Performance Analysis of Optical CDMA using Fuzzy Logic Generator

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by

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CERTIFICATE

This is to certify that my work presented in this thesis entitled **"Performance Analysis of Optical CDMA using Fuzzy Logic Generator"** submitted by **Mr. Harmandeep Singh** in partial fulfillment of the requirement for the award of the degree of **Master of Engineering in Electronics Instrumentation and Control Engineering** at **Thapar University**, Patiala, is an original record under supervision and guidance of **Dr Yaduvir Singh**. The matter embodied in this report has not been submitted anywhere for the award of any degree.

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It is certified that the above statement made by the student is correct to the best of our knowledge and belief.

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DEDICATED TO MY PARENTS

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LIST OF ABBREVIATIONS

- MAI Multiple Access Interference
- SNR Signal to Noise Ratio
- OCDM Optical Code-Division Multiplexing
- WDM Wavelength-Division Multiplexing
- TDM Time Division Multiplexing
- FDD Frequency division duplexing
- BER Bit Error Rate
- LAN Local Area Network
- MMI Multimode Interference
- OOC Optical Orthogonal Code
- FL Fuzzy Logic
- MF Membership Function
- PSO Pseudo Orthogonal
- FS Fuzzy Set

ABSTRACT

Multiple accesses which uses the spread spectrum technology for transmission has become very popular in cellular radio networks. Optical CDMA is a technique in which user uses a specific unique code rather a specific wavelength or a time slot. Optical CDMA uses the spread spectrum technique of CDMA combined with the optical link for transmission of data. Optical CDMA provides the large communication bandwidth along with the capability of secure data transmission. The key advantage of Optical CDMA is the multiple access technique which allows many users to share the same optical link simultaneously. This is done by giving each user a specific code which can be decoded only by the required user. OCDMA has many unique features that make it favorable data transmissions. Its characteristics make it suitable to increase the capacity and number of users in bursty networks. OCDMA can accommodate a large no. of channels on a single carrier frequency. It can utilize the bandwidth effectively through coding system. OCDMA systems provide high degree of scalability and security. It provides high noise tolerance. Optical CDMA had the potential to generate some of the previously unused bandwidth of the optical fiber and to carry over to the optical domain the benefits of CDMA in radio frequency systems. The early attempts of implementing of optical CDMA were not so successful. At that time technology available was not so advanced. In the last 20 years the optical CDMA field has matured substantially. The Optical CDMA systems suffer from the problem of Multiple Access Interference (MAI).As the number of users increase the BER error rate degrades because the effect of MAI increases.So, there is a limitation in number of users, as the number of users increase SNR decrease and probability of error increase. There is a limitation of speed also in optical CDMA systems-since very short pulses are to be required within each bit time, therefore it limits the bit rate for a finite pulse width transmitter. There is also a problem of high optical splitting at encoder/decoder.

Now as the complexity of the system increases it becomes difficult and eventually impossible to make precise statements about its behavior. At such a point of problem we use fuzzy logic. Fuzzy Logic provides a simple way to arrive at a definite conclusion based on imprecise, vague and ambiguous data. Fuzzy Logic systems have a high

potential to understand the complex systems. Complex systems can be new systems that have not been tested..Fuzzy logic theory can also be utilized for assessing some conventional, less complex systems. Hence Fuzzy Logic is is very useful in two cases:(1) in situation involving highly complex system whose behavior is not understood and (2)in situations where an approximate but fast solution is required. A fuzzy logic system can be thought as combination of both of them as it attempts to understand the system for which no model exists and it does so with information that can be uncertain in a sense of being vague or fuzzy. Systems whose behavior is understood and controllable exhibit certain robustness to spurious changes. In this way robust systems are the ones whose output does not change significantly under the influence of changes in input.

In this thesis, a highly spectral-efficient transmission technique based on optical code-division multiplexing (OCDM) is investigated. Optical transmission systems have to meet the rapid increase in the demand of data bandwidth and spectral efficiency Over the years several modulation formats and optical receiver designs have been proposed. OCDM is one of spectrally efficient technique. OCDM multiplexing technique is different from optical time-division multiplexing and wavelength-division multiplexing (WDM). OCDM provides asynchronous transmission, secure communication, soft capacity on demand, and high degree of scalability. In this paper, we have applied OCDM technique alongwith fuzzy logic generator which gives us improvement .Fuzzy Logic generator accepts V_π and R_{on}/R_{off} and generates I/I_0 in a non – linear fashion.Such fuzzy logic augmented OCDM has shown better performance which is quite evident from various diagrams of BER Tester Decision Eye Diagrams, BER Tester Eye Lids Diagram, IstmpEye Eye Diagrams and autocorrelation Diagrams.

LITERATURE SURVEY

Murat Azizoglu, Jawad A. Salehi, and Ying Li provided an analysis to the performance of optical orthogonal codes (OOC) in an optical code division multiple access (CDMA) network by considering the probability distribution of the interference patterns. They showed that the actual performance is close to a previous estimate. They also considered a less structured temporal code in which the code words are allowed to overlap at two pulse positions. We obtain the bit error probability for this class of codes for two cases: with and without optical hard limiting at the receivers. We show that this code may increase the number of users in the network considerably without a significant loss in the performance[1].

Park E.,Mendez A.J. and Garmire E.M. presented the design and experimental results for a temporal/spatial (T/S) non coherent optical code-division multiple access (CDMA), based on matrix codes, using a breadboard of passive multimode fiber-optic couplers and delay lines. It is shown that a T/S CDMA network allows for shorter bit times, given a set laser pulse width, compared to a temporal CDMA network. Also, T/S codes result in a reduction of autocorrelation sidelobes and cross-correlation peaks, and the T/S network has lower losses. It is also shown that the couplers are critical components in maintaining code integrity[2].

Robert M. Gagliardi, Antonio J. Mendez, Mark R. Dale, and Eugene Park proposed the use of laser pulsing in the form of code-division multiple access (CDMA) to multiplex a set of digital video signals over a fiber network is proposed. The laser pulsing is used to generate unique code sequence addresses which identify each source, and the video data are modulated on these sequences. Digital encoding using pulse position modulation (PPM) is proposed, having advantages that permit efficient integration of optical and electronic processing. Data recovery is achieved by optical correlation for sequence recognition, followed by standard electronic PPM decoding. The relation between key system parameters of the encoding, decoding, and optics is derived, and indicates that compressed video rates between 5-20 Mb/s/channel, with 25-50 channels, is possible with relatively standard hardware. Experimental breadboard results being carried out at USC on this system are reported, and indicate the feasibility of the CDMA concept for fiber multiplexing[3].

D. Zaccarin and M. Kavehrad proposed an optical code-division multiple access (CDMA) system based on amplitude spectral encoding of low-cost broadband sources such as light-emittingdiodes. The proposed system uses a standard nondispersive lens-grating apparatus, and simple direct-detection receivers. They showed that by assigning to *N* subscribers the *N* cycles shifts of a single unipolar m-sequence of period *N,* complete orthogonality between the users can be achieved, provided that the spectrum is properly equalized. They showed that without any equalization, and for $N = 511$, up to 200 users can transmit asynchronously with an average error probability equal to lop9, depending on the received power level. An aggregate network throughput of 100 Gb / s can therefore be obtained[4].

Hossam M. H. Shalaby investigated Direct-detection optical synchronous code-division multiple-access (CDMA) systems with M-ary pulse-position modulation (PPM) signaling . Optical orthogonal codes are used **as** the signature sequences of our system. A union upper bound on the bit error rate is derived taking into account the effect of the background noise, multiple-user interference, and receiver shot noise. The performance characteristics are then discussed for a variety of system parameters. Another upper bound on the probability of error is also obtained (based on ChernofF inequality). This bound is utilized to derive achievable expressions for both the maximum number of users that can communicate simultaneously with asymptotically zero error rate and the channel capacity. The results show that under average power and bit error rate constraints, there always exists a pulse position multiplicity that permit all the subscribers to communicate simultaneously[5].

Svetislav V. Maric, Oscar Moreno, and Carlos J. Corrada in this paper, addressed the problem of multimedia transmission in fiber-optic networks. They applied the code-division multiple-access (CDMA) technique for such a network. The necessary conditions for successful operation of the network are given. It is shown that for successful operation, new families of optical orthogonal codes (OOC's) are needed which will have not only good correlation properties within one code family, but also between families of different code lengths. Some possible constructions of multimedia OOC's and the corresponding basic structure of the receiver for the multimedia network are given. Specific examples of OOC's for the case of users with two different data rates are given, and the probability of error (using the Gaussian approximation) as a function of the number of low and high rate users is calculated[6].

Tomoaki Ohtsuki, Kazumi Sato, Iwao Sasase and Shinsaku Mori proposed an optical code-division multiple-access (CDMA) system with double optical hard-limiters is proposed where the optical hard-limiters are placed before and after an optical correlator. Moreover, the effect of the optical hard-limiter on the performance of the optical synchronous CDMA systems using modified prime sequence codes as signature codes is analyzed under the assumption of Poisson shot noise model for the receiver photodetector where the noise due to the detector dark currents exists. They evaluated the performance under average power and bit rate constraints. Our results show that using the single optical hard-limiter slightly degrades the performance of the optical CDMA systems under the assumption of Poisson shot noise model for the receiver photodetector where the noise due to the detector dark currents exists. Moreover, we show that the optical CDMA systems with double optical hard-limiters have better performance than other conventional CDMA systems with and without the optical hard-limiter when the number of simultaneous users is not so large[7].

Xiang Zhou, H.H.M. Shalaby, Chao Lu and Teehiang Cheng proposed a new code structure for spectral amplitude coding optical code division multiple access (CDMA) . It is shown that such codes can effectively suppress the intensity noise and in turn increase the number of active users and improve the bit error rate performance[8].

Wei Huang, Mohamed H. M. Nizam, Ivan Andonovic, and Moshe Tur described that as the wavelength resource in mainstream wavelength-division multiple-access (WDMA) systems becomes exhausted, and the bit-rate limitation within a single wavelength bandwidth is reached, alternative approaches to implementing a high-capacity optical fiber network need to be investigated. Coherent optical code-division multiple-access (OCDMA) systems, that can access many users simultaneously and asynchronously (or synchronously) across the single wavelength and same timeslot via spread spectrum techniques, are one alternative. In the longer term, the advantages of OCDMA in tandem with WDMA (OCDMA/WDMA) networks are compelling and worthy of further investigation in the goal of realising an extensive, flexible, high throughput and easily managed optical telecommunication infrastructure. In this paper, coherent OCDMA systems are introduced, and the issues of the system implementation within high-capacity optical fiber networks are discussed. A performance comparison between OCDMA and OTDMA systems is then carried out, both of them using narrow pulse laser sources. An optical fiber network utilizing coherent OCDMA techniques as one layer of a multiplexing hierarchy, in tandem with WDMA, is illustrated and a possible hybrid OCDMA/WDMA network architecture (and its performances and advantages) has been described[9].

Sheng Peng Wan and Yu Hu proposed a new fast optical time-spreading/frequency hopping differential code division multiple access system with Prime/optical orthogonal codes. The performance of a multiple Bragg grating fiber is analyzed. By assigning two orthogonal codes for one user and using these two codes to encode “1” and “0,” respectively, differential detection can be adopted[10].

Elie Inaty, Hossam M. H. Shalaby, Paul Fortier and Leslie A. Rusch in this paper addressed the problem of real-time multimedia transmission in fiber-optic networks using code division multiple access (CDMA). They presented a multirate optical fast frequency hopping CDMA (OFFH-CDMA) system architecture using fiber Bragg gratings (FBGs). In addition, they argued that, in multimedia applications, different services have different quality of service (QoS) requirements; hence, the user only needs to use the minimum required power to transmit the signal, such that the required signal-to-interference ratio (SIR) is met. They showed that a variable bit rate optical communication system with variable QoS can be implemented by way of power control with great efficiency. Present-day multirate optical CDMA systems concentrate on finding the code structure that supports a variable rate system, neglecting the importance of the transmission power of active users on the multiple access interference (MAI) and, therefore, on the system capacity. In this work, they assigned different power levels to each rate through a power control algorithm using variable optical attenuators, which minimizes the interference and, at the same time, provides variable QoS constraints for different traffic types. Although they are using a code family that preserves good correlation properties between codes of different lengths, simulations show a great improvement in the system capacity when power control is used[11].

Andrew Stok and Edward H. Sargent investigated the possible role of optical CDMA (O-CDMA) in future access networks. They began with a short review of the O-CDMA technique for those unfamiliar with the technology. Next, they investigated in detail those characteristics of O-CDMA that make it an attractive technology for application in metro access networks: fairness, flexibility, simplified network control and management, service differentiation, and increased security. Although O-CDMA has many favorable attributes, it also has several actual or perceived drawbacks. They discussed the technical, economic, and perception barriers that may have limited the wide scale deployment of O-CDMA access networks. They tried to determine which of these drawbacks may be surmountable in the near future and which may be true "showstoppers"[12].

Purushotham Kamath, Joseph D. Touch and Joseph A. Bannister demonstrated that Optical CDMA Local Area Networks allow shared access to a broadcast medium. Every node on the network is assigned an Optical Orthogonal Codeword (OOC) to transmit or receive on. OOCs are designed to be pseudo-orthogonal, i.e., the correlation (and therefore the interference) between pairs of codewords is constrained. They demonstrated that the use of optical CDMA does not preclude the need for a media access control (MAC) layer protocol to resolve contention for the shared media. OOCs have low spectral efficiency. As more codewords are transmitted simultaneously, the interference between codewords increases and the network throughput falls. This paper analyzes a network architecture where there is virtually no MAC layer, except for choice of the codeset, and shows that its throughput degrades and collapses under moderate to heavy load. They proposed an alternate architecture called *Interference Avoidance* where nodes on the network use media access mechanisms to avoid causing interference on the line, thereby improving network throughput. Interference avoidance was analyzed and it was shown that it can provide up to 30% improvement in throughput with low delays and no throughput collapse[13].

Sangjo Park, Bong Kyu Kim, and Byoung Whi Kim proposed a new optical code division multiple access (OCDMA) scheme for reducing multiple access interference (MAI) and enhancing performance for optical subscriber access networks using modified pseudorandom noise (PN)-coded fiber Bragg gratings with bipolar OCDMA decoders. Through the bipolar OCDMA decoder and the modified PN codes, MAI among users is effectively depressed. As the data are encoded either by a unipolar signature sequence of the modified PN code or its complement according to whether the data bit is 1 or 0, the bit error ratio (BER) can be more improved with the same signal to interference plus noise ratio over the conventional on-off shift keying-based OCDMA system. They proved by numerical analysis that the BER of the proposed bipolar OCDMA system is better than the conventional unipolar OCDMA system. They also analyze the spectral power distortion effects of the broadband light source[14].

Frederik Vanhaverbeke and Marc Moeneclaey introduced a new type of OCDMA/OCDMA for oversaturated channels, by displacing in time the orthogonal signature sets of the users. A displacement by an integer multiple of a chip period considerably improves the performance of iterative detection of the user data, as compared to quasi-orthogonal sequences (QOS) and conventional random O/O sequences. An additional displacement by half a chip period reduces the variance of the cross correlation between the users of the two sets by up to 50%, and results in an additional performance improvement for square root cosine rolloff chip pulses. This improved O/O system can accommodate a number of users equal to twice the spreading gain N, when N 32. For a practical rolloff of 25% and N = 128, the acceptable channel *over*load can almost be tripled with improved O/O as compared to conventional O/O[15].

Ivan B. Djordjevic and Bane Vasic proposed two novel classes of optical orthogonal code (OOC) based on balanced incomplete block designs: OOC based on mutual orthogonal Latin squares/rectangles and the codes based on finite geometries. Both OOC families can be applied to synchronous and asynchronous incoherent optical CDMA, and are compatible with spectral-amplitude-coding (SAC), time-spreading encoding and fast frequency hoping schemes. Large flexibility in cross-correlation control makes those OOC families interesting candidates for applications that require a large number of users. Novel fiber Bragg grating decoding scheme for canceling the multi-user interference from SAC-signals with nonfixed in-phase cross-correlation is proposed as well[16].

Avi Pe'er, Barak Dayan, Yaron Silberberg, and Asher A. Friesem presented a novel approach for an optical direct-sequence spread spectrum . It is based on the complementary processes of broad-band parametric down-conversion and up-conversion.With parametric down-conversion, a narrow-band continuous-wave (CW) optical field is transformed into two CW broad-band white-noise fields that are complex conjugates of each other. These noise fields are exploited as the key and conjugate key in optical direct-sequence spread spectrum. The inverse process of parametric up-conversion is then used for multiplying the key by the conjugate key at the receiver in order to extract the transmitted data. A complete scheme for optical code-division multiple access (OCDMA) based on this approach is presented. The salient feature of the approach presented in this paper is that an ideal white-noise key is automatically generated, leading to high-capacity versatile code-division multiple-access configurations[17].

B. Huiszoon, L. Bakker, H. de Waardt, G.D. Khoe, E.R. Fledderus and A.M.J. Koonen presented theoretical results on the modular construction of orthogonal tree and cascade encoders/decoders of any size for truly asynchronous and cost efficient spectral amplitude encoded OCDMA on a passive optical network. Three modular building blocks are proposed and described in detail. The tree structure is introduced that enables parallel code processing with a single device. The orthogonality of the code set is evaluated whereafter a revised construction method is proposed. Analysis and simulation confirm that a tree constructed via this method is orthogonal[18].

Song-Ming Lin , Jen-Fa Huang , Chao-Chin Yang proposed a new hybrid code for optical CDMA systems based on modified maximal-length sequence (M-sequence) codes for wavelength-hopping and prime codes for time spreading. Using the proposed hybrid code, two optical encoder/decoders are constructed using either fiber-Bragg gratings (FBGs) and optical delay lines, or arrayed-waveguide gratings (AWGs) and optical delay lines, respectively. The system performance is compared with that provided by the well-known prime-hop sequence code. The results show that the merged-M-sequence codes not only provide a higher capacity, but can also be realized via a simpler configuration. Furthermore, the proposed code is less expensive than prime-hop code under virtually identical BER conditions[19].

C.Goursaud-Brugeaud, A.Julien-Vergonjanne and J.P.Cances studied the Prime Codes (PC) efficiency ,in Direct Sequence Optical Code Division Multiple Access system (DS-OCDMA) using Parallel Interference Cancellation receiver(PIC).They developed the analytical expression of the error probability upper bound in the chip synchronous case,for PC.The main result of our work is that the PIC receiver totally suppresses the effect of Multiple Access Interference(MAI) for Prime Codes,and leads to an error free O-CDMA link in the noiseless case,for whichever employed PC.Simulation results are presented to validate the theoretical analysis.We also show that the PIC receiver permits reducing the required code length for a given Bit Error Rate compared to the Coventional Correlation Receiver.Finally,they compared the Pc to the Optical Orthogonal Codes(OOC),and showed that the use of PC allows a significant reduction of the required SNR[20].

B. Huiszoon , L. M. Augustin , R. Hanfoug, L. Bakker, M. J. H. Sander-Jochem, E. R. Fledderus, G. D. Khoe, J. J. G. M. van der Tol, M. K. Smit, A. M. J. Koonen and H. de

Waardt, in this letter,presented a passive integrated device that enables cost-effective parallel encoding and decoding in a spectral amplitude encoded optical code-division multiple-access transmission system. The device is monolithically integrated in InP–InGaAsP[21].

Ronald G. Broeke, Jin Cao, Chen Ji, Sang-Woo Seo, Yixue Du Nick K. Fontaine, Jong-Hwa Baek, John Yan, Francisco M. Soares, Fredrik Olsson, S. Lourdudoss, Anh-Vu H. Pham, Michael Shearn, Axel Scherer, and S. J. Ben Yoo described the InP platforms for photonic integration and the development on these platforms of an optical code division multiple access (O-CDMA) system for local area networks. They demonstrated three building blocks of this system: an optical pulse source, an encoder/decoder pair, and a threshold detector. The optical pulse source consists of an integrated colliding pulse-mode laser with nearly transform-limited 10 Gb/s pulses and optical injection locking to an external clock for synchronization.The encoder/decoder pair is based on arrayed waveguide gratings.Bit-error-rate measurements involving six users at 10 Gb/s showed error-free transmission, while O-CDMA codes were calibrated using frequency resolved optical gating. For threshold detection after the decoder, we compared two Mach–Zehnder interferometer (MZI)-based optical thresholding schemes and present results on a new type of electroabsorber-based MZI[22].

N.Elfadel, A.A.Aziz, E.Idriss, A.Mohammed and N.M.Saad proposed effective method to reduce the hardware complexity, processing time and cost while maintaining the same bit error probability at the cost of increasing threshold value. Optical Code Division Multiple Access (OCDMA) is considered as the strongest candidates for the future high speed optical networks due to the large bandwidth offered by the system, Based on the vast amount of bandwidth, OCDMA systems have received much attention in fiber optic Local Area Networks where the traffic is typically bursty. However, Multiple Access Interference (MAI), which is originated from other simultaneous users, severely limits the capacity of the system. Optical Parallel Interference Cancellation (OPIC) has been used to reduce the effect of MAI. However, the usage of OPIC in OCDMA systems will increase the demand for hardware complexity which results in higher processing time and cost. The hardware complexity increases in the receiver side of OPIC when the number of transmitter (users) increases. To overcome these difficulties, an efficient method is presented in this paper called, One Stage Optical Parallel Interference Cancellation (OS-OPIC) which is based mainly on the OPIC. Optical Orthogonal Code (OOC) is adopted as a signature sequence for the performance analysis and a new expression for the error probability is derived[23].

Chapter 1
INTRODUCTION

Multiple accesses which uses the spread spectrum technology for transmission has become very popular in cellular radio networks. Optical CDMA is a technique in which user uses a specific unique code rather a specific wavelength or a time slot. Optical CDMA uses the spread spectrum technique of CDMA combined with the optical link for transmission of data. Optical CDMA provides the large communication bandwidth along with the capability of secure data transmission. The key advantage of Optical CDMA is the multiple access technique which allows many users to share the same optical link simultaneously. This is done by giving each user a specific code which can be decoded only by the required user. OCDMA has many unique features that make it favorable data transmissions. Its characteristics make it suitable to increase the capacity and number of users in bursty networks. OCDMA can accommodate a large no. of channels on a single carrier frequency. It can utilize the bandwidth effectively through coding system. OCDMA systems provide high degree of scalability and security. It provides high noise tolerance.

Optical CDMA had the potential to generate some of the previously unused bandwidth of the optical fiber and to carry over to the optical domain the benefits of CDMA in radio frequency systems.The early attempts of implementing of optical CDMA were not so successful.at that time technology available was not so advanced. In the last 20 years the optical CDMA field has matured substantially.The Optical CDMA systems suffer from the problem of Multiple Access Interference(MAI).As the number of users increase the BER error rate degrades because the effect of MAI increases.So,there is a limitation in number of users,as the number of users increase SNR decrease and probability of error increase.There is a limitation of speed also in optical CDMA systems-since very short pulses are to be required within each bit time,therefore it limits the bit rate for a finite pulse width transmitter. There is also a problem of high optical splitting at encoder/decoder.

CODE-DIVISION multiple access (CDMA) is a well-known scheme for multiplexing communication channels that is based on the method of direct-sequence spread spectrum . In CDMA, every channel is identified by a unique pseudo noise key, whose bandwidth is much larger than that of the input data. Ideally, the key should mimic the correlation properties of white noise and should be as long as possible in order to minimize the interference noise introduced by other channels; thus, a great deal of effort is invested in finding practical keys with good autocorrelation and cross-correlation properties.

