fiber impairments and limitations was done. Around this time there was a flurry of interest in coherence multiplexing.

1995-1999

This era of OCDMA was marked by optimism, almost exuberance. Deutsche Telekom, charged with installing a telecom infrastructure in what had been East Germany, tasked the Heinrich Hertz Institute (HHI) and the Technische Universitat

Ilmenau with determining the state of the art of OCDMA for potential applications in this Greenfield. This survey included a comparison and classification of all appropriate systems explored to that time and with potential applications for future telecom networks. The survey included theoretical constructs and significant experimental achievements to that date that could be used a point of departure for appropriate new concepts. The survey was used to select approaches for the new fiber infrastructure. This survey was then collected into a basic theory of fiber–optic cdma that included coherent and incoherent implementations.

2000-2004

Trends established in previous era continued in this era. A detailed treatment and analysis of coherence multiplexing, including the potential effects of amplified spontaneous emission noise was developed. A NOLM device coupled with differential detection to reduce the effects of MAI in coherence multiplexing was proposed and demonstrated for two channels. A coherence multiplexing scheme suitable for access and local area networks was proposed. It depicted a receiver that could be realized as an optical integrated circuit, including a multimode interference (MMI) coupler. The work went onto compute performance as a function of number of concurrent users for both OOK and PSK.

1.3 Optical CDMA codes

Since the early 1980's there have been steady developments in the coding schemes and enabling technologies in the area of optical code division multiple access. (OCDMA).Based on different choices if optical sources (e.g. coherent vs. incoherent, narrowband vs. broadband), detection schemes (e.g. coherent vs. incoherent), and coding techniques (e.g. time vs. wavelength, amplitude vs. phase), coding schemes can be classified into six main categories:

1. Pulse-amplitude coding
2. Pulse phase coding
3. Spectral amplitude coding
4. Spectral phase coding
5. Spatial coding
6. Wavelength hopping time spreading coding.

Optical CDMA (OCDMA) or fiber optic CDMA (FO-CDMA) was proposed considering that the optical fiber has an available bandwidth in the order of 25 THz for information transmission. However, the processing capacity of electronic devices used in the electric-optic electric conversion reduces the throughput of data in an optical network. This problem can be minimized if both signal spreading and correlation are realized in the optical domain. Having this as a goal, research on OCDMA has focused on the development of compatible pseudo-random sequences and on device projects able to process optically those sequences. In this sense, Salehi proposes a class of optical orthogonal codes (OOC) [6, 7]. The basic difference between OOC and codes used in RF systems is in the polarity of the PN sequences. Bipolar signals, levels +1 or –1, used in conventional spread spectrum systems are unrealizable in Optical systems. The OOK (On-Off keying) technique is the simplest form of modulating light in order to generate OOC codes. Figure 1.1 illustrates a 32 chips per- bit optical code with 4 active chips.

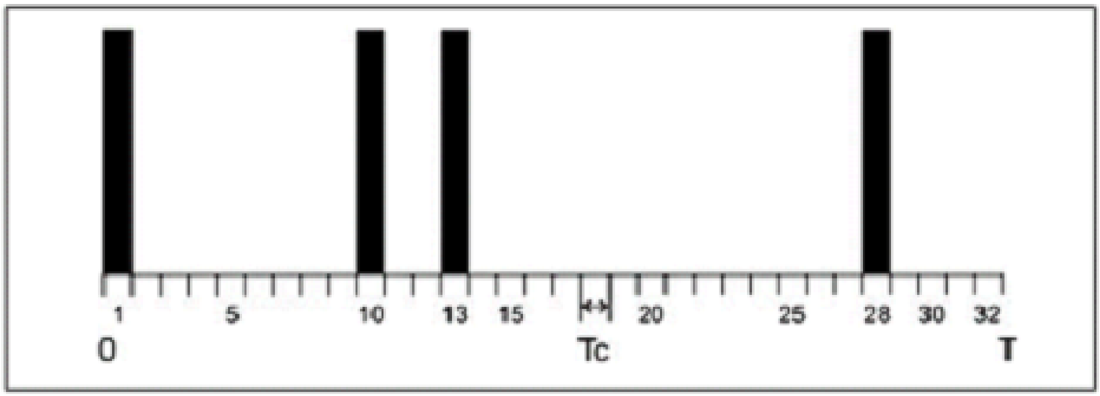


Figure 1.1: Optical code represented by light pulses in the chip positions 1, 10, 13 and 28.

Alternatively, this code can be presented by means of an optical disc as shown in Figure 1.2, in which the disc perimeter is equivalent to a bit period (T_b) and each chip period (T_c) corresponds to a disc sector equal to $2\pi T_c / T_b$.

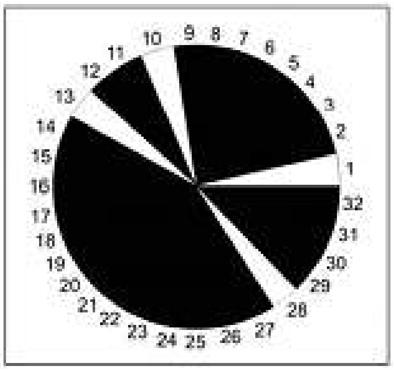


Figure 1.2 : Alternative representation of Fig. 1.1's optical code.

This representation is useful to make an analogy to maximum autocorrelation values, Figure 1.3a, and with sequence shifting, by rotating the disc, Figure 1.3b.

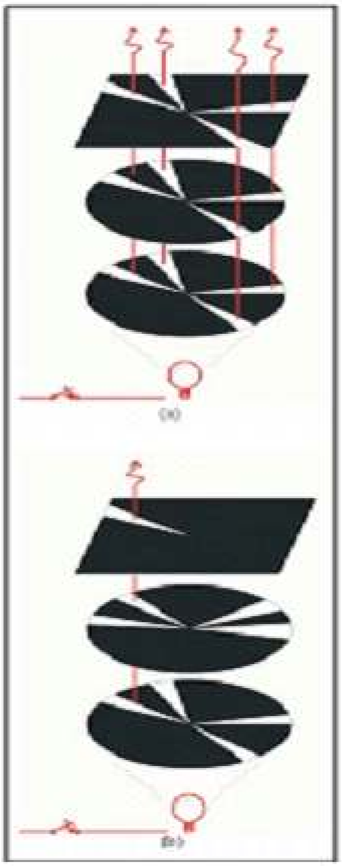


Figure 1.3: Autocorrelation demonstration of a disk representing an optical PN sequence. (a) Peak value. (b) Autocorrelation with some shifting in the sequence.

If many users are simultaneously connected, the use of OOC, along with a non-linearity optical limiter, minimizes the interference caused by multiple signals on the desired signal. This way, the performance of the optical system improves and a number up to five times greater of users can access the system, maintaining a constant BER. In relation to optical processing devices, in some models are proposed for transmitter and receiver architecture that work, in theory, for bipolar OCDMA systems. At the transmitter, a laser generates ultra-fast pulses that are split and sent through distinct paths. At the receiver end, the pulses are recombined and transformed in electrical pulses. Even though it uses optical processing, this proposal still has a limitation due to the noise presented in the optical-to-electrical conversion in the final decision stage of the receiver. Research groups in Canada, United States and England have also developed studies involving OOCs and optical processing of information. A particularly interesting characteristic of the CDMA technique is the efficient asynchronous transmission. In the case of local area networks (LAN), that use a mechanism of bursty transmissions in a shared medium, the OCDMA technique allows the implementation of access to these LANs at high bit rates and with a better cost benefit relationship. A practical system for such proposal would have the following aspects different from a standard CDMA RF system : the bit coding would be unipolar; the bit 1 is determined by a PN sequence; the bit 0 is not transmitted.

1.4 The Role of Fiber Optic Communication Technology

Fiber optic communications technology has not only already changed the landscape of telecommunications, but it is still doing so and at an extreme pace. Because of the telecommunication appetite for capacity, the bandwidth of commercial systems has increased more than a hundred fold. The potential information carrying capacity of a single fiber optic channel is estimated at 50 terabits a second (Tbit/s) but, from a practical point of view, commercial links have transmitted far fewer than 100 Gbps, an astounding amount of data that cannot be achieved with any other transmission medium. Two recent major technological advances i.e. wavelength division multiplexing (WDM) and Erbium Doped Fiber Amplifier (EDFA) have boosted the capacity of existing systems and have brought about dramatic improvements in the capacity of systems, now in development. In fact, WDM is fast becoming the technology of choice in achieving smooth, manageable capacity expansion. But, OCDMA combines the large bandwidth of the fiber medium with the flexibility of the CDMA technique to achieve high speed connectivity.

Telecommunication is growing at a furious pace, and fiber–optic communications is one of its most dynamically moving sector. Infact, its impact is increasing felt in nearly all aspects of communications technology. The demand for transmission over the global telecommunications network will continue to grow at an exponential rate and only fiber optics will be able to meet this challenge.

1.5 Motivation

The use of optical fiber enables transmission of data at very high rates in excess of terabits per second and beyond over distances of thousands of kilometers. As the capacity of the backbone increases, bandwidth demanding applications have emerged. High resolution video conferencing is being introduced. High quality full length movies can be downloaded in digital format. Large and powerful application software can be purchased and immediately downloaded from the Internet. Multimedia and fully interactive web-pages have been developed to enable business to business (B2B) and business-to-consumer (B2C) e-commerce, distance learning and ultimately telemedicine.

Optical fiber has been deployed very successfully in long haul communication. These long-haul links serve as the backbones of worldwide communication networks. As the demand for such bandwidth intensive applications continues to explode, the bandwidth of access networks will need to grow rapidly. Since most of these local networks currently employ traditional transmission media such as twisted pair and coaxial cable, their bit rate-distance products BL are restricted to 100s (Mb/s)-Km, while that of optical fibers can reach 1000s. To overcome this bandwidth bottleneck in the access market, optical fiber must be brought to the local area network (LAN). There exists an urgent need to develop efficient, economical optical local area networks. So to take the full advantage of the high speed in optical fibers, one of the basic concepts in fiber optical communication is the idea of allowing several users to transmit data simultaneously over the communication channel. This is called Multiple Access.

There are several techniques to provide multiple accesses and one of them is Fiber Optic Code Division Multiple Accesses (FO-CDMA). OCDMA is the method of sharing the bandwidth of optical fiber among multiple active users. It plays a main role in digital communication, backbone networks, high speed LAN, MAN. Thus the main advantage of using optical fiber communication is high speed, large capacity and large reliability. Optical CDMA is most suitable to be applied to high speed LAN to achieve contention-free, zero delay access, where traffic tends to be bursty rather than continuous. Optical systems use different types of optical codes. Codes can be bipolar or unipolar.

1.7 Timing Jitter

The timing jitter in optical communication system has been observed to have great impact on optical link design at higher data rate. In the fiber links, optical amplifiers after certain distance are essential to compensate attenuation of the optical signal over long lengths. Deployment of such repeated amplifiers adds amplified spontaneous noise to the system which is assumed to be the main cause of timing jitter [i, **Error! Bookmark not defined.**]. Timing jitter generated by the transmitter and receiver devices is also one of the components when overall system performance is evaluated in this context. Further, the fiber nonlinearities, dispersion present in the optical link and optical signal generation and detection components i.e. modulators, detector diodes -PIN, -APD generated noise exaggerate the problem. It can also be accounted to review the overall performance of the system. In literature, timing jitter under different setups and models in the optical communication systems has been found to be studied by various researchers.

1.8 Aims of this Thesis

- To evaluate the effect of dispersion on Optical CDMA System.
- To analyze the fiber type with timing jitter in fiber optics communication systems.

1.9 Thesis Organization

This *chapter* has provided an introduction of this thesis. It has explained the motivation and aims of this thesis. The remainder of this thesis is organized as follows.

In *chapter 2*, provide the literature survey. This is useful to understand the basics of this thesis.

In *chapter 3,* give the brief introduction of Optical CDMA.

In *chapter 4,* discuss the effect of dispersion on Optical CDMA System.

In *chapter 5*, discuss the the fiber type with timing jitter in fiber optics communication systems.

In *chapter 6*, summarized the result and provide suggestions for future work.

CHAPTER 2

Literature Review

Hiroyuki Yashima et. al.[1] proposed Optical code-division multiple access (OCDMA) for high-speed multimedia transmission and its performance is investigated. The proposed system introduces time hopping to vary transmission bit rate and power control to control performance of transmission signal, which allows various signals with different desired rate and performance. An expression for the bit error rate (BER) of the proposed system is derived and the numerical results are shown. Optical power selector (OPS) coupled with hard limiter are also proposed to improve system performance. F. Han [2] analyzed the characteristics of the spurious spectrum due to the RF bursting signals and its potential interaction with surrounding electronic equipment and proved that the level and feature of the interference would be basically determined by four factors: transmitter output power, RF carrier frequency, duty cycle, rise/fall time, repetition frequency of the RF pulses, modes of RF transmission, as well as the immunity of receptive equipment. The interference level caused by the TDMA system would basically be determined, as studied so far, by the radiated peak power level. RF carrier frequency, duty cycle, pulse rise/ fall times.

Paul R. Prucnal et. al. [3] proposed a spread spectrum CDMA LAN and demonstrated a system which employs optical fiber delay-line signal processing. The performance of new CDMA sequences designed specifically for incoherent optical correlation is analyzed and compared to conventional CDMA. Measurements of the performance of an experimental optical CDMA system operating at 100 MBd is reported. This system involving a mode-locked laser, optical modulator, fiber-optic delay-line encoder, fiber-optic channel, fiber-optic delay-line decoder, and monostable or bistable optical switch used as a threshold detector.

Tung-Wah Frederick Chang et.al. [4] proposed a universal scheme, which reproduce the effect of bipolar signaling in a unipolar optical channel. Without any hardware modification, the electro-optic/ opto-electronic (EOE) system proposed enables the transmission of any bipolar code sequence through the unipolar optical channel while maintaining the correlation properties of the codes. The bit error rate performance of the EOE system is shown to be identical to that of an optimal baseband bipolar phase shift keying code-division multiple access (CDMA) system. Hence, the maximum spectral efficiency of an incoherent optical CDMA system using bipolar codes is the same as that of an optimal bipolar baseband CDMA system.

Tung-Wah Frederick Chang et. al. [5] proposed that the AND detector is the optimum single user detector which gives the lowest averaged BER for a two-dimensional OCDMA code. The decision is bit "1" only if the threshold is exceeded in all of the "1" chips. By replacing the conventional SUM detector with the AND detector, the spectral efficiency can be at least doubled with the same bandwidth, number of active users, and BER. They have further shown that the BER performance of a random code can serve as a tight upper bound on that of any deterministic code with the same weight and dimension. In respect of multiple access interference, therefore, the AND detector is the optimum single-user detector for any code with any dimension and weight.

Tung-Wah Frederick Chang et. al. [6] present that once the acceptable BER has been determined (based, for example, n user requirements as well as the error detection/correction codes and protocols available), a single choice of the number of wavelength channels suffices in accommodating different numbers of users with maximum spectral efficiency. The network can thus be made adaptive in two way, 1. A readily scalable network. The SPR codes considered permit the introduction of additional users through increased time spreading for a given number of wavelength channels. 2. A time-dependent network. The code set can be dynamically readjusted (again, with fixed hardware, and therefore, fixed number of wavelengths) in order to accommodate more or less simultaneous users, depending on the traffic load over any given interval.

Camille-Sophie Brès et. al. [7] introduced an all-optical 2-D OCDMA code-drop unit and experimentally demonstrated its use for ring networks. In their design, an all-optical switch is used to discriminate the dropped-code autocorrelation peak from the cross-correlation noise of the through traffic. Due to the asynchronous nature of OCDMA, the cross correlation pulses could overlap with the autocorrelation data. In this special case, part of the recovered code energy can be lost in the code-drop unit leading to a partial code recovery. However, due to the sparse nature of the CHPC and low code weight, the probability of overlapping is small, in our demonstration, and rapidly decreases with the code length. The control signal to trigger the optical switch in their experiment was derived and synchronized from the same laser source as the data traffic. In a real network environment, the control pulse would be derived directly from a synchronization channel that is distributed on the ring along with the data. The code drop can also be used in other multi hop networking environments such as bus and mesh fiber topologies. By simply adding a 2x1 power combiner and tunable OCDMA transmitter to the output of the node, the complete architecture for an OCDMA add–drop multiplexer can be realized.

Jawad A.Salehi [8] examined fiber-optic code division multiple access was, a technique in which low information data rates are mapped into very high rate address codes (signature sequences) for the purpose of achieving random, asynchronous communications free of network control, among many users. Specifically discussed was the need for a special class of signature sequences that can achieve the above multiple-access capability using fiber-optic signal processing techniques. A new class of signature sequences, which are called “optical orthogonal codes” was introduced, for which they satisfy auto and cross correlation properties required for FO-CDMA. These newly invented codes were used in an experiment to show the principles of FO-CDMA.In this experiment they demonstrated the auto- and cross correlation properties of this new class of codes. Furthermore, optical disk patterns were introduced; the equivalent way of representing optical orthogonal codes, and were used to demonstrate the properties of interfering optical orthogonal codes. Described also an experiment in which the probability density functions for any two interfering OOC’s were developed.

David W. Matolak et. al. [9] presents a reduced-complexity parallel interference cancellation (PIC) technique, in which PIC is performed only on "unreliable" bits (blocks). They term their technique statistical PIC (STPIC), since the decision to employ PIC for any user signal is based upon received signal statistics. Here they propose two different methods: one is bitwise (instantaneous) STPIC (ISTPIC), in which IC is performed only on the bits whose absolute log likelihood ratio (LLR) is below a preselected threshold; the other method is block STPIC (BSTPIC), in which IC is performed only on the blocks whose average signal-to-noise-plus-interference ratio (SNIR) is below a preselected threshold. Both LLR and SNIR statistics reduce to quantities simple to obtain. They show that STPIC can achieve performance equivalent to conventional full PIC (FPIC) and other partial PIC techniques in flat Rayleigh fading channels, but with reduced computational complexity. They also show their proposed ISTPIC can achieve performance better than FPIC in good channel conditions (e.g., AWGN), still with reduced computational complexity. The ISTPIC performance gain over conventional FPIC is larger in conditions of larger loading factor where coefficient IC techniques are more likely to be needed.

Jawad A. Salehi et. al. [10] investigated a technique to establish fiber-optic-code division multiple access (FO-CDMA) communications system. In particular, they discussed the need for a new class of signature sequences that satisfy the auto- and cross-correlation properties that are essential for a successful FO-CDMA system. They introduced a new class of sequences that are called optical orthogonal codes (OOC's). Furthermore, we investigated the probability density function for any two interfering OOC's. In Part I1 of this paper, they utilize the results of Part I to derive the bit error rate of the proposed FO-CDMA system as a function of data rate, code length, code weight, number of users, and receiver threshold; and they discussed the performance characteristics for a variety of system parameters. Furthermore, they discussed a means of reducing the effective multiple-access interference signal by placing an optical hard-limiter at the front end of the desired optical correlator and calculate the performance of the FO-CDMA with an ideal optical hard limiter, and they show that using a optical hard-limiter would, in general, improve system performance.

Chao-Chin Yang et. al. [11] proposed a scheme to use power control for differentiated service provision is proposed for the optical code-division multiple-access network. The main advantages of this scheme are:- 1) Interference from other users can be eliminated theoretically; 2) The decoder with simple configuration can be used as compared to that in a previous power control scheme; and 3) The design procedure of various service requirements in one network is simplified.

Istvan Frigyes [12] analysis the role of cdma in optics. As spectrum spreading and CDMA proved themselves as very efficient in radio communication CDMA application in optical communication seemed to be reasonable as well. Research in this field started two decades ago or so and is still flourishing. After giving a brief listing of relevant concepts in optical communications - concept of optical spectrum spreading, techniques of temporal and spectral coding are described, possibilities of long-haul application and some networking issues are discussed.

Chia-Hao Tsai et. al. [13] proposed a new family of wavelength-time codes. The new 2D codes used the 1D (n,w, 2,2) OOCs as the time-spreading codes to achieve the larger code cardinality and weight. The larger cardinality allows the support of more possible subscribers. Their numerical examples showed that the heavier code weight supported by our new 2D codes resulted in a better code performance than the MWOOCs and the 2D codes in [8], under certain condition. Moreover, the performance difference of the codes always increases with the difference of code weight w_d.

Babak M. Ghaffari et. al. [14] present an in-depth analysis on the operability and the viability of a typical wireless optical CDMA (OCDMA) local area network. Three receiver structures for OCDMA systems, using optical orthogonal codes (OOC) with minimum auto and cross-correlations as signature sequence, namely, correlation, correlation with hard-limiter, and chip-level detection are studied and proposed for such a network. For the synchronization circuit design the performance of two algorithms for OOC based OCDMA networks, namely, simple serial-search and multiple-shift in the context of wireless OCDMA LAN are studied. Furthermore, they studied a synchronization method based on matched filtering and show that it presents a much better performance in our wireless OCDMA system. The effect of sampling rate and its performance on tracking circuit is analyzed. Bit-error-rate (BER) analysis is performed by photon counting methodology. Multi-user interference (MUI), ambient light, and photo-detector dark current are considered in our analysis. Their analysis strongly indicates the viability and practicality of such systems in certain important wireless optical communications systems.

Mohsen Razavi et. al. [15] present a thorough analysis based on photon-counting techniques on temporal/spatial fiber-optic code division multiple-access systems incorporating both post- and pre optical amplifiers. In this analysis, they consider the effect of shot noise, thermal noise, and source extinction on system bit-error rate. Their results can be used to estimate them maximum tolerable amount of quantum fluctuations in the received signal.

L. Tan Cevski et. al.[17] proposed a novel optical CDMA concept based on integration between time spreading and Wavelength hopping pattern was described in detail. The autocorrelation function of the prime-hop sequences is a maximum at the zero time shift and zero otherwise, and the cross correlation is at most 1 (i.e. the sequences exhibit optical orthogonality). Having a needle shaped autocorrelation function. The system is suitable for a truly asynchronous operation. The low cross-correlation properties allow the system to support increased number of simultaneous users, the number of possible stations in the network being also significantly increased due to the integration of both patterns. The system can be configured to allow very secure communications by increasing the number of discrete wavelengths or by using asymmetric p numbers, one for the spreading pattern and one for the hopping pattern. The system is suitable for fully asynchronous secure LAN applications.

Tung-Wah Frederick Chang et. al. [19] presents a multiwavelength O-CDMA system using SPR codes, the maximum spectral efficiency of the code converges to a fixed level as the total bandwidth expansion of the code set increases. Using the AND detection technique, rather than the SUM, the spectral efficiency of a 2-D SPR code system is as high as that of baseband bipolar CDMA systems for a broad range of BERs. Their results imply that, once the acceptable BER has been determined (based, for example, on user requirements as well as the error detection/correction codes and protocols available), a single choice of the number of wavelength channels suffices in accommodating different numbers of users with maximum spectral efficiency.

Seong-sik Mill et. al. [20] analyzes the TS-WII 2-D code system, suggesting the expression for estimating the upper bound of BER. The system with an optical hard limiter is also analyzed. In OCDMA system with 2-D codes, they use optical hard limiter (OHL) as well as the system with 1-D codes. The hard limiter is an effective component to mitigate the channel interference due to many other simultaneous user so that the bit error probability is improved and the number of simultaneous users so that the bit error probability is improved and the number of simultaneous users is increased.

S. A. Aljunid' et. al. [21] proved that AND subtraction technique gives better Bit Error Rates (BER) performance than Complementary subtraction technique against the received power level. . The overall system cost and complexity can be reduced by using less number of filters in this technique. At the same time, the performance of the OCDMA system is improved significantly because with less number of filters in the decoder, the total power loss can be reduced and this can be clearly seen in the result.