The essential difference between CDMA and other multiplexing methods, such as time-division multiple access (TDMA) and frequency-division multiple access (FDMA), is that in CDMA, the resource allocated per channel is power, as opposed to time or bandwidth. This difference leads to three major advantages of CDMA compared with traditional multiplexing methods. First, CDMA is inherently flexible to dynamic changes in the bit rate and the quality of service [signal-to-noise ratio (SNR)] of any channel without affecting the total amount of data transmitted by all channels. If a channel is allowed to transmit more power, it can either improve the SNR or increase the bit rate of that channel. Consequently, this shared resource (power) can be dynamically allocated between the channels, and any channel can dynamically trade bit rate for signal to noise, and vice versa, at a given power. Second, CDMA is well adapted to dynamic changes of the number of simultaneously operating channels. Specifically, when one channel becomes inactive, the other channels benefit from the fact that the noise level is reduced. Thus, an allocated channel in CDMA that is not transmitting at a given time, *automatically* “frees its space” to other channels that need the bandwidth at that time, whereas in conventional methods, a costly system for dynamic allocation and compression is required in order to exploit inactive channels. Third, in CDMA all channels are equivalent, whereby the quality of service is that of the average channel, while in conventional methods, the quality of service is dictated by the worst channel. These advantages are eventually translated to an improved usage of the spectrum resource and a higher capacity for CDMA in many configurations.

It is obvious that the CDMA approach would be most attractive if it could be implemented optically. Optical code-division multiple access (CDMA) provides congestion-free transmission of multiple simultaneous users, with variable bit rates and qualities of service (QoS). The soft-blocking properties of optical CDMA can be used to mediate congestion and allow graceful scaling of the size of networks. The orthogonality properties of the OCDMA codes, independent of code length or weight, can be used to flexibly and dynamically assign bandwidth and QoS to different priority traffic. Optical CDMA can also be used to provide privacy for the physical layer of the network, in several ways. 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. Compared with TDMA, CDMA is attractive in other points. Channel assignment is much easier with CDMA. CDMA isolates irregular channels so that they do not influence other channels, while with TDMA, even one irregular channel, such as continuous emission from a transmitter, causes the failure of all other channels. Furthermore, CDMA can be efficiently used in conjunction with TDMA and WDMA on multimedia communication networks where multiple services with different traffic requirements are to be integrated.

The advantages of Optical CDMA are summarized as follows:

- Random and simultaneous access protocol. No need for the strict timing synchronization.
- No need for the strict wavelength control
- No need for the centralized network control, Simple protocols (e.g. tell-and-go protocol),
- Self-routing by code sequence. Effective utilization of bandwidth
- High tolerance to noises. Inherent security, Low-cost devices

Now as the complexity of the system increases it becomes difficult and eventually impossible to make precise statements about its behavior. At such a point of problem we use fuzzy logic. Fuzzy logic was originally developed by professor Lofti A. Zadeh,Ph.D,university of California. Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth -- truth values between "completely true" and "completely false". Fuzzy Logic provides a simple way to arrive at a definite conclusion based on imprecise ,vague and ambigious data. Fuzzy Logic systems have a high potential to understand the complex systems. Complex systems can be new systems that have not been tested..Fuzzy logic theory can also be utilized for assessing some conventional, less complex systems. Hence Fuzzy Logic is is very useful in two cases:(1) in situation involving highly complex system whose behavior is not understood and (2)in situations where an approximate but fast solution is required. A fuzzy logic system can be thought as combination of both of them as it attempts to understand the system for which no model exists and it does so with information that can be uncertain in a sense of being vague or fuzzy. Systems whose behavior is understood and controllable exhibit certain robustness to spurious changes. In this way robust systems are the ones whose output does not change significantly under the influence of changes in input. Fuzzy systems are too robust because they are designed to operate under some window of uncertain conditions. They are robust because the uncertainties contained in both the inputs and outputs of the system are used in formulating the structure of the system unlike the conventional system which needs a model first, based on a collective set of assumptions needed for a mathematical form. Then uncertainties in parameters are considered.

Fuzzy Logic offers several unique features that make it a particularly good choice for many control problems.

1) It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

2) Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.

3) FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and

reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.

4) Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated, although defining the rulebase quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined. It would be better to break the control system into smaller chunks and use several smaller FL controllers distributed on the system, each with more limited responsibilities.

5) FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation.

In this thesis, parametric selection of Mach Zehnder modulator of the OCDMA system has been done in non-linear manner using Fuzzy logic generator accepts V_π and R_{on}/R_{off} as its inputs and generates I/I_0 as its output. Performance comparison has been done for OCDMA system for both the cases viz. without and with fuzzy logic generator, Simulation and testing has been carried out using various test inputs and finally it has been shown that fuzzy logic based OCDMA system shows significant perform improvements as evident from BER tester decision eye diagrams, BER eyelid diagrams, signal plots and autocorrelation diagrams.

Chapter 2
OPTICAL CDMA

As global network infrastructures expand to support various type of traffic, photonic networks are expected to take an important rule. The increasing demand for bandwidth forces network infrastructures to be of large capacity and reconfigurable. The efficient utilization of bandwidth is a major design issue for ultrahigh-speed photonic networks. the two main techniques for multiplexing data signals are currently time division multiplexing (TDM) and wavelength division multiplexing (WDM).Optical code division multiple access (OCDMA) is an alternative method, which performs encoding and decoding through an optical signature code, in order to allow the selection of a desired signal so that different users can share the same bandwidth. In such a systems, data signal overlap both in time and wavelength.

The roots of OCDMA are found in spread spectrum communication techniques. Spread spectrum was developed in the mid -1950s mainly as a novel form of transmission, overcoming the grid restrictions in radio bandwidth allocation. It is based on the idea of spreading the spectrum of the narrow band message over a much wider frequency spectrum by means of digital codes. Due to the spreading, the transmitted signal arrives at the receiver as a noise like signal. And message recovery is impossible unless the original code is known. The received signal is correlated by the authorized receiver with a local code, which is a replica of a transmission code.Despreading and signal recovery in the presence of the interference from other users can be accomplished. As a result, spread spectrum found applications in military communications, as a mechanism of transmitting signals in a very noisy environment with a very high security. Furthermore, with the emergence of satellite and mobile communications, spread spectrum was considered as a basis of a new multiple access technique named CDMA.The first work in OCDMA occurred in the late 1970s in the area of fiber delay lines for signal processing. In OCDMA each channel is optically encoded with the specific code. Only an intended user with the corrected code can recover the encoded information. A proper choice of optical codes allow signals from all connected network nodes to be carried without interference between signals.Therefore,simultaneous multiple access can be achieved without a complex network protocols to coordinate data transfer among thee communicating nodes. As a result, multi-user can share the same transmission bandwidth. The selection of the desired signal is based on matched filtering ,followed by thresh holding .OCDMA can provide advantages when applied to photonic networks ,such as asynchronous transmission, a potential of communication security, soft capacity on demand ,and high degree of scalability.

The performance of TDM systems is limited by the time –serial nature of the technology. Each receiver should operate at the total bit rate of the system. The allocation of dedicated time slots does not allow TDM to take advantages of statistical multiplexing gain, which is significant when the data traffic occurs in burst. TDMA is a complimentary access technique to FDMA. Global Systems for Mobile communications (GSM) uses the TDMA technique. In TDMA, the entire bandwidth is available to the user but only for a finite period of time. In most cases the available bandwidth is divided into fewer channels compared to FDMA and the users are allotted time slots during which they have the entire channel bandwidth at their disposal. This is illustrated in figure 1.1. TDMA requires careful time synchronization since users share the bandwidth in the frequency domain. Since the number of channels are less, inter channel interference is almost negligible, hence the guard time between the channels is considerably smaller. Guard time is spacing in time between the TDMA bursts. In cellular communications, when a user moves from one cell to another there is a chance that user could experience a call loss if there are no free time slots available. TDMA uses different time slots for transmission and reception. This type of duplexing is referred to as Time division duplexing (TDD). TDD does not require duplexers.

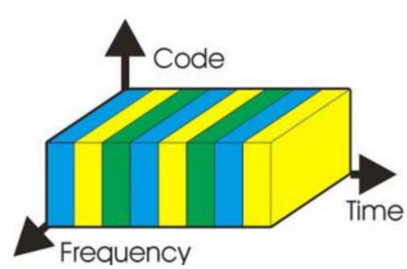


Figure 2.1: Channel usage by TDMA

FDMA is one of the earliest multiple-access techniques for cellular systems when continuous transmission is required for analog services. In this technique the bandwidth is divided into a number of channels and distributed among users with a finite portion of bandwidth for permanent use as illustrated in figure 2.2. The vertical axis that represents the code is shown here just to make a clear comparison with CDMA. The channels are assigned only when demanded by the users. Therefore when a channel is not in use it becomes a wasted resource. FDMA channels have narrow bandwidth (30Khz) and therefore they are usually implemented in narrowband systems. Since the user has his portion of the bandwidth all the time, FDMA does not require synchronization or timing control, which makes it algorithmically simple. Even though no two users use the same frequency band at the same time, guard bands are introduced between frequency bands to minimize adjacent channel interference. Guard bands are unused frequency slots that separate neighboring channels. This leads to a waste of bandwidth. When continuous transmission is not required, bandwidth goes wasted since it is not being utilized for a portion of the time. In wireless communications, FDMA achieves simultaneous transmission and reception by using Frequency division duplexing (FDD). In order for both the transmitter and the receiver to operate at the same time, FDD requires duplexers. The requirement of duplexers in the FDMA system makes it expensive.

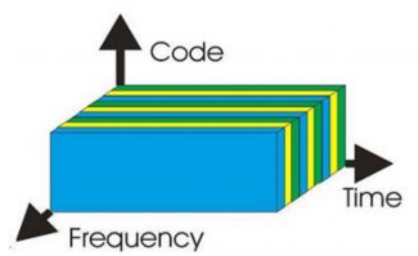


Figure 2.2: Channel usages by FDMA

OCDMA offers an interesting alternative because neither time management nor frequency management at the transmitting nodes is necessary.OCDMA can operate asynchronously and does not suffer from packet collisions; therefore very low latencies can be achieved. In contrast to TDM and WDM, in which the maximum transmission capacity is determined by the total number of time slots or wavelength channels, respectively, OCDMA allows flexible network design- the signal quality depends on the number of active channels.

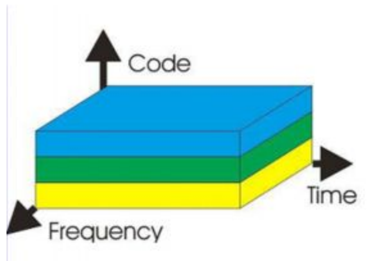


Figure 2.3: Channel usage by OCDMA

2.1 A Historical Perspective

Early History (Before 1980)

During the 1970s when laser target designation was maturing, there were development efforts in pulse repetition rate codes, preffered 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).A special class of OOCs, the optimum Golomb ruler was defined and described. It is a special class because the values of the cross –correlations are ones or zeroes, and the autocorrelation side lobes are ones or zeroes.

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 femtosecond 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 on to compute performance as a function of number of concurrent users for both OOK and PSK.

2.2 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 and
6. Wavelength hopping time spreading coding.

The Pulse-amplitude coding and Pulse phase coding involved coding in the time domain. The schemes in the Pulse-amplitude coding are based on incoherent processing (i.e., summing of optical intensity) with fiber optic delay lines incoherent optical sources. While they are the easiest to implement, these schemes require the use of unipolar pseudoorthogonal codes, such as optical orthogonal codes and prime codes with nonzero cross-correlation functions. Borrowing the idea from wireless CDMA, the schemes in Pulse phase coding utilize optical fields by using phase modulators with-in fiber optic delay –lines for introducing 0^0 and 180^0 phase shift to pulses in a code sequence. Using coherent processing, the schemes allow the use of bipolar orthogonal codes, such as maximal-length sequences and Walsh codes, with close to zero cross-correlation functions, thus reducing multiple –access interference (MAI) and resulting in better code performance. Nevertheless, these two time –domain techniques are not inherently suitable for dense, high-speed, long-span optical networks because ultra short pulses required, making the systems susceptible to fiber dispersion and non-linearities.

In Spectral amplitude coding and Spectral phase coding, coding is performed in wavelength domain. The spectral nature of code is decoupled from temporal nature of data so that code length is now independent of data rate. Spectral OCDMA systems are code synchronous, on the condition that coded spectra must be aligned to a common wavelength reference plane. An ultra short pulse is first dispersed in multiple wavelengths by a grating in free space, spectral coding is performed by spectral components of the pulse through a phase or amplitude mask, and the coded spectral components are finally recombined by another grating to form a code sequence. The length of the code sequence is determined by the resolution of the gratings and masks.

The Spatial coding require the use of multiple fibers or multicore fibers with two-dimensional (2D) optical codes in the time and space domains simultaneously.Similarly, the wavelength –time schemes in Wavelength hoping time spreading coding requires 2D coding in the time and wavelength domains. The wavelength time schemes provide lower probability of interception and offers scalability and flexibility. Probability of interception is enhanced because the pulses of each code sequence are transmitted in different wavelengths making eavesdropping more difficult. This feature in physical layer can be useful for time sensitive secure transmissions, such as in strategic or military systems, where encryption delay is critical. In addition, with 2D codes, the requirement of ultra short pulses is lessened and wavelength –time systems are less vunrelable to fiber dispersion than coherent spectral coding systems, even though some degree of fiber dispersion management strategy may still be employed.

To support multiple users in OCDMA systems, one-dimensional (1D) unipolar codes, such as OOCs and prime codes were originally designed to provide thumbtack –shape autocorrelation and very low cross-correlation function in order to optimize the discrimination between the correct sequence and interference.However, good incoherent optical codes are very sparse in binary ones. Very long code length is required in order to obtain a good ratio of autocorrelation peak to the maximum cross-correlation value. One possible value of reducing code length is to use 2D code. In particular, Wavelength hopping time spreading coding require coding with multiple wavelengths and involve the so called wavelength time codes. They can be viewed as fast wavelength –hoping codes, in which wavelength –hops take place at every pulse of code sequences

At first, 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 2.4 illustrates a 32 chips per- bit optical code with 4 active chips.

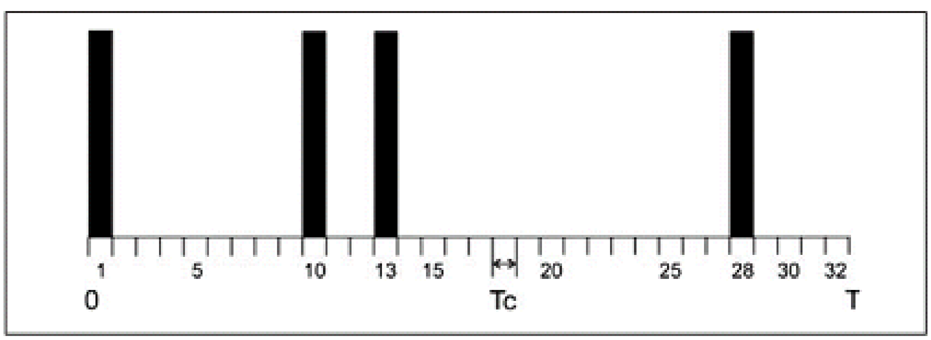


Figure 2.4: Optical code represented by light pulses in the chip positions 1, 10, 13 and 28.

Alternatively, this code can be presented by means of an optical disc as shown in Figure 2.5, in which the disc perimeter is equivalent to a bit period (Tb) and each chip period (Tc) corresponds to a disc sector equal to $2\pi T\text{c}/T\text{b}$.

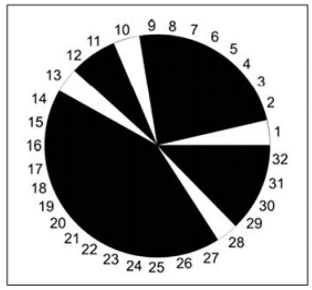


Figure 2.5 : Alternative representation of Fig. 2.4's optical code.

This representation is useful to make an analogy to maximum autocorrelation values, Figure 2.6a, and with sequence shifting, by rotating the disc, Figure 2.6b.

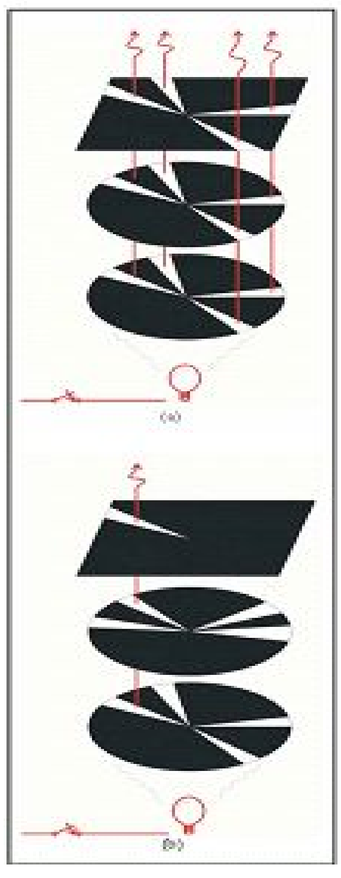


Figure 2.6 : Autocorrelation demonstration of a disk representing an optical PN sequence. (a) Peak value. (b) Autocorrelation with some shifting in the sequence.

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.

2.3 Optical CDMA with Optical Orthogonal Code

There have been many efforts to take the full advantage of fiber-optic signal processing techniques to establish an all optical CDMA communication systems since CDMA was first applied to the optical domain in the mid-1980s by Prucnal, Salehi, and others . Traditional fiber optic communication systems use either TDMA or WDMA schemes to allocate bandwidth among multiple users. Unfortunately, both present significant drawbacks in local area systems requiring large numbers of users. In a TDMA system, the total system throughput is limited by the product of the number of users and their respective transmission rates since only one user can transmit at a time. For instance, if 100 users wish to transmit at 1 gigabit per second, at a minimum the communication hardware would need to be capable of sustaining a throughput of 100 gigabits per second, a data rate that would strain even the highest performance optical networking equipment. In addition, TDMA systems show significant latency penalties because of the coordination required to coordinate and grant requests for time slots from users by the central node[12] . Unlike TDMA, a WDMA system allows each user to transmit at the peak speed of the network hardware since each channel is transmitted on a single wavelength of light. A WDMA system could easily support a bandwidth of one terabit per second, ideal for the needs of a local area network. Unfortunately, it is difficult to construct a WDMA system for a dynamic set of multiple users because of the significant amount of coordination among the nodes required for successful operation. To build a WDMA network with a dynamic user base, control channels and collision detection schemes would need to be implemented that would waste significant bandwidth. Fortunately, an alternative to TDMA and WDMA networking schemes, optical CDMA communication systems, require neither the time nor the frequency management systems. Optical CDMA can operate asynchronously, without centralized control, and it does not suffer from packet collisions. As a result, optical CDMA systems have lower latencies than TDMA or WDMA. Furthermore, since time and frequency (or wavelength) slots do not need to be allocated to each individual user, significant performance gains can be achieved through multiplexing. Also, TDMA and WDMA systems are limited by hardware because of the slot allocation requirements. In contrast, CDMA systems are only limited the tolerated bit error rate relationship to the number of users, affording the designer a much more flexible network design . To establish the optical CDMA, we have to overcome the code orthogonality problem. Many researchers have proposed several codes such as prime code, optical orthogonal code, and so on. Here we focus on optical orthogonal codes (OOC) among those codes.

2.3.1 Optical Orthogonal Code

An optical orthogonal code is a family of (0, 1) sequences with good auto- and cross-correlation properties. Thumbtack-shaped auto-correlation enables the effective detection of the desired signal (Fig. 2.8c), and low-profiled cross-correlation makes it easy to reduce interference due to other users and channel noise (Fig. 2.8d). The use of optical orthogonal codes enables a large number of asynchronous users to transmit information efficiently and reliably. The lack of a network synchronization requirement enhances the flexibility of the system. The codes considered here consist of truly (0, 1) sequences (Fig. 2.7a) and are intended for “unipolar” environments that have no negative components since you either have light, or you don't, while most document ed correlation sequences are actually (+1, -1) sequences (Fig.2.7b) intended for systems having both positive and negative components.

An (*n, w, a, c*) optical orthogonal code *C* is a family of (0, 1) sequences of length *n* and weight *w* which satisfy the following two properties [5].

The Auto-Correlation Property:

$$\sum_{t=0}^{n-1} x_t x_{t+\tau} \leq \lambda_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

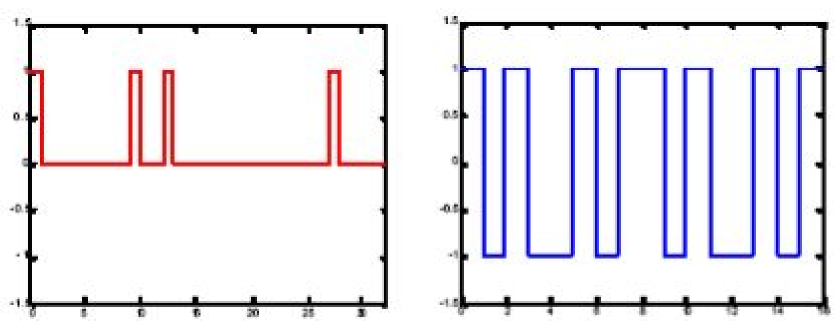
for any $x \in C$ and any integer t, 0<t<n.

The Cross-Correlation Property :

$$\sum_{t=0}^{n-1} x_t y_{t+\tau} \leq \lambda_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

for any $y \in C$ and any integer t.

The numbers *a* and *c* are called the auto- and cross correlation constraints. The (0, 1) sequences of an optical orthogonal code are called its codewords



(a) (b)

Fig. 2.7: Examples of sequences (a) Sequence for fiber optics (b) Sequence for radio frequency

An (n, w, a, c) OOC C can be alternatively considered as a family of w sets of integers modulo n in which each w set corresponds to a codeword and the integers within each w set specify the nonzero bits. For instance, let's think of a simple OOC, 1101000, characterized by (7, 3, 1, 1). Here we can see three 1s as the nonzero bits. Their positions are 0th, 1st, and 3rd, respectively. Thus 1101000 can be simply represented by {0, 1, 3} (mod 7). This notation can simply represent codes instead of exhaustively describing long (0, 1) sequences. Table below shows some optimal (n, 3, 1, 1) codes in this notation.

n	Optimal (n, 3, 1, 1)-codes
7	{0,1,3}
13	{0,1,4}, {0,2,7}
19	{0,1,5}, {0,2,8}, {0,3,10}
25	{0,1,6}, {0,2,9}, {0,3,11}, {0,4,13
31	{0,1,7}, {0,2,11}, {0,3,15}, {0,4,14}, {0,5,13}
37	{0,1,11}, {0,2,9}, {0,3,17}, {0,4,12}, {0,5,18},{0,6,12}
43	{0,1,19}, {0,2,22}, {0,3,15}, {0,4,13}, {0,5,16},{0,6,14},{0,7,17}

Let's think of C represented by {{0, 10, 13, 28}, {0, 5, 12, 31}} (mod 32) with two code words. Two code words are shown in Fig. 2.8 (a) and (b), respectively. C also can be represented by (32, 4, 1, 1) in (n, w, a, c) notation. Fig. 2.8 (c) shows auto-correlation of OOC 1. Its maximum value is w at the correlation time and one or zero at any other time following (1). Fig. 2.8 (d) shows the cross correlation between OOC 1 and OOC 2. It always takes one and zero at any time following (2). Here 1s are taken as auto-correlation constraint, a, and cross-correlation constraints, c, since 1s are the lowest value they can be, and correlation is calculated by convolution sum of two sequences.

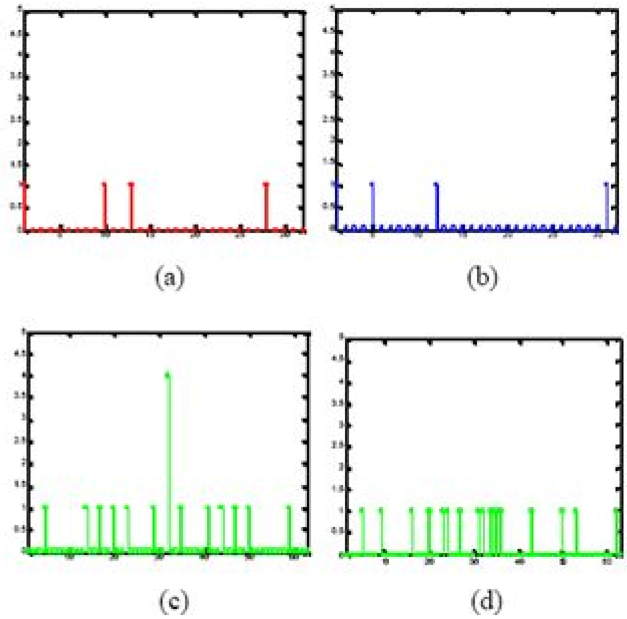


Fig. 2.8: (a) OOC 1 (b) OOC 2 (c) Auto-correlation (d) Cross-correlation

2.3.2 Optical CDMA

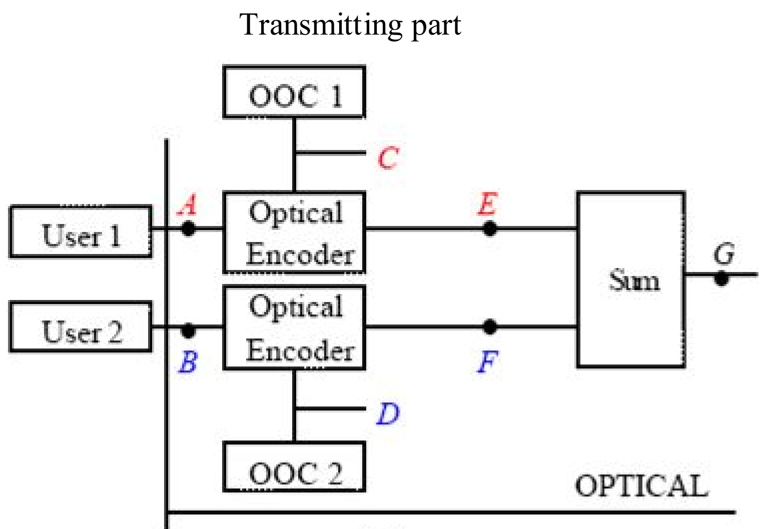
2.3.2.A. Two-User Synchronous Channel

The two-user synchronous channel simulated here can be characterized by the follows.

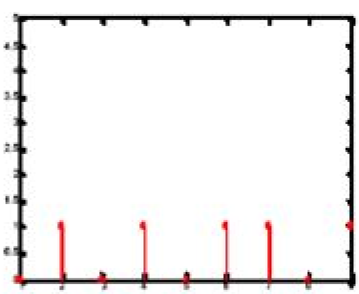
$$y(t) = A_1 b_1 s_1(t) + A_2 b_2 s_2(t) + \sigma n(t) \quad A_1 = A_2 = 1, \quad t \in [0,T]$$

$$\rho = < s_1, s_2 > = \int_0^T s_1(t) s_2(t) dt = \begin{cases} w, s_1 = s_2 \\ 0 \text{ or } 1, s_1 \neq s_2 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

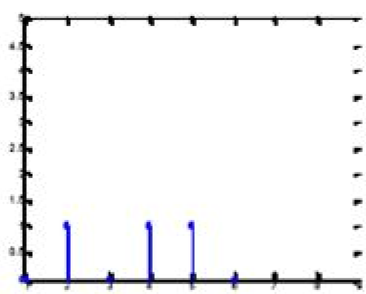
Let an (32, 4, 1, 1) optical code *C* with 2 code words be used. *C* can be represented by {{0, 10, 13, 28}, {0, 5, 12, 31}} mod (32) in Fig. 2.9 (d) and (e). Thus, the system can accommodate 2 transmitters simultaneously. Each transmitter is assigned a *w* (=4) set from *C*, i.e. transmitter1 is assigned a {0, 10, 13, 28} set and transmitter 2 is assigned a {0, 5, 12, 31} set. At a transmitter, every information bit is encoded into a frame of *n*(=32) optical chips in the following way. (A chip is an optical time slot which can assume one of two values: ON of OFF) Let the assigned *w* set for a particular transmitter be *S*={*s1*, *s2*, · · · , *sw*}. In this case, *s1* is a {0, 10, 13, 28} set and *s2* is a {0, 5, 12, 31} set. Assume the information bit is 1. In the corresponding frame, which consists of n optical chips, photon pulses (i.e., ON signals) are sent at exactly the $s1$th, $s2$th, · · · and swth chips (Fig. 2.9. f and g). In the other n-w chips, no photon pulse (i.e., OFF signals).



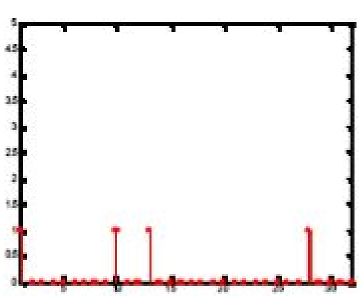
(a)



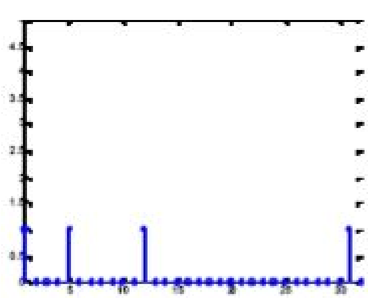
(b)



(c)



(d)



(e)

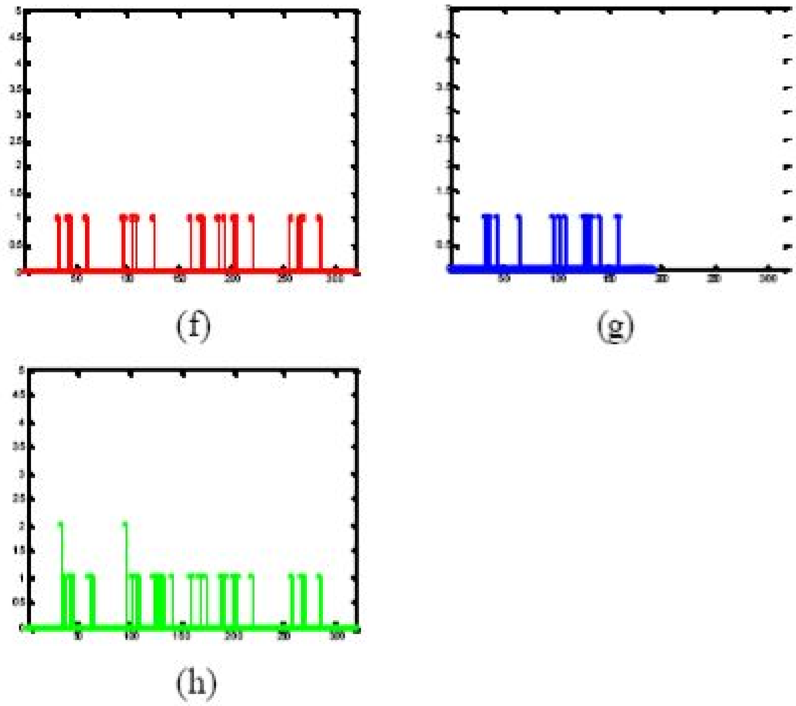
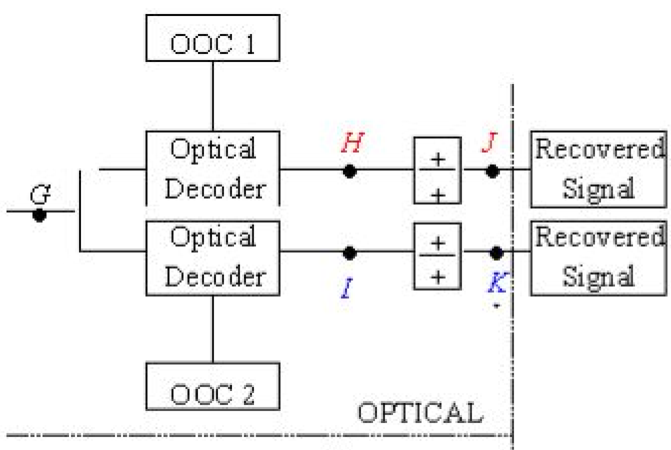


Fig. 2.9: (a) Schematic diagram for a transmitting part (b)Signal at *A* (c) Signal at *B* (d) Signal at *C* (e) Signal at *D* (f) Signal at *E* (g) Signal at *F* (h) Signal at *G*

On the other hand, if the information bit is 0, no photon pulses are sent in the corresponding frame, i.e., all OFF signals are sent. In other words, the codeword set is used as the signature sequence of the transmitter.

Receiving part



(a)

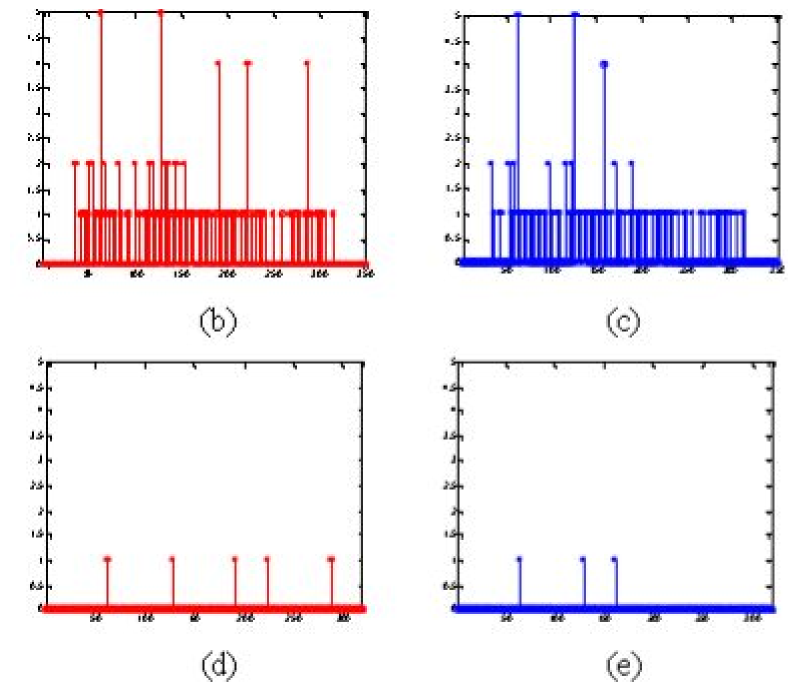


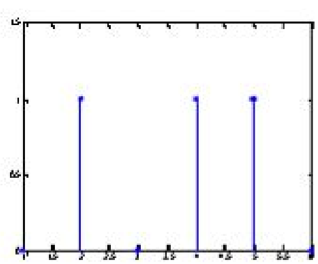
Fig. 2.10: (a) Schematic diagram for a receiving part (b) Signal at *H* (c) Signal at *I* (d) Signal at *J* (e) Signal at *K*

Basically, optimal CDMA scheme is same as radio frequency CDMA scheme except using the special codes. Here, we use the matched filter to convert the received signal in Fig. 2.9 (h) assuming *n(t)* in (2.3) is zero. At the receiving end, correlation-type decoders are used to separate the transmitted signals. The decoder consists of a bank of 2 tapped delay -lines, one for each codeword. The delay taps on a particular line exactly mat ch the signature sequence, i.e., the delays between successive taps are equal to s2-s1, s3-s2, · · · , optical chips, respectively. Each tapped delay-line effectively calculates the correlation of the received waveform with its signature sequences. In Figure 2.10 (b) and (c), there are five different correlation values, 0, 1, 2, 4, and 5. Because of the properties of optical orthogonal codes, the correlation between different signature sequences is low, 0 and 1. Thus the delay-line output is high, 4 and 5, only when the intended transmitter's information bit is 1. However, a potential problem due to interference can be happened. When correlation value has 2, it is definitely due to the interference. In this case, the value is always below 4 so it can be discarded by choosing relevant threshold value. But when total number of users goes up, the cross correlation due to interfering users adds up quickly to severely degrade the system performance. For instance, when *w* is 4 like this case, accommodating 4 users make it possible to have 4 as the correlation value even if the intended transmitter's information bit is 0. To avoid this phenomenon, both high *w* which can be considered as the sum of 1s in the sequence, and long *n* are required. If we increase only *w* fixing *n*, cross-correlation value due to the interference can be lowered. However, OOC has very sparse marks to keep the cross-correlation low, i.e. a number of zeros is much higher than that of ones in the sequence. It means that cross-correlation increases by itself by increasing only *w*. Therefore, both *w* and *n* should be increased simultaneously. But this solution also reveals a drawback, long signal processing time due to long *n*.

Finally the transmitted information is extracted by thresholding the correlator output in Figure 2.10 (d) and (e). In this case, they are successfully recovered as intended. Here, 2.3 is chosen as the threshold values.

2.3.2. B. Two-User Asynchronous Channel

In optical CDMA, all users are allowed to transmit at any time. There is no network synchronization required. In this section, we simulate a two-user asynchronous channel to investigate above statement. To verify no network synchronization, the same scheme in 2.4.2.A. is used here except the time delay at *F* in Figure 2.9 (a). Fig. 2.11 (b) and (c) show the recovered signals from asynchronous and synchronous channel, respectively. They agree well even if synchronous channel does not use any special



(a)

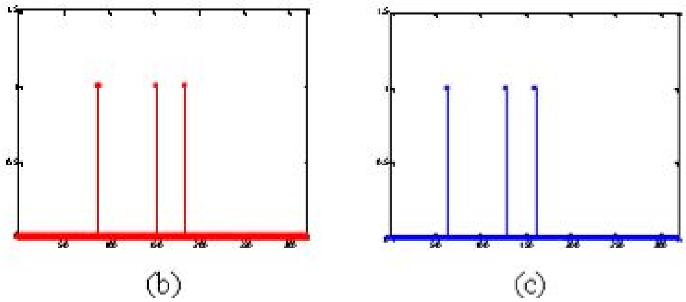


Fig. 2.11: (a) Intended information binary signal (b) Recovered signal from asynchronous channel (c) Recovered signal from synchronous channel

scheme for synchronization. Therefore, now we can say that optical CDMA does need no network synchronization

2.3.2. C. *K*-User Synchronous Channel

In the previous section, we investigated a simple 2-user channel to understand the optical CDMA. In this section, we explore problems faced by increasing *K* (Figure 2.12 a). Here we choose 7 as *K*, and *C* is (43, 3, 1, 1) having 7 sets, {{0, 1, 19}, {0, 2, 22}, {0, 3, 15}, {0, 4, 13}, {0, 5, 16}, {0, 6, 14}, {0, 7, 17}}. The first issue is a threshold value. As we saw in the previous section, interfering signal can be effectively discarded by setting a relevant threshold value. The threshold value can be chosen under the following condition.

$0 \lneqq threshold \leqq w$ (4)……………………………(2.4)

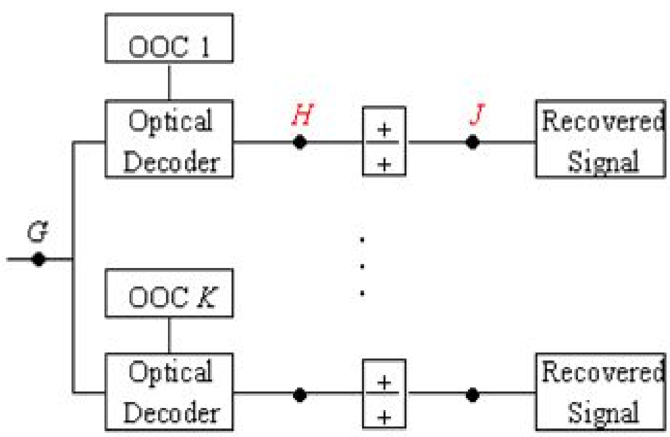
Figure 2.12 (d) through (g) show results from several threshold values, 1, 2, 3, and 5. As the threshold value goes up, the recovered signal gets similar to the ideal signal in Figure 2.12 (c). However, the threshold value can not be over *w*. If the intended information bit is 1, the correlation value is *w*. Therefore, the threshold over *w* incorrectly converts it to 0 when the intended information bit is 1. Fiure.2.12 (g) shows the results by choosing threshold over *w*. We can clearly see that a dotted line is missed comparing to Figure 2.12 (c).

Even if the highest value under (2.4) is chosen (Figure 2.12 f), the recovered signal can not be exactly same as the ideal pattern. In the Figure 2.12(a), if the intended information bit is 1, the correlation value is *w*(=3). But as we already discussed in the previous section, the cross correlation due to interfering users adds up very quickly to severely degrade the system performance. Here, the correlation value due to interference is even higher than w(=3). This is the reason why the received signal can not be recovered perfectly.

To figure it out above problem we introduce optical hard-limiter [3] located before the optical tapped-delayline (Figure 1.13a). An ideal optical hard-limiter is defined as

$$g(x) = \begin{cases} 1, x \geq 1 \\ 0, 0 \leq x < 1 \end{cases} \quad \dots\dots\dots\dots\dots\dots\dots (2.5)$$

Therefore, if an optical light intensity (x) is bigger than or equal to one, the hard-limiter would clip the intensity back to one, and if the optical light intensity is smaller than one, the response of the optical hard-limiter would be zero. This ideal nonlinear process would enhance the system performance because it would exclude some combinations of interference patterns from causing errors as in the soft-limiter case, i.e., the patterns that caused errors by analog summation of light intensity rather than by exact reproduction of the particular pattern with no analog effect. Figure 2.13 shows comparison between the systems with and without the optical hard-limiter.



(a)

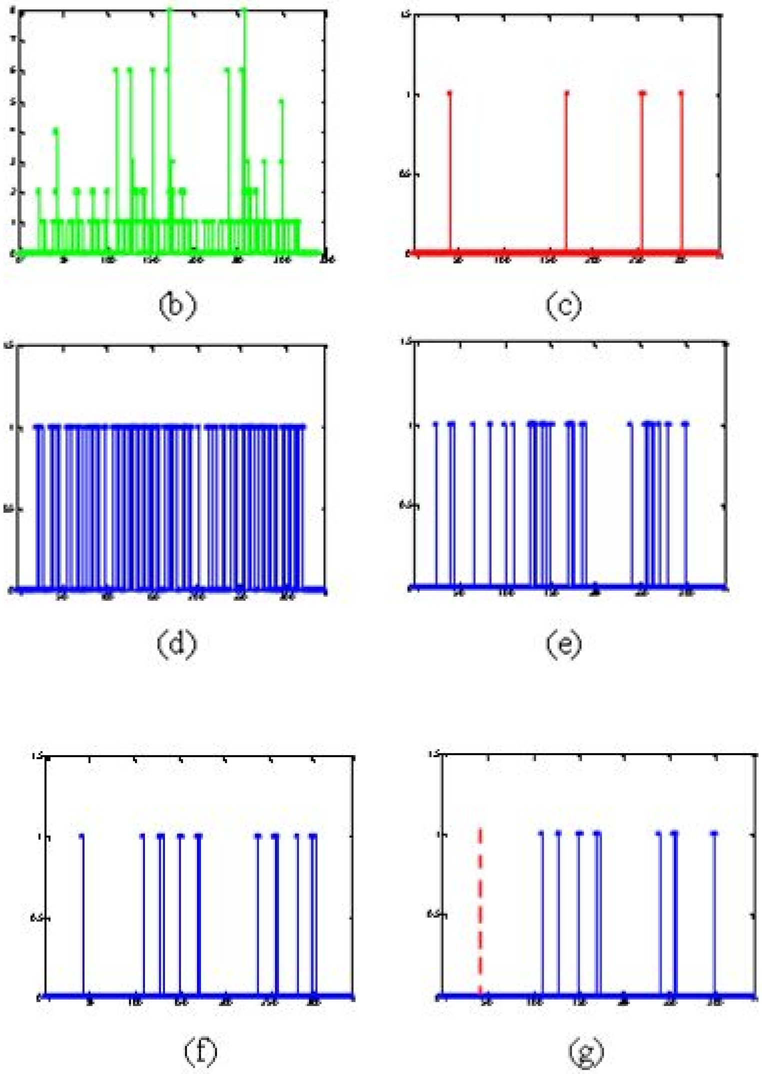
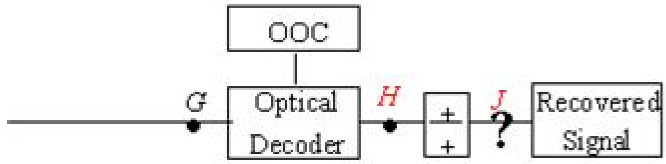
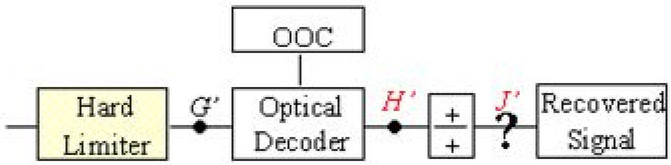


Fig. 2.12: (a) Schematic diagram of a receiving part for *K* users (b) Signal at H (c) Ideal signal at *J* (d) Signal at *J* when threshold=1 (e) Signal at *J* when threshold=2 (f) Signal at *J* when threshold=3 (g) Signal at *J* when threshold=5

All optical light intensity which is bigger than or equal to one are clipped back to one in Figure 2.13 (d). In Figure 2.13 (f), the cross-correlation value over *w* due to the interference does not exist any more. From these, the thresolding can much effectively recover the information. Figure 2.13 (g) and (h) show the recovered signals without and with the optical hard-limiter, respectively. We can clearly see that Figure 2.13 (h) is much similar to the intended signal (Figure 1.13 i). Consequently, we can say that the optical hard-limiter can effectively lower the interference effect.


OOC
G
Optical
Decoder
H
+
+
J
?
Recovered
Signal

(a)


OOC
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Limiter
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Decoder
H'
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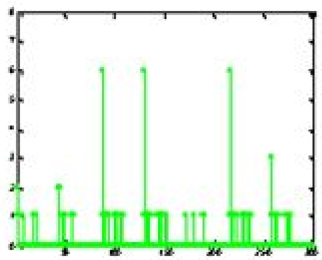
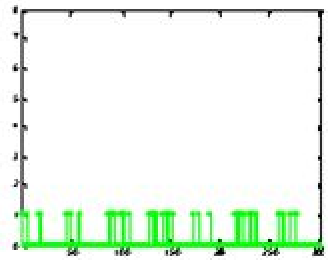
J'
?
Recovered
Signal

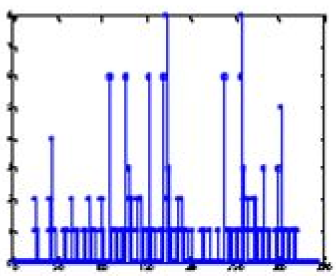
(b)



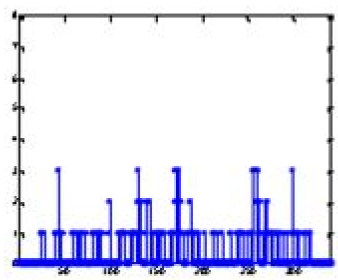
(c)



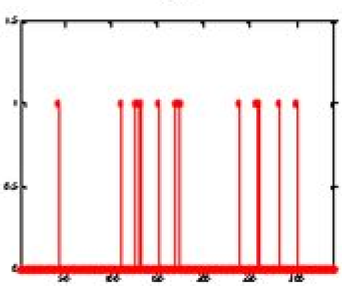
(d)



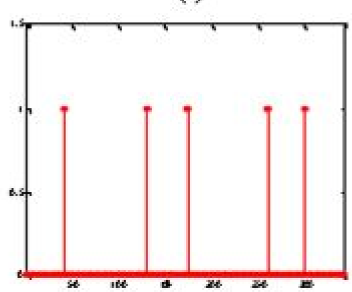
(e)



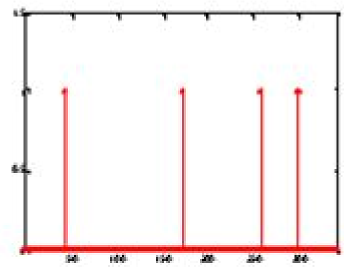
(f)



(g)



(h)



(i)

Fig. 2.13: (a) Receiving part without optical hard-limiter (b) Receiving part with optical hard-limiter (c) Signal at *G* (d) Signal at *G'* (e) Signal at *H* (f) Signal at *H'* (g) Signal at *J* (h) Signal at *J'* (i) Ideal signal expected at *J*.