N. R. Newbury et. al. [22], Abstract demonstrated the coherent transfer of an optical signal over a 251 km link of optical fiber by use of the standard Doppler-cancellation approach to remove the effects of the fiber-link noise. The fundamental limit to the frequency instability on the transmitted optical frequency is set by residual phase noise on the optical frequency resulting from the unavoidably imperfect Doppler cancellation of the fiber-link noise. Here they demonstrate that it is possible to quantitatively predict the phase noise and instability of the Doppler-cancelled transmitted optical frequency directly from the measured fiber-link noise. The ability to predict the frequency instability from the measured fiber noise can be a useful tool in evaluating whether a coherent fiber optic link is operating at its fundamental limit, or whether there is additional excess noise from the measurement system present in the link.

Tamer Khattab et. al. [23] propose a novel simplified mathematical analysis technique for modeling and calculating the effect of multiple access interference on bit error rate in optical code division multiple access (OCDMA) systems. Their technique applies to OCDMA systems using optical orthogonal codes (OOC) with optical time-domain spreading. The proposed analysis uses combinatorial methods on the combined signal at the output of the optical correlator decoder to derive a mathematical expression for the bit error rate.

Alper Demir [24] describe novel formulations and computational techniques for the analysis of the fiber nonlinearity as they propagate together along the fiber link. Their formulations are similar, in spirit, to the linear (ized), time varying formulations for noise analysis in anolog/ RF electronics circuits and investigate signal noise mixing due to optical fiber nonlinearities using the techniques developed.

Elwyn D. J. Smith et. al. [25] derived the performance limit of a spectral-amplitude OCDMA system, using a balanced receiver structure. This performance limit arises due to the interference between light from incoherent sources. The use of additional PPM coding with spectral-amplitude OCDMA has been proposed as a possible way of achieving greater performance. A simple and robust PPM decoder has been proposed that follows the spectral-amplitude OCDMA receiver and analyzed the performance of the combined PPM-OCDMA system. And shown that performance levels can be achieved that are greater than the performance limit of the system without PPM.

Martin Rochette et. al. [26] presents the spectral efficiency of frequency-encoded (FE) optical code-division multiple-access (OCDMA) systems with incoherent sources. The spectral efficiency of five code families compatible with FE-OCDMA is calculated as a function of the number of users. Analytical equations valid in the limiting case of Gaussian noise are also developed for the bit-error rate and the spectral efficiency. Among the code families considered, the modified quadratic congruence code leads to the maximum achievable spectral efficiency.

Jawad A, Salehi [27] proposed a new class of codes (signature sequences), namely, optical orthogonal codes (OOC's), that are suitable for FO-CDMA are introduced. An experiment that shows the desired auto- and cross-correlation properties of these codes and their use in FO-CDMA is reported. Furthermore, the concept of optical disk patterns, an equivalent way of representing OOC's is introduced. The optical disk patterns are used to derive the probability density functions associated with any two interfering OOC's. Also presented is a detailed study of different interference patterns from which the strongest and the weakest interference patterns are introduced.

Wenhua Ma et. al. [28] analyzed the properties of the phase-encoded optical signal (pseudorandom optical signal with low intensity) in a view of random process. The phase-encoded optical signal was seen as a sample function of a certain random process. The variance of the corresponding random process is inversely proportional to code length F . The rms width of the phase-encoded width is proportional to the width of initial Gauss optical pulse and the code length F. Neglecting the influence of the transmission medium, they have evaluated the performance of asynchronous phase-encoded OCDMA system and obtained the optimal threshold of receivers. The numerical results revealed that larger code length F or shorter initial Gauss optical pulse is beneficial to improving the system performance.

Habib Fathallah et. al. [29] propose and analyze a novel high bandwidth optical fast frequency-hop CDMA communication system. Encoding/decoding operations are performed passively, using an all optical, all-fiber device. In a typical example of 500 Mb/s user data bit rate, a length 20 cm multiple Bragg gratings performs the function of a 6-GHz hopping-rate frequency synthesizer. Apodization of each grating is important to improve the reflectivity spectrum and hence enhance system capacity and spectrum efficiency. Tunability using piezoelectric devices allows the programmability of the encoding/decoding device. They derived new code design criteria that better match requirements in optical fiber transmission medium. They proposed a suboptimal family of codes that guarantees a specific frequency separation between successive chip pulses, alleviating the effects of side lobes in the reflection spectrum.

L. Tancevski et. al. [30] introduced an incoherent optical guided wave CDMA concept based on the integration of time spreading and wavelength hopping. Because the autocorrelation function of these prime-hop sequences is maximum at zero time-shift and zero otherwise and because the cross-correlation is at most 1, the number of possible stations the network can address is greatly increased as is the number of simultaneous users. Systems based on these codes can function in a truly asynchronous manner with increased security. An initial assessment of system performance and hardware requirements has been performed.

S. P. Majumder et. al. [31] evaluate the impact of fiber chromatic dispersion on the bit-error-rate (BER) performance of a direct sequence optical code-division multiple-access (OCDMA) system with intensity modulation direct detection transmission link using sequence inverse keying optical correlator operating at 10 Gchip/s. It is observed that the difference between the two curves is less than 0.5 dB which validates the approximation made in carrying out the theoretical analysis for BER.

Timing Jitter

Introduction

The timing jitter in optical communication system has been observed to have great impact on optical link design at higher data rate. In the fiber links, optical amplifiers after certain distance are essential to compensate attenuation of the optical signal over long lengths. Deployment of such repeated amplifiers adds amplified spontaneous noise to the system which is assumed to be the main cause of timing jitter [i, **Error! Bookmark not defined.**]. Timing jitter generated by the transmitter and receiver devices is also one of the components when overall system performance is evaluated in this context. Further, the fiber nonlinearities, dispersion present in the optical link and optical signal generation and detection components i.e. modulators, detector diodes -PIN, -APD generated noise exaggerate the problem. It can also be accounted to review the overall performance of the system. In literature, timing jitter under different setups and models in the optical communication systems has been found to be studied by various researchers. In this chapter timing jitter in the optical communication systems is being reviewed in the context of its classification, theoretical estimation methods and reduction methods proposed so far.

Timing Jitter Classification

Timing jitter has four main categories as per the literature: Gordon Haus-, PMD induced-, Interaction induced-, Acoustic Induced- and Raman Induced- jitter. The definition of each is described in brief through the following lines.

Gordon Haus Timing Jitter

Real optical fibers have losses which must be canceled by optical amplifiers for long distance transmission systems. The amplifiers do more than just restore the pulse energy to its original value by producing spontaneous emission noise. The amplifier noise induces timing jitter in the bit stream by shifting optical pulses from their original time slot in a random fashion. Such jitter was first studied in 1986 in the context of solitons and is called Gordon-Haus jitter [**Error! Bookmark not defined.**]. It was later recognized that timing jitter can occur with any transmission format NRZ, RZ, or chirped RZ (CRZ) and imposes a fundamental limitation on all long-haul systems designed with a cascaded chain of optical amplifiers.

Polarization Mode Dispersion induced Jitter

Polarization Mode Dispersion can generate timing jitter through random fluctuations in the fiber birefringence. In a practical lightwave system, all solitons are launched with the same polarization at the input end of the fiber link. However, as the solitons are periodically amplified, the state of polarization becomes random because of ASE added at every amplifier. Such polarization fluctuations lead to timing jitter in arrival time of individual solitons through fiber birefringence because the two orthogonally polarized components travel with slightly different group velocities Polarization Mode Dispersion can generate timing jitter through random fluctuations in the fiber birefringence. In a practical lightwave system, all solitons are launched with the same polarization at the input end of the fiber link. However, as the solitons are periodically amplified, the state of polarization becomes random because of ASE added at every amplifier. Such polarization fluctuations lead to timing jitter in arrival time of individual solitons through fiber birefringence because the two orthogonally polarized components travel with slightly different group velocities [i]. Incidentally, it is observed that the fundamental limiting factor for long-haul transmission is the timing jitter due to Gordon–Haus effect provided the PMD effect is reduced [ii].

Table 2.2 Timing Jitter Classification

S. No.	Topic	Reference
	Gordon Haus Timing Jitter	Dietrich et al [1992]; P. B. Haboe et al [], Ruomeri Mu et al [1993]; N. J. Smith et al [1994]; M. Suzuki et al [1995]; M. Matsurmoto et al [1995]; N. J. Smith et al [1996]; Rene Jean et al [1996]; TJ7 N. J. Smith et al[1997]; J.N. Kutz et al [1998]; Takao et al [1998]; J. Nathan Kutz et al [1998]; Itsuro Morita et al. [1999]; C.J. McKinstrie [2001]; Mathias Westlund et al [2001]; C. J. McKinstrie [2002], Heider N. Erifej et al [2002], Jacob et al [2003].
	PMD induced Timing Jitter	Willam Shieh [2000]; C. Xie et al [2000]; Sunnerud et al [2001]; Liang chen et al [2001]; Sunnerud et al [2002]; Magnus et al [2006].
	Interaction or Collision-Induced Timing Jitter	G. P. Agrawal [1995], [1998]; Msyuki Thierry Georges [1996]; V. Milkhailov et al [1996];E. A. Golovchenko et al [1997]; Armando Nolasco et al [1998]; S. Chi et. Al [1997]; J.F.L Devaney at el [1997], [1998]; Michael Eiselt et al [1999], V. S. Grigoryan at el [2000], Masyuki Matsumo [2001], G. Falkovich [2001], [2002]; Yi Cai et al [2002], Oleg V. Sinkin et al [2006].

	Acoustic Induced Jitter	G. P. Agrawal [1995]; A. N. Pilipetskii et al [1997]; L. du Maouza et al [1998], Tulay Adaly et al [1998], [2000]. Yves Jaouen et al [2001].
	Raman Induced Jitter	Jayanthi Santhanam et al [2002], Fan Zhang pieda [2002]

Interaction induced jitter or Collision induced jitter

When the individual pulses are assumed to be sufficiently far apart that their position is not affected by the phenomenon of soliton interaction. This is not always the case in practice. Even in the absence of amplifier noise, solitons may shift their position because the attractive or repulsive forces. As the interaction force between two solitons is strongly dependent on their separation and relative phase, both of which fluctuate because of amplifier noise, soliton-soliton interactions modify the ASE-induced timing jitter. By considering noise-induced fluctuations of the relative phase of neighboring solitons, timing jitter of interacting solitons is generally found to be enhanced by amplifier noise. In contrast, when the input phase difference is close to 180o between neighbouring solitons, phase randomization leads to reduction in timing jitter [i]. For WDM systems, a semi analytical approach has been developed that creates an efficient numerical algorithm to accurately evaluate collision-induced timing jitter with RZ modulation format [iii].

Acoustic induced Jitter

The timing-jitter mechanism that limits the total transmission distance at high bit rates has its origin in the propagation of acoustic waves inside optical fibers. Confinement of the optical mode within the fiber core creates an electric field gradient in the radial direction of the fiber. The gradient creates an acoustic wave through electrostriction, a phenomenon that produces density variations in response to changes in the electric field. As the refractive index of any material depends on its density, the group velocity also changes with the generation of acoustic waves.

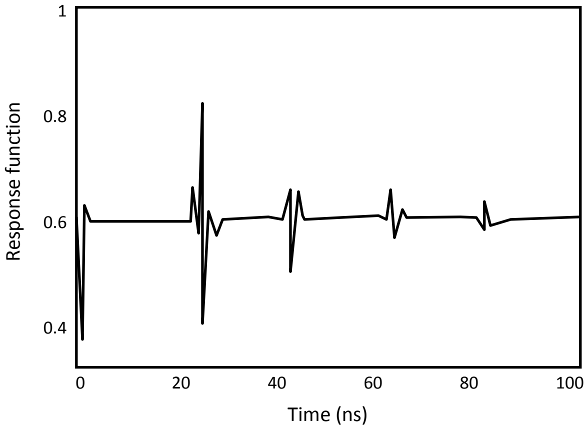


Figure 2.2: Response function of the electrostrictive interaction δn(t).

The acoustic-wave-induced index changes produced by a single pulse can last for more than 100 ns the damping time associated with acoustic phonons. They can be measured through the XPM induced frequency shift Δν = - (Leff / λ) d(δna)/dt, where Leff is the effective length of the fiber. As seen in

Fig 2.1, the measured frequency shift is in the form of multiple spikes, each lasting for about 2 ns, roughly the time required for the acoustic wave to traverse the fiber core. The 21 ns period between spikes corresponds to the round trip time taken by the acoustic wave to reflect from the fiber cladding. Noting that Leff ≈ 20 km for 0.2 dB/km fiber losses, acoustically induced changes are relatively small (~ 10-14) but lead to measurable jitter even at a bit rate of 10 Gb/s [i].

Raman induced Jitter

The Raman jitter is a new source of timing jitter that dominates at high bit rates requiring short optical pulses (T0 < 5 ps). The Raman induced frequency shift depends on the pulse energy. This frequency shift by itself does not introduce jitter because of its deterministic nature. However, fluctuations in the pulse energy introduce by amplifier noise can be converted into fluctuations in soliton frequency through Raman effect, which are in turn translated into time fluctuations, in turn translated into position fluctuations by the GVD. The Raman jitter occurs for both the standard and DM solitons. In case of standard solitons, the use of DDFs is often necessary but the analysis is simplified because the solitons are unchirped and maintain their width during propagation [i].

Analytical Estimation of Timing Jitter

An optical pulse traveling in +z direction and polarized in x direction is expressed by a partial differential equation as:

$$
\begin{aligned}
\frac{\partial}{\partial z} A(z,t) = & -\frac{\alpha}{2} A(z,t) && (linear\ \ Attenuation) \\
& + j\frac{\beta_2}{2}\frac{\partial^2}{\partial^2 t} A(z,t) && (Second\ \ order\ \ dispersion) \\
& + \frac{\beta_3}{6}\frac{\partial^3}{\partial^3 t} A(z,t) && (third\ \ order\ \ dispersion) \\
& - j\gamma \left|A(z,t)\right|^2 A(z,t) && (Kerr\ \ effect) \\
& + j\gamma T_R \frac{\partial}{\partial t}\left|A(z,t)\right|^2 A(z,t) && (SRS) \\
& - \frac{\gamma}{\omega_0}\frac{\partial}{\partial t}\left|A(z,t)\right|^2 A(z,t) && (Self - steepening\ \ effect)
\end{aligned}
\tag{0.1}
$$

Where $A(z,t)$ = the slowly varying envelope of the electric field

z = propagation distance

$t = t' - z/v_g$ (t' = physical time, v_g = the group velocity at the center wavelength)

α = the fiber loss coefficient (km-1)

β_2 = the second order propagation constant (ps2 / km)

β_3 = the third order propagation constant (ps3 / km)

γ = the nonlinear coefficient = $2\pi n_2/(\lambda_0 A_{eff})$

n_2 = the nonlinear index coefficient

A_{eff} = the core effective area of the fiber

λ_0 = the center wavelength

ω_0 = the center angular frequency

T_R = the slope of the Raman gain $(\sim 5\, fs)$

The equation 1.5 is applicable for propagation of pulses as short as ~50fs. It corresponds to a spectral width of ~20THz. When the pulse width is greater than 1ps, the equation can be considerably simplified because the Raman effect term and the self-steepening effect term are negligible compared to the Kerr effect term and expressed as equation 1.6.

$$\frac{\partial A}{\partial z} = -\frac{i}{2}\beta_2 \frac{\partial^2 A}{\partial t^2} - \frac{\alpha}{2} A + i\gamma |A|^2 A \tag{0.2}$$

The above equation describes the propagation of picoseconds optical pulse in single-mode fibers. It is often referred equation to as the nonlinear Schrodinger equation. In the expression third order dispersion term is also ignored being negligible compared to the second order dispersion term unless operation is near the zero – dispersion wavelength. Considering that the bit period of a 10 Gb/s non-return-to-zero (NRZ) system is 100 ps (>1ps), can serve as a propagation equation in contemporary optical communication systems with a fairly good accuracy. The GVD parameter β_2 can be positive or negative. In the anomalous dispersion regime $\beta_2 < 0$ and the fiber can support optical solitons.

Analytically solitons employs the NLS equation satisfied by the pulse envelope $A(z, t)$ in the presence of GVD and SPM. In order to discuss the solution to this equation in a simple way consider that the fiber is lossless $\alpha = 0$ Hence normalizing Eq. 1.6 using transformation

$$\tau = \frac{t'}{T_0}, \qquad \zeta = \frac{z}{L_D}, \qquad U = \frac{A}{\sqrt{P_0}} \tag{0.3}$$

where T0 is a measure of the pulse width, P0 is the peak power of the pulse and $LD = T_0^2 / \beta_2$ is the dispersion length, it takes the form

$$i\frac{\partial U}{\partial \zeta} - \frac{s}{2}\frac{\partial^2 U}{\partial \tau^2} + N^2 |U|^2 U = 0 \tag{0.4}$$

where $s = \mathrm{sgn}(\beta_2) = +1 \;\; or \;\; -1$, depending on whether β_2 is positive (normal GVD) or negative

(anomalous GVD). The parameter N is then defined as

$$N^2 = \gamma P_0 L_D = \gamma P_0 T_0^2 / |\beta_2| \tag{0.5}$$

It is useful to introduce another length scale called the nonlinear length, $L_{NL} = 1/\gamma P_0$. The dispersion length L_D and the nonlinear length L_{NL} provide the length scales over which the dispersive or nonlinear effects become important for pulse evolution along the fiber length L. When the fiber length L is such that L<<LNL and L<<LD, neither dispersive nor nonlinear effects play a significant role during pulse propagation. When the fiber length L is such that L << LNL and L ≥ LD, the pulse evolution is governed by GVD and nonlinear effects play a minor role. This can happen for short pulses or pulses with peak power P0 << 1 W. When the fiber length L is such that L << LD and L ≥ LNL, the pulse evolution is governed by SPM and dispersive effects play a minor role. This can happen for relatively wide pulses with a peak power P0 ≥ 1 W. When the fiber length is comparable to LD and LNL, dispersion and nonlinearity act together as the pulse propagates along the fiber.

Study of pulse propagation in optical fibers can be performed by numerical methods too. It is broadly categoried in two methods known as the finite difference methods and the pseudo spectral methods. One example of the pseudo spectral methods is the split-step fourier method. A numerical approach is often necessary to understand the nonlinear effects in optical fibers. Hence understanding these numerical methods becomes essential. [Santhanam, GP Agrawal book]

Split-Step Fourier Method

The propagation equation describes the effects of the dispersion in a linear medium and the nonlinear effects that arise due to fiber nonlinearities. Hence rewriting Eq. (1.8) in terms of the linear and nonlinear operators,

$$\frac{\partial A}{\partial z}=\left(\hat{D}+\hat{N}\right)A \tag{0.6}$$

Where $\hat{D}$ is the differential operator that describes the effects of dispersion and $\hat{N}$ accounts for fiber nonlinearity. These operators are given by

$$\hat{D}=-\frac{i\beta_2}{2}\frac{\partial^2}{\partial t^2}+\frac{\beta_3}{6}\frac{\partial^3}{\partial t^3} \tag{0.7}$$

$$\hat{N}=i\gamma\left|A\right|^2 \tag{0.8}$$

In general, dispersion and nonlinearity act together along the length of the fiber. The split-step Fourier method obtains an approximate solution by assuming that in propagating through the optical fiber over a small distance h, the dispersive and nonlinear effects can be considered to act independently. More specifically, propagation from z to z +h is carried out in two steps. In the first step, the nonlinearity acts alone, and $\hat{D}=0$ in equation 1.11. In the second step, dispersion acts alone and $\hat{N}=0$ in eq. 1.11. The effect of dispersion is then found by taking the Fourier transform of the equation. The accuracy of the split-step Fourier method can be improved by keeping the step size h small.

Finite-Difference Method

An inherent fundamental approximation in the derivation of the NLS equation is the slowly varying envelope approximation. In order to relax this approximation finite-difference methods are used in place of the split-step Fourier method. Another approximation used in deriving the NLS equation is that there is no backward propagating wave. Such problems require the simultaneous considering of both forward and backward propagating waves. Also in order to consider the birefringence effects of the fiber one needs to consider the vector nature of the electromagnetic fields. For the case of linear medium the algorithms that solve the Maxwell equations directly in the time domain by using finite-difference methods have been developed for many years. However in 1992, such algorithms were extended to the case of nonlinear media. In particular this method was used to study pulse propagation in optical fibers in. Conceptually, the main difference between the finite-difference time-domain method and split-step Fourier method is that the former deals with all electromagnetic components. The finite-difference time-domain method is certainly more accurate since it solves the Maxwell equations directly with a minimum number of approximations. However it is more time consuming than the split-step Fourier method. It may be necessary to use this method for ultrashort pulses whose width is less than 10 fs. However in most applications of nonlinear fiber optics, pulses are much wider than 10 fs and using the split-step Fourier method provides reasonably accurate solution in such cases.

Analytically, Timing jitter is estimated by the use of methods based on nonlinear Schrodinger equation 1.8. Gordon Haus timing jitter category produced by amplified spontaneous emission (ASE) noise is known to impose a fundamental limitation on periodically amplified lightwave systems which is theoretically analyzed using variational method, perturbation method, or the moment method. Here below the methods are briefed.

CHAPTER 3

Optical CDMA

3.1 Introduction

O-CDMA is one technique of the multiple access technique to allow several users to transmit simultaneously over the same optical fiber. OCDMA combines the large bandwidth of the fiber medium with the flexibility of the CDMA technique to achieve high speed connectivity.

OCDMA is a highly flexible technique to achieve high–speed connectivity with large bandwidth. Data access security and ability to support asynchronous, bursty data transmission are two of the main driving forces behind a lot of interest in the OCDMA techniques. On the other hand, the poor spectral efficiency of OCDMA systems demand appropriate choice of coding techniques and multiple access interference (MAI) is often a limiting factor. Code division multiple access is relatively poor in terms of spectral efficiency resulting in low throughputs. But using two-dimensional (2-D) optical CDMA can improve the overall network throughput. WDM and CDMA are combined in such a way that the beneficial aspects of each technique overcome the shortcomings of each other. Using different wavelengths improves spectral efficiency of OCDMA and using OCDMA greatly release frequency control requirements.

A local area network (LAN) may well comprise hundreds of users, each of whom may employ data visualization, high–definition digital video broadcasts, or other bandwidth intensive applications. Each user require individual data rates in gigabits per second, leading to aggregate data rates reaching hundreds of gigabits per second. It will not be sufficient to provide raw bandwidth alone. The network must also provide quality of service (QOS) guarantees for these applications, even as the number of users and aggregate throughput with time. This challenge is not insignificant the network must simultaneously accommodate traffic, whose requirements vary over order of magnitude:

1. Bandwidth ranging from kilobits (compressed voice) to gigabits per second (high quality dynamic, three dimensional, real time image sharing).
2. Bit error rates ranging from 10^{-3} (internet telephony) to 10^{-12} (highly sensitive data transfer).
3. Delays/ latencies ranging from speed of light limited shared memory applications (e.g. less than 1 ms in a LAN of modest size) to file transfer (e.g. seconds to minutes).

3.2 Block diagram of OCDMA In Optical CDMA, the same principles are retrieved as radio frequency CDMA even if these techniques are adapted to the specificity of optical transmission channel. The aim of Optical Code Division Multiple Access is to take benefits of radio frequency communications. CDMA technique to share the huge optical bandwidth. Specific constraints associate to the optical communication systems have to be taken into account, while preserving the advantages brought by this technique. i.e.

1. Improvement of multiplexing capacity.
2. Resource sharing
3. Asynchronous emission of the subscribers.
4. Cost reduction of network installation.