2.3.3 Probability of error

The probability of error per bit is defined as

PE=*p* (*LI*≥*th* | *b*=0)? *p* (*b*=0) +*p* (*LI*<*th* | *b*=1)?*p*(*b*=1) ……………..(6)

where *PE*, *LI*, *th*, and *b* are the probability of error, light intensity, threshold, and intended binary information bit, respectively. Here, an interesting point is that *p*(*LI*<*t*h | *b*=1) is always equal to zero because *p*(*LI*<*t*h | *b*=1)=*p*(*w*+*I* < *t*h) = *p*(*w*+*I*-*th* <0)=0 under (4) where *I* is the interference due to other users. According to [4], one can easily calculate the probability of error using the followings.

$$PE = \frac{1}{2}\sum_{i=th}^{K-1}\binom{K-1}{i}\left(\frac{w^2}{2n}\right)^{i}\left(1-\frac{w^2}{2n}\right)^{K-1-i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.7)$$

Fig. 2.14 shows several dependency of *PE*. In Figure 2.14 (a), a length of code, *n*, is tested in different values, 200, 500, 1000, and 2000. As *n* goes up, *PE* gets lowered resulting in long processing time. So we need to deal with the trade off problem on the low error rate and processing time. Figure 2.14 (b) shows *w*-dependency of *PE*. As the sum of 1s in the code, *w*, goes up, *PE* gets lowered. Note that the highest threshold value under (4) would make the lowest *PE* on the same *w*. In the Figure 2.14 (c), we can find *K*-dependency of PE. As the number of accommodated users, *K*, goes up, *PE* gets higher. This is definitely due to the increasing interference.

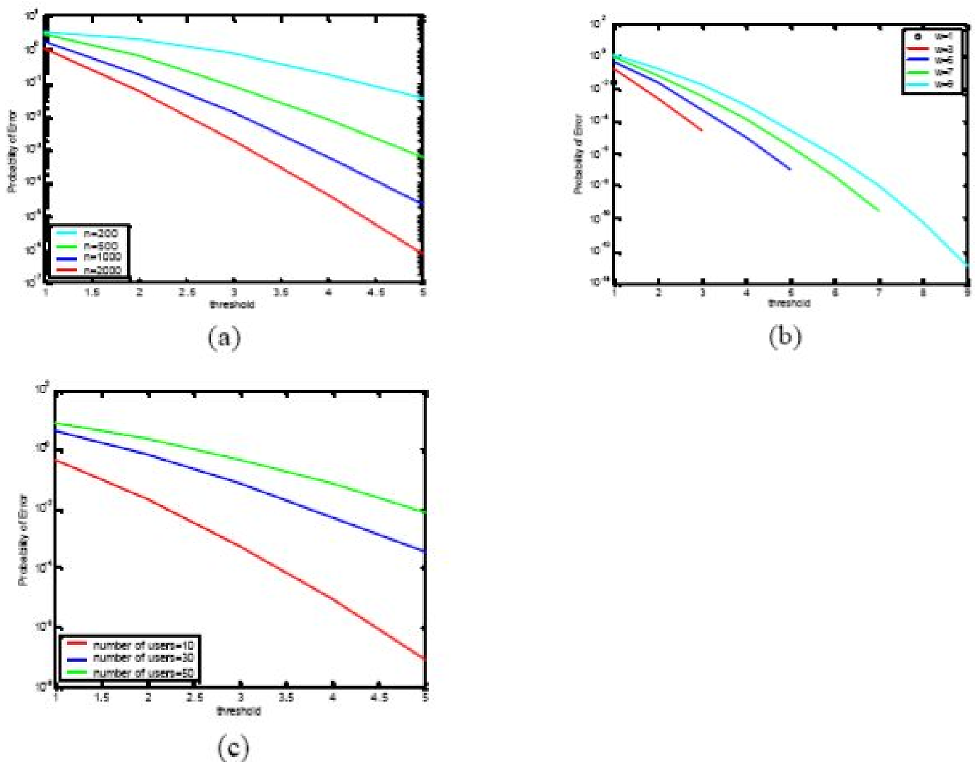


Fig. 2.14: (a) n-dependency of probability of error (b) w -dependency of probability of error (c) K-dependency of probability of error

Chapter 3
FUZZY LOGIC

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control. If feedback controllers could be programmed to accept noisy, imprecise input, they would be much more effective and perhaps easier to implement. Unfortunately, U.S. manufacturers have not been so quick to embrace this technology while the Europeans and Japanese have been aggressively building real products around it.

In this context, FL is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster.

3.1 Difference between Fuzzy Logic and conventional control methods

FL incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as "SP =500F", "T <1000F", or "210C <TEMP <220C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or

"IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are imprecise and yet very descriptive of what must actually happen. Consider what you do in the shower if the temperature is too cold: you will make the water comfortable very quickly with little trouble. FL is capable of mimicking this type of behavior but at very high rate.

3.2 How does Fuzzy Logic work?

FL requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them. For example, a simple temperature control system could use a single temperature feedback sensor whose data is subtracted from the command signal to compute "error" and then time-differentiated to yield the error slope or rate-of-change-of-error, hereafter called "error-dot". Error might have units of degs F and a small error considered to be 2F while a large error is 5F. The "error-dot" might then have units of degs/min with a small error-dot being 5F/min and a large one being 15F/min. These values don't have to be symmetrical and can be "tweaked" once the system is operating in order to optimize performance. Generally, FL is so forgiving that the system will probably work the first time without any tweaking.

3.3 Features of Fuzzy Logic

FL offers several unique features that make it a particularly good choice for many control problems.

1) It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

2) Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.

3) FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.

4) Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated, although defining the rulebase quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined. It would be better to break the control system into smaller chunks and use several smaller FL controllers distributed on the system, each with more limited responsibilities.

5) FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation.

3.4 Use of Fuzzy Logic

1) Define the control objectives and criteria: What am I trying to control? What do I have to do to control the system? What kind of response do I need? What are the possible (probable) system failure modes?

2) Determine the input and output relationships and choose a minimum number of variables for input to the FL engine (typically error and rate-of-change-of-error).

3) Using the rule-based structure of FL, break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. The number and complexity of rules depends on the number of input parameters that are to be processed and the number fuzzy variables associated with each parameter. If possible, use at least one variable and its time derivative. Although it is possible to use a single, instantaneous error parameter without knowing its rate of change, this cripples the system's ability to minimize overshoot for a step inputs.

4) Create FL membership functions that define the meaning (values) of Input/Output terms used in the rules.

5) Create the necessary pre- and post-processing FL routines if implementing in S/W, otherwise program the rules into the FL H/W engine.

6) Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained.

3.5 Fuzzy expert system

A fuzzy expert system is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, to reason about data. The rules in a fuzzy expert system are usually of a form similar to the following:

if x is low and y is high then z = medium

where x and y are input variables (names for know data values), z is an output variable (a name for a data value to be computed), low is a membership function (fuzzy subset) defined on x, high is a membership function defined on y, and medium is a membership function defined on z. The antecedent (the rule's premise) describes to what degree the rule applies, while the conclusion (the rule's consequent) assigns a membership function to each of one or more output variables. Most tools for working with fuzzy expert systems allow more than one conclusion per rule. The set of rules in a fuzzy expert system is known as the rulebase or knowledge base.

The general inference process proceeds in three (or four) steps.

1. Under FUZZIFICATION, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise.

2. Under INFERENCE, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Usually only MIN or PRODUCT are used as inference rules. In MIN inferencing, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND).

In PRODUCT inferencing, the output membership function is scaled by the rule premise's computed degree of truth.

3. Under COMPOSITION, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Again, usually MAX or SUM are used. In MAX composition, the combined output fuzzy subset is constructed by taking the pointwise maximum over all of the fuzzy subsets assigned to variable by the inference rule (fuzzy logic OR). In SUM composition, the combined output fuzzy subset is constructed by taking the pointwise sum over all of the fuzzy subsets assigned to the output variable by the inference rule.

4. Finally is the (optional) DEFUZZIFICATION, which is used when it is useful to convert the fuzzy output set to a crisp number. There are more defuzzification methods than you can shake a stick at (at least 30). Two of the more common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as the crisp value for the output variable.

3.6 Fuzzy Set

The very basic notion of fuzzy systems is a fuzzy (sub)set. In classical mathematics we are familiar with what we call *crisp sets*. For example, the possible interferometric coherence values are the set *X* of all real numbers between 0 and 1. From this set *X* a subset *A* can be defined, (e.g. all values 0< □< 0.2). The *characteristic function* of A, (i.e. this function assigns a number1 or 0 to each element in *X,* depending on whether the element is in the subset *A* or not) is shown in Figure 3.1.

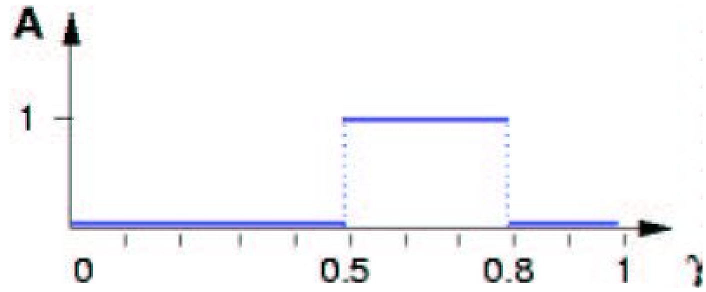


Figure 3.1: Characteristic Function of a Crisp Set

The elements which have been assigned the number 1 can be interpreted as the elements that are in the set *A* and the elements which have assigned the number 0 as the elements that are not in the set *A*. This concept is sufficient for many areas of applications, but it can easily be seen, that it lacks in flexibility for some applications like classification of remotely sensed data analysis. For example it is well known that water shows low interferometric coherence γ in SAR images. Since γ starts at 0, the lower range of this set ought to be clear. The upper range, on the other hand, is rather hard to define. As a first attempt, we set the upper range to 0.2. Therefore we get B as a crisp interval B=[0,0.2]. But this means that a γ value of 0.20 is low but a γ value of 0.21 not. Obviously, this is a structural problem, for if we moved the upper boundary of the range from γ =0.20 to an arbitrary point we can pose the same question. A more natural way to construct the set *B* would be to relax the strict separation between *low* and *not low*. This can be done by allowing not only the (*crisp*) decision *Yes/No*, but more flexible rules like " fairly low". A fuzzy set allows us to define such a notion.The aim is to use fuzzy sets in order to make computers more intelligent, therefore, the idea above has to be coded more formally. In the example, all the elements were coded with 0 or 1. A straight way to generalize this concept, is to allow more values between 0 and 1. In fact infinitely many alternatives can be allowed between 0 and 1, namely the unit interval I =[0, 1]. The interpretation of the numbers, now assigned to all elements is much more difficult. Of course, again the number 1 assigned to an element means, that the element is in the set *B* and 0 means that the element is definitely not in the set *B*. All other values mean a gradual membership to the set *B*. This is shown in Figure 3.2. The *membership function* is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion.

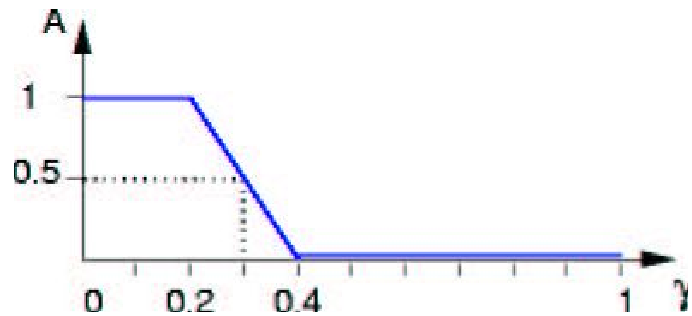


Figure 3.2: Characteristic Function of a Fuzzy Set

The membership function, operating in this case on the fuzzy set of interferometric coherence γ.returns a value between 0.0 and 1.0. For example, an interferometric coherence γ of 0.3 has a membership of 0.5 to the set *low coherence* (see Figure 3.2).

It is important to point out the distinction between fuzzy logic and probability. Both operate over the same numeric range, and have similar values: 0.0 representing *False* (or non membership), and 1.0 representing *True* (or full membership). However, there is a distinction to be made between the two statements: The probabilistic approach yields the natural language statement, "There is an 50% chance that γ is low," while the fuzzy terminology corresponds to "γ 's degree of membership within the set of low interferometric coherence is 0.50." The semantic difference is significant: the first view supposes that γ is or is not low; it is just that we only have an 50% chance of knowing which set it is in. By contrast, fuzzy terminology supposes that γ is "more or less" low, or in some other term corresponding to the value of 0.50.

3.6.1 Operations on Fuzzy Sets

We can introduce basic operations on fuzzy sets. Similar to the operations on crisp sets we also want to intersect, unify and negate fuzzy sets. In his very first paper about fuzzy sets [1], L. A. Zadeh suggested the minimum operator for the intersection and the maximum operator for the union of two fuzzy sets. It can be shown that these operators coincide with the crisp unification, and intersection if we only consider the membership degrees 0 and 1. For example, if *A* is a fuzzy interval between 5 and 8 and *B* be a fuzzy number about 4 as shown in the Figure below

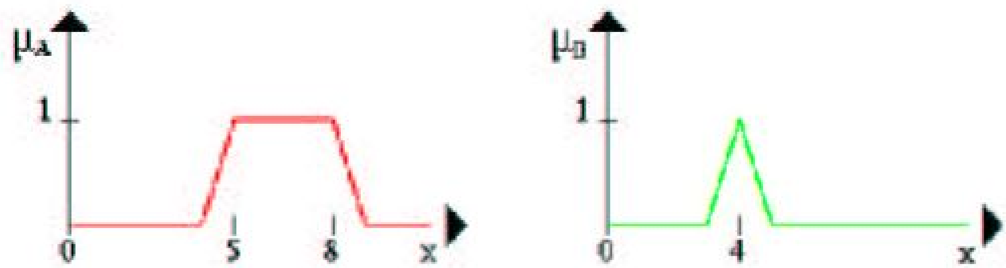


Figure 3.3: Example fuzzy sets

In this case, the fuzzy set between 5 and 8 *AND* about 4 is

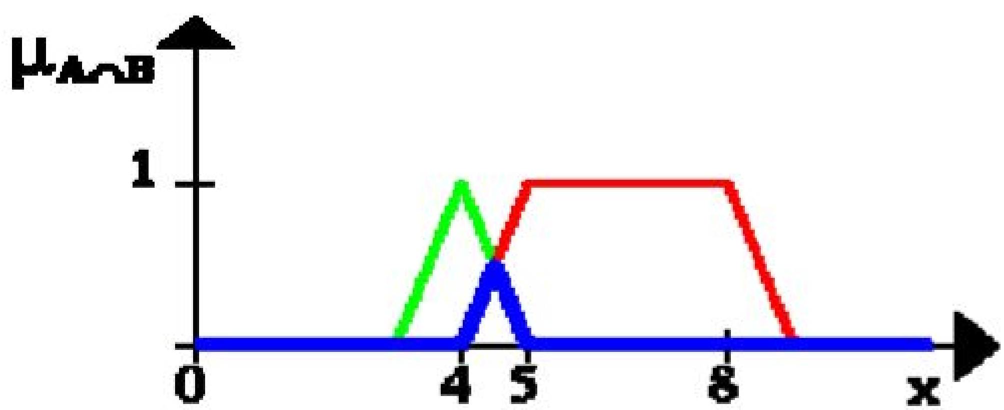


Figure 3.4: Fuzzy *AND*

set between 5 and 8 *OR* about 4 is shown in the next figure

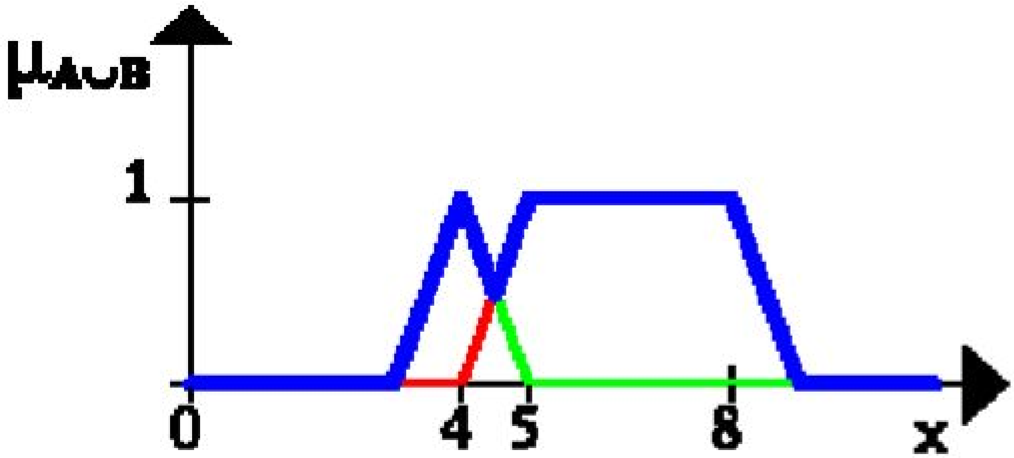


Figure 3.5: Fuzzy *OR*

the NEGATION of the fuzzy set A is shown below

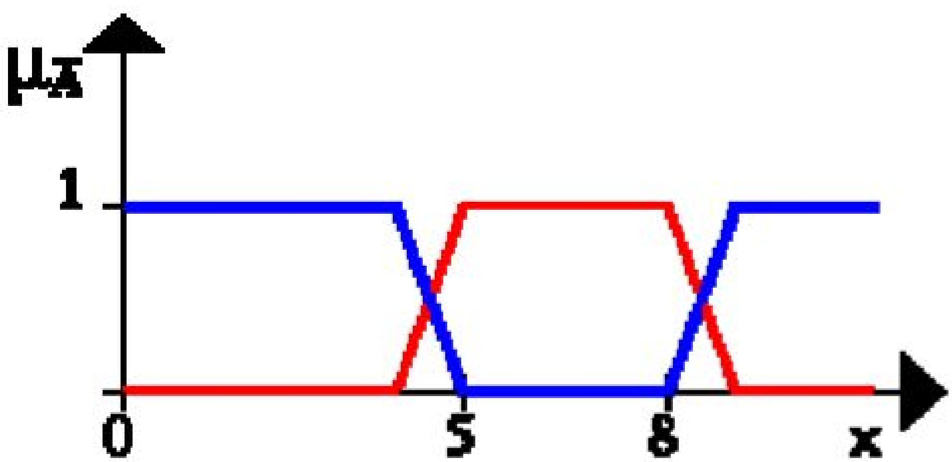


Figure 3.6: Fuzzy NEGATION

3.7 Fuzzy Control

Automatic control belongs to the application areas of fuzzy set theory that have attracted most attention. In 1974, the first successful application of fuzzy logic to the control of a laboratory-scale process was reported (Mamdani and Assilian 1975). Control of cement kilns was an early industrial application (Holmblad and Ostergaard 1982). Since the first consumer product using fuzzy logic was marketed in 1987, the use of fuzzy control has increased substantially. A number of CAD environments for fuzzy control design have emerged together with VLSI hardware for fast execution. Fuzzy control is being applied to various systems in the process industry (Santhanam and Langari 1994, Tani et al. 1994), consumer electronics (Hirota 1993, Bonissone 1994), automatic train operation (Yasunobu and Miyamoto 1985), traffic systems in general (Hellendoorn 1993), and in many other fields (Hirota 1993, Terano et al. 1994).

A fuzzy logic controller describes a control protocol by means of if-then rules, such as "if temperature is low open heating valve slightly". The ambiguity (uncertainty) in the definition of the linguistic terms (e.g., *low temperature*) is represented by using *fuzzy sets*, which are sets with overlapping boundaries, see Figure 3.7. In the fuzzy set framework, a particular domain element can simultaneously belong to several sets (with different degrees of membership, μ). For instance, $t = 20°$ C belongs to the set of *High* temperatures with membership 0.4 and to the set of *Medium* temperatures with membership 0.2. This gradual transition from membership to non-membership facilitates a smooth outcome of the reasoning (deduction) with fuzzy if-then rules.

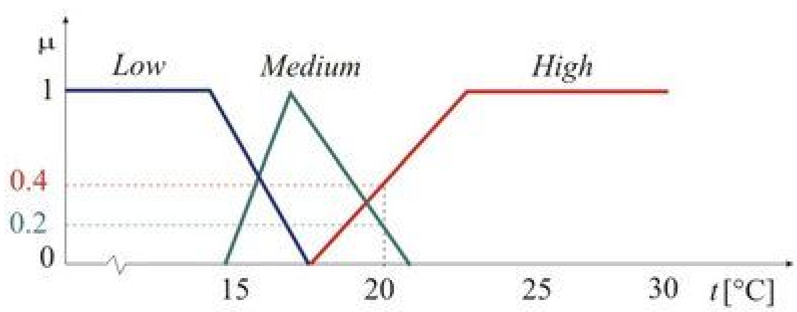


Figure 3.7: Partitioning of the temperature domain into three fuzzy sets.

3.7.1 Historical perspective

Fuzzy Control emerged from a doctorate thesis in Artificial Intelligence. The work was carried out around 1972 to 1974. The objective of the research was to see if computers can learn to perform a task by observing a human carry it out. The task chosen was the control of a model steam engine. The controls available were "heat" which produced the steam pressure in a boiler; and, "throttle" which injected the steam into the single cylinder engine affecting its speed. The control objective was to maintain constant pressure in the boiler and speed of the engine. Several key issues about this research project have to be highlighted to gain a good understanding of how Fuzzy Control emerged from this research project.

3.7.2 The Computational Environment

A small hybrid computer was available built around a PDP-8S mini-computer with 8K words (12 bit words) of magnetic core RAM. Paper tape was the main form of back up store. The mouse had not been invented yet and the communication was via a teletype. The steam engine inputs and outputs were set and read via the hybrid computer. An individual run of the experiment would involve the teletype printing out the present speed and pressure and waiting for the operator to respond by typing in the values for heat and throttle settings. On pressing the return key, the computer carried out these settings and responded by typing the new readings of the speed and pressure. This went on until the boiler ran out of water whereupon a new run could be started.

The study was agnostic with respect to any particular mathematical formalism to be used. Given the limited resources of our computational environment, we felt it was easiest to begin by using a Bayesian learning approach. The idea was to update the probabilities of an action given the state of the steam engine. This was obviously a naïve approach and not surprisingly the learnt probabilities failed to converge. It was naïve because it failed to take into account the fact that we were controlling a dynamic system, and the human operator did not merely take the current state into account in determine his action but was aware of the system's previous state trajectory. The algorithm had to be revised in such a way that it needed to take the previous states into account but it was feared that this would make it more complex and could stress the available RAM.