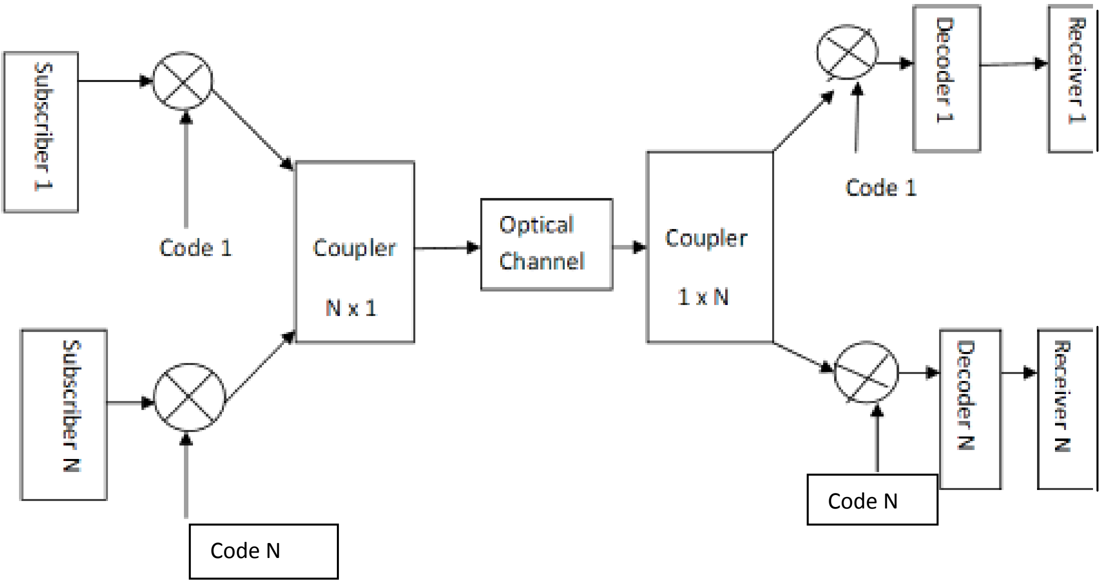


Figure 3.1: Block diagram of Optical CDMA system.

An OCDMA system for each user can be described by a data source, containing the data that will be sent, followed by an encoder and then a laser that maps the signal from electrical form to an optical pulse sequence. At the receiver end, an optical correlator is used to extract the encoded data. Many subscribers transmit data simultaneously. Each user has its own codeword, which is approximately orthogonal to all other code words. The encodes data is send to the N*1 star coupler, from where the optical channel carries the signal through the optical fiber and couples to a 1*N coupler and broadcast to all nodes. All users encoded data are then added together chip by chip and the result, which is called the superposition, are sent over the channel. The presence of the light pulse represent the binary bit '1'and the absence of the light pulse represent the binary bit '0', the superposition mechanism has the following properties:

$$0+1=1; \quad 1+0=1; \quad 1+1=1; \quad 0+0=0;$$

The individual receivers consisting of optical correlator continuously observe the superposition of all incoming pulse transmission and recover the data from the corresponding transmitter .This is done by correlation between the incoming signal and stored copies of that user unique sequence. The correlator will give a peak, if the incoming stream of optical pulses contains the unique sequence and the presence of other users will be considered as noise .The decoding process is accomplished by using optical correlation. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independent with no knowledge of the users.[9]

3.3 Fundamental Concept of Optical CDMA

High speed can be achieved in optical CDMA by combining large bandwidth of the optical medium with the flexibility of CDMA. CDMA was originally investigated in the context of radio frequency (RF) communications systems and was first applied to the optical domain in the mid 1980 by Prucnal and Salehi [3, 10, 11]. They tried to use the excess bandwidth in single-mode fibers to modulate low-information rate electrical signals into high rate optical pulse sequences to achieve random, asynchronous operation without the need for a centralized network controller.

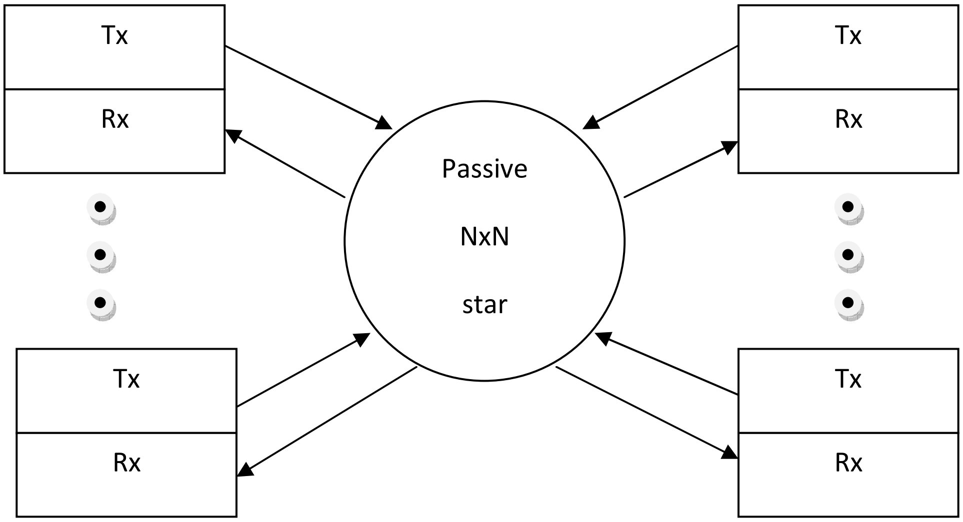


Fig.3.2 A Fiber optic CDMA network using a passive NxN coupler

In an OCDMA system, each bit is divided into n time periods called chips. By sending short optical pulse during some chip intervals, which represents 1 and no pulse which represents 0 an optical signature sequence can be created. Each user has a unique signature sequence i.e. each user is assigned one signature sequence called codeword. When this sequence is sent, it represent that user with that unique has sent the information bit'1'. If the information bit is '0', it simply means that user send the corresponding length of zeroes i.e. no light pulses during that interval. Since each data bit is represented by high rate signature sequence, the bandwidth of the data stream is increased .Therefore O-CDMA is spread–spectrum technology.

The OCDMA encoded data is thus sent to the N*N star coupler or 1*N coupler and broadcast to all nodes. A typical fiber optic CDMA system is shown in figure 3.2, where the nodes are connected together through a passive N*N star coupler. At the logical level this configuration is a broadcast -and- select network. The crosstalk between different users sharing a common fiber channel, known as multiple access interference (MAI) is usually the important source of noise in an optical CDMA system, therefore intelligent design of the codeword sequence is important to reduce the contribution of MAI to the total received signal [7].

3.4 Multi-wavelength Optical CDMA

TDMA and WDMA only take advantage of a single degree of freedom (time and wavelength respectively).The multiple-wavelength optical CDMA scheme spreads data in both the time and wavelength domains to achieve greater flexibility and eliminate centralized network control. Instead of viewing each wavelength as a separate channel that can support a set of optical orthogonal codes, the time chips and wavelength channels can be viewed as the axes of a two dimensional codeword. Analogous to the one dimensional OOC's these multi wavelength OOC's (MWOOCs) are designed to meet the auto-correlation and cross-correlation constraints in order to manage MAI. MWOOCS can in general support a much larger number of simultaneous users, since the code cardinality is much larger.

The crosstalk between different users sharing the common fiber channel, known as the multiple access interference (MAI) is usually the dominant source of bit errors in an O-CDMA system, therefore, intelligent design of the codeword sequences is important to reduce the contribution of MAI to the total received signal. An alternative approach, which reduces the demands on the electronic hardware, is to spread the optical orthogonal codes both in time and wavelength domains simultaneously.

In moving from single-wavelength optical CDMA systems to multi-wavelength networks, there is the danger of introducing additional latency. To keep costs low, it may be desirable to use a single tunable laser to produce the chips at multiple wavelengths, but at high data rates, tuning the laser from one chip to the next at a different wavelength, may not be possible within a chip period. A guard time could be added to allow the laser to settle to the desired wavelength before the pulse is required, but this would reduce overall network speed and complicate operation since the settling time would depend on the distance in wavelength between two adjacent chips. The guard time may be eliminated if a bank of fixed–wavelength lasers, each tuned to one of the required wavelengths, were provided in each transmitter. The performance of the network is improved, but the cost of the system is increased. Alternatively a single broadband source may be spectrally sliced to provide all the required wavelength channels. With a large wavelength spacing (i.e.200 GHZ) lower–tolerance spectral filters could be used to keep costs low.[14]

3.5 Principle of OCDMA

The principle of OCDMA is based on spread spectrum techniques, which have been widely used in mobile-satellite and digital cellular communication system. The concept is to spread the energy of the optical signal over a frequency band that is much wider than the minimum bandwidth required to send the information. For example, a signal that conveys 10^3 b/ s may be spread over a 1 MHZ bandwidth. This spreading is done by a code, that is independent of the signal itself. Thus, an optical encoder is used to map each bit of information into a high rate optical sequence.

The CDMA technique has its origin in the spread spectrum (SS) technique. In SS transmission, the input signal is coded in such a way that its spectrum spreads over a much wider range than the original signal. At the receiver, the spreaded signal is decoded and its original form is restored. While despreading the input signal, unwanted noise or intentional jamming signals are spreaded, i.e. though input signal and distortion might carry the same power, the power spectral density of the distortion covers a wider area, thus, enabling the receiver to detect the input signal and noticing some additional, but

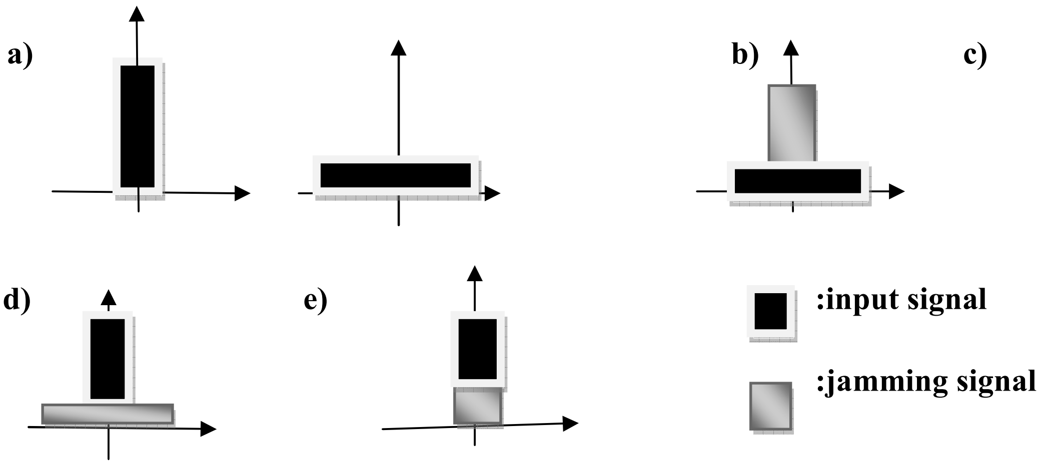


Fig.3.3.Principle of spread spectrum communication

only weak noise. Furthermore a despreading of the input signal is impossible without exact knowledge of the code sequence, thus increasing the security of the transmission.

a) Spectrum of input signal.
b) Spectrum of coded input signal (to be transmitted).
c) Jamming signal/noise overlapping input signal during transmission.
d) Decoded signal input signal is compressed; jamming signal/noise is spreaded.
e) Filtered signal at receiver, input signal can be detected.[11]

If each of the users is assigned to its own code sequence, which is orthogonal to all others they can all access the transmission medium at the same time, at the same carrier frequency, resulting is the so-called CDMA. CDMA has been of high attractiveness as multiple access schemes in radio applications because of:

1. Non-sensitivity against narrow-band jamming signals.

2. Efficient use of transmission medium in bursty traffic scenarios.

3. High security due to coded transmission.

In fiber optic communication, narrow band jamming signals are not to be expected on a fiber link, traffic is, if not in local area networks, rather of continuous nature than of bursty. Still, OCDMA can be of interest. Again, in LAN applications with burst traffic environment, CDMA is a first choice multiple access scheme due to low co-ordination necessary between different users. Whereas in TDMA schemes, all users are assigned to fixed time frames or, in WDMA schemes, to a fixed wavelength, this is not the case in CDMA transmission. In case of temporal or spectral overlapping, system performance decreases immediately in pure TDMA/WDMA applications. Especially in DWDM systems, wavelength drift has serious influence on an acceptable bit error ratio. This fact can be overcome by an upgrade of the DWDM system with OCDM. OCDM in a WDM transmission system can also help to weaken the effects of nonlinearities.

Spread spectrum multiple access (SSMA) uses signals, which have a transmission bandwidth that is several orders of magnitude greater than the minimum required RF bandwidth. A pseudo-noise (PN) sequence converts a narrow band signal to a wideband noise–like signal before transmission. SSMA also provides immunity to multipath interference and robust multiple access capability. SSMA is not very bandwidth efficient when used by a single user. Since many users can share the same spread spectrum without interfering with one another, spread spectrum systems become bandwidth efficient in a multiuser environment. [12]

There are two main types of spread spectrum multiple access techniques. Direct sequence multiple access (DS) and Frequency hopped multiple access (FH). Direct sequence multiple access is also called code division access.

3.6 Synchronous and Asynchronous OCDMA

Both synchronous and asynchronous OCDMA techniques have been used. Each of these has its own strengths and limitations. Since synchronous accessing schemes follow rigorous transmission schedule, they produce more successful transmission i.e. higher through puts than asynchronous methods, where network access is random and collisions between users can occur. In applications that requires real time transmission, such as voice or interactive video, synchronous accessing techniques are most efficient. When traffic tends to be bursty in nature or when real time communication requirements are relaxed, such as in data transmission or file transfer, asynchronous multiplexing schemes are more efficient than synchronous multiplexing.

3.7 Implementation of OCDMA Technology

Generally, there are two ways of implementation of OCDMA:

I. Encoding and decoding in electrical domain and transmission in optical domain: At the transmission, for encoding and decoding in electrical domain and transmission in optical domain requires electrical to optical converter and at the receiver requires optical to electrical converter. As we know the bandwidth of optical fiber is in tera Hertz, electrical devices that are used in it introduces electronic bottleneck and avoids the full utilization of fiber bandwidth.

II. All in optical domain: Above problem can be solved by using second technique i.e. all in optical domain/ photonic network that avoids optoelctronic conversion network. This technique uses some kinds of Orthogonal Codes (OOC) prime codes.

These codes make availability of full utilization of optical fiber bandwidth, that is the order of Tera bits/ second. OCDMA can be categorized into two types:

I. On the basis of working principle: It is further classified as in two types: Incoherent OCDMA and coherent OCDMA. In incoherent OCDMA the operation is performed on the basis of optical power and handled in unipolar manner (0,1) and in Coherent OCDMA operation is performed on the basis of field amplitude and optical codes are handled in bipolar manner (+1,-1) optical.

II. By processing dimensions: It is classified in two types, 1-Dimensional that are performed in time and frequency domain; and 2-D that is performed in time and frequency domain simultaneously. 2-Dimensional codes for incoherent OCDMA has been designed to reduce overall code dimension, provide increased flexibility in code design.

3.8 Features of Optical CDMA

1. CDMA finds application both in radio and optical communication systems.
2. Radio frequency communications systems use Bipolar codes, which cannot be used in asynchronous ,bursty environments
3. Radio communication system use two models: Direct sequence and Frequency Hopping CDMA Models.
4. Optical systems use unipolar codes, thus can be used in asynchronous environments.
5. Each user has its own code sequence.
6. Many users can transmit data simultaneously.

7. OCDMA communication systems require neither time nor frequency management schemes.
8. Lower latency.
9. No requirement of centralized control and does not effect from packet collisions.
10. Flexible network design.

3.9 Advantages of OCDMA

3.9.1 All Optical Processing: Unlike the wireless CDMA, the coding operations are performed all optically in OCDMA that is desirable for all the PON requirement. The all optical multiplexing results in as system in which channels can be carried at any combination of data rates and formats in an independent unsynchronized fashion.

3.9.2 Full asynchronous access: OCDMA network can work with fully asynchronous access without the requiring of complex and expensive electronic equipment and protocols. This unique advantage of supporting full asynchronous transmission mode makes OCDMA best suited for bursty traffic network. Since there is no need for TDM or temporal encoding, each channel operates at its native data rate. Since there is no need for repetitive optical to electrical to optical conversion at each node, there is no accumulation of temporal jitter and electronic regeneration is unnecessary.

3.9.3 Fair division of bandwidth: Dynamic allocation of bandwidth makes the adding of new subscribers or removing unsubscribed users from the network much easy. OCDMA provides a way for many active users to share the optical bandwidth in a fair manner.

3.9.4 Latency access: OCDMA could also provide low delay of access as the coding operations are performed all optically and passively .Multiple logical topologies can be supported simultaneously on the same physical network .For example ,a physical ring could be implemented for optical layer protection on top of which virtual rings, meshes, stars and trees can also exist. The broadcast nature of the system also lends itself to video distribution in a point to multipoint configuration.

3.9.5 Flexibility: The flexibility afforded by the tap-and-insert nature of the optical bus combined with the programmability of the trans-receivers enables the assignments of bandwidth and logical connections where they are needed. Increased flexibility of controlling the quality of service (QOS): OCDMA systems have the potential to be very flexible.QOS guarantees could be managed in physical layer by assigning different code in OCDMA networks.

3.9.6 Network Control and Management: If the optical codes are designed such that the non-shifted autocorrelation peak is large and the shifted autocorrelation peak is minimized, each receiver is able to operate asynchronously without the need for a global clock signal. Since the number of unique codes is equal to the number of stations on the network, there is no need for a centralized node to arbitrate channel contentions. Adding a new user on an O-CDMA system is as easy as assigning a new code. Unused codes are provided to the new user. If no free codes were available, the system could be upgraded to support more users by increasing the amount of time or wavelength domain spreading. The amount of coding overhead could also be increased if it were being violated .The use of incoherent sources and the spreading of each channel over multiple wavelengths affords spectral OCDMA an inherent tolerance to a variety of imperfections in optical components and the transmission medium such as centre wavelength shifts, slow drop offs at the edges of filters, polarization dependent loss and fiber non-linearities.

3.9.7 Service Differentiation: CDMA offers the possibility of offering differentiated service or QOS at the physical layer. Through the use of multirate OCDMA codes different service classes for multimedia traffic can be defined .Low rate codes could be used for email and file transfer. While high rate codes could be used for transfer of audio and video information. Each node would be assigned a distinct signature sequence for each of the possible code sets that may be encountered to avoid having two nodes transmit with a same address code.

3.9.8 Security: Finally, optical CDMA would offer an advantage that current access networks do not offer: inherent security. Sophisticated encryption is not required because OCDMA is already encoded and does not suffer from the same type of adjacent –channel crosstalk as DWDM i.e. centre wavelength shifts in filters do not results in the accidental reception of someone's else signal. Similarly OCDMA cannot result in the accidental reception of an unwanted channel as could occur with errors in synchronization in TDM. [7]

3.10 Disadvantages of OCDMA

Inspite of being a promising technology, there are still many drawbacks that limit its wide scale deployment. Following are some major disadvantages:-

3.10.1 Cost: The biggest barrier to the wide scale deployment of OCDMA is "cost". Cost not only affects OCDMA rather other multiple access technologies like WDMA also suffers from the same problem. They are also constrained by the need for expensive optical hardware .The need for all optical encoding/decoding hardware and broadband light source for OCDMA makes it much expensive.

In OCDMA each bit of information data is encoded by the signature sequence consisting of a number of shorter bits called chips. Each user is assigned one signature sequence called codeword. So the head end of an OCDMA network as well as user terminals would need to be able to generate 2D code words. At the encoder tunable fiber Bragg gratings are used. The tunability is achieved with piezoelectric devices that shift the centre frequencies of the gratings. Hence change the pattern of the code .So in order to avoid this optical hardware is required which is both expensive and bulky. Broadband light source: Filtering the output of a broadband light emitting diode (LED), spectrally slicing the amplified spontaneous emission (ASE)of an EDFA or combining the output of a number of laser diodes tuned to distinct wavelengths generate a broadband light source. Light produced by using laser diode array and the EDFA have the required power but are currently expensive but broadband LED is comparatively cheap, but light generated may not have enough intensity as is required by OCDMA applications.

3.10.1.1 Remedy to cost problem:

If an array of tunable lasers could be integrated on the same substrate as a waveguide based encoder and modulator costs as well as size would drop rapidly, while reliability and robustness would also improve. Install a single broadband light source at the head-end. The multi-wavelength light could be distributed by fiber to all nodes on the network for use in encoding data on the return path. So each node requires only encoding/ decoding hardware and not a dedicated broadband source.

3.10.2 Shot and beat noise: Shot noise is mainly due to quantized character of light radiation causes noise in the photo detected current. Average magnitude of the shot noise current is

$$E[i^2]=2\ e\ I\ B \tag{3.1}$$

Where, e= electron charge, I=DC current, B=Bandwidth

Beat noise or Phase induced intensity Noise (PIIN) is due to interference if fields of partially coherent light sources are added. Mean square noise current is

$$E[i^2]=1/2(1+P^2)\tau c\ B \tag{3.2}$$

Where τc =coherence time of light source, P= degree of its polarization

Shot noise and optical beat noise are considered as major physical channel impairments that limits the performance of OCDMA. As the bandwidth is shared in OCDMA, it is the optical power from other users on the same wavelength channels that leads to the beat and shot noise. The shot noise builds as the square root of the received optical power, proportional to the number of active users in an OCDMA systems thereby limiting the scalability of optical systems. Optical beat noise is considered as the dominant source of noise.[13]

3.10.2.1 Remedy to shot and beat noise: Forward Error Correction

Optical beat noise in O-CDMA systems can be cancelled through control of the optical phase coherence, but the shot noise cannot. Rather than rely on control of the optical phase which is both complex and expensive, a better approach may be to add forward error correction (FEC). FEC is expensive and impractical since the electronics necessary for error correction must run at the speed of optical transport. This may apply to high capacity backbone links, but the modest per user rate of access networks may render FEC cost-effective.

One solution would be to limit the maximum number of users on an O-CDMA access system, without changing the amount of coding overhead. This approach is equivalent to making the cells smaller in RF cellular networks. Controlling the MAI in the way would allow a 10^{-9} error rate at 1 Gb/s per user, without the need of FEC. The downside is an increased cost per user, since the subscriber base must be smaller.

Implement the FEC encoding/decoding using optical, rather than electronic, processing. It may be possible to design FEC codes that would rely solely on those signal-processing operations that could be implemented in optics, such as addition. Splitting, multiplexing, and demultiplexing. Fourier transforms and wavelength conversion. The electronic bottleneck would be removed, allowing the FEC coding to run at very high data rates.

3.10.3 Perception

A barrier to the acceptance of OCDMA in access or local area networks is the perception of the technology as inefficient, exotic or difficult to commercialize.

3.10.3.1 Remedy to perception problem: Inefficient OCDMA

Optical CDMA compensates for the scarcity of processing power by throwing more bandwidth at the problem. The “inefficient” use of spectrum by O-CDMA is really an attempt to perform processing functions in the optical, rather than electrical domain. Competing optical access technologies, such as WDMA, that do not employ spectral spreading may appear to use bandwidth more effectively; however, other factors should be included in these efficiency calculations. For example, WDMA will require a method to mediate channel access to avoid wavelength contention. Contention–based media access schemes such as carrier sense multiple access with collision detection (CSMA/CD) are difficult to implement and have the drawback of non-deterministic service. Time sharing could also be used to avoid contention; however, this requires synchronization among the nodes and may need a more complex protocol, especially if dynamic slot assignment is used. Through spectral spreading, OCDMA addresses these channel control problems without the need for complex protocols or extensive electronic processing. [7]

3.11 Basic limitation of OCDMA

A basic limitation of OCDMA using a coded sequence of pulses is that as the number of users increases, the code length has to be increased in order to maintain the same performance .Since this leads to shorter and shorter pulses, various ideas for solving this problem have been proposed. Alternatively, frequency domain methods based on spectral encoding of broadband incoherent sources e.g. LEDs or Fabry Perot Lasers have been proposed.[7]

3.12 Multiple Access Interference (MAI)

The optical CDMA systems suffer from other simultaneous users. As the number of simultaneous users increases, the bit error rate (BER) degrades because the effect of MAIs increases. In addition, even if the received optical power is large enough i.e. if the effect of noise is small, the effect of noise is small, the effect of MAIs is constant because the power of the transmitted pulse is equal among all users. Light pulses transmitted by different users may overlap. As the light source in each transmitter is assumed to be incoherent, total intensity at a chip is the sum of the intensities of the individual light pulses existing in that chip. The codes are designed to be sufficient different that the probability of mistaking one code for another is very low. However, when many users are transmitting simultaneously, many overlaps may occur. A receiver may then conclude that its target code was sent. This phenomenon is known as an error due to multiple access interference (MAI).As more users share the channel simultaneously; the effect of MAI becomes more significant. MAI increases the level of a pulse by integer multiple of the original pulse level. When pulse power is high and the photo detectors are of low noise, MAI is the dominant cause of performance degradation in OCDMA systems.

3.13 Optical Codes for OCDMA Networks

One of the common applications of Optical communication is Local Area Networks (LAN). The data traffic in a LAN originates from several users and has a bursty character. Therefore, CDMA which has asynchronous multiplexing and multiple access properties is suitable for LAN’s.

In CDMA system, spreading codes play an important role in the system performance. When codes are constructed from CDMA systems, two issues should be considered. One is the correlation property and is the code size. The correlation property is related to BER and the code size is connected to the capacity of the system. The latter is the major problem for one dimensional code, such as OOC's and prime codes. To overcome limitation of one-dimensional code, two dimensional codes are deployed.

There are several advantages of using two dimensional codes. Firstly, both the security and the cardinality of the code family are greatly increased. Secondly, the peaks of cross-correlation and out of auto correlation are reduced.

In earlier proposed systems, the spectrum was spread only in time domain (1-D). With the advent of cost effective multiwavelength optical communication technologies, two dimensional (2-D) spectral spreading codes have been developed. Two dimensional codes are categorized into time/space and time/wavelength encoding schemes. In the time/ space scheme each codeword is coded in time and space simultaneously .The system requires more ribbons and multiple star couplers. A configuration using many fiber ribbons and multiple star couplers may be complicated and hard to implement especially, when the number of users is large. Two dimensional codes spread along both the temporal and either the wavelength or spatial axis.

Due to non negativity constraint of the incoherent optical channel, conventional electronic codes cannot be directly applied. While optical codes with good correlation properties have been developed using exclusively the time axis, the spectral (Wavelength channel) domain has emerged in the development of pseudo orthogonal codes.

The 2-D spectral spreading codes allow greater exploitation of the fiber bandwidth. Using modest time domain chip rates result in cost effective implementation. The dramatically increased sophistication of functional photonic and opto electronic integrated circuits, which allow combined optical and electronic signal processing via a scalable process makes multiwavelength O-CDMA (MW-O-CDMA) a natural choice for local area networking.

3.14 Optical Orthogonal Codes

An optical orthogonal code is a family of (0,1) sequences with good auto and cross-correlation properties.

The choice of efficient address codes with good correlation properties for encoding the source bits is the key to an efficient CDMA system. In the RF CDMA systems, sequences consists of {-1,+1} values and are called the bipolar codes. Since the phase of the electromagnetic field can be detected directly, so the choice of both positive and negative bit values is natural. As CDMA is one of the dominant technologies of wireless microwave communication, the problem of optical code selection has been addressed. However, in optical systems, the signal energy is measured at the detector. Due to the non negative nature of incoherent photo detector, the direct application of bipolar codes to optical CDMA communication is not possible. As a result, only unipolar sequences consisting of {0,1} values can be used for optical CDMA systems. So, new families of CDMA codes called optical orthogonal codes (OOCs) have been designed specifically for unipolar systems. To reduce the crosstalk between users, an important property of the sequences (code words) is that produce a low correlation. OOC are a set of binary sequences with desired auto and cross correlation properties providing asynchronous multi-access communications with easy synchronization and good performance in OCDMA communications networks.

3.15 Fundamental properties of OOC's:

An (n, w, λ_a, λ_c) optical orthogonal codes C is a set of (0,1) sequences of length n and weight w (the number of one's in every codeword). The set is constructed so that it has the following two properties:

3.15.1 Autocorrelation Property :

For any code words x = (xo,x1,……,xn-1) Є C and any integer τ,0 ≤τ < n, the following inequality holds

$$\sum_{t=0}^{n-1} x_t x_{t+\tau} \leq \lambda_a \qquad 3.3$$

Cross correlation property:

For any two other code words x, y Є C and any other integer τ, the following inequality holds.

$$\sum_{t=0}^{n-1} x_t y_{t+\tau} \leq \lambda_c \qquad 3.4$$

When $\lambda_a=\lambda_c=\lambda$, OOC is denoted by (n, w, λ) for simplicity. The number of codeword is called the size of orthogonal codes. The size of the codeword is the number of codeword in C and is called cardinality and is denoted by[C].

There is an important additional consideration in any shared medium network. Since only a fraction of the nodes on a network will be transmitting at any given time, it is necessary to accommodate additional network members than simultaneous network users. Since each network member must be assigned a distinct code with all of the desired correlation properties, the size of the set of all allowed code words i.e. the cardinality of the code must meet or exceed the number of network members to be supported. The cardinality of a unipolar code set, which meets specified correlation properties is much less than the cardinality of a corresponding set of bipolar codes. Bipolar codes can be constructed such that the signals add to zero, leading to lower cross–correlation values and hence a larger number of available address codes; this cancellation is not possible in positive systems.

The upper bound on the cardinality of a set of CDMA codes with unity autocorrelation and unity cross correlation is

$$\Phi\ (n,w) \leq \frac{(n-1)}{w(w-1)} \qquad 3.5$$

Where n is the code length, and w is the code weight. To maximize the number of users that can be served simultaneously, the length should be made large and the weight small. The correlation being low tells that each sequence in the code can be easily be distinguished from a shifted version of itself i.e. the auto correlation is low and it can be easily distinguished from any combination of shifted version of other sequence in C i.e. the cross correlation is low.

A desirable property of a code is that it should be as large as possible i.e. contains as many code words as possible. This is to enable more users to access the channel. An OOC is said to be optimal if it has the maximum cardinality for a given n, w, λ. Optical CDMA extract data with desired code in the presence of all other user's optical pulse sequences, therefore set of code words should be designed to satify three fundamental conditions:

1. For any codeword the non shifted auto correlation, equal to the hamming weight of the codeword, should be made large as possible, this ensures that the receiver signal is much larger than the background noise in the system.

2. For any codeword the shifted auto correlation must be much less than the hamming weight of the codeword. This requirement ensures that the output of correlator receiver will be a small when the receiver is not synchronized with the transmitter and allows OCDMA to operate asynchronously without to operate asynchronously without the need for a global clock signal.
3. The cross–correlation between any pair of code words must be small .This property ensures that the each codeword can easily be distinguished from every other address sequence. This makes MAI insignificant compared to the energy contained in the receiver information bit.

3.16 Application of OOC's

In OCDMA many users are transmitting information over a common wide-band optical channel. The target is to design an efficient system, to allow the users to share the common channel. Traditional multiple access techniques such as frequency division multiplexing, time division multiplexing, collision detection or demand assignment require network synchronization at high speed (optical speed), and frequent conversions between the optical domain and the electronic domain. These requirements limit the efficiency of such an optical multiple access system. But if a code division multiple access system with optical orthogonal codes is applied, it simplifies greatly the complexity of the system, and achieves potentially higher transmission efficiency.[17]

3.17 Problem of OOC's

As the length of OOC's required should be large and weight required is small, effective optical orthogonal codes are very sparse. This has two important consequences for CDMA system design. Firstly the energy per encoded bit is low and may compromise the overall energy budget of the system. Secondly, very sparse codes imply that the chip period must be smaller than the source bit length. Very high speed (and hence expensive) electronic and optical equipment will be required to produce these very short pulses. Thus as the duration of each chip becomes shorter, dispersion effects could start to limit performance severely. The code weight also has a direct effect on the performance of an optical CDMA system. If the code weight were increased but the threshold level kept low, system performance would degrade since, by increasing the number of pulses per frame, one increases the probability of multiple code words overlapping in the same chip. To improve system performance both the code weight and threshold should be increased. It is then less probable that multiple users will occupy the same chip up to the level of the threshold, so MAI is reduced.[5]

3.18 Prime Codes

Prime codes are efficient for use in MW-O-CDMA systems. Prime codes have been focused as new codes for asynchronous sharing of a fiber-optic medium. The prime codes support all network users simultaneously with a bit error rate (BER) of less than 10^{-9}. Prime codes have low shifted auto correlation (λ_a) ensures synchronizability and low cross correlation (λ_c) suppress multi access interference (MAI) and thereby permits simultaneous access to the channel by many users. In a CDMA system, each data bit is encoded into a wavelength s(n), consisting of a code sequence or signature of N chips, which represents the destination address of that bit. Data bit 0 are not encoded. Each receiver correlates its own address f(n) with the received signal s(n).The receiver output r(n) is

$$r(n) = \sum_{k=1}^{N} s(k)f(k-n) \tag{3.6}$$

If the signal arrived at the correct destination ,then $s(n)=f(n)$, and equation 1 represents an auto correlation function .If the signal has arrived at an incorrect destination ,then $s(n)\neq f(n)$,and equation 1 represents a cross correlation function. At each receiver, it is necessary to maximiz the auto correlation function and minimize cross correlation function in order to optimize the discrimination between the correct signal and the interference. This can be accomplished by selecting a set of orthogonal codes sequences.[11] Many classes of binary signature sequences ,a strong auto correlation peak and zero cross correlation function can be obtained through bipolar(-1,+1) sequences. However current direct detection optical systems can only accommodate unipolar (0,+1) sequences ,so that codes intended for communication system in which both positive and negative levels are available are not necessarily optimal in a fiber optic environment using optical signal processing. Various optical (unipolar) pseudo orthogonal (non-zero cross correlation function) codes, such as Optical Orthogonal Codes. Among them a set of code sequences of length $N=P^2$ derived from sequences of length P, where P is a prime number. Prime sequence codes offer less possible code words within a code family, but the BER for a given code word length and number of simultaneous users is some orders of magnitude lower compared to an equivalent OOC code. Although CDMA systems generally have very low spectral efficiency, therefore it is of great interest to identifying the maximum spectral efficiency achievable using CDMA on non negative optical channel.[14]

3.19 Optical Orthogonal Codes

An optical orthogonal code is a family of (0, 1) sequences with good auto and cross-correlation properties. The choice of efficient address codes with good correlation properties for encoding the source bits is the key to an efficient CDMA system. In the RF CDMA systems, sequences consists of {-1, +1} values and are called the bipolar codes. Since the phase of the electromagnetic field can be detected directly, so the choice of both positive and negative bit values is natural. As CDMA is one of the dominant technologies of wireless microwave communication, the problem of optical code selection has been addressed .However, in optical systems; the signal energy is measured at the detector. Due to the non negative nature of incoherent photo detector, the direct application of bipolar codes to optical CDMA communication is not possible. As a result, only unipolar sequences consisting of {0, 1} values can be used for optical CDMA systems. So new families of CDMA codes called optical orthogonal codes (OOCs) have been designed specifically for unipolar systems. To reduce the crosstalk between users, an important property of the sequences (code words) is that produce a low correalation.OOC are a set of binary sequences with desired auto and cross correlation properties providing asynchronous multi-access communications with easy synchronization and good performance in OCDMA communications networks.

3.20 Applications of Optical CDMA

3.20.1 Wireless Optical CDMA LAN:

Wireless optical LANs will acquire importance where security is of great concern and where obtaining radio frequency band would not be economical. Wireless local area networks have gained attraction due to its feasibility, wide range of applications, market needs and consumer's considerable demands. Wireless LANs are of immense interest in places such as hospitals and inside planes where electromagnetic interference is of great concern. With progress in optical devices, technologies, considerable improvement in quality of service for such networks is achieved.

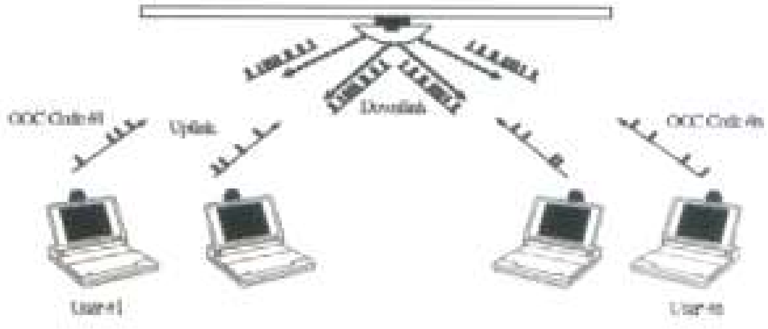


Fig.3.4. A typical Wireless OCDMA LAN[15]

WDM and TDM systems imposes higher cost and complexity in LAN, therefore CDMA find its place as it allows very flexible access of the large communication bandwidth available in optical fiber networks with a capability to conceal the data content in LAN. So, OCDMA is an attractive candidate for LAN application.[15]

3.20.2 Radio Over Fiber network based on OCDMA

Microcellular systems have difficulties such as radio signals transfer. To solve these radio-over fiber(ROF)systems are proposed, where microcells in wide area are connected by optical fibers and radio signals are transmitted over fiber links.

Optical code-division multiple access (OCDMA) is one of the candidate multiple access method for ROF systems because it has asynchronous access property and guarantees the high process gain by using the broad bandwidth of optical devices. In optical CDMA methods, there are time spreading CDMA, coherent coding CDMA , two dimensional(2-D)CDMA ,spectral encoding CDMA and so on. However the coherent coding CDMA and 2-D CDMA are complicated for radio signal transmission .And this time spreading CDMA for ROF systems might need or carrier synchronization, and the band pass sampling technique with an aliasing canceller has been introduced for improving the carrier-to-interference ratio(CIR).[16]

On the other hand, the spectral encoding CDMA can regenerate the information data without any synchronization. Furthermore, the proposed spectral encoding CDMA with the bipolar capacity can receive radio signals without any sampling techniques. The bipolar capacity can be obtained by pseudorandom noise (PN) codes or walsh codes in time spreading CDMA and spectral encoding CDMA. In the general optical CDMA by using PN codes ,the difference between the number of “1”and the number of “0” which is always one causes the channel interference or multiple access interference (MAI).The modified PN codes to reduce the channel interference have the same number of “1” and “0”.

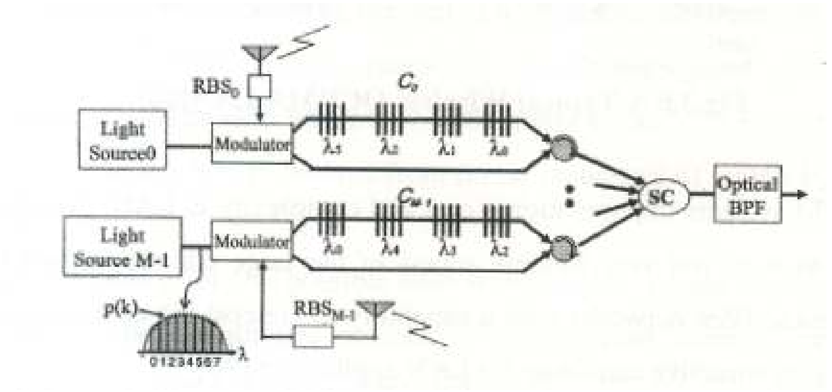


Fig.3.5: FBG encoder for receiving the radio signal [18]

The schematic diagram of the proposed ROF system using FBG-based CDMA with modified PN codes is depicted in Fig.3.5.The light from a broad band light sources(such as a light emitting diode)is inserted to a 1*2 dual output intensity modulator. The received radio signal from a radio base station (RBS) modulates the optical signal from the light source at the dual output intensity modulator is in-phase and the other upper output is π out of phase with the received radio signal.The upper and lower outputs are inserted to a star coupler (SC) by transmitting and reflecting at the FBGs of which the centre wavelengths are arranged by modified PN codes, respectively.

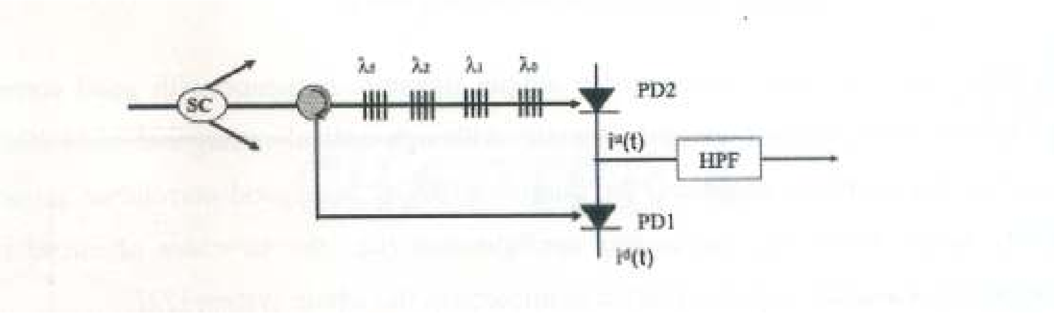


Fig.3.6:FBG decoder with bipolar capacity by using balanced detection[18]

The light outputs from the modulators of the encodes are emerged at an M*1 SC and transmitted into the decoders through one fiber in Fig.3.8. In order to discriminate the light of the unused wavelength, an optical band pass filter is needed. As a 1*M SC connects with FBG decoders ,each FBG encoder transmits its spectral encoded signal to all FBG decoders .The FBG decoder with bipolar capacity is shown in fig.3.8[18].The transmitted light field and the reflected light field complements each other at the FBGs. Out of the received signal spectra, the transmitted light field is detected by the upper photodiode PD2 and the reflected light field is directed to the lower photodiode PD1 by a circulator and detected .The two output current signals are subtracted, and the desired data are regenerated at the output of a high pass filter (HPF).[18]

3.20.3 Multimedia Transmission employing OCDMA

Multimedia communication has been expected in high speed optical networks due to the growing applications of multimedia. In such communications, various signals with different required performance are included in the network according to the media such as data, voice and so on. Since the required data rate and bit error rate (BER) are different depending on these information sources, various signals with different rate and quality must be accompanied in the network. In optical communication systems, there has been increasing interest in optical code-division multiple access (OCDMA) system due to its many attractive features such as vast bandwidth, high speed signal processing and accommodating large number of simultaneous users.

In OCDMA, each user is assigned a unique signature with good correlation properties, consisting of unipolar signals. Although, optical orthogonal code (OOC) is used as the signature sequence, the number of OOC with good correlation property is fairly small. Moreover, the coding configuration (i.e. the structure of encoders and decoders) is another important factor to implement the whole system.[22]

CHAPTER 4

Effects of Dispersion in an OCDMA System

4.1Abstract: The effect of dispersion and dispersion compensation in an OCDMA system is studied. An OCDMA system with no dispersion is also analyzed. An analysis is presented to evaluate the impact of fiber chromatic dispersion on the bit-error-rate (BER) and the Q factor.. Eye diagrams have been taken at different stages in OCDMA system in order to study the effect of dispersion.

4.2.Introduction

Optical fiber with its infinite bandwidth opened a new area in telecommunication technology, that is optical networking. Multiple access technique would be the key to realize high-speed and large-capacity of optical networks by allowing multiple users to share the fiber bandwidth. O-CDMA has drawn much attention in recent years due to its potential for enhanced information security [1], simplified and decentralized network control and management [2], improved spectral efficiency [3], and increased flexibility in the granularity of bandwidth that can be provisioned in local-area-networks (LANs) [4].

In an O-CDMA system, each bit is divided into n time periods, called chips. By sending a short optical pulse during some chip intervals, but not others, an optical signature sequence, or codeword, can be created. Each user on the O-CDMA system has a unique signature sequence. The encoder of each transmitter represents each 1 bit by sending the signature sequence; however, a binary 0 bit is not encoded and is represented using an all-zero sequence. Since each bit is represented by a pattern of light and no-light chips, the bandwidth of the data stream is increased. O-CDMA is therefore a spread-spectrum technology. The O-CDMA encoded data is then sent to the N x N star coupler (in a local-area-network) or a 1 x N coupler (in an access network) and broadcast to all nodes. Figure 4.1 [5] shows one such network in a star configuration.

The set of O-CDMA optical pulse sequences basically becomes a set of address codes or signature sequences for the network. To send information from user j to user k, the address code for receiver k is impressed upon the data by the encoder at the jth node. One of the primary goals of O-CDMA systems is to extract data with the desired optical pulse sequence in the presence of all other users' optical pulse sequences.

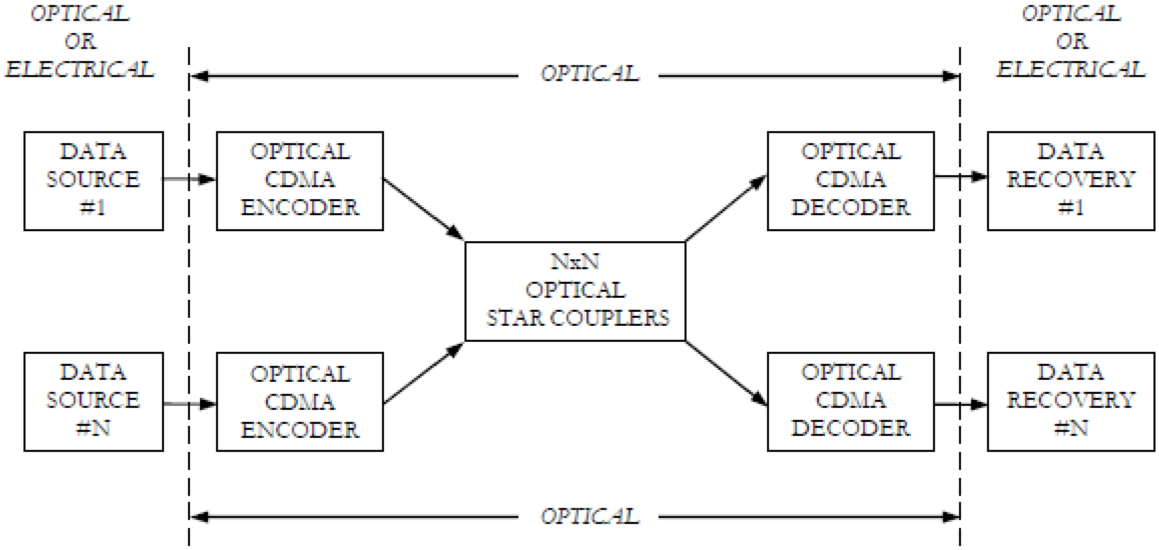


Figure 4.1. A schematic diagram of an O-CDMA communication system with an all-optical encoder and decoder in a star configuration.

The crosstalk between different users sharing the common fiber channel, known as the multiple access interference (MAI), is usually the dominant source of bit errors in an O-CDMA system.

An intelligent design of the codeword sequences is important to reduce the contribution of MAI to the total received signal. One therefore needs to design sequences that satisfy two conditions [6]-[9], namely:

i. Each sequence can be easily distinguished from a shifted version of itself (autocorrelation property).
ii. Each sequence can be easily distinguished (a possibly shifted version of) every other sequence in the set (cross-correlation property).

Recently, the performance of an asynchronous phase-encoded OCDMA system considering fiber chromatic dispersion has been reported in [10] in the case of standard single-mode and dispersion-shifted optical fiber. In this chapter, analysis is carried out for direct-sequence OCDMA system with intensity modulation and direct detection (IM/DD) sequence, in the presence of fiber chromatic) to evaluate the bit-error-rate (BER) performance degradation due to dispersion. Two dimensional wavelength time codes [11] are considered to investigate the performance for different values of fiber dispersion.