3.7.3 Motivation for fuzzy control

Conventional control theory uses an explicit mathematical (analytical) model of a process to be controlled and specifications of the desired closed-loop behavior to design a controller. This approach may fall short if the model of the process is difficult to obtain, (partly) unknown, or highly nonlinear. The design of controllers for seemingly easy everyday tasks such as driving a car or grasping a fragile object continues to be a challenge for robotics, while these tasks are easily performed by human beings. Yet, humans do neither use mathematical models nor exact trajectories for controlling such processes.

Many processes controlled by human operators in industry cannot be automated using conventional control techniques, since the performance of these controllers is often inferior to that of the operators. One of the reasons is that linear controllers, which are commonly used in conventional control, are not appropriate for nonlinear plants. Another reason is that humans aggregate various kinds of information and combine control strategies, that cannot be integrated into a single analytic control law. The underlying principle of *knowledge-based (expert) control* is to capture and implement experience and knowledge available from experts (e.g., process operators). A specific type of knowledge-based control is the fuzzy rule-based control, where the control actions corresponding to particular conditions of the system are described in terms of fuzzy if-then rules. Fuzzy sets are used to define the meaning of qualitative values of the controller inputs and outputs such *small* error, *large* control action. Fuzzy logic can capture the continuous nature of human decision processes and as such is a definite improvement over methods based on binary logic (which are widely used in industrial controllers).

The early work in fuzzy control was motivated by a desire to
mimic the control actions of an experienced human operator (knowledge-based part)
obtain smooth interpolation between discrete outputs that would normally be obtained (fuzzy logic part).

Since then the application range of fuzzy control has widened substantially. However, the two main motivations still persevere. The linguistic nature of fuzzy control makes it possible to express process knowledge concerning how the process should be controlled or how the process behaves. The interpolation aspect of fuzzy control has led to the viewpoint where fuzzy systems are seen as smooth function approximation schemes.

In most cases a fuzzy controller is used for direct feedback control. However, it can also be used on the supervisory level as, e.g., a self-tuning device in a conventional PID (Proportional-Integral-Differential) controller. Also, fuzzy control is no longer only used to directly express a priori process knowledge. For example, a fuzzy controller can be derived from a fuzzy model obtained through system identification. Most often used are *Mamdani (linguistic) controller* with either fuzzy or singleton consequents. This type of controller is usually used as a *direct* closed-loop controller.

Takagi-Sugeno (TS) controller, typically used as a *supervisory* controller.

3.8 Fuzzy Controller

When a person controls a process, perhaps as commonplace as a car engine or as specialized as a chemical plant, they describe their expertise in an apparently imprecise way. In starting a car a person may accelerate the engine "a little" before engaging the clutch and driving away. The chemical plant operator may reduce process heating "slightly" if the product temperature is rising "slowly". While imprecise, such rules appear to work well in practice. If such a process needs to be automated one approach is to attempt to emulate the human operator. The usual starting point in the development of such a control system is the process of knowledge elicitation in which a record is constructed of the human operator's expertise. In some cases such expertise is expressed in the form of rules which make use of linguistic variables. It is at this point that the system developers can make an implementation decision. The human's expertise could be applied directly. Alternatively, control technologists could be called in to do in-depth numerical analysis of the process and to recommend an algorithm for control.

In some cases the latter approach would turn out to be too expensive and time consuming, in others it might yield no results at all. In control technology terms there would be no process model obtainable within reasonable time and budget limitations. To control the process what is therefore needed is a computer based system which can use the control rules directly to implement an automatic control system. A fuzzy controller, which will make direct use of the control rules, is a strong candidate as a technical solution.

Developing a fuzzy control knowledge base is divided into two main tasks. The first is to choose a suitable set of linguistic variables to describe the values of the main control parameters. This selection plays an important role in the smoothness of control. When all the different labels have been selected, their membership function must be defined. This process is highly subjective. One might also use the neural networks to learn the membership function from examples. The second task is to state the rules in the control knowledge base with the aid of the chosen linguistic description. This can be done in several ways, for instance by interviewing an experienced human operator.
The basic architecture of a fuzzy controller is depicted in the figure. The decision making logic consists of the inference and composition sub process.

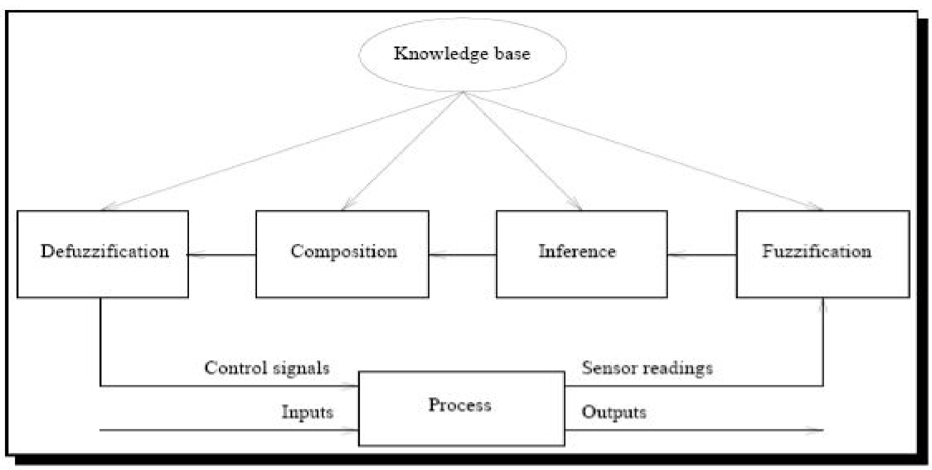


Figure 3.8: Topology of a typical fuzzy controller

3.8.1 Fuzzification

In the Fuzzification process, the membership functions defined on the input variables are applied to their actual values if the input variables are crisp. If the sensor is fuzzy (noisy), fuzzification refers to finding the intersection of the label's membership function and the distribution for the sensed data. Figure (3.9) shows how a sensor reading x_0 is matched with the membership function $\mu(x)$ to get $\mu(x_0)$ in both the crisp and fuzzy case. Usually the sensor reading is crisp.

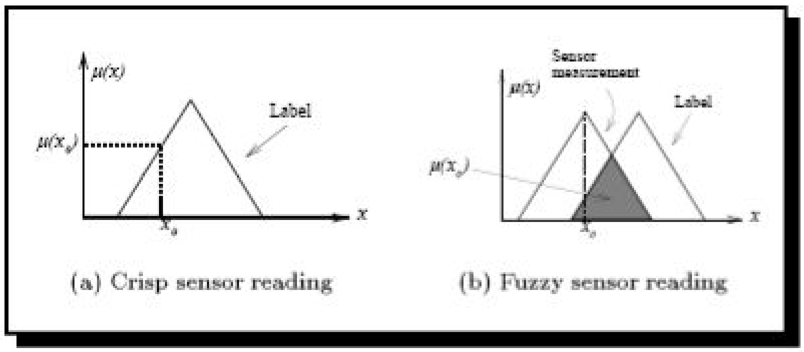


Figure 3.9: The fuzzification sub process

What fuzzification does is to turn the measurement into a degree of membership. Suppose a temperature measurement is made and corresponds to 80^0C. This measurement is required for an application in which the linguistic variable temperature might take on the values "high", "OK and "low". Fuzzification takes the measurement and decides to what degree it is "high", "OK" and "low". This matter of degree is decided on the basis of the framework suggested by the "expert" and is usually expressed as a membership function. The expert might consider that 80°C should be considered more "hot" than "OK". Where "1" represents full membership, the measurement might be "high" to a degree 0.8 because it is well above normal operating temperature, but it could get higher "OK to a degree 0.35 because operating temperature could be this high but would normally be lower "low" to a degree 0 because this temperature could never be considered low.

In a simple implementation the control rules will be applied to the degree implied by a single measurement. In this case the controller would apply rules applicable under high temperature conditions to a degree 0.8, and rule applying to "OK" temperature condition to a degree 0.35. The control action is in this way biased according to conditions.

The fuzzification process thus determines how applicable each component of a rule's premise is. The applicability of the premise (if the rule applies at all) is its truth value so to speak. If a rule's premise has a non-zero degree of truth then the rule is said to fire.

3.8.2 Inference

In the inference subprocess, the truth value for the premise of each rule is computed and applied to the conclusion part of the rule. The result of this is assigning a fuzzy subset to each output variable of each rule. The truth value of the precondition of a rule is referred to as its strength and is denoted by α . The rule's strength is computed by the means of equations of complement, union and intersection.

Example: Assume we have the following rule:

$$R: \quad \text{IF } x \text{ is } A \text{ AND } y \text{ is } B \text{ THEN } z \text{ is } C$$

If we have the sensor readings x_0 and y_0 for x and y respectively, the strength of the rule R can be computed as $\alpha = \mu_A(x_0) \cap \mu_B(y_0)$.

Of course, the rule's premise may include disjunctions and negations as well as conjunctions. The premise is then computed on the basis of the previous given definitions of union, intersection and complement of fuzzy sets. We also apply more complex operations than min and max for fuzzy inferencing.

There are two widely used inference methods: Min-inferencing and Product-inferencing. In MIN-inferencing, the output membership function is clipped off at a height corresponding to rule's degree of truth. In Product-inferencing, the output membership function is scaled by the rule's computed degree of truth. A graphical illustration of the two inferencing methods is shown in figure

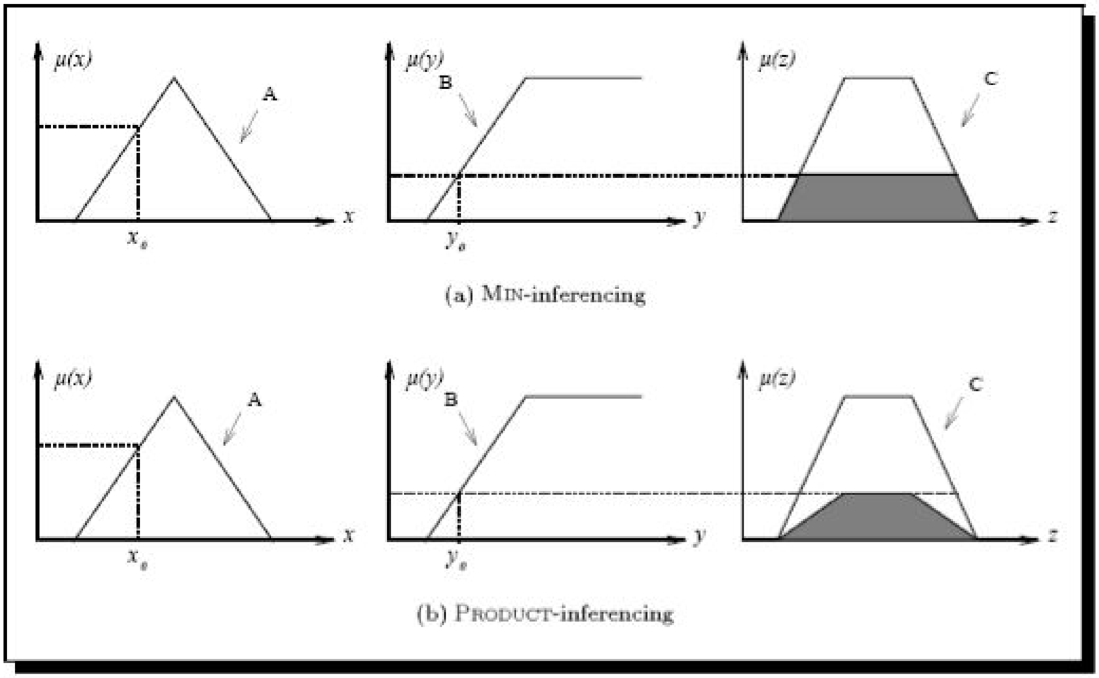


Figure 3.10: Two inferencing methods

EXAMPLE: Let the rule R be defined as in the previous example. In Min-inferencing, the variable z would be assigned the fuzzy set $C^{/}$ defined by $\mu_{C^{/}}(w) = \alpha \cap \mu_C(w)$ where w ranges over all the values the rule conclusion can take. In other words, z is assigned an entire set and not a crisp value. In Product-inferencing, the output variable z would be assigned the fuzzy set $C^{/}$ defined by $\mu_{C^{/}}(w) = \alpha \times \mu_C(w)$.

3.8.3 Composition

Many rules in the rule base may fire at the same time. If they involve the same output variable, some sort of conflict resolution has to be made. Consider the following rule base:

R_1: IF x is A_1 AND y is B_1 THEN z is C_1

R_2: IF x is A_2 AND y is B_2 THEN z is C_2

In the composition subprocess, all the fuzzy sets assigned to each output variable are combined together to form a single fuzzy set for each output variable

The most common rule of composition is Max-composition. In Max-composition, the combined output fuzzy subset is constructed by taking the point-wise maximum over all the fuzzy subsets assigned to the output by the inference rule. Assuming MIN-inferencing was used, the fuzzy set C assigned to the output variable z in the rule base above would be defined through the membership function $\mu_C(w)$ given below.

$$\begin{aligned}\mu_C(w) &= \mu_{C_1'}(w) \cup \mu_{C_2'}(w) \\ &= (\alpha_1 \cap \mu_{C_1}(w)) \cup (\alpha_2 \cap \mu_{C_2}(w))\end{aligned} \quad \text{.....................} (3.1)$$

The figure illustrates Max-composition graphically.

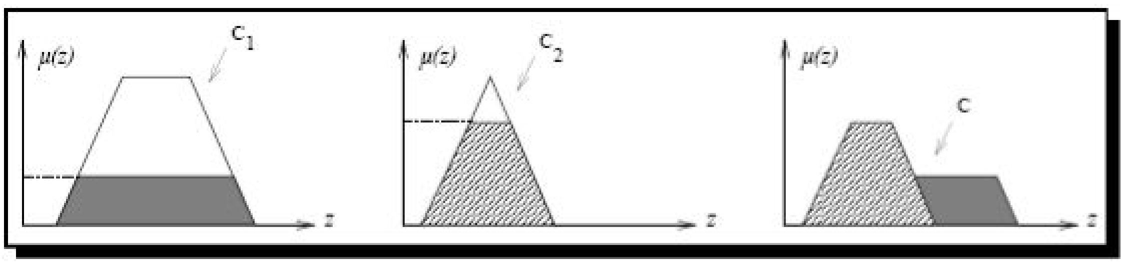


Figure 3.11: An example of MIN-inferencing followed by MAX-composition

Another composition rule is Sum-composition. In Sum-composition the combined output fuzzy subset is constructed by taking the point-wise sum over all the fuzzy subsets assigned to the output variable by the inference rule. As this can result in truth values greater than one, Sum-composition is only used when followed by some kind of defuzzification method that does not have with this odd case.

3.8.4 Defuzzification

Ordinarily, the control action must be in the form of a crisp value. Defuzzification is the process of transforming the fuzzy set assigned to a control output variable into such a crisp value.

There are various methods for defuzzification. The following two are the most prominent in fuzzy control.

Centre of Area Method

Mean of Maxima Method

The centre of area method calculates the centre of gravity of the distribution for the control action. Assuming a discrete universe, this can be written as

$$z^* = (\sum_{j=1}^{q} z_j \mu_C(z_j)) / (\sum_{j=1}^{q} \mu_C(z_j)) \quad \text{.................................} (3.2)$$

In the formula above, q is the number of quantization levels of the output; z_j is the amount of control output at level j and $\mu_C(z_j)$ represents its membership value in C.

The mean of maxima method generates a crisp control action by averaging the support values whose membership values reaches the maximum. Again assuming a discrete universe, this can be written as

$$z^* = \frac{1}{l} \sum_{j=1}^{l} z_j \quad \text{..} (3.3)$$

Here l is the number of quantized z values which each their maximum membership.

Chapter 4
SYSTEM MODEL

In OCDMA system each channel is optically encoded with the specific code as shown in Figure 4.1, below. This data is then decoded at receiver side. As shown in figure below the data from the channel 1 is fed to the encoder.The pattern type of data used is PRBS Generator.The pattern length used is 6 and it's range is from 0 to 18. The offset used for data is 0 and it's range is from 0 to 262144.The encoder codes the data for transmission.The encoder is made up of optical shifter and shift signal..The loss of optical shifter is 1 and it's range is from 0 to $1+e^{32}$. The shift signal type used is time delay.The time shift of shift signal is 0.The encoded signal from different channels reaches the multiplexer which combines the data into a single line for transmission.The multiplexer loss is 3db and range is 0 to $1+e^{32}$. Then comes the demultiplexer which demultiplexes the data.The properties of Demultiplexer are same as multiplexer.The data from the demultiplexer is then decoded to get the original data.

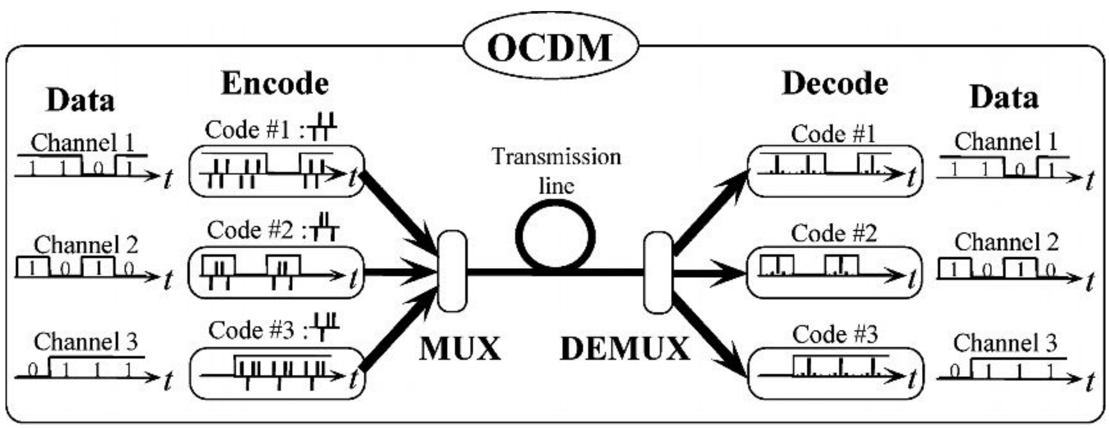


Figure 4.1: OCDM basic block diagram

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 multi-access interference (MAI) is often a limiting factor..The layout of OCDMA network is shown in figure 4.2 below. The below layout has been designed in Optsim.It consists of four mode -locked lasers which have been used to create a dense WDM light frequency source.There are sixteen users requiring sixteen distinct signature codes.

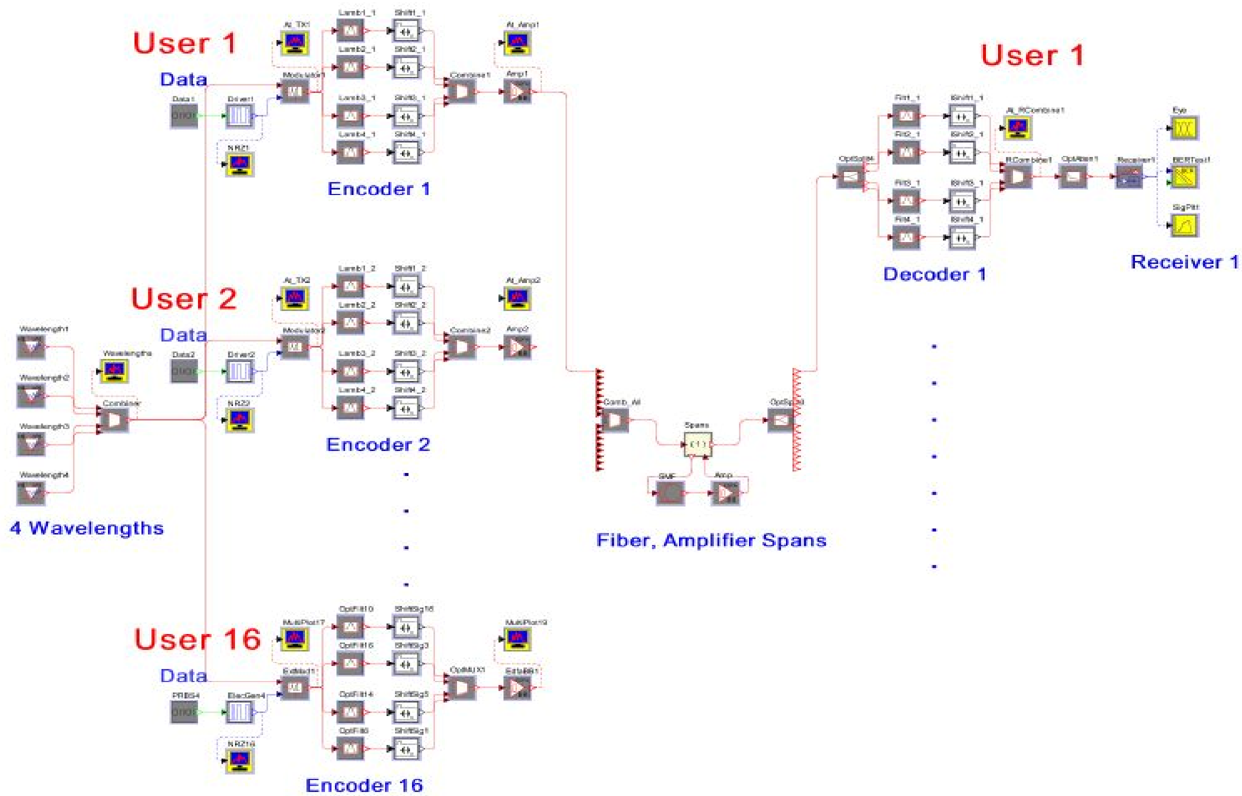


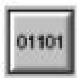
Figure 4.2: Optsim setup for simulation of OCDM system

Pseudo Orthogonal(PSO) matrix codes have been used as they are popular with OCDMA applications primarily because they retain the correlation advantages of PSO linear sequences while reducing the need for bandwidth expansion. PSO matrix codes also generate a larger code set.The data from the user is first encoded by the encoder and then it is transmitted over the optical link and finally it is decoded at the receiver side.

4.1 Components used in Optsim

The following components have been used in optsim model.

4.1.1 PRBS Pattern Generator



This model generates a binary sequence of several different types. A single model instance may be used to provide multiple pattern outputs, optionally offset from each other, to drive different channels of a WDM or parallel optical bus simulation. Or, each channel may have its own model instance configured to provide a different pattern than the other model instances. The different pattern types are described according to their name in the user parameter list:

- PRBS

Produces a maximal length pseudo-random binary sequence.

- Alternating

Produces a series of bits alternating between 0 and 1.

- Single

Produces a single 1 bit in the center of a series of 0 bits.

- One

Produces a series of 1 bits.

- Zero

Produces a series of 0 bits.

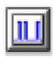
- Custom

Produces a bit sequence as specified by the user in a data file. This file is to be placed in the directory in which the simulation will be performed, which is the directory in which the topology data file is located. This data file must be formatted as follows: Each line must contain 8 binary numbers separated by spaces. Each bit is represented as either ‘0’ or ‘1’. There must be as many bits in the data file as are specified to be generated by the model.

PreBits and PostBits

The bit sequence can be modified such that the first few bits (prebits) and the last few bits (postbits) are set to 0. This is useful in simulations because it increases the accuracy of the FFT when the begin and end of the sequence match. The default values should be sufficient for most applications.

4.1.2 Electrical Signal Generator



This model converts an input binary signal into an output electrical signal. The output signal may be specified as either voltage or current. The user parameters are used to configure the electrical signal output.

Four different electrical drive types are modeled, as described below.

- On_off

A square wave electrical signal is generated. No jitter is included in this square wave. For each bit period, the output signal data is set according to the value of the input bit and the voltage levels specified by the user: Vmax for a 1 bit, and Vmin for a 0 bit. After generation of this signal, it may optionally be passed through a ringing generation filter according to the

user parameter setting for filterType.