4.3. Simulation system

The simulation setup of an OCDMA system is shown in figure 4.2. Four wavelengths laser sources are multiplexed to form a broadband source. The output of multiplexer is given to the optical input of modulator. Another input to the multiplexer is the data. A PN sequence is generated in the form of logical data from the PN sequence generator. This logical data is converted to the electrical data through the NRZ driver. After that this data is fed into the electrical input of modulator. The modulator modulates the light according to the input data. After the modulator, encoder is placed to encode the data. This is two dimensional encoder which encodes the data in both the time and wavelength domain. After that amplifier is placed. Then single mode fiber is used. At the receiver side decoder is implemented by inversing the encoder. Then the receiver is placed which will convert the optical signal into the electrical one. Eye diagram analyzer, BER tester and Electrical signal plotter is used to analyze the various outputs. Eye diagram analyzer is used to take the eye diagrams. BER tester is used to measure the BER of the received signal. Electrical signal plotter is used to take the received electrical signal.

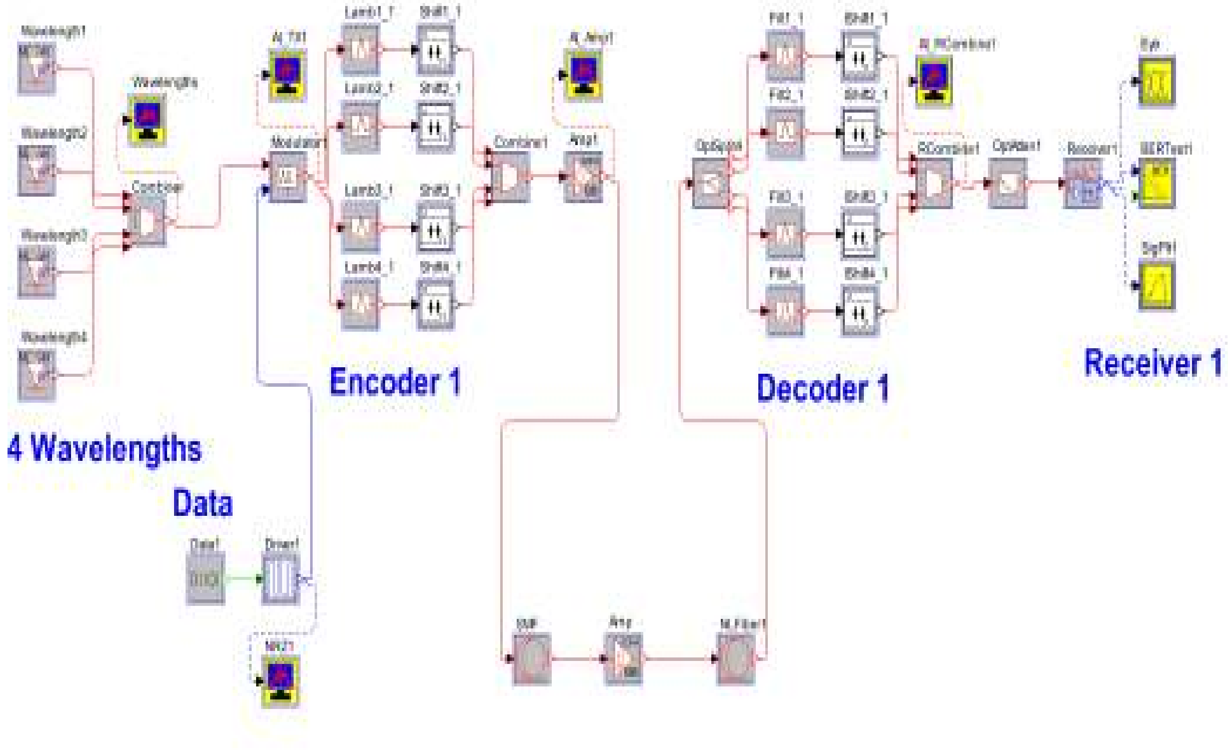
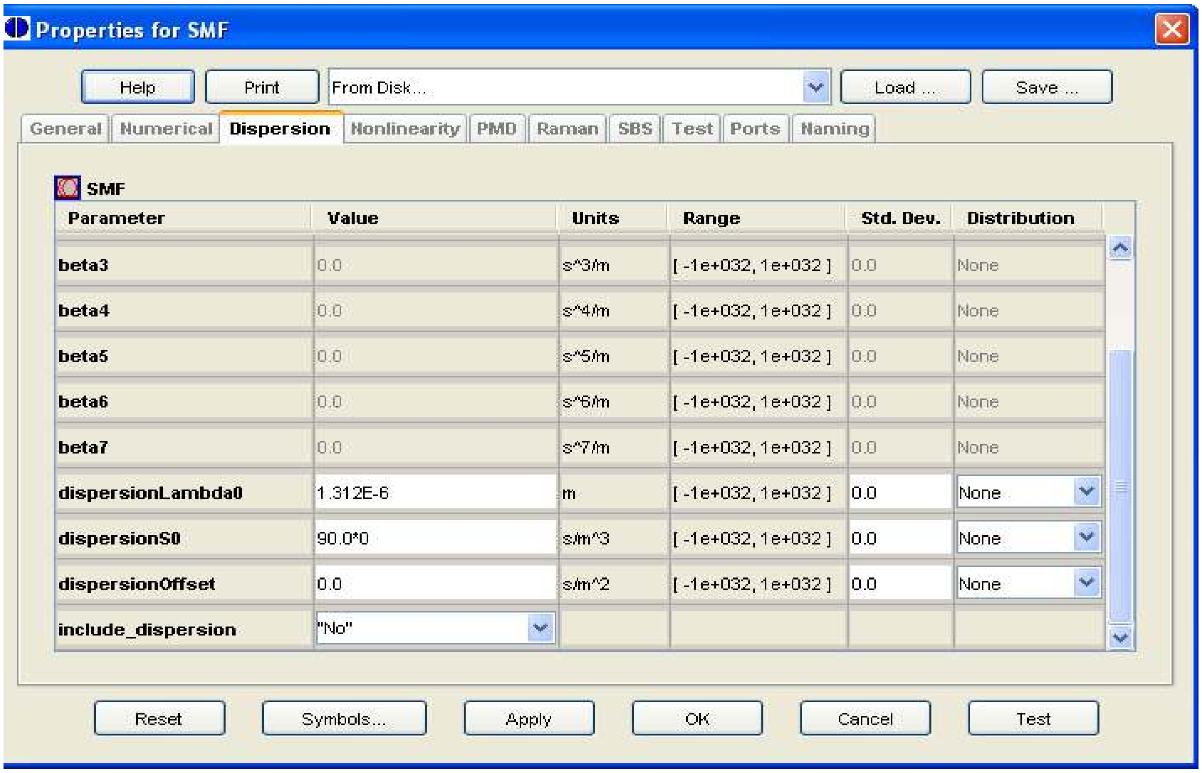


Figure4.2. Simulation setup of an OCDMA system

The circuit is simulated for three cases

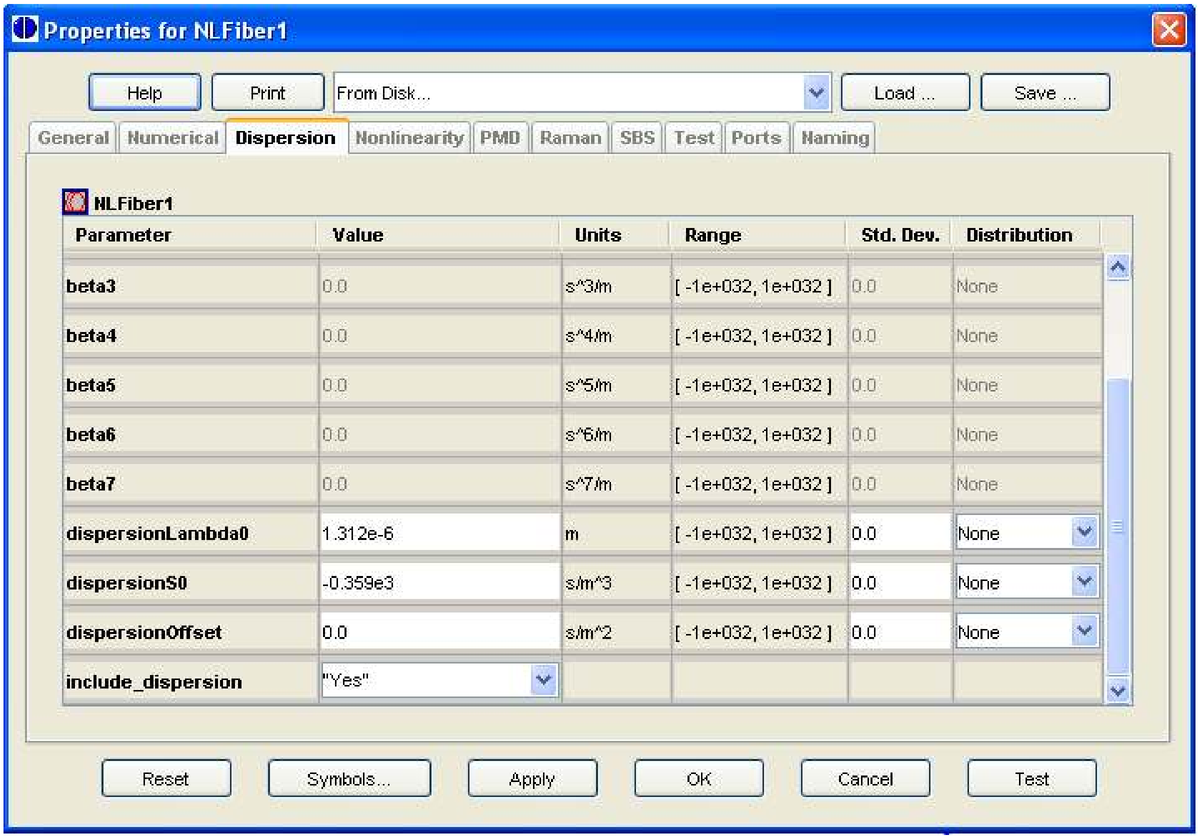
1) No dipersion
2) With dispersion
3) With dispersion compensation

For the first case, no dispersion is applied to the optical signal. For the second case, a particular value of dispersion is applied after the optical fiber. The dispersion parameters are shown in table 1. For the third case, dispersion compensating fiber (DCF) is used to compensate the applied dispeersion in the optical fiber. The most common dispersion compensation technique used in long-haul links uses short lengths of DCFs followed by relatively longer lengths of transmission fibers. This is also known as post-compensation of chromatic dispersion. The 20-km of DCF has negative dispersion slope. The net accumulated dispersion is non-zero in order to help control nonlinearity-induced performance penalties..The various parameters for DCF are shown in table 2. Various graphs have been taken for these three cases to analyze the effect of dispersion in an OCDMA system using the software Optsim.



Parameter	Value	Units	Range	Std. Dev.	Distribution
beta3	0.0	s^3/m	[-1e+032, 1e+032]	0.0	None
beta4	0.0	s^4/m	[-1e+032, 1e+032]	0.0	None
beta5	0.0	s^5/m	[-1e+032, 1e+032]	0.0	None
beta6	0.0	s^6/m	[-1e+032, 1e+032]	0.0	None
beta7	0.0	s^7/m	[-1e+032, 1e+032]	0.0	None
dispersionLambda0	1.312E-6	m	[-1e+032, 1e+032]	0.0	None
dispersionS0	90.0*0	s/m^3	[-1e+032, 1e+032]	0.0	None
dispersionOffset	0.0	s/m^2	[-1e+032, 1e+032]	0.0	None
include_dispersion	"No"				

Table4.1 – Dipersion parameters for Single mode fiber to apply dispersion.



Parameter	Value	Units	Range	Std. Dev.	Distribution
beta3	0.0	s^3/m	[-1e+032, 1e+032]	0.0	None
beta4	0.0	s^4/m	[-1e+032, 1e+032]	0.0	None
beta5	0.0	s^5/m	[-1e+032, 1e+032]	0.0	None
beta6	0.0	s^6/m	[-1e+032, 1e+032]	0.0	None
beta7	0.0	s^7/m	[-1e+032, 1e+032]	0.0	None
dispersionLambda0	1.312e-6	m	[-1e+032, 1e+032]	0.0	None
dispersionS0	-0.359e3	s/m^3	[-1e+032, 1e+032]	0.0	None
dispersionOffset	0.0	s/m^2	[-1e+032, 1e+032]	0.0	None
include_dispersion	"Yes"				

Table4.2- Dispersion parameters for dispersion compensating fiber.

4.4. Results and Discussion

The components are used for measuring, analysis and plotting are multiplot, spectrum analyzer, eye diagram analyzer, signal plotter, BER tester. The component multiplot is used to measure electrical spectrum, eye diagram, and electrical signal. Eye diagram analyzer is used to take the eye diagrams. BER tester is used to measure the BER of the received signal. Electrical signal plotter is used to take the received electrical signal.

Figure 4.3 shows the transmitted spectrum consisting of four wavelengths. The input signal before transmission is shown in figure 4.4. The output spectrum of the encoder is shown in figure 4.5. In the encoding process, different wavelengths are given different delays according to the coe used in the encoder. Then eye diagram after encoding is also shown in the figure 4.6. In figure 4.7 spectrum after decoding is shown in orde to show that same code is used at the reciever side in the decoder.

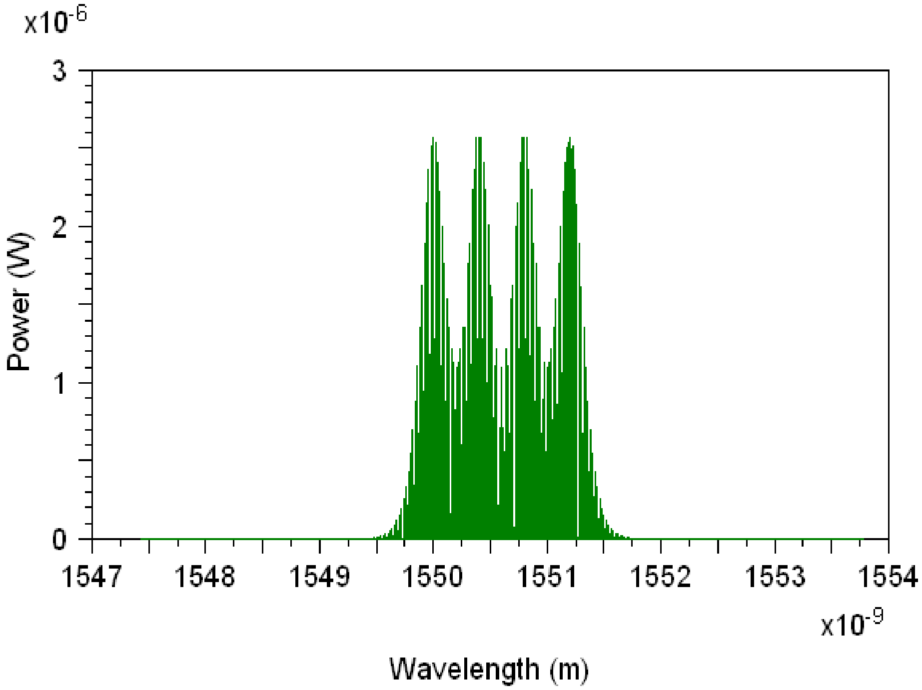


Figure4.3- Trasmitted spectrum consisting of four wavelengths.

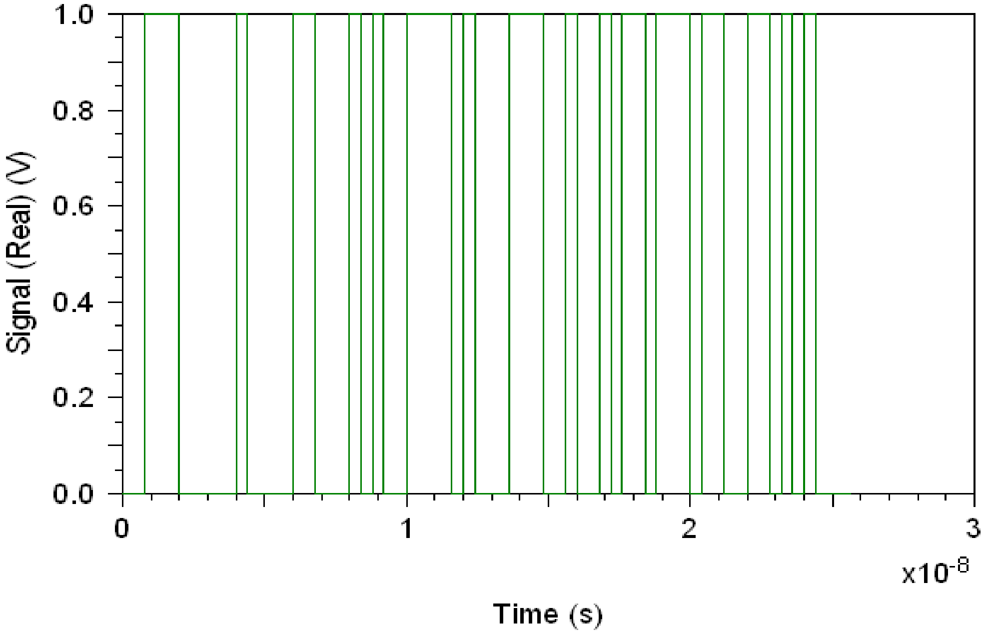


Figure 4.4- Input signal before transmission

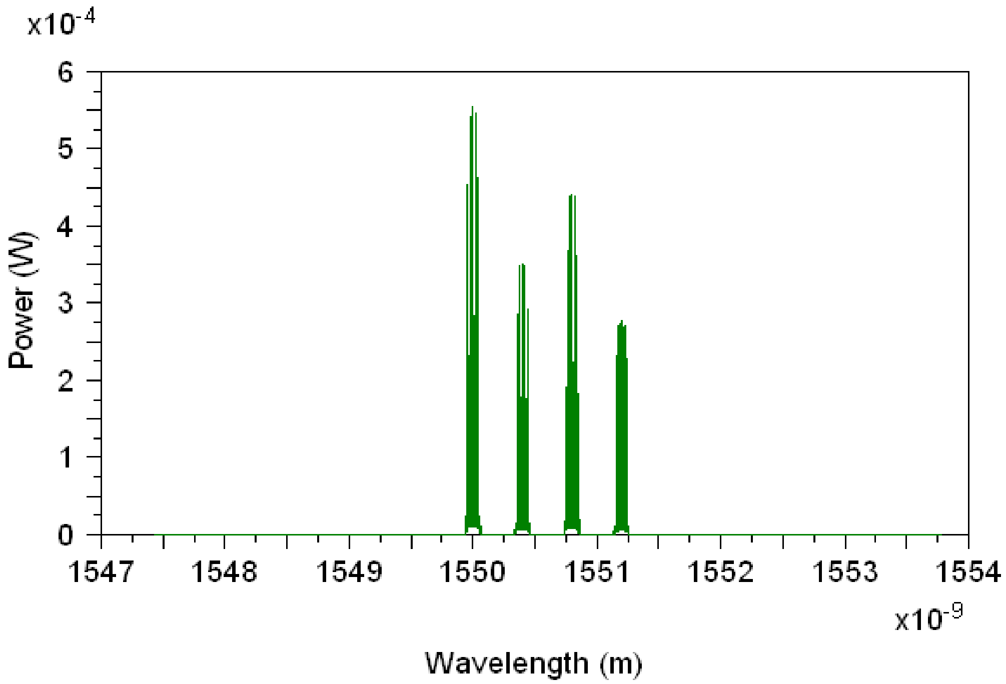


Figure 4.5 – Spectrum after encoding

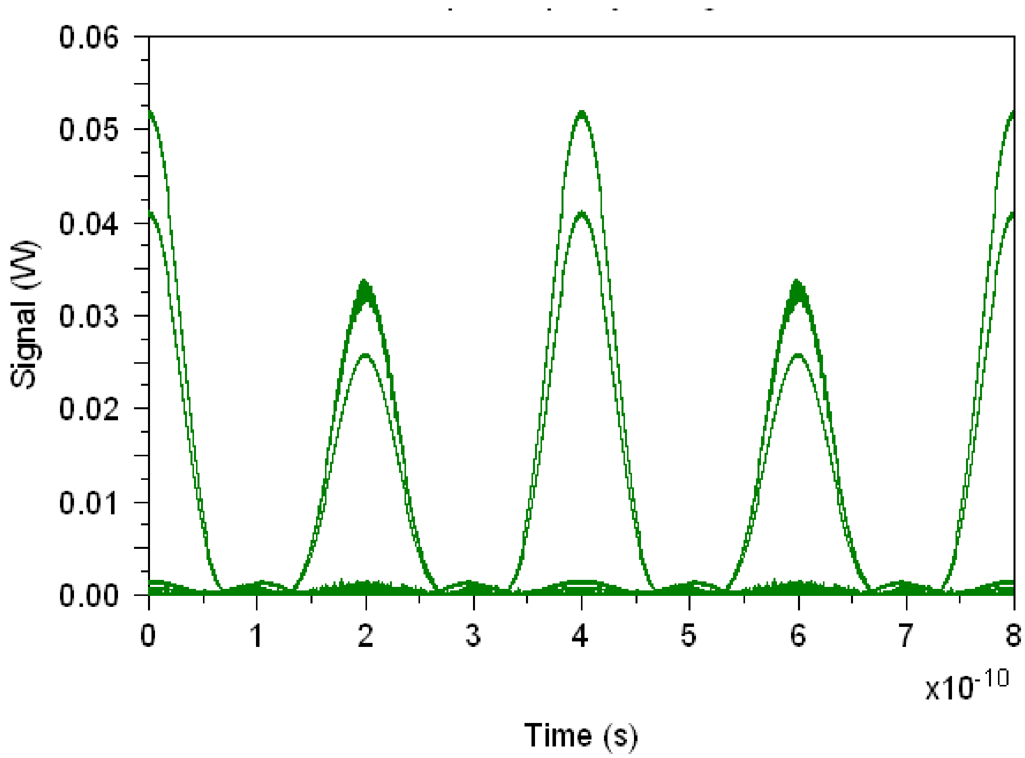


Figure 4.6- Eye diagram after encoding

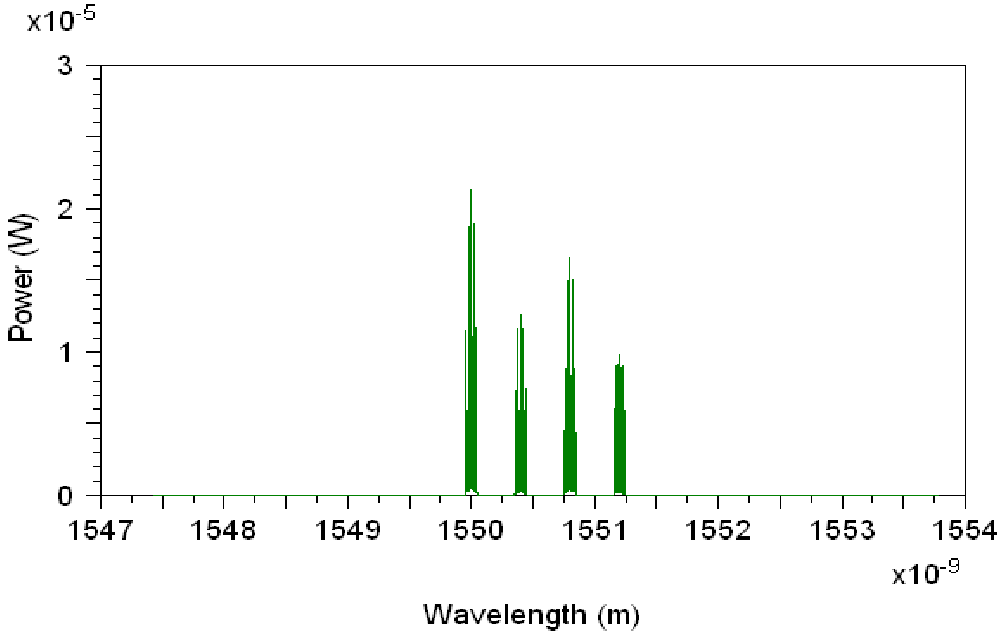


Figure4.7 – Spectrum after decoding

Figure 4.8 shows eye diagram after the decoder with no dispersion. Figure 4.9 shows the eye diagram at the reciever side with no dispersion. In this figure, a clear eye diagram can be observed. Figure 4.10 shows received siganl with no dispersion.