- On_off_exp

A square wave electrical signal is generated using the specified timing jitter. After the signal is generated, it is optionally passed through a ringing generation filter according to the user parameter setting for filterType with specified rise time.

- On_off_ramp

An electrical signal is generated using the specified rise time, fall time, and timing jitter. The signal rise and falls are ramped between the high and low levels. After the signal is generated, it is optionally passed through a ringing generation filter according to the user parameter setting for filterType.

- RaisedCosine

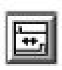
An electrical signal is generated using a raised cosine shape to represent the binary signal. This signal includes the timing jitter, but does not include the user-specified rise and fall times because the signal shape is specified as a raised cosine. This signal type is not passed through the ringing generation filter. The duty cycle of the pulse may be varied from nearly 0% to 50% using the alpha parameter. The raisedCosine electrical signal is genenerated using the following formula:

$$A(t) = A_{max} \cdot \frac{1}{2}\left[1 + \cos\left(\frac{\pi}{\alpha}\frac{t}{T_B}\right)\right] \ldots\ldots\ldots\ldots\ldots (4.1)$$

where α is the pulsewidth parameter (α = 1 for *TP= 0.5 TB*), *TP* is the pulse width and *TB* is the bit period.

Three different modulation formats are also available. These are the NRZor non-return to zero format, the RZ or return to zero format, and Manchester format.

4.1.3 Shift Signal



This model may be used to do one of two primary functions: delay the output signal relative to the input signal, or shift the signal data around in the data structure's array without modifying the signal timing. Note that when signal data is shifted by this block, it wraps around the edges of the data array. These two functions are described below.

Time Delay Function

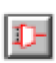
The 'timeDelay' mode (set by the parameter shiftType) delays the output signal relative to the input signal by a specified amount by either adjusting the start time of the signal while leaving the signal data array alone (when keepStartTime is set to 'No'), or by shifting the signal data around within the data array to implement the delay (when keepStartTime is set to 'Yes'). Time delays are specified in units of time only. Use of the time delay feature is useful whenever a time delay needs to be modeled for any type of signal, whether it be binary, electrical, or optical. When setting keepStartTime to 'Yes' for bit-streams, the requested time shift will be rounded to the nearest multiple of the bit period. For example, a 10Gbps bit sequence can only be shifted by 0, ± 100ps, ± 200ps, etc. Thus, a 10ps shift effectively gets rounded to zero. This is necessary since binary signals are only stored as ones and zeros, and so fractional bit shifts can't be taken into account while also keeping the start time unchanged.

Shift Function

The 'timeShift', 'bitShift', and 'percentShift' modes (set by the parameter shiftType) shift the signal data array without changing the actual signal timing. The user may specify the amount of shift in time units, percentage of the signal array, or number of bits. Appropriate adjustments are made to the start time of the signal to maintain the original signal timing. A positive shift will advance the start time of the signal while rotating the data to the left in the data array. The use of this block to shift signal data around in the data array is not generally required for simulations, but is useful in cases where the location of a bit in the data array is significant. For example, if it is desired to simulate a single Gaussian pulse and view the flat phase of the frequency spectrum, this block could be used to center the pulse around time = 0. Note that the relation between shifts in time and the frequency spectrum are described by the following basic Fourier transform pair:

$$\delta(t - t_0) = e^{-j2\pi f t_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

4.1.4 Optical Multiplexer (Nx1 MUX)



This model represents an optical WDM multiplexer (see also the General Multiport Optical Device described below). It accepts multiple optical signals at its input ports and produces a WDM optical signal at its output port which includes all the input WDM optical signals. There are two signal representations that may be used at the output, depending on whether four wave mixing is desired for use in the fiber model. The multiple-band mode will put each optical signal band in its own signal representation, thereby decreasing the overall memory load of the simulation by not including the unused frequency bands between the bands. This approximation can only be made when the bands do not overlap significantly. If there is significant overlap, or it is desired to include the effects of four wave mixing in the fiber simulation, the single-band mode must be used. To use the single-band mode, the samples per bit (pointsPerBit) in the signal generator for all the bands must be set high enough to include all the frequency components of each of the bands in the frequency domain representation of the signal. A good rule of thumb is that the simulation bandwidth be chosen to be about 3 times the total signal bandwidth (number of bands times band spacing). The simulation bandwidth is given by the following:

$$BW_{sim} = \frac{1}{T_s} = bitRate \cdot 2^{pointsPerBit} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

$$T_s = \frac{1}{bitRate \cdot 2^{pointsPerBit}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.4)$$

where *BWsim* is the simulation bandwidth, *Ts* is the time step between data points, bitRate is the bit rate specified in the PRBS generator, and pointsPerBit is the sampling rate specified in the electrical signal generator. The pattern length, samples per bit and bit rate must be equal for all the bands. These may be set conveniently through user defined variables in the symbol table. To represent a more realistic optical MUX, an optical filter may be specified for the input channels. For details on the optical filter types supported, see the documentation on the Optical Filter model. When the filter is used, the spacing between the filters may be uniform in either frequency or wavelength, depending on the setting of the filterSpecMode parameter. If this parameter is set to *Frequency*, then all filter bandwidths and centers are specified in units of Hz, along with the spacing between the filter centers. When the custom filter types are used, different custom filter responses may be specified for each of the input ports by using the file format of the General Multiport Optical Device and specifying that file in the filename parameter.

4.1.5 Physical EDFA

This block models the operation of an erbium-doped fiber amplifier (EDFA) via a set of well-established physical equations. The model supports component specifications at different levels of complexity, as well as a variety of pump and signal configurations. Figure 4.3 illustrates an OptSim schematic that utilizes the Physical EDFA model. Forward-propagating optical signals are launched into the EDFA via the first input node, while backward-propagating signals (e.g., counter-propagating pumps) enter via the second input node. OptSim's multiplexer components can be used to combine signals and pumps at either input. The EDFA output is available at the output node, and includes any signals, pumps, and amplified spontaneous emission (ASE) that are exiting the amplifier. The EDFA may also be used to simulate bidirectional signal propagation, in which case input signals are expected at both input nodes, and an additional backward output appears at the backward output node.

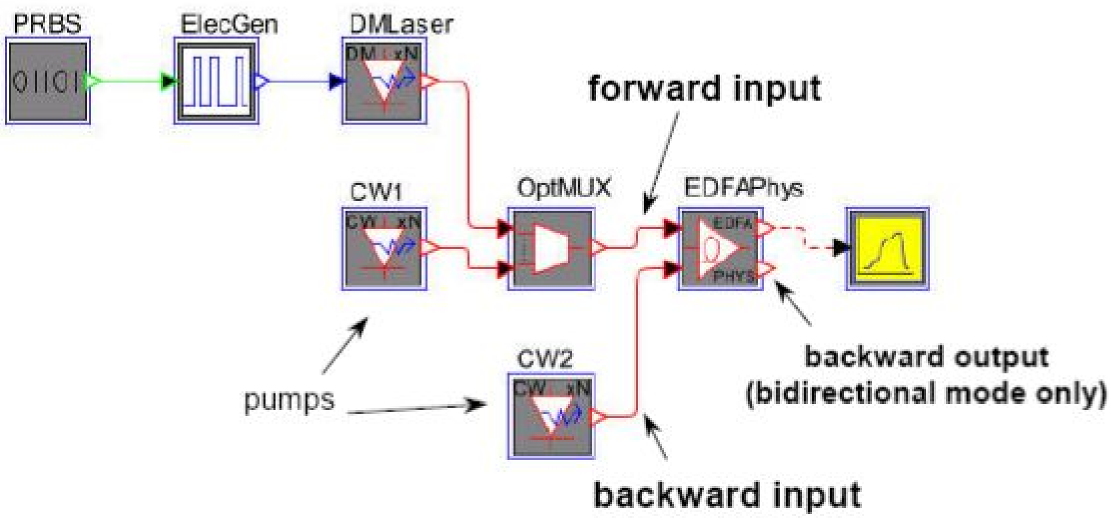


Figure 4.3: Basic OptSim topology depicting an EDFA with forward and backward Inputs.

4.1.6 Optical Attenuator

This model attenuates the input optical signal by the specified level of attenuation. This model may be used anywhere in the topology where a specified level of optical attenuation is desired. It has two parameters. The first and primary parameter is the attenuation value in units of dB. This attenuation is applied to the x polarization portion of the signal. If the signal contains a y polarization component as well, then the second parameter, xy_differential, is used to set the attenuation of the y polarization component. The attenuation of the y polarization component (y_attenuation) is expressed as follows: y_attenuation = attenuation – xy_differential

4.1.7 Compound Optical Receiver

This models an optical receiver and all its standard parts. The OptSim photoreceiver model is composed of several individual building blocks: the photodetector, the preamplifier, and the postamplifier/filter complex:

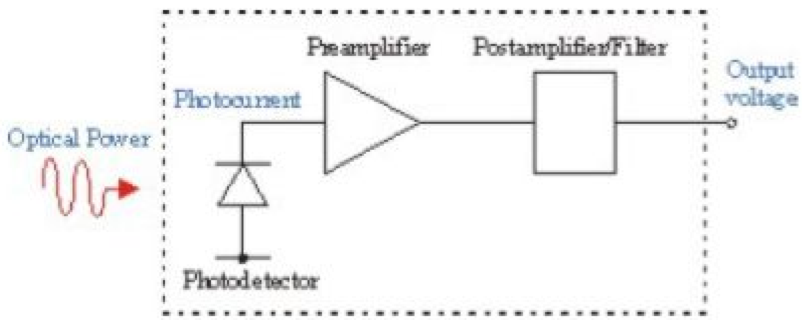
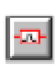


Figure 4.4: Basic components of an optical receiver

Each block is a separate entity complete with its own input parameters and options. The photodetector model converts an optical input signal to an electrical current. This photocurrent is then passed to the preamplifier model which converts it to a voltage. Finally, the postamplifier model contains a set of baseband filters that shape the output waveforms. The model also computes the photoreceiver noise components.

4.1.8 Optical Filter



This model represents one of the following types of optical filters: *Fabry Perot*, *Gaussian*, *RaisedCosine,Lorentzian,* *Trapezoidal*, *Ideal*, *Custom1*, *Custom2*, and *Custom3*. Each filter type except for the custom types may also be inverted. A wavelength signal whose filtered peak power does not exceed the userspecified drop threshold will not be passed by the filter.

The *Ideal* filter type is an ideal filter in which the response is 1 from $\lambda_0 - BW/2 \ to \ \lambda_0 + BW/2$ and zero outside this range.

The *Trapezoidal* filter type uses a Trapezoidal filter response to filter the optical signal amplitude. The user specifies the bandwidth in the wavelength domain (units of m) for the flat portion of the response as BW0dB. The user also specifies the 3dB bandwidth in the wavelength domain.

The *Gaussian* filter type uses a Gaussian filter response to filter the optical signal amplitude. The user specifies the 3dB bandwidth in the wavelength domain, and the order of the filter.

The *Fabry-Perot* option models a Fabry-Perot filter. The optical filter will affect both the optical signal and the noise level and bandwidth. The transfer function for the Fabry-Perot resonant cavity model is computed as

$$T(v) = \frac{(1-R).e^{i\delta/2}}{1-R.e^{i\delta}}\frac{1}{L} \dots\dots\dots\dots\dots\dots\dots\dots\dots (4.6)$$

where L is the insertion loss of the filter, R is the power reflectivity of the facets (assuming equal reflection at both facets), δ is a phase delay.

4.1.9 Carrier shifting

The model may be used to shift the carrier frequency of the optical signal(s) output from the filter. When the signals being filtered are of the multiple channel representation, in which each channel's signal is represented in its own frequency band centered about a specified carrier frequency, this option would not be desired. When the optical filter is being used to filter a particular channel out of a single channel representation, in which all channels are represented together in one frequency band, this option can be used to reset the center frequency of the filtered frequency band to match the center of the filter. If the desired channel is centered at the center wavelength of the filter, using this option will ensure that the center wavelength of the signal output from the filter is the desired channel’s center wavelength.

4.1.10 Optical Splitter (1xN)

This model represents an ideal optical splitter. It takes a single input signal, and divides it equally among N output ports with 1/N splitting loss, plus excess loss determined by the transmission model parameter.

Chapter 5

PROBLEM FORMULATION

Mach Zehnder modulator has been configured by Fuzzy Logic generator. It is shown in fig.5.1 below

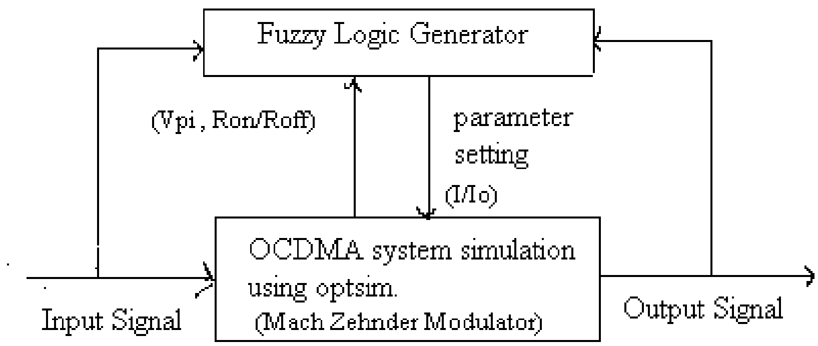


Figure 5.1 : Optical CDMA System augmented with Fuzzy Logic Generator

For the Mach-Zehnder type modulator, the following intensity response function is used:

$$\frac{I_o}{I_i} = \begin{cases} \sin^2\left[\frac{\pi}{2}\left(\frac{V_{signal} + V_{bias} - V_{offset}}{V_\pi}\right)\right] & \frac{I_o}{I_i} \geq \frac{1}{R_{on/off}} \\ \frac{1}{R_{on/off}} & \frac{I_o}{I_i} < \frac{1}{R_{on/off}} \end{cases}$$

where *Ron off* is the extinction ratio of the modulator in linear units (to be input by user as parameter onOffRatio in dB units) and *Vsignal* represents the electrical signal after being modified by the parasitic frequency response and optionally being level-shifted such that the average level is zero, modeling the behavior of the bias circuitry. The sine function is used instead of the cosine function in the Mach-Zehnder modulator so that the modulated signal will have the same polarity as the original binary sequence. This is important for increased numerical accuracy in simulation. To deactivate the extinction ratio modification to the signal, set the extinction ratio parameter to 0.

Figure 5.2, 5.3 and 5.4 show input fuzzy sets and output set for configuring the Mach – Zehnder Modulator.

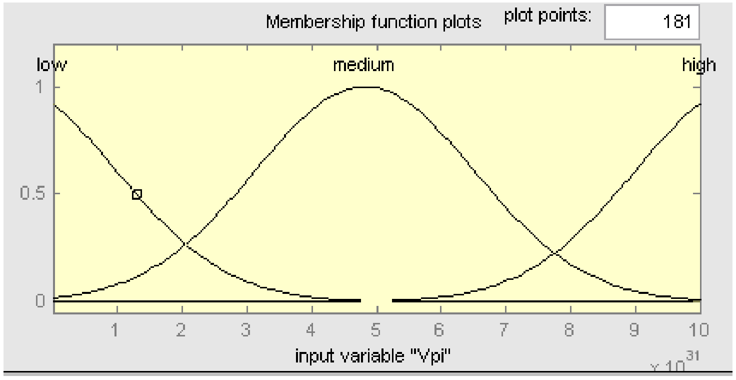


Figure 5.2: Fuzzy input sets for Vpi

The above figure shows the input fuzzy sets for Vpi.

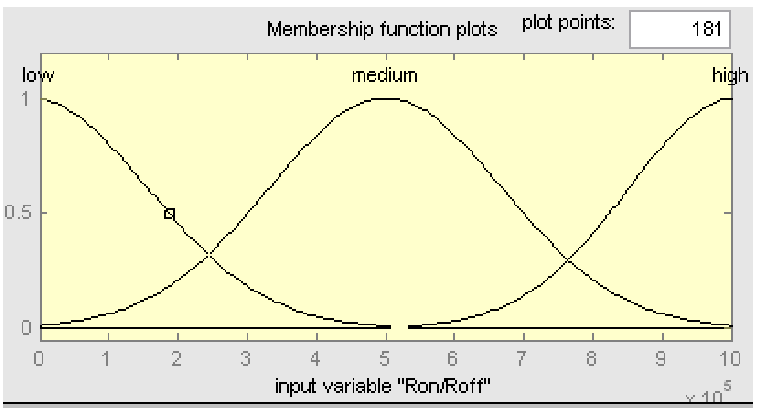


Figure 5.3: Fuzzy input sets for Ron/Roff

The above figure shows thr input fuzzy sets for Ron/Roff.

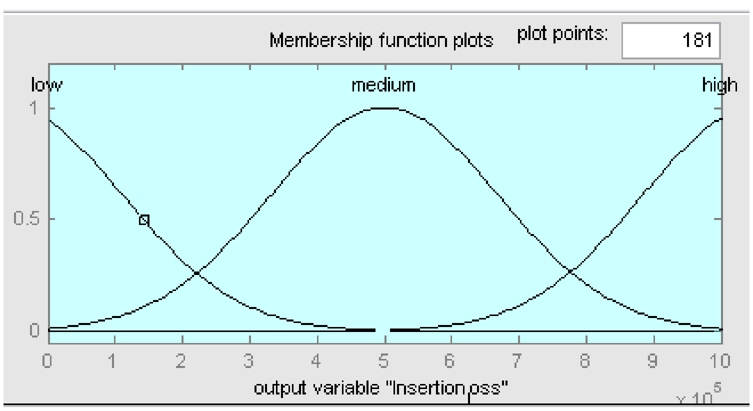


Figure 5.4: Fuzzy output sets for I/I_0

The above figure shows the input fuzzy sets for I/I_0

Following rules have been generated for fuzzy logic based generator in this case

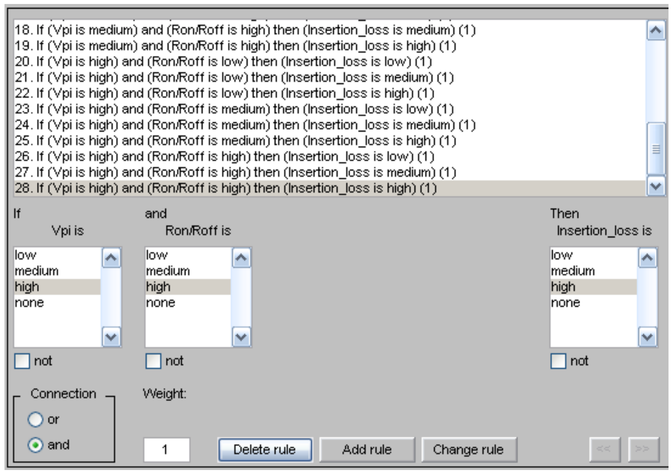


Figure 5.5: Fuzzy Logic Rules

5.1 Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox extends the MATLAB® technical computing environment with tools for designing systems based on fuzzy logic. Graphical user interfaces (GUIs) guide you through the steps of fuzzy inference system design. Functions are provided for many common fuzzy logic methods, including fuzzy clustering and adaptive neurofuzzy learning. The toolbox lets you model complex system behaviors using simple logic rules and then implement these rules in a fuzzy inference system. You can use the toolbox as a standalone fuzzy inference engine. Alternatively, you can use fuzzy inference blocks in Simulink® and simulate the fuzzy systems within a comprehensive model of the entire dynamic system.

5.2 Working with the Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox provides GUIs to let you perform classical fuzzy system development and pattern recognition. Using the toolbox, you can develop and analyze fuzzy inference systems, develop adaptive neurofuzzy inference systems, and perform fuzzy clustering. In addition, the toolbox provides a fuzzy controller block that you can use in Simulink to model and simulate a fuzzy logic control system. From Simulink, you can generate C code for use in embedded applications that include fuzzy logic.

5.3 Building a Fuzzy Inference System

Fuzzy inference is a method that interprets the values in the input vector and, based on userdefined rules, assigns values to the output vector. Using the GUI editors and viewers in the Fuzzy Logic Toolbox, you can build the rules set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS). The following editors and viewers are provided.

FIS Editor—Displays general information about a fuzzy inference system.Key features of FIS Editor are :-

1. Specialized GUIs for building fuzzy inference systems and viewing and analyzing results
2. Membership functions for creating fuzzy inference systems
3. Support for AND, OR, and NOT logic in user-defined rules
4. Standard Mamdani and Sugeno-type fuzzy inference systems
5. Automated membership function shaping through neuroadaptive and fuzzy clustering learning techniques
6. Ability to embed a fuzzy inference system in a Simulink model
7. Ability to generate embeddable C code or stand-alone executable fuzzy inference engines.

Membership Function Editor— Lets you display and edit the membership functio associated with the input and output variables of the FIS.

Rule Editor—Lets you view and edit fuzzy rules using one of three formats: full Englishlike syntax, concise symbolic notation, or an indexed notation.

Rule Viewer—Lets you view detailed behavior of an FIS to help diagnose the behavior of specific rules or study the effect of changing input variables.

Surface Viewer—Generates a 3-D surface from two input variables and the output of an FIS.

5.4 Modeling Using Fuzzy Logic

The Fuzzy Logic Toolbox lets you apply neurofuzzy and clustering techniques to model and classify system behavior.

5.4.1 Adaptive Neurofuzzy Inference

Using the Adaptive Neuro-Fuzzy Inference System (ANFIS) Editor, you can shape membership functions by training them with input/output data rather than specifying them manually. The toolbox uses a back propagation algorithm alone or in combination with a least squares method, enabling your fuzzy systems to learn from the data.

5.4.2 Fuzzy Clustering

The Fuzzy Logic Toolbox provides support for fuzzy C-means and subtractive clustering, modeling techniques for data classification and modeling.

5.5 Simulating and Deploying Fuzzy Inference Systems

You can evaluate FIS performance by using the Fuzzy Logic Controller block in a Simulink model of your system. The Fuzzy Logic Controller block automatically generates a hierarchical block diagram representation for most fuzzy inference systems. This representation uses only built-in Simulink blocks, enabling efficient code generation (using Real-Time Workshop®, available separately). You can also save your FIS in ASCII format for use outside the MATLAB environment. The toolbox supplies a fuzzy inference engine that can execute your fuzzy system as a stand-alone application or embedded in an external application

Chapter 6

SIMULATION AND TESTING

Optsim simulation has been done for OCDMA system for both the cases viz.without Fuzzy Logic Generator and with Fuzzy Logic generator.

No. of user(s): 1

Case I: Testing without Fuzzy Logic generator

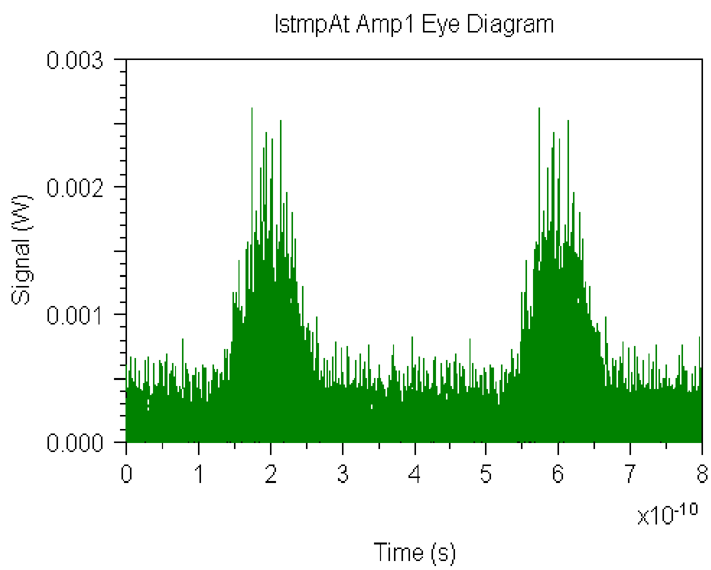


Figure 6.1: Eye Diagram without Fuzzy Controller after encoder

The above diagram shows the Eye diagram without Fuzzy controller taken after the first encoder.

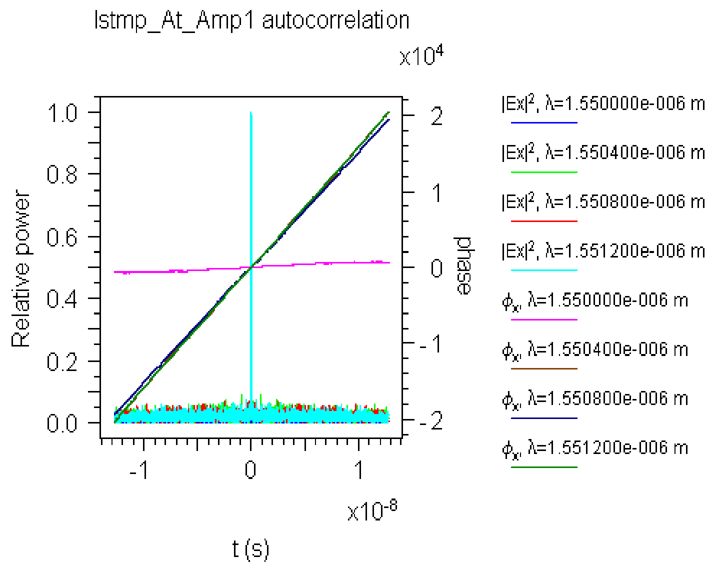


Figure 6.2: Auto correlation Diagram without Fuzzy Controller after encoder

The above diagram shows the Auto correlation diagram without Fuzzy controller taken after the first encoder.

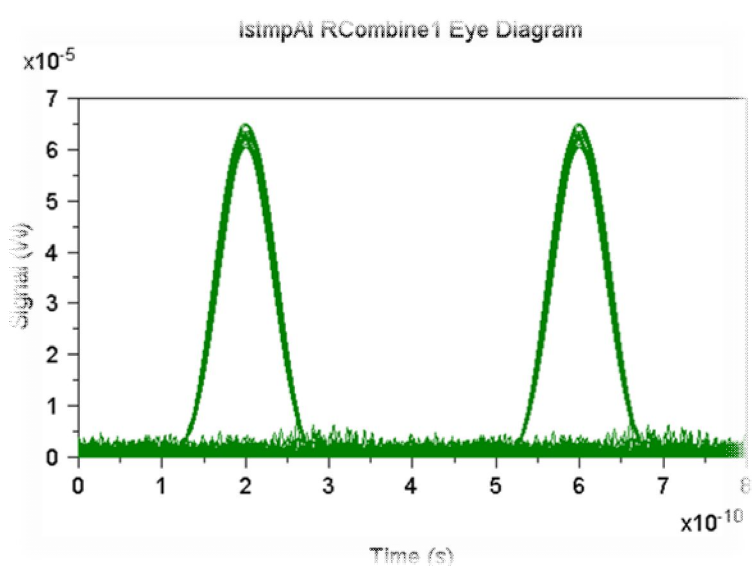


Figure 6.3 : Eye Diagram without fuzzy controller after the combiner

The above diagram shows Eye diagram without Fuzzy controller taken after the combiner.

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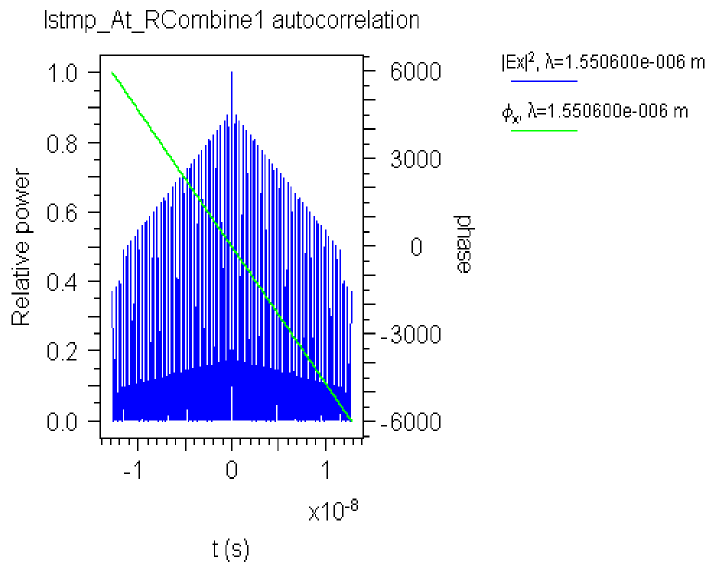

Figure 6.4: Autocorrelation diagram without Fuzzy Controller after combiner

The above diagram shows the Auto-correlation diagram without Fuzzy controller taken after the combiner.

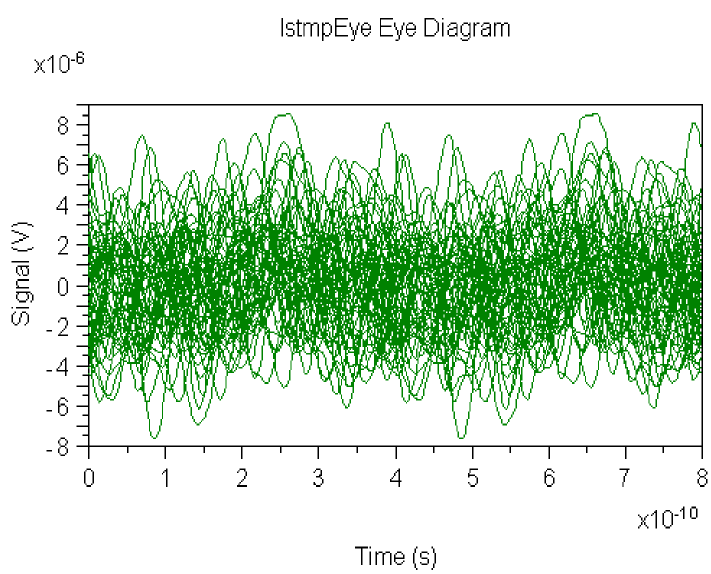

Figure 6.5 : IstmpEye Eye Diagram without Fuzzy controller

The above diagram shows the IstmpEye Eye diagram taken at the end of the circuit.

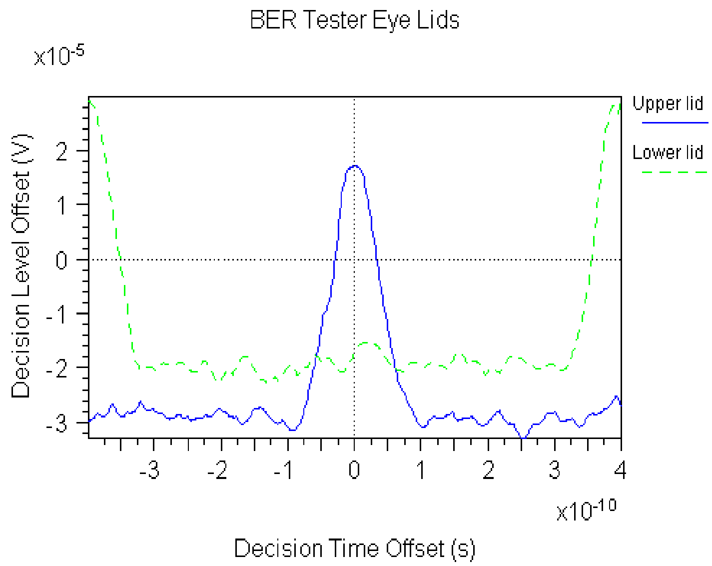

Figure 6.6 : BER Tester Eye Lids Diagram without fuzzy controller

The above diagram shows Ber Tester Eye Lids diagram without Fuzzy controller generated by the BER analyzer at the receiver.

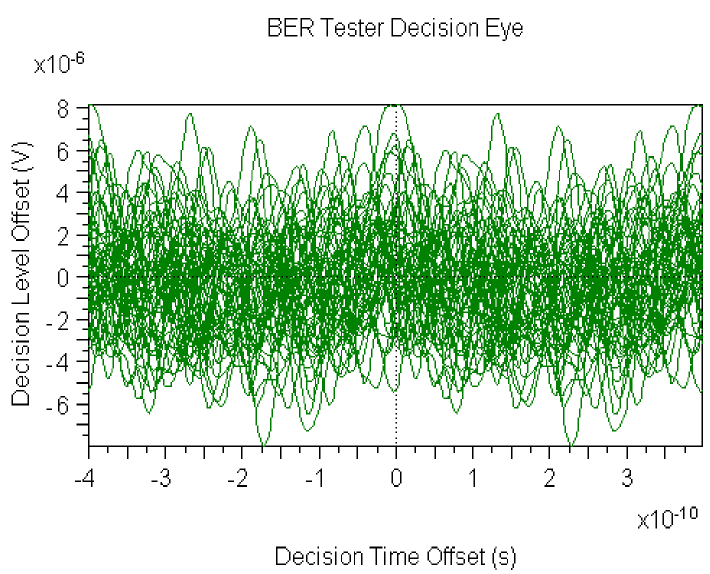

Figure 6.7 : BER Tester Decision Eye diagram without Fuzzy controller

The above diagram shows the BER Tester Decision Eye diagram without Fuzzy controller taken at the receiver.

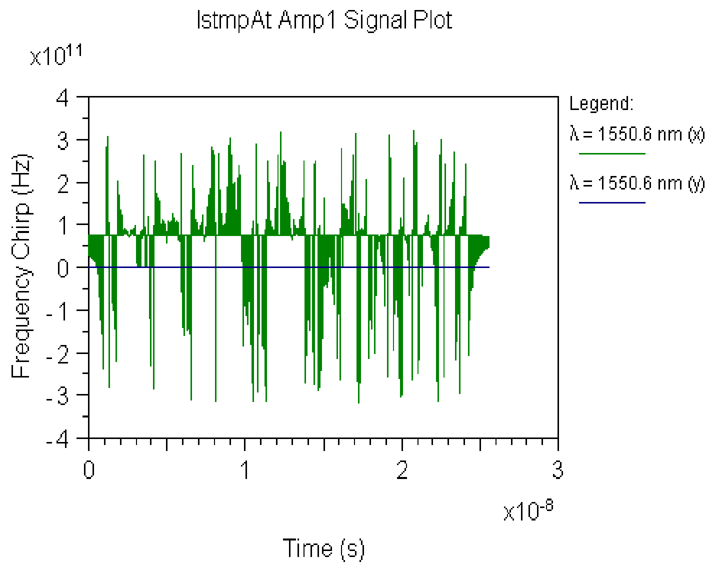

Figure 6.8: Signal Plot without Fuzzy controller

The above diagram shows Signal Plot without Fuzzy controller taken at the receiver.

Case II :-Testing with Fuzzy Controller

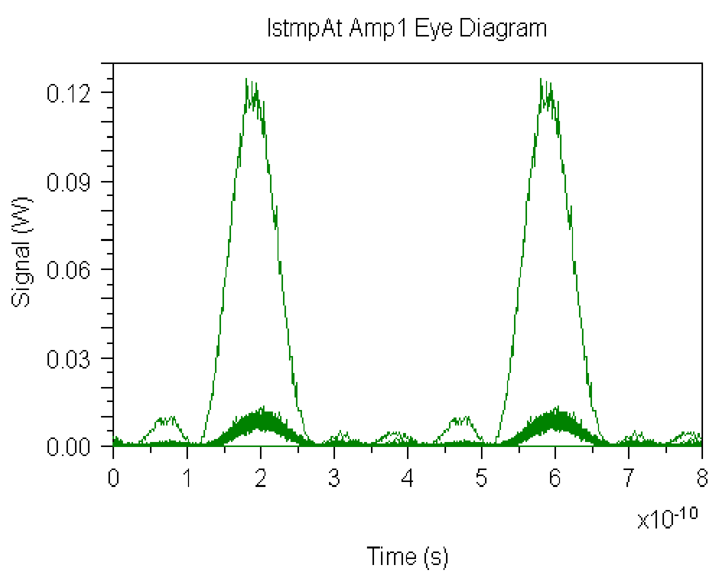

Figure 6.9: Eye diagram with Fuzzy Controller after encoder

The above diagram shows the Eye diagram with Fuzzy controller taken after the first encoder.

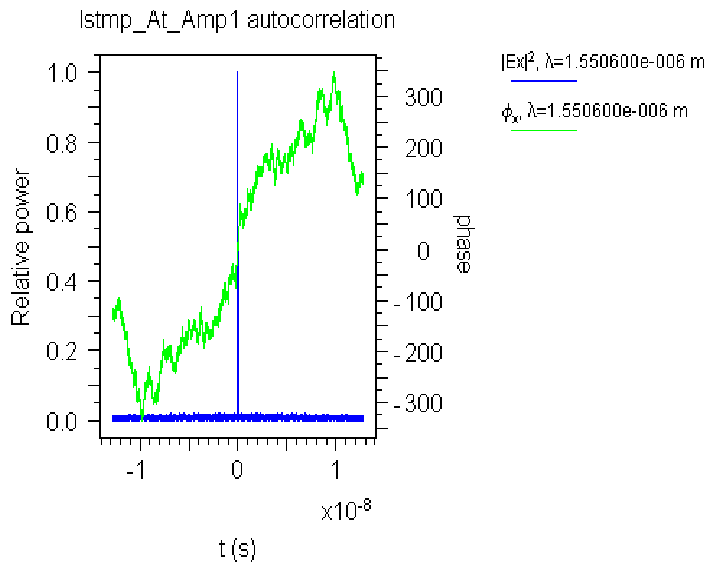

Figure 6.10: Auto correlation Diagram with Fuzzy Controller after encoder

The above diagram shows the Auto correlation diagram with Fuzzy controller taken after the first encoder.

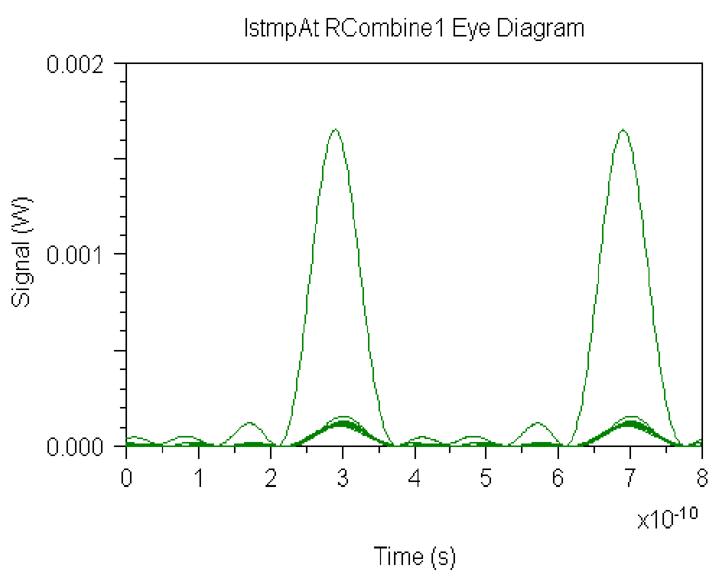

Figure 6.11 : Eye Diagram with Fuzzy Controller after the Combiner

The above diagram shows Eye diagram with Fuzzy controller taken after the combiner.

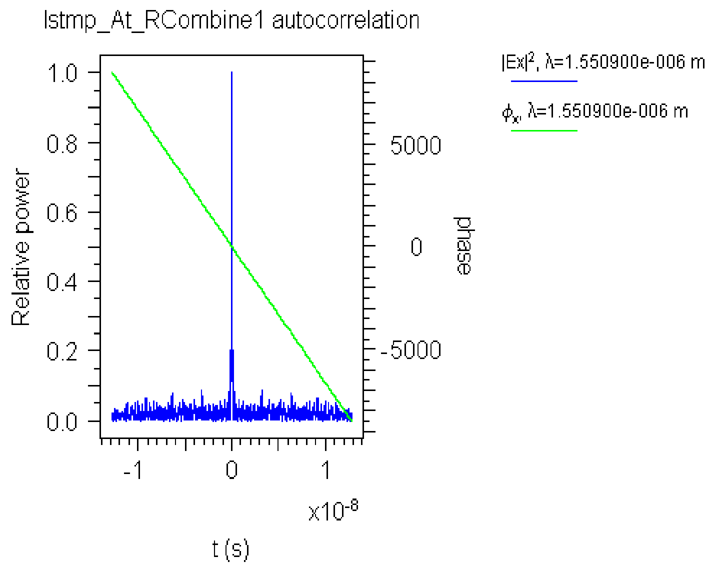

Figure 6.12: Auto correlation Diagram with Fuzzy Controller after combiner

The above diagram shows the Auto-correlation diagram with Fuzzy controller taken after the combiner.

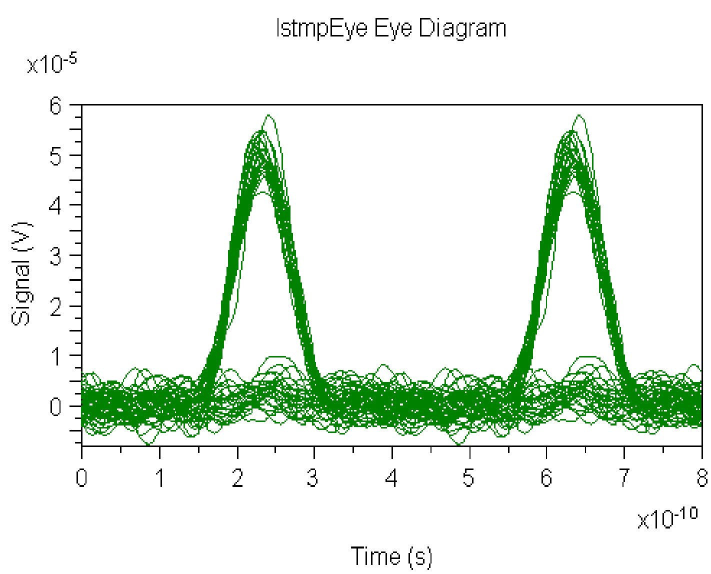

Figure 6.13: IstmpEye Eye Diagram with Fuzzy controller

The above diagram shows the IstmpEye Eye diagram with Fuzzy controller taken at the receiver.

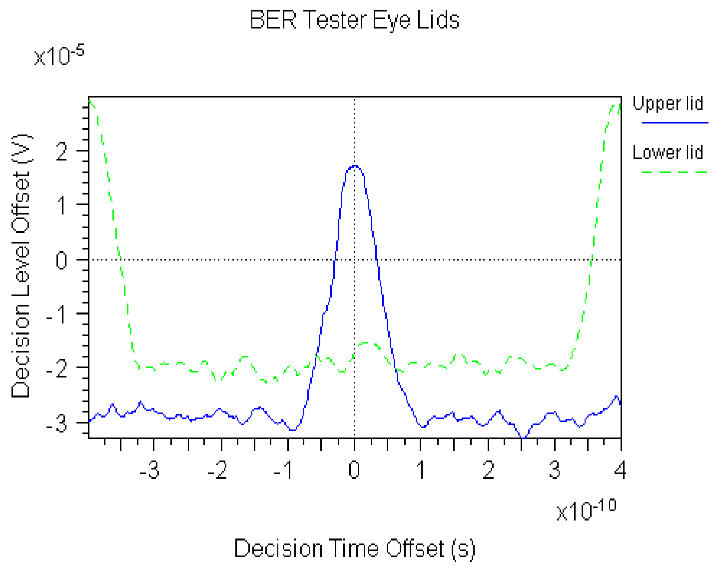

Figure 6.14: BER Tester Eye Lids Diagram with Fuzzy Controller

The above diagram shows Ber Tester Eye Lids diagram with Fuzzy controller generated by the BER analyzer at the receiver.

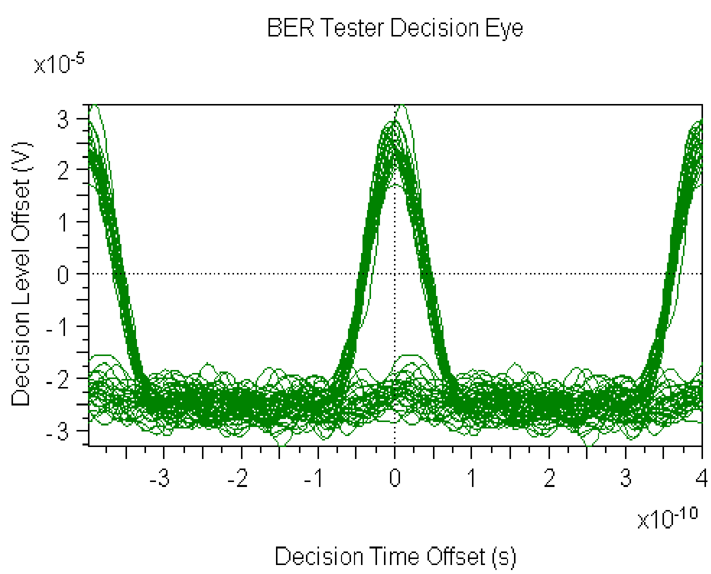

Figure 6.15: BER Tester Decision Eye Diagram with Fuzzy Controller

The above diagram shows the BER Tester Decision Eye diagram with Fuzzy controller taken at the receiver.

No. of user(s): 2.

Case I: Testing without Fuzzy Logic generator

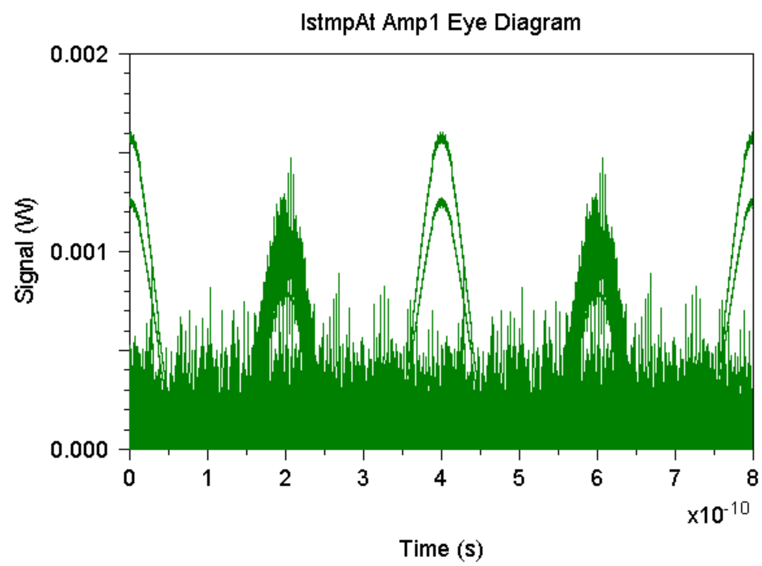

Figure 6.16:Eye diagram with Fuzzy Controller after encoder

The above diagram shows the Eye diagram without Fuzzy controller taken after the first encoder.