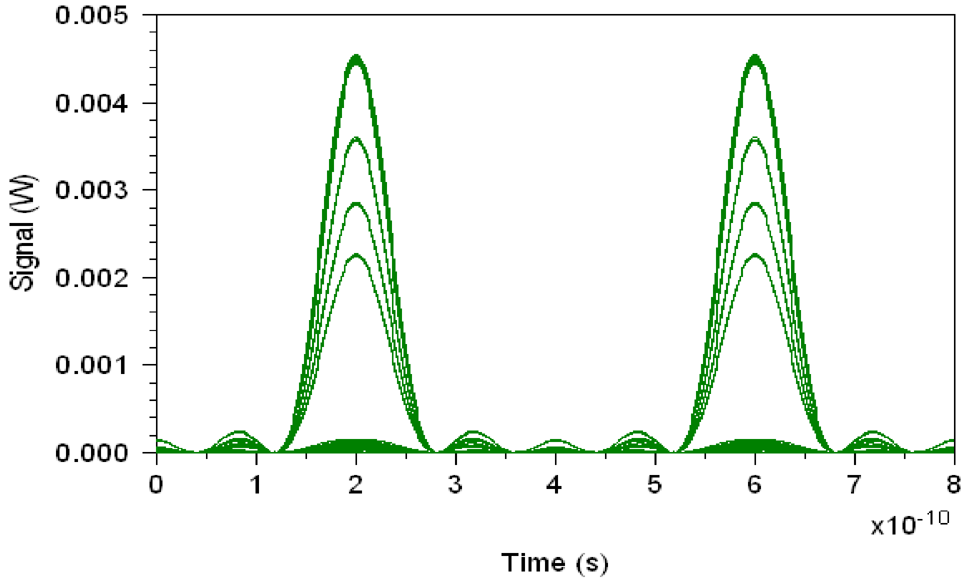


Fig 4.8 - Eye diagram after the decoder with no dispersion.

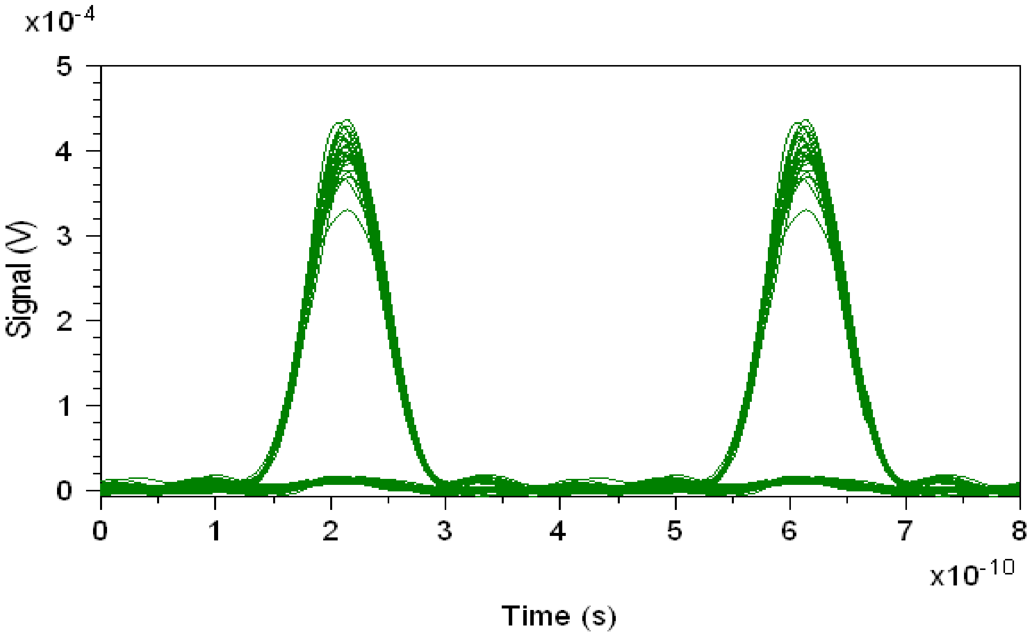


Figure 4.9 - Eye diagram at the receiver side with no dispersion

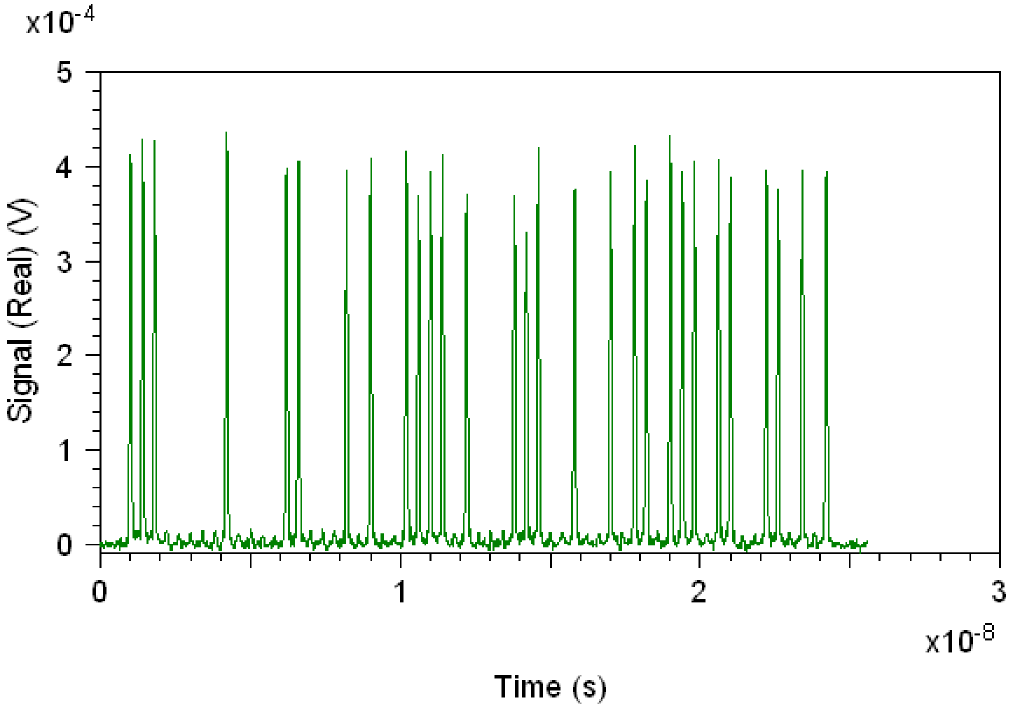


Figure 4.10 – Received signal with no dispersion

Figure 4.11 shows eye diagram after the decoder with dispersion. Figure 4.12 shows the eye diagram at the receiver side with dispersion. In this figure, eye opening decreases as compared to eye opening in the eye diagram with no dispersion. The BER rate is very high which is $10^{-1.1}$. Figure 4.13 shows received signal with dispersion.

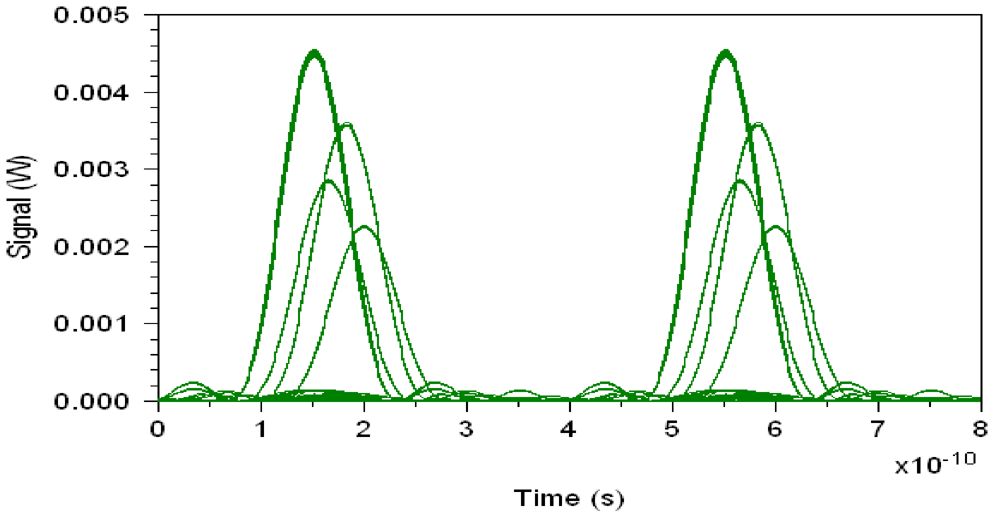


Figure 4.11 - Eye diagram after the decoder with dispersion.

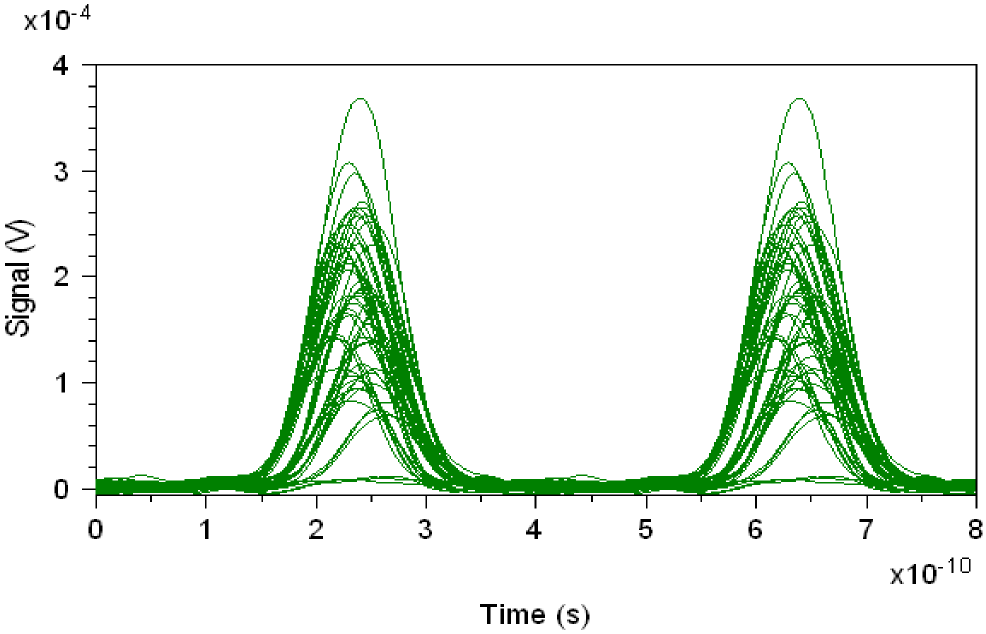


Figure 4.12 - Eye diagram at the receiver side with dispersion

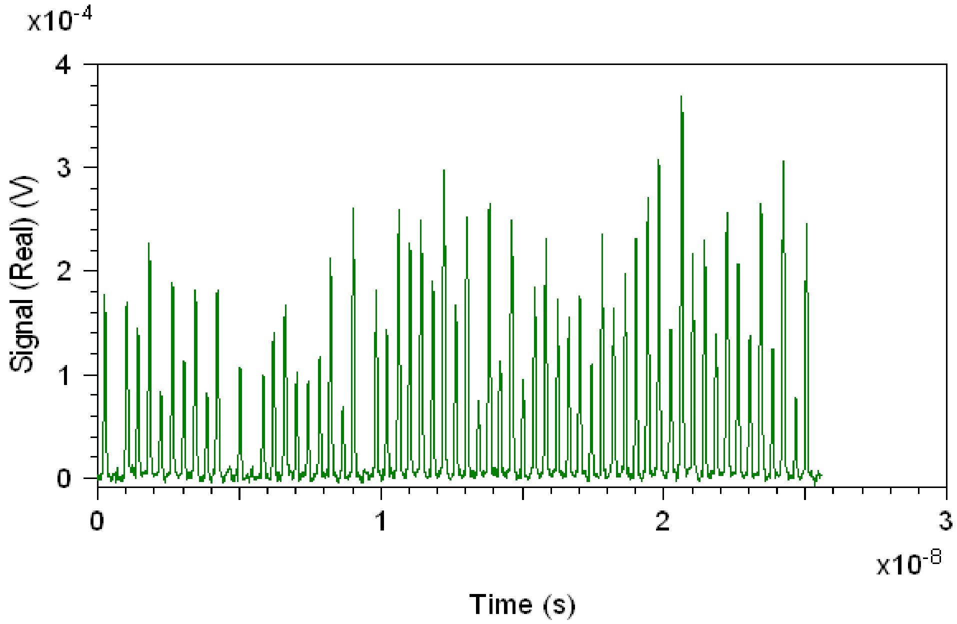


Figure 4.13 – Received signal with dispersion

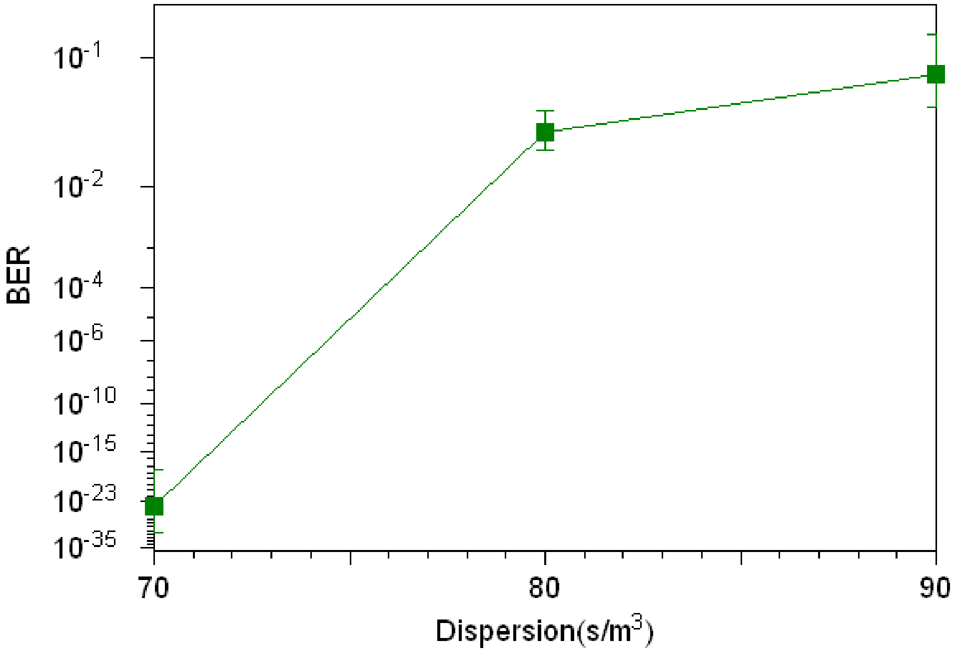


Figure 4.14- BER versus Dispersion

Figure 4.14 shows variation of BER for different dispersion values. As the dispersion is increased BER als increases and the received signal degrades. Figure 15 show variation of Q factor with the dispersion value. Q factor decreases with the increase in dispersion value.

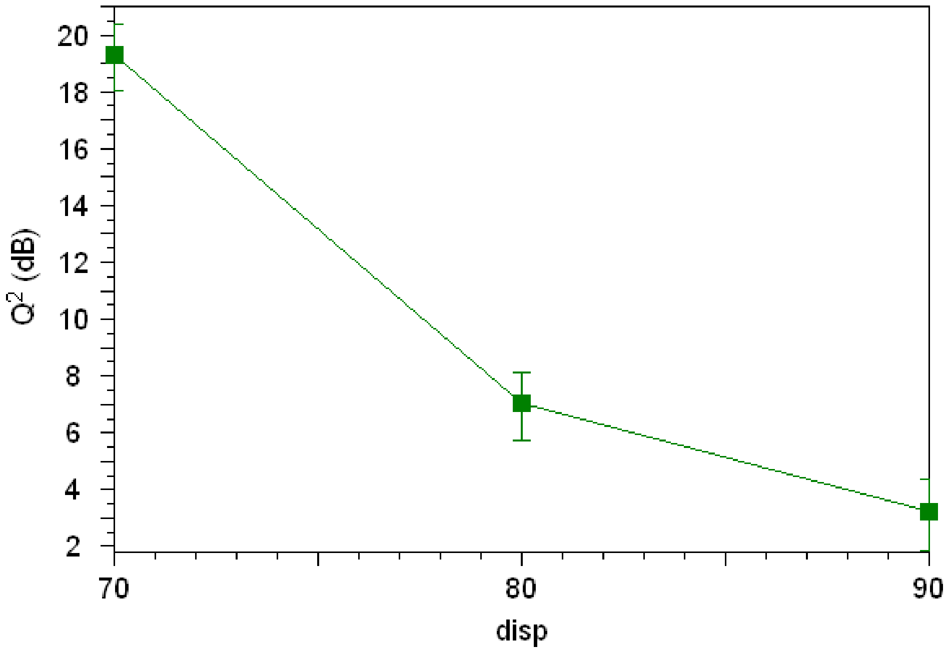


Figure 4.15- Q factor versus Dispersion

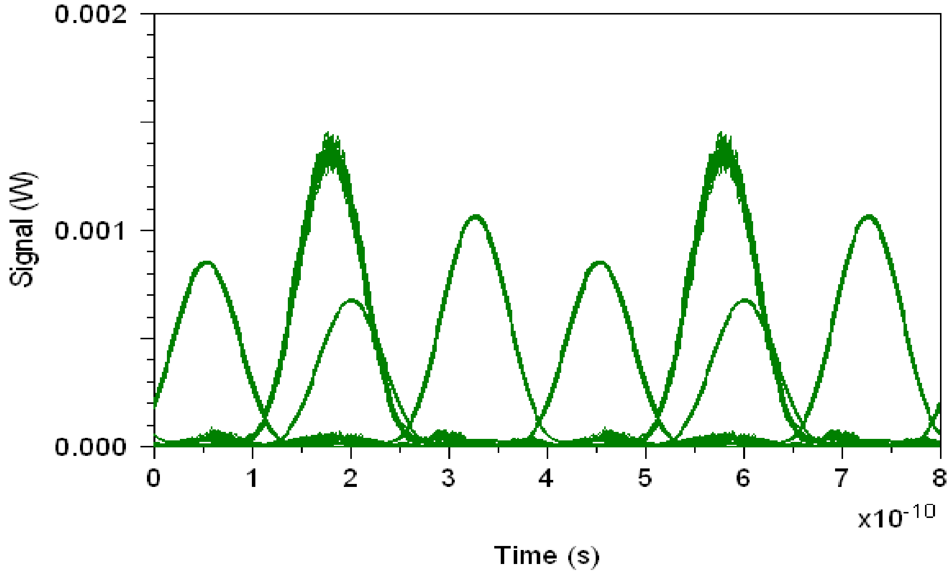


Figure 4.16 - Eye diagram after the decoder with dispersion compensation

Figure 4.16 shows eye diagram after the decoder with dispersion compensation. Figure 4.17 shows the eye diagram at the receiver side with dispersion compensation. In this figure, eye opening increases as compared to eye opening in eye diagram with dispersion. For this eye diagram the BER rate is very is 10^{-9} which is acceptable. Figure 4.18 shows received signal with dispersion compensation. The degradation of eye is due to the noise which is added at the receiver.

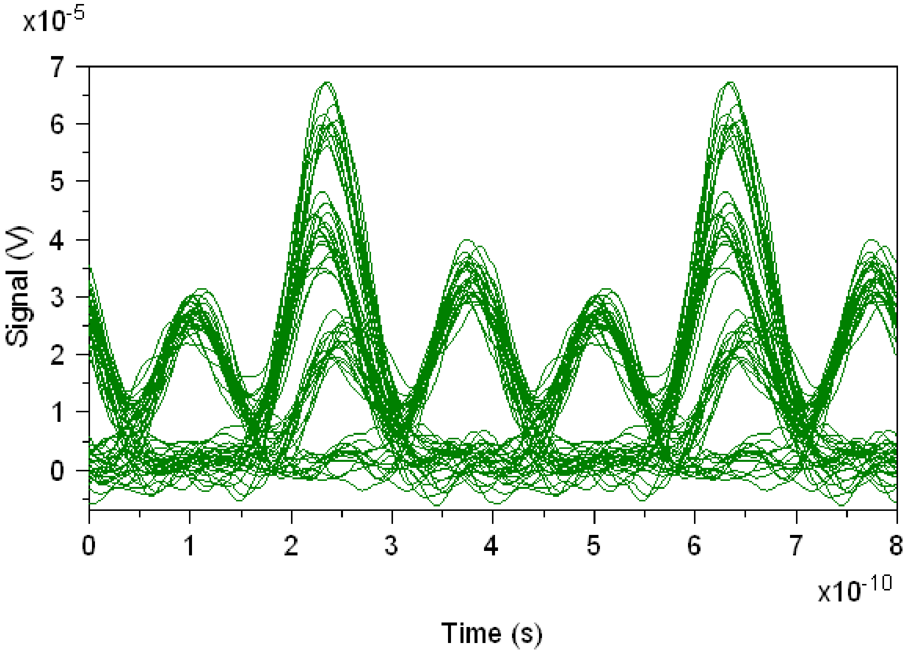


Figure 4.17 - Eye diagram at the receiver side with dispersion compensation

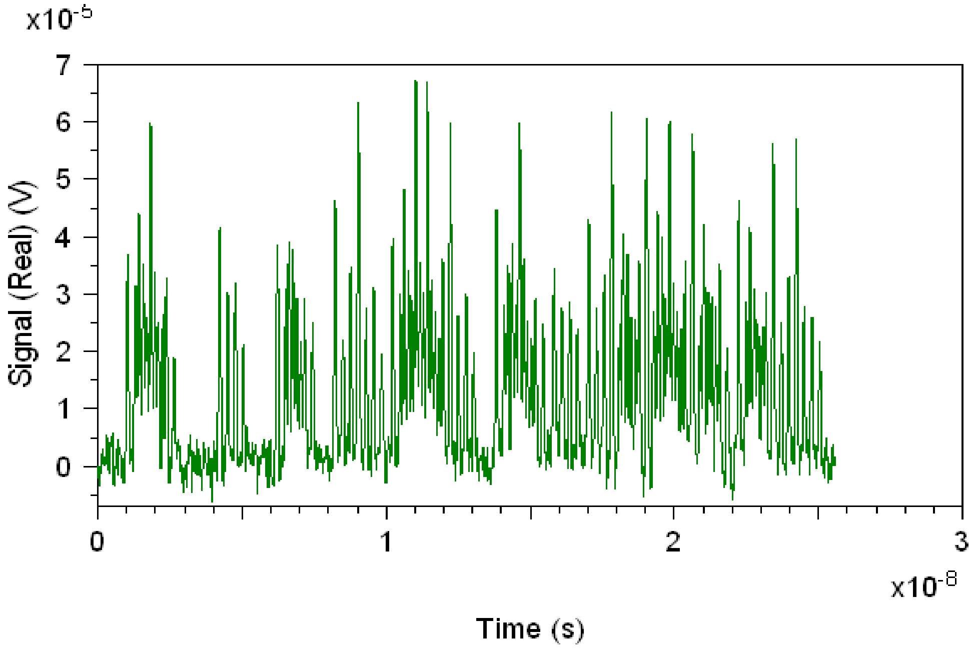


Figure 4.18 – Received signal with dispersion compensation

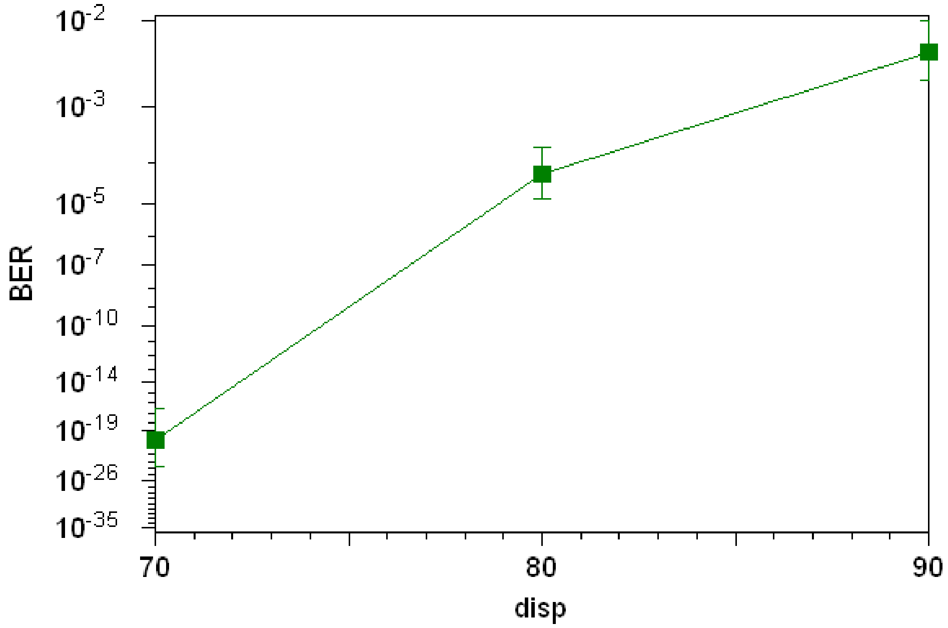


Figure 4.19- BER vesus Dispersion with Dispersion compensation

Figure 4.19 shows variation of BER for different dispersion values when dispersion compensation is applied. As the dispersion is increased BER als increases but the BER rate is low as compared with the BER values when dispersion is applied. Figure 20 show variation of Q factor with the dispersion value. Q factor decreases with the increase in dispersion value.