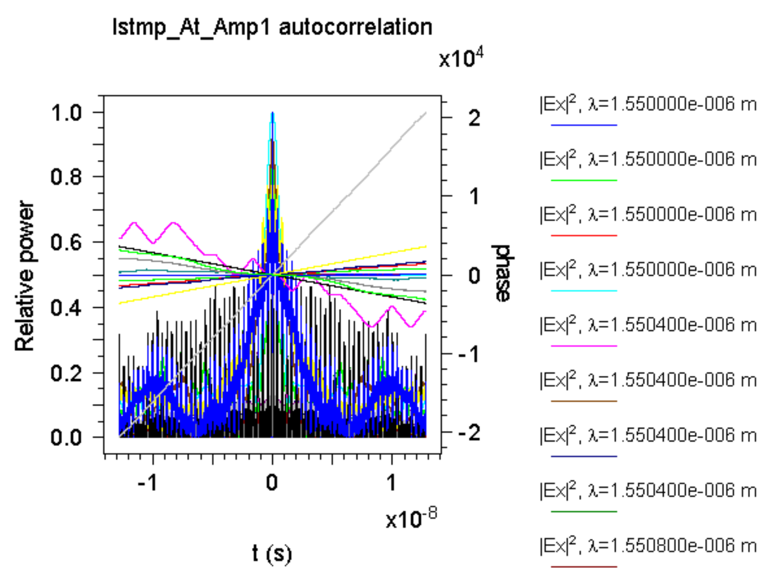

Figure 6.17: Auto correlation Diagram with Fuzzy Controller after encoder

The above diagram shows the Auto correlation diagram without Fuzzy controller taken after the first encoder

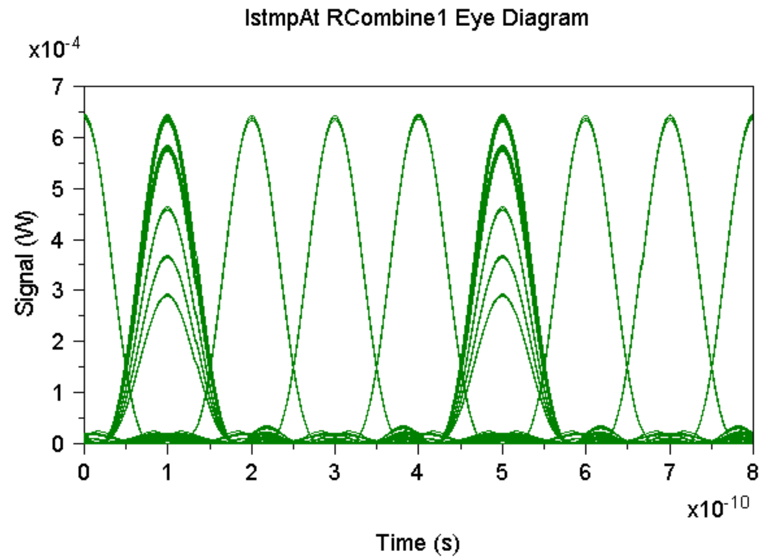

Figure 6.18 : Eye Diagram without Fuzzy Controller after combiner

The above diagram shows Eye diagram without Fuzzy controller taken after the combiner

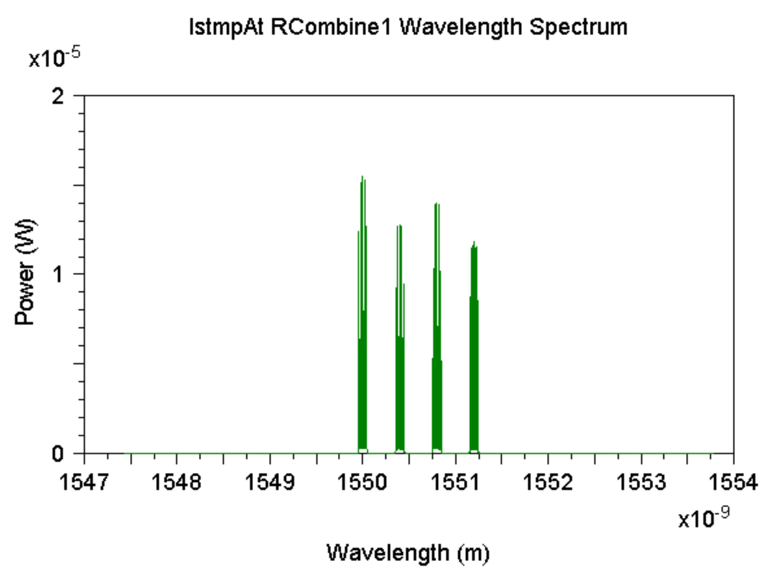

Figure 6.19: Wavelength spectrum without fuzzy controller

The above diagram shows the Wavelength Spectrum diagram without Fuzzy controller taken after the combiner.

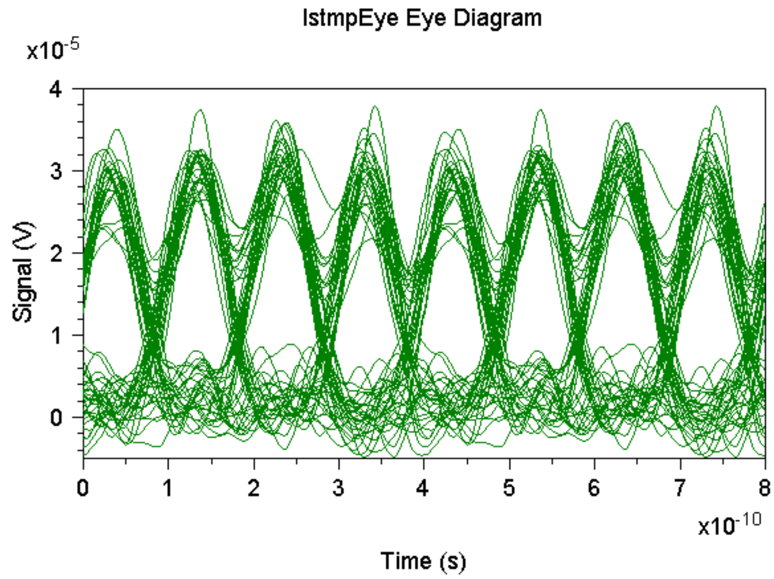

Figure 6.20: IstmpEye Eye Diagram with Fuzzy controller

The above diagram shows the IstmpEye Eye diagram without Fuzzy controller taken at the receiver.

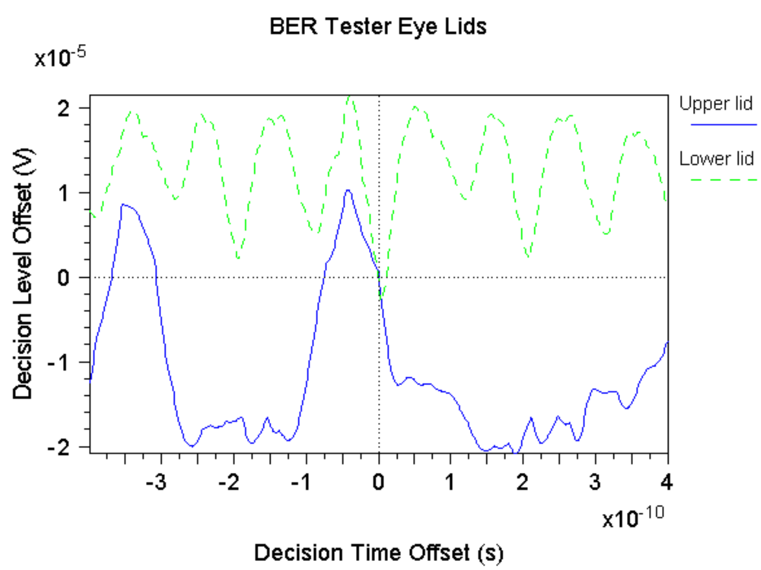

Figure 6.21 : BER Tester Eye Lids Diagram with Fuzzy Controller

The above diagram shows Ber Tester Eye Lids diagram without Fuzzy controller generated by the BER analyzer at the receiver

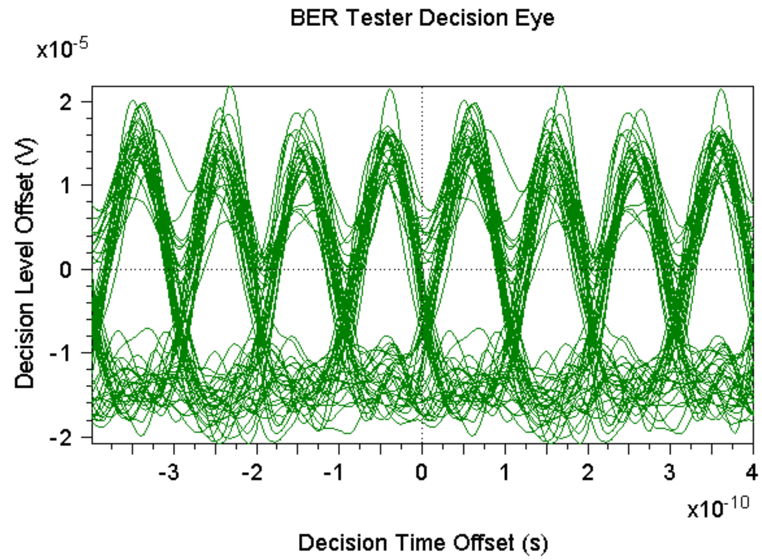

Figure 6.22 : BER tester decision eye diagram with Fuzzy Controller

The above diagram shows the BER Tester Decision Eye diagram without Fuzzy controller taken at the receiver.

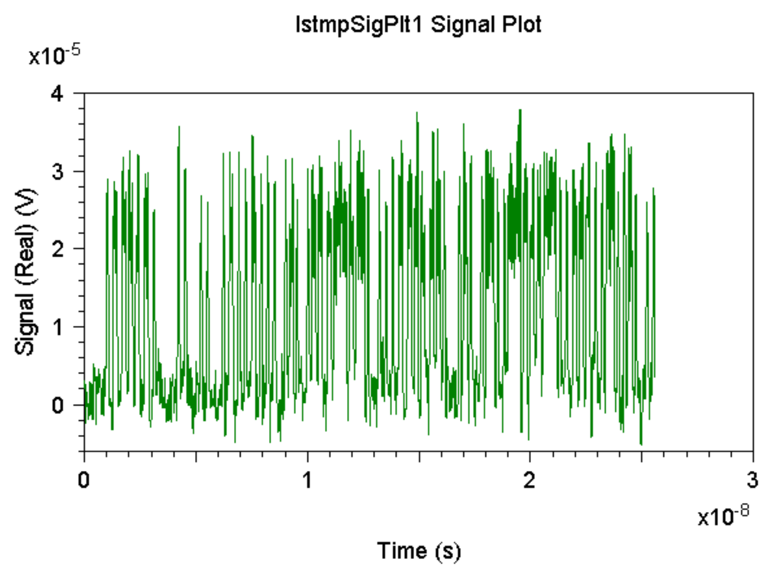

Figure 6.23: Signal Plot with fuzzy controller

The above diagram shows Signal Plot without Fuzzy controller taken at the receiver.

Case II: Testing with Fuzzy Logic generator

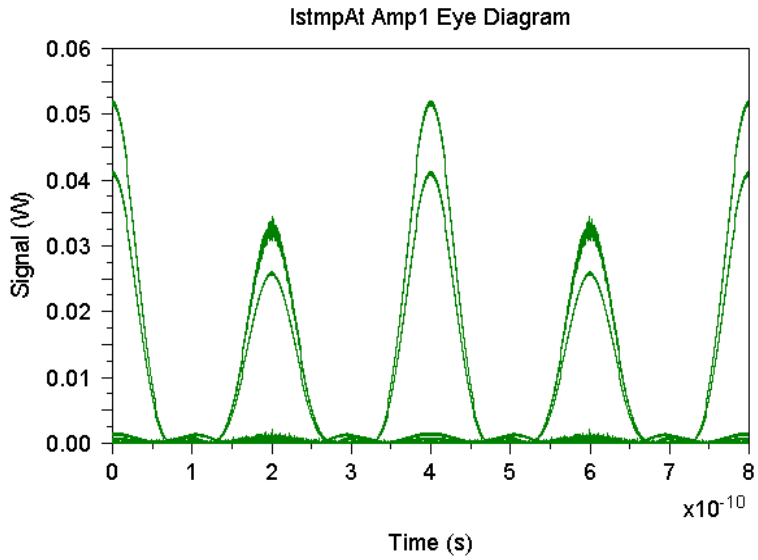

Figure 6.24:Eye diagram without Fuzzy Controller after encoder

The above diagram shows the Eye diagram without Fuzzy controller taken after the first encoder.

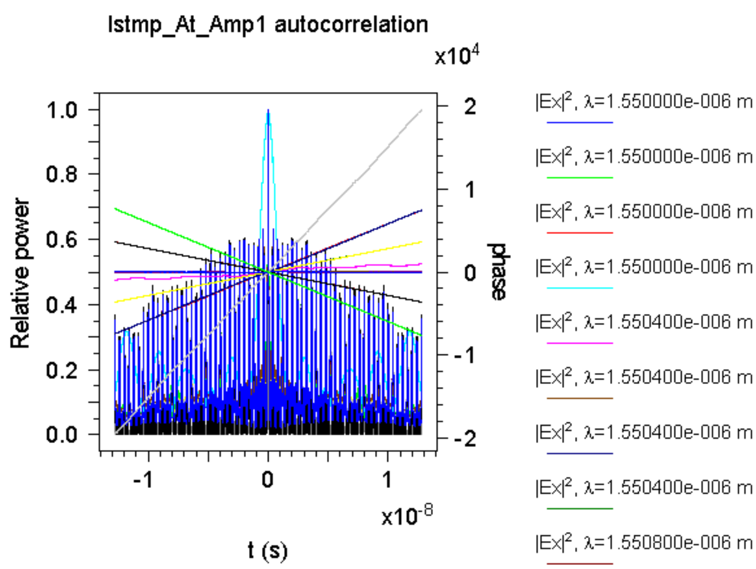

Figure 6.25 : Auto correlation Diagram without Fuzzy Controller after encoder

The above diagram shows the Auto correlation diagram without Fuzzy controller taken after the first encoder

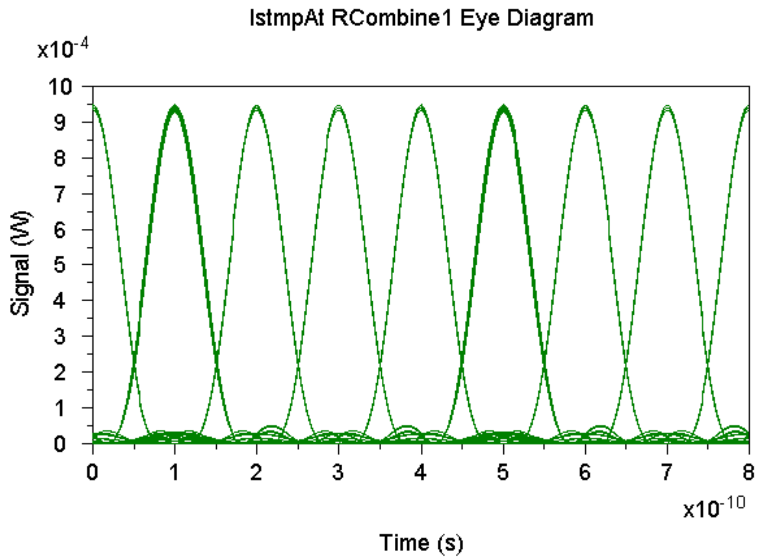

Figure 6.26 : Eye Diagram with Fuzzy Controller after combiner

The above diagram shows Eye diagram without Fuzzy controller taken after the combiner.

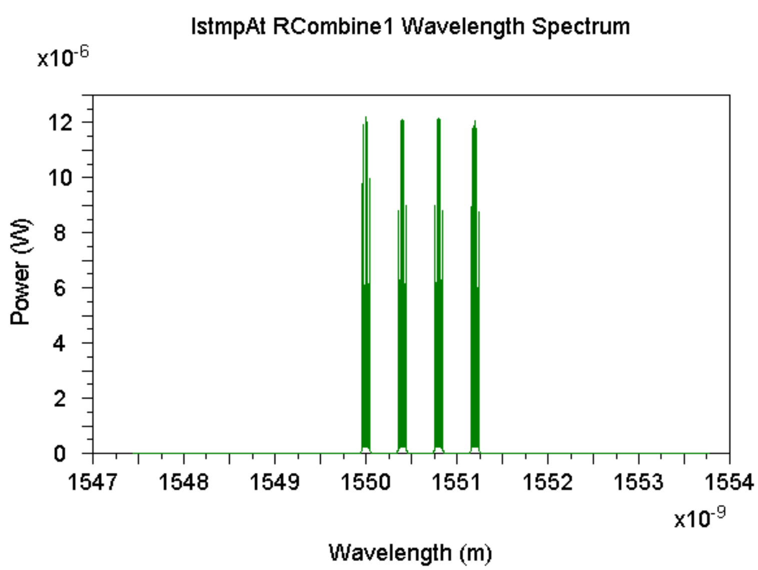

Figure 6.27: Wavelength spectrum with fuzzy controller

The above diagram shows the Wavelength Spectrum diagram without Fuzzy controller taken after the combiner.

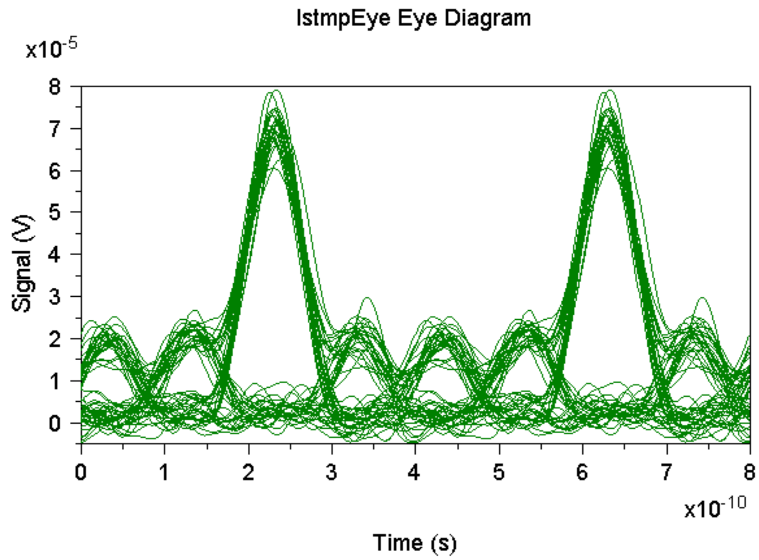

Figure 6.28: IstmpEye Eye Diagram without Fuzzy controller

The above diagram shows the IstmpEye Eye diagram without Fuzzy controller taken at the receiver.

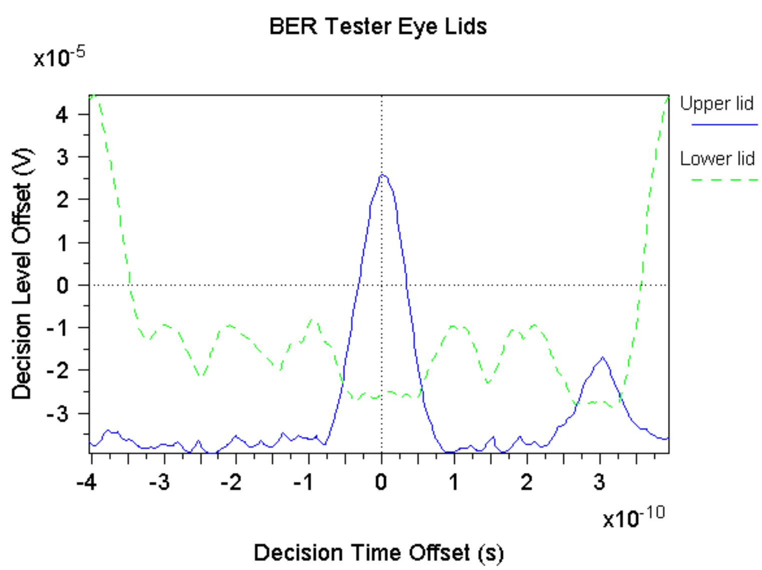

Figure 6.29 : BER Tester Eye Lids Diagram without Fuzzy Controller

The above diagram shows Ber Tester Eye Lids diagram without Fuzzy controller generated by the BER analyzer at the receiver.

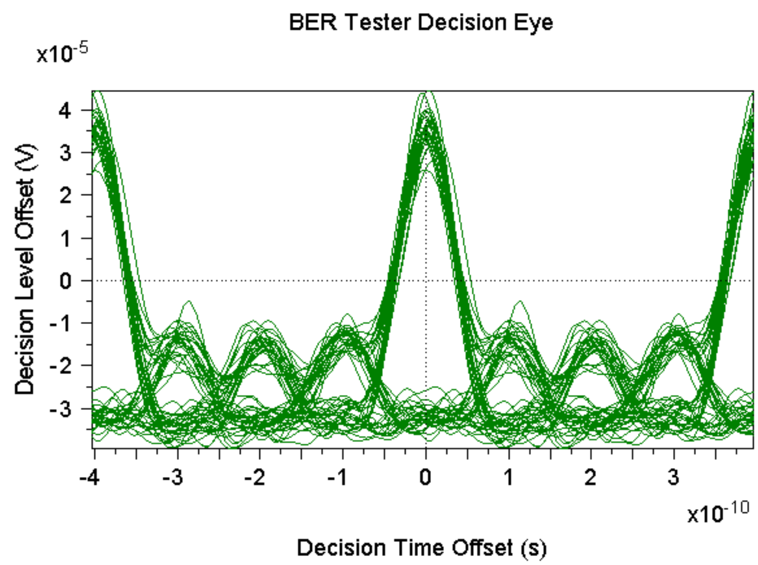

Figure 6.30 : BER tester decision eye diagram without Fuzzy Controller

The above diagram shows the BER Tester Decision Eye diagram without Fuzzy controller taken at the receiver.

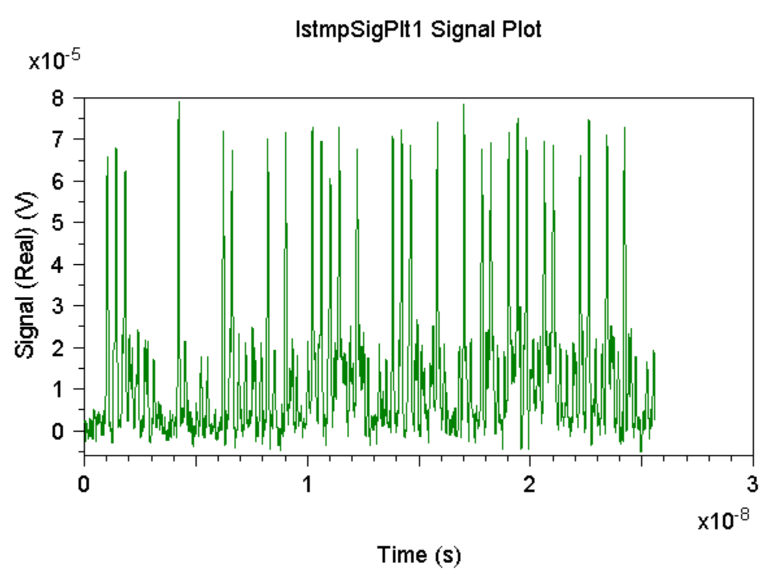

Figure 6.31: Signal Plot without fuzzy controller

The above diagram shows Signal Plot without Fuzzy controller taken at the receiver.

Chapter 7

RESULT AND DISCUSSION

Multiple accesses which uses the spread spectrum technology for transmission has become very popular in cellular radio networks. Optical CDMA is a technique in which user uses a specific unique code rather a specific wavelength or a time slot. Optical CDMA uses the spread spectrum technique of CDMA combined with the optical link for transmission of data. Optical CDMA provides the large communication bandwidth along with the capability of secure data transmission. The key advantage of Optical CDMA is the multiple access technique which allows many users to share the same optical link simultaneously. This is done by giving each user a specific code which can be decoded only by the required user. OCDMA has many unique features that make it favorable data transmissions. Its characteristics make it suitable to increase the capacity and number of users in bursty networks. OCDMA can accommodate a large no. of channels on a single carrier frequency. It can utilize the bandwidth effectively through coding system. OCDMA systems provide high degree of scalability