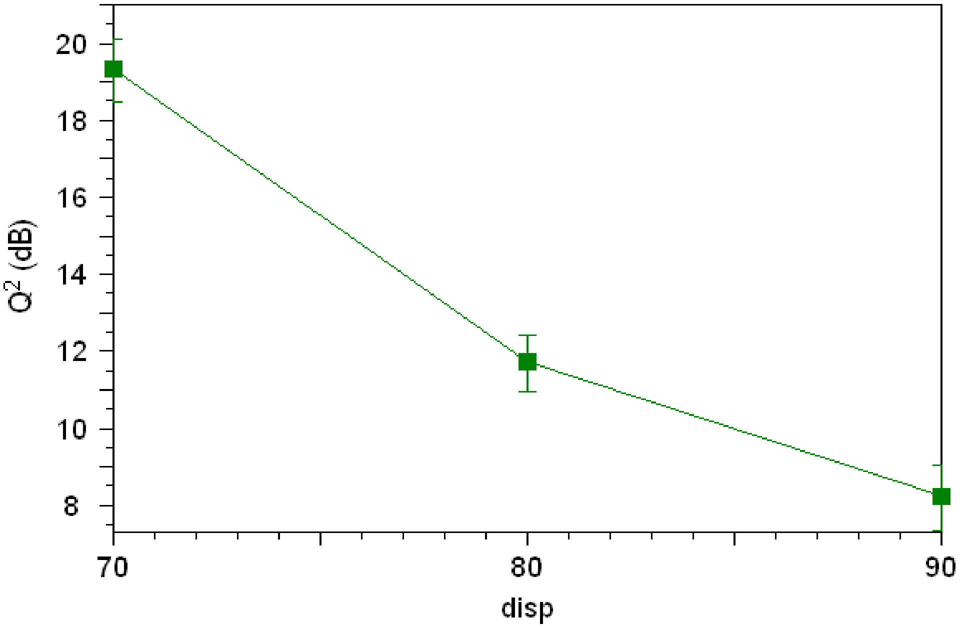


Figure 4.20- Q factor versus Dispersion with Dispersion compensation

4.5 Conclusion

An OCDMA system is simulated with no dispersion, dispersion and dispersion compensation in order to analyze the effects of dispersion. Various graphs have been taken to evaluate the impact of fiber chromatic dispersion on the bit-error-rate (BER) and the Q factor. Eye diagrams have been taken at different stages in OCDMA system in order to study the effect of dispersion. Received signal is also measured in all the cases.

CHAPTER 5

Investigations on 10 Gb/s optical communication system with fiber type on timing jitter performance

5.1 Abstract: In this chapter, a simulation effort for 10 Gb/s optical communication system is done to select the fiber from the standard fibers available from some reputed fiber sources. The comparison on the basis of measured bit error rate (BER), Q-value, timing jitter and eye diagrams has been taken and presented. It was found that dispersion shifted normal & anomalous fibers give best performance among the fibers considered, second best performance is given by Corning LEAF fibers.

5.2:Introduction

For long distance optical communication systems, the performance deciding parameter are bit error rate (BER), quality factor (Q value) and timing jitter (TJ). Many sources of degradation of these parameters in optical communication systems have been found and its remedial solutions have been proposed [1], [2]. Still there is lot to be done to find the proper solution of timing jitter and dispersion compensation.

It is widely known fact that communication channel plays a major deciding role in defining the performance of a communication system. Signal through the fiber as channel in the form of pulses, whatsoever shape may be, lose its identity at the farthest end over long distance of transmission. Periodically spaced amplifiers are added to the fiber line to boost the signal power and hence helping to preserve the information being carried. In the mid-eighties, it was discovered by Gordon and Haus that these amplifiers add noise to the pulses which caused a timing shift [3], [4], [5]. Essentially it means, the pulses are moved out of their allotted time slot and hence are misread at the receiver end of the channel. The problem of not maintaining the pulse position in such system due to spontaneous emission is known as Gordon-Haus timing jitter. Other factors that affect the optical system performance are Kerr effect, PMD, Raman crosstalk, fiber birefringence etc. With the addition of wavelength-division multiplexing, the role of pulse interactions in the system becomes important to watch. Sending multiple pulses along a fiber line requires that more than one pulse in the same channel and pair wise interactions will further degrade performance. The two main issues that arise when dealing with multiple pulse interactions are: collision-induced timing jitter, four-wave mixing products. Ultra-high performance optical fiber greatly reduces jitter and maintains optimum signal integrity.

To observe the effect of the fiber selection in optical communication system different type of fibers with typical values are taken & listed in the table 1. System simulations are done under the objective to select a fiber of best performance is presented, onwards.

5.3 System description

The optical communication system model considered for simulation is shown in the following figure 1. The model consists of components with their respective characteristics as per details given in the following lines, starting with data source. Data source block simulates a pseudo-random or a deterministic logical signal generator. Besides the logical signal, this component generates an electrical signal synchronized to the baud rate. The bit-time in simulation, i.e. the time-duration of the bit, must be an integer number of time-samples NS (Samples per bit value). Parameters of basic attribute section taken are 10 Gb/s bit rate, 10 Gb/s baud rate, 474 samples per bit, one bits/symbol and 7 degree pseudorandom sequence.

Driver block simulates an electrical driver which converts the logical input signal to a binary sequence of zeros and ones into an electrical signal. This component acts as RZ rectangular driver. It has an output signal that can assume two electrical levels. When a "1" is transmitted, the output signal is at the high level for a time equal to the product of the duty cycle by the bit time. Then it goes down to the low level for the remaining time. When a "0" is transmitted, the output is constant at the low level for the entire bit time. Switching between the two levels is instantaneous with resulting square edges. It uses RZ rectangular shape as signal type, -2.5, 2.5 are low level and high level respectively with duty cycle 0.5.

Laser block shows simplified continuous wave (CW) laser. Its phase noise is taken into account by generating a Lorentzian emission line shape whose FWHM (Full Width Half Maximum) is specified by Laser parameters. In model considered has 193.42 THz center emission frequency, 1550 nm wavelength, 0 dBm CW Power, 1 mw CW power, ideal laser noise bandwidth, 10 FWHM line width and laser random phase.

The block Amplitude modulator simulates a single input modulator and implements a single arm Mach-zehnder amplitude modulator with $\sin^2$ electrical shaped input-output P-V characteristics. This transfer function is typical for a Mach-zehnder external modulator based on the electro-optic effects in the $LiNbO_3$ devices. It has 3db excess loss, 2.5 maximum transmissivity offset voltage, realistic extinction ratio, 30db extinction ratio and 0 chirp factor.

Optical splitter component simulates an "Ideal" optical splitter. It works as a balanced splitter with the same attenuation on each output. Attenuation is set to a default value of 0 dB, so this component implements an ideal splitter without any insertion loss, i.e. a component that perfectly splits the input signals.

Optical filter component implements a raised cosine transfer function filter having band pass filter synthesis, 1 as raised cosine exponent, 0.2 raised cosine roll off, 193.41 THz Center freq., 1550 nm center wavelength, 40 GHz B.W.

Sr. No.	**Fiber Type**	**Attenuation** α	**Chromatic Dispersion**		**MFD** A_{eff}	**Polarization** PMD
			D	D' slope		
1.	SMF@1550nm Alcatel	0.2	16		81.7	≤ 0.1
2.	SMF @ 1550nm ERALIGHT	0.21	8	0.06	65	≤ 0.1
3.	Corning LEAF	0.2	4	0.1	72	≤ 0.1
4.	Corning LEAF	0.2	4	0.1	71	≤ 0.1

	Submarine					

Table 5.1 Typical values of parameter of optical fiber types considered in the optical communication system simulation. Where parameter units are D [ps/nm/km], D' slope [ps/nm^2/km], α_0 [dB/km], A_{eff} [μm^2] and PMD [ps/√km].

Photodiode considered as a PIN photodiode. The output current generated by the photo detection process depends on the input optical power and on the dark current. Its parameter are 193.42 THz/1550 nm reference freq./wavelength, 0.80 quantum efficiency, 0.99A/W responsitivity and zero dark current. The Bessel filter block is numerically implemented using an IIR (*Infinite Impulse Response*) algorithm together with the bilinear transformation method having 5 poles in number and as -3db B.W. 10 GHz. Electrical scope component simulates an oscilloscope for electrical signals. It collects data that will be available for the eye diagrams shown. Also may be used to obtain amplitude of the electrical signal, eye diagram, histogram at the optimum sampling instant, power spectrum of the electrical signal. Other parameters are 10 Gb/s bit rate and stimulated bit rate, 474 samples per bit over whole measured time span.

The fiber models the propagation of the optical signal along an optical fiber span. It is one of the fundamental and most complex components decide channel/medium performances. The non-linear Schrodinger equation governing the propagation of the optical field is integrated using Time Domain Split-Step (TDSS). Characteristics of fibers apart from type & length considered are the presence of fiber nonlinearity, fiber PMD, fiber birefringence but without Raman crosstalk and Raman amplifier. The typical fiber characteristics are shown in the table 1 for the various fibers considered in table.

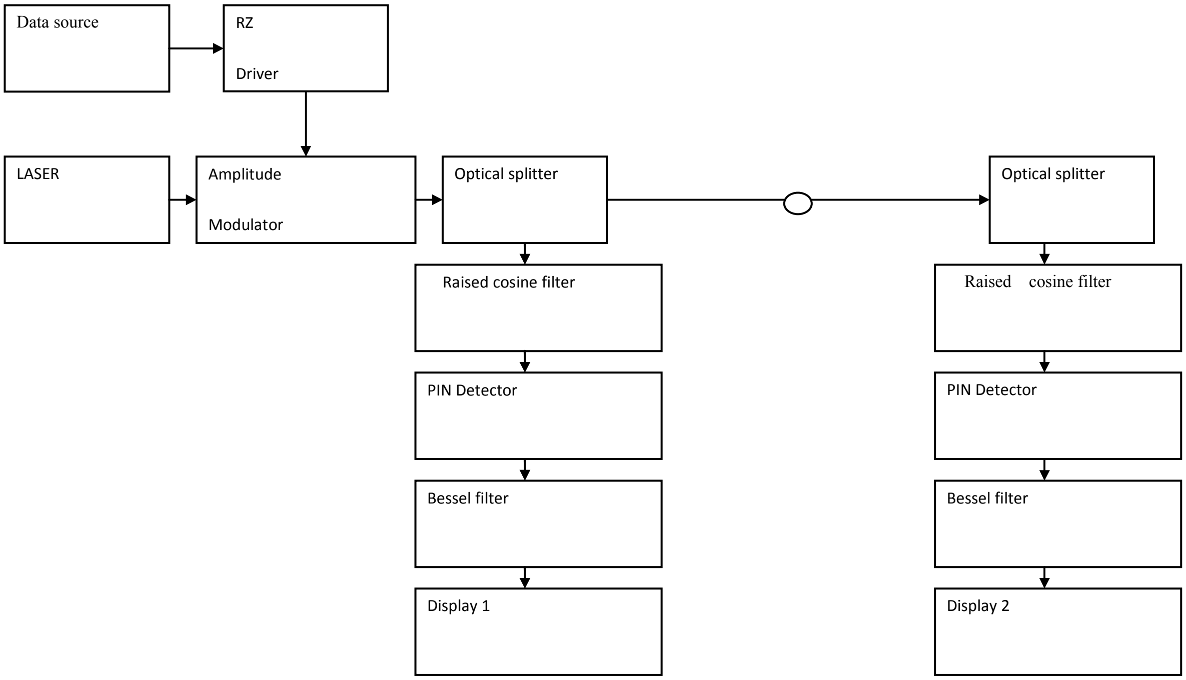


Figure 5.1: Simulation model under investigation to estimate timing jitter, Q value, BER of different optical fibers.

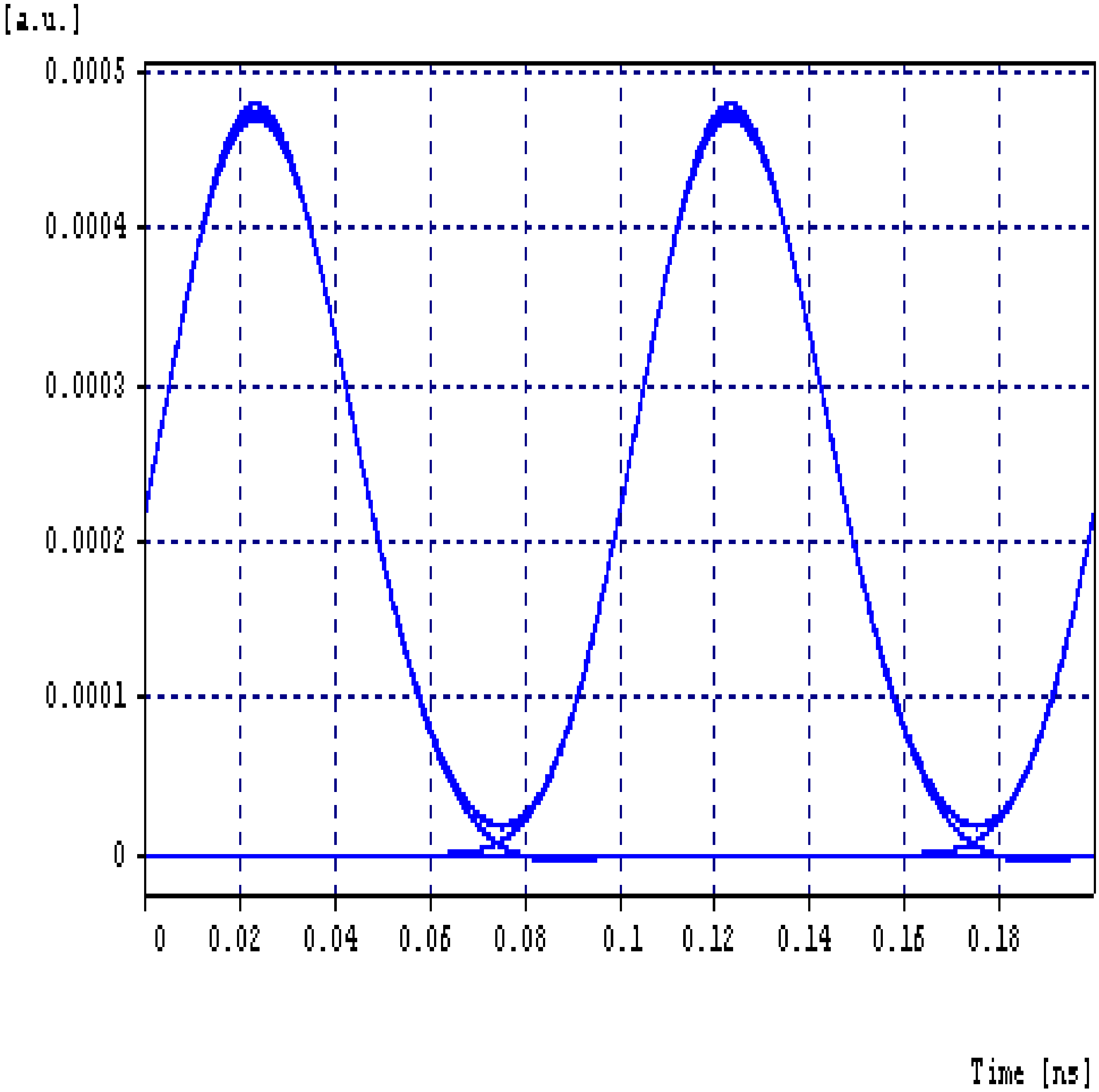


Figure 5.2 Eye diagram at display 1 to measure BER, Q and Timing Jitter at transmitter side.

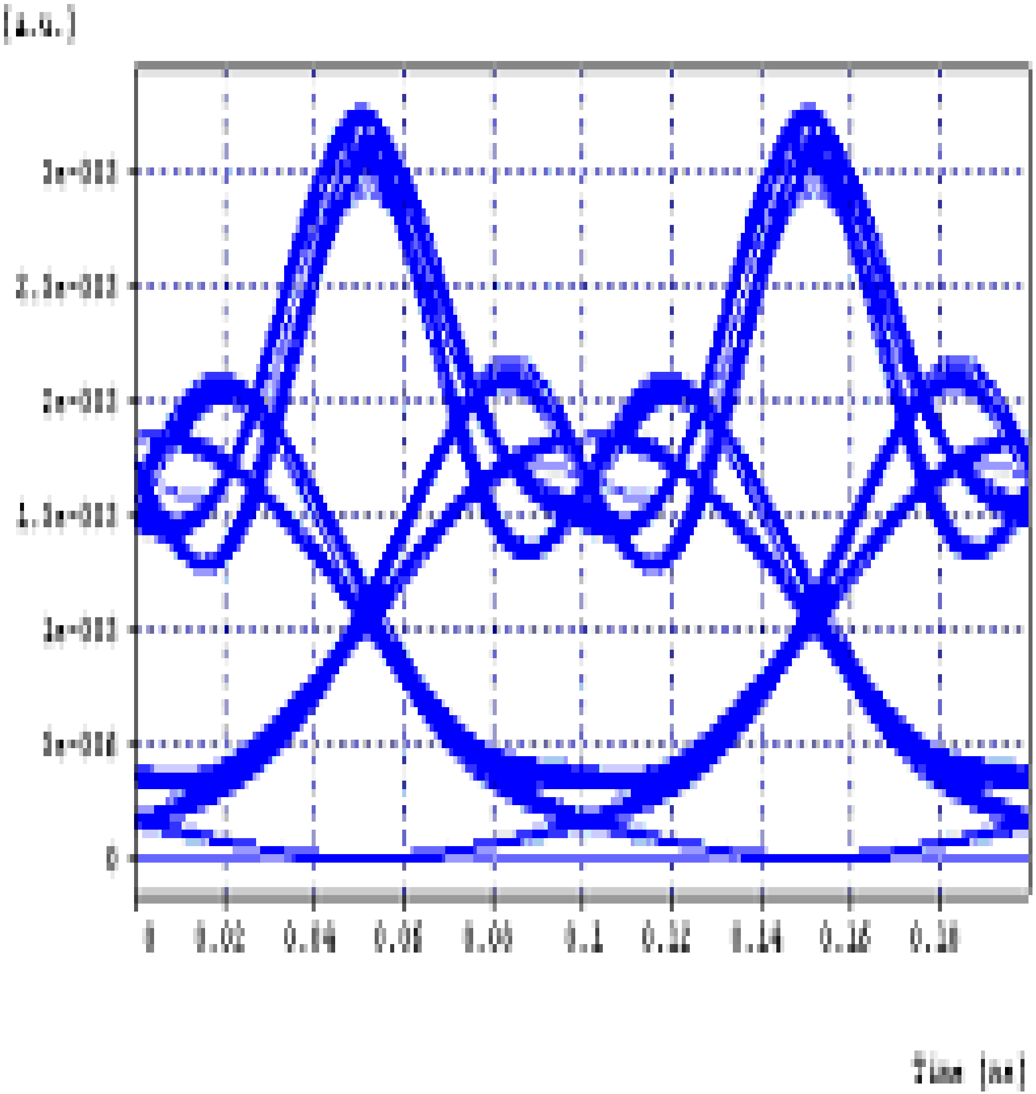


Figure5. 3 Eye diagram at receiver side of standard SM fiber.

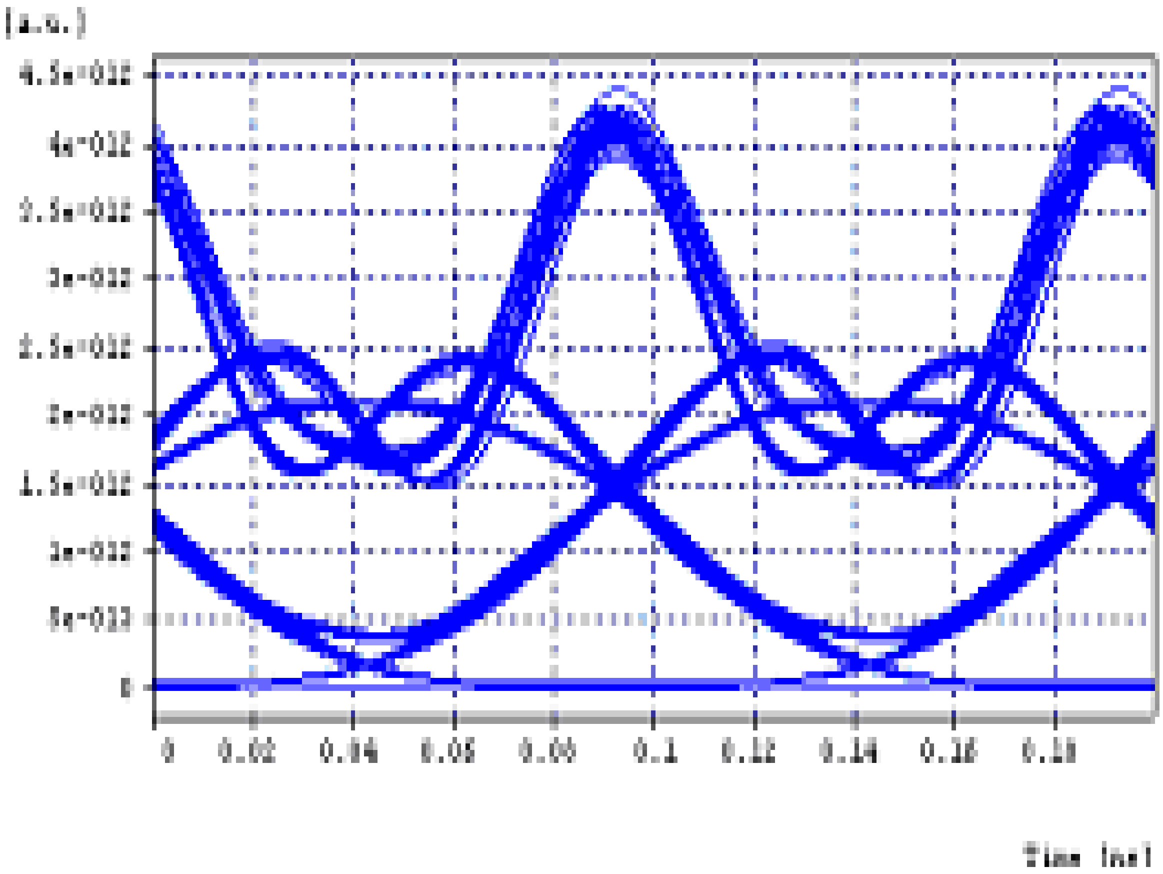


Figure 5.4 Eye diagram at receiver side of DS_Normal.

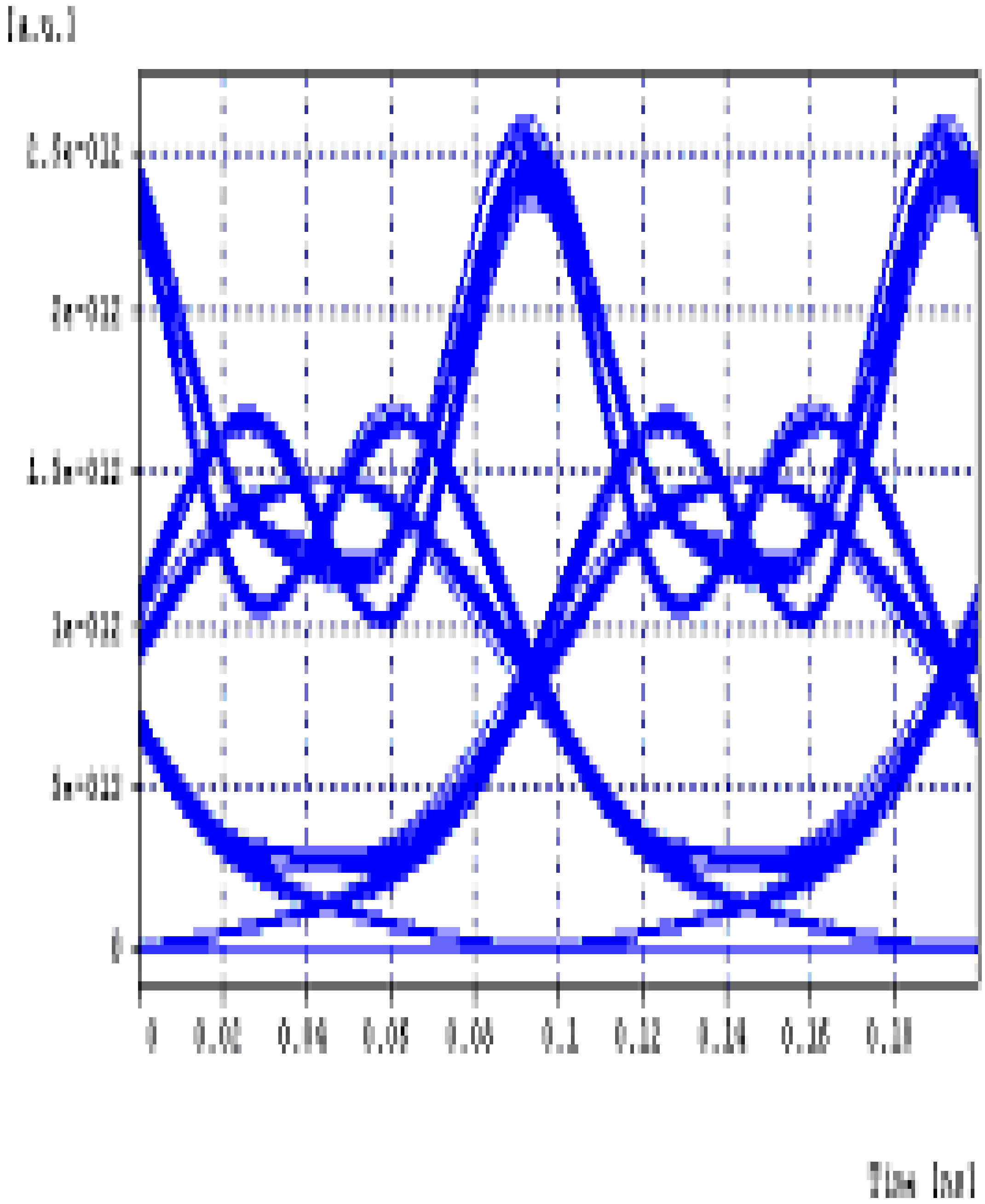


Figure 5.5 Eye diagram at receiver side of DS_Anomalous

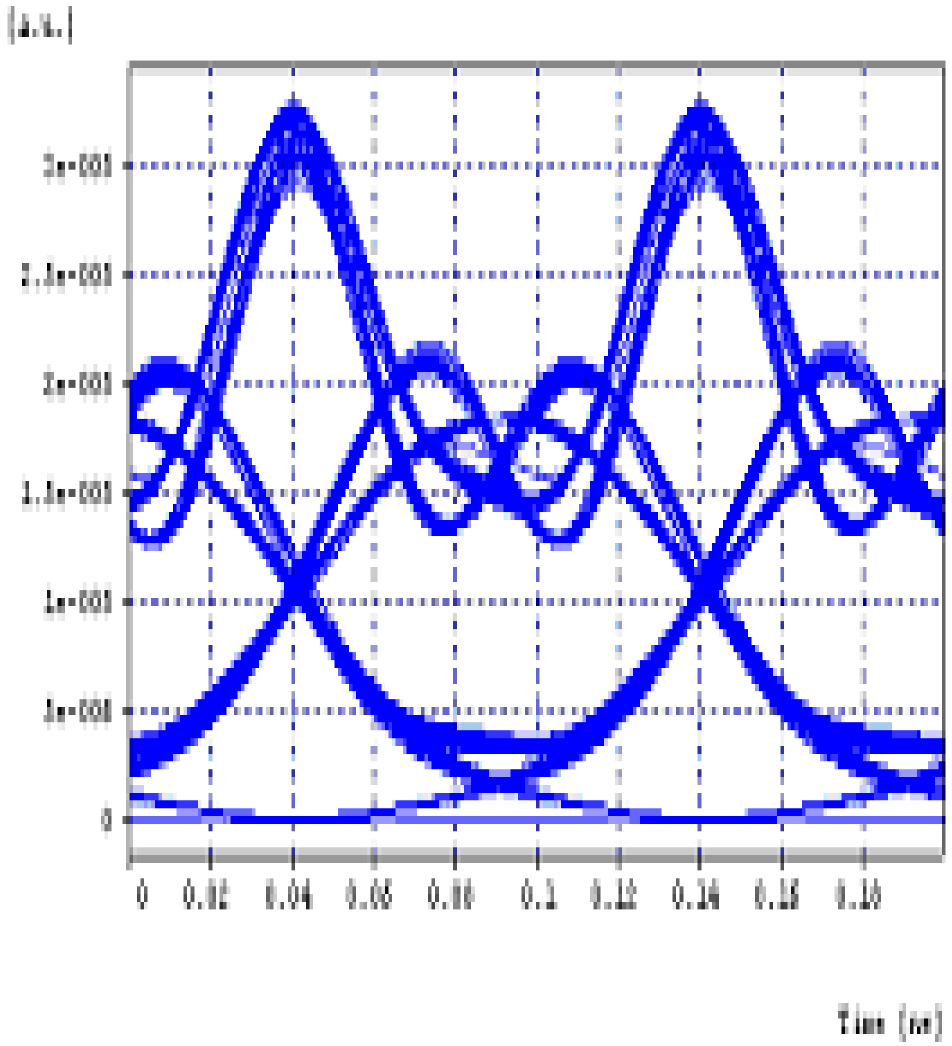


Figure 5.6 Eye diagram at receiver side of Alcatel SMF_1550

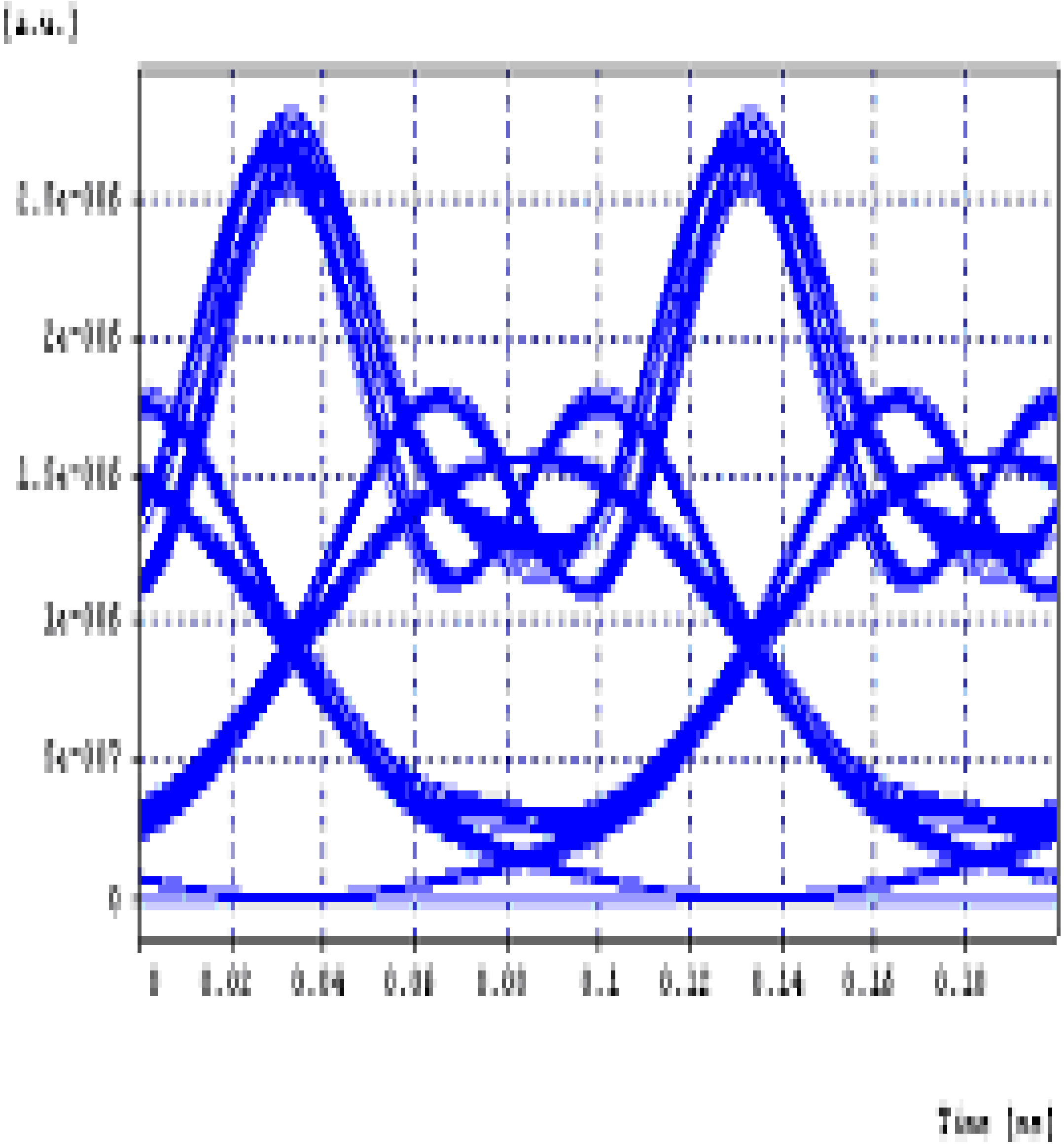


Figure 5.7 Eye diagram at receiver side of Alcatel ITERA LIGHT.

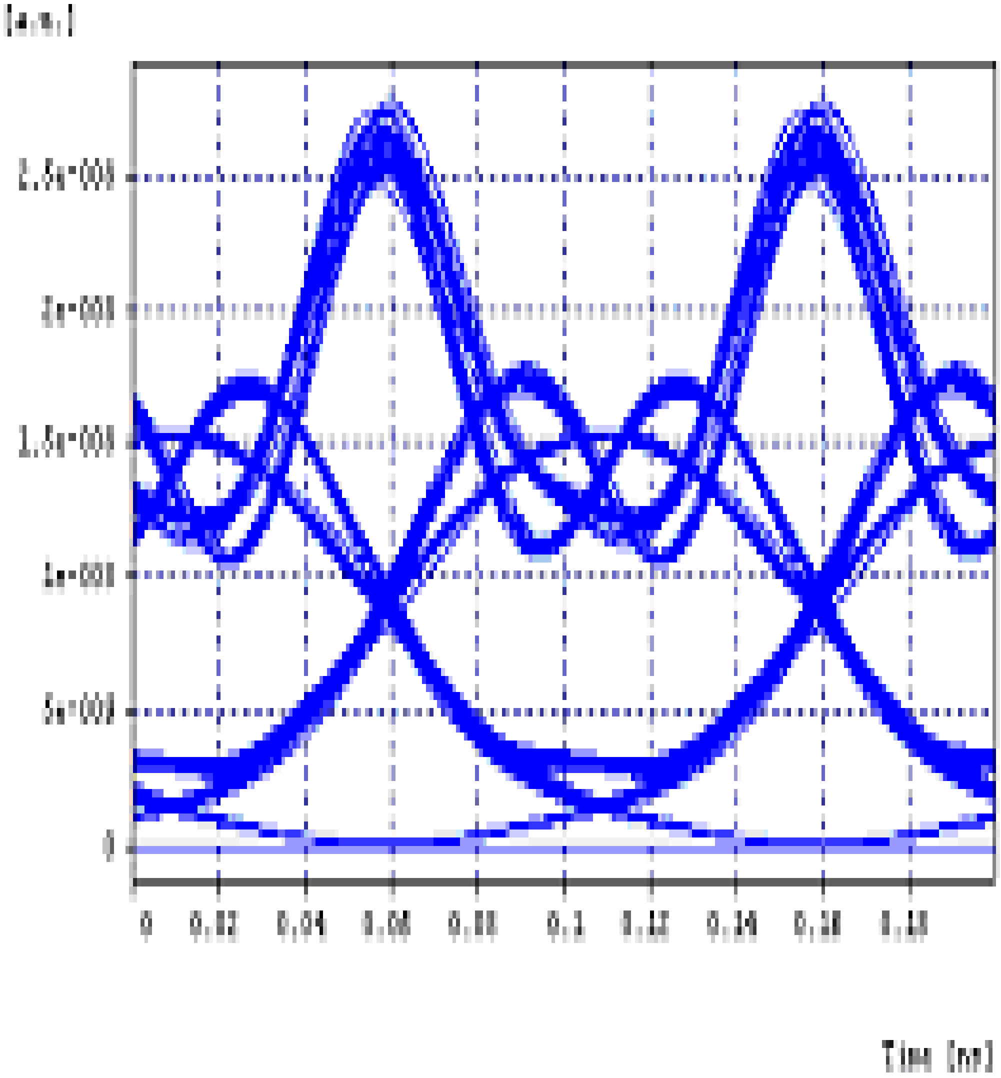


Figure 5.8 Eye diagram at receiver side of yy_corning LEAF.

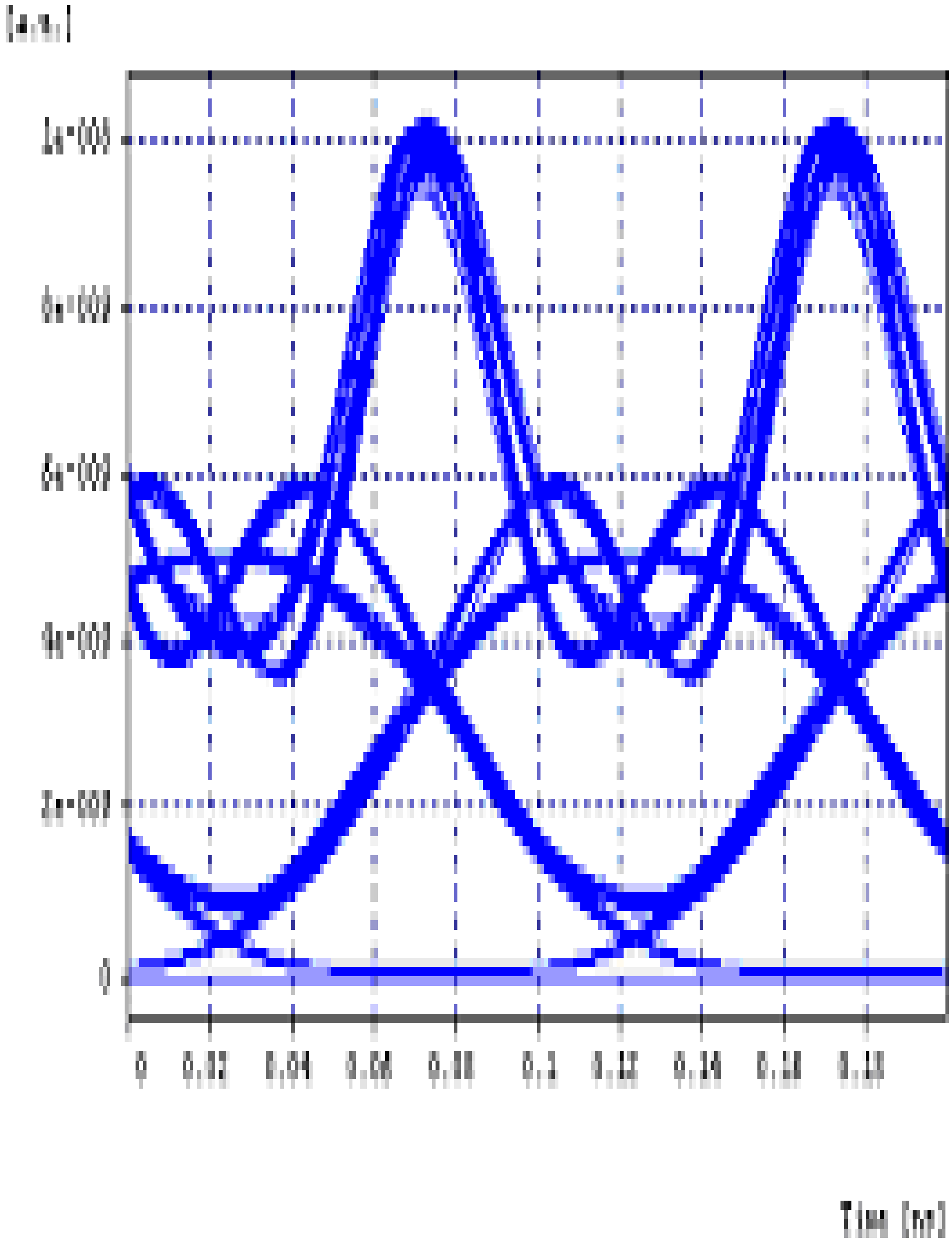


Figure 5.9 Eye diagram at receiver side of yy_corning LEAF submarine.

5.4 Results and Discussion:

We evaluate the performance of different types of fibers in terms of bit error rate (BER), Q factor and timing jitter by taking fixed length of different types of fibers. The results are shown in table (5.2) and figures 5.2-5.9.

Sr. No.	TYPES OF FIBER	LENGTH (km)	BER	Q (dB)	TIMING JITTER (ns)
1.	Standard SM	51	8.09e-9	15.27	0.028
2.	DS_normal	51	1e-40	40	0.086
3.	DS_Anomolous	51	1e-40	40	0.000233
4.	Alcatel_SMF_1550	51	8.68e-9	15.26	0.028125
5.	Alcatel TERALIGHT	51	1e-40	31.08	0.000667
6.	Corning_leaf	51	1e-40	40	0.000371
7.	Corning_leaf submarine	51	1e-40	40	0.00031

Table 5.2: **Shows the BER, Q and Timing jitter values for different fibers of length 51 Km each.**

It indicates that the least BER $1x10^{-40}$ & Timing jitter 0.000233 are noticed in DS anomalous fiber. Also standard single mode fiber and Alcatel SMF give maximum bit error rate $8x10^{-9}$ approximately.

Sr. No.	TYPES OF FIBER	LENGTH (Km)	BER (10^{-9})	Q (dB)	TIMING JITTER (ns)
1.	Standard SM	51	7.128	15.17	0.028
2.	DS_Normal	396	3.28	15.68	0.029
3.	DS_Anomalous	406	2.91	15.64	0.028
4.	Alcatal_ SMF_1550	51	5.63	15.21	0.028
5.	AlcatelTERALIGHT	102	4.71	15.20	0.028
6.	CorningLEAF	205	5.61	15.14	0.029
7.	CorningLEAF_submarine	227	2.53	15.55	0.029

Table 5.3: Table indicating length, BER, Q dB for various types of fibers.

Since the practical optical communication systems work on acceptable bit error rate around 10^{-9} and timing jitter around 0.028-0.029, we optimize our system by evaluating different lengths for this acceptable BER and timing jitter . In reference to the table 5.3 & evident from eye diagrams figures 5.2 to 5.9, the simulation results show that dispersion shifted anomalous fiber gives best performance giving BER = 2.91×10^{-9} at a length up 406 km. Close performance is also observed in the case of dispersion shifted normal fibers giving usable length 396 Km. Worst performance is noticed in Standard Single mode fibers giving usable length 51 km. Corning LEAF fibers are giving performance up to the middle distances i.e. 200 km. Q value & timing jitter remains almost same. As indicated in table 5.2 timing jitter is can not controlled by the selection fiber type. We need to apply other techniques like dispersion management, selection of data format type to control timing jitter & Q value. Now if the fiber nonlinearities are taken into consideration, the results are presented in table 5.4

Sr. No.	TYPES OF FIBER	LENGTH (Km)	BER (10^{-9})	Q (dB)	TIMING JITTER (ns)
1.	Standard SM	51	7.128	15.17	0.028
2.	DS_Normal	396	3.28	15.68	0.029
3.	DS_Anomalous	406	2.91	15.64	0.028
4.	Alcatal_ SMF_1550	51	5.63	15.21	0.028
5.	AlcatelTERALIGHT	102	4.71	15.20	0.028
6.	CorningLEAF	205	5.61	15.14	0.029
7.	CorningLEAF_submarine	227	2.53	15.55	0.029

Table: 5.4:Types of fibers

Conclusion

The bit error rate becomes deciding factor to select the fiber over long distance. From the results & discussion, it can be concluded that Dispersion shifted fibers anomalous & normal are performing better for long distances. Also observed, Q value & Timing jitter are not affected much by the selection of fiber type.

CHAPTER 6

Result and Future Scope

6.1 Results

The objective of the thesis is to analysis the effect of dispersion of fiber on the performance of OCDMA system and to find the limitations imposed by dispersion on number of user and length of transmission. It has been observed that in the bit error rate performance curve the error is decreased when the number of subscriber is increased side by side the optical power is reduced when the users is added. Here for the user sequence is the m sequence. In the case of SNR it is found that the system performance is improved with raising the level of signal to noise ratio.

An OCDMA system is simulated with no dispersion, dispersion and dispersion compensation in order to analyze the effects of dispersion. Various graphs have been taken to evaluate the impact of fiber chromatic dispersion on the bit-error-rate (BER) and the Q factor. Eye diagrams have been taken at different stages in OCDMA system in order to study the effect of dispersion. Received signal is also measured in all the cases.

The simulation effort for 10 Gb/s optical communication system is done to select the fiber from the standard fibers available from some reputed fiber sources. The comparison on the basis of measured bit error rate (BER), Q-value, timing jitter and eye diagrams has been taken and presented. It was found that dispersion shifted normal & anomalous fibers give best performance among the fibers considered, second best performance is given by Corning LEAF fibers.

6.2 **Future Scope**

In this thesis, the work is limited to 2-D codes. The 3-D codes have not been considered in this thesis work. The present work can be enhanced for 3-D codes. The timing jitter can also be studied with advanced modulation formats.

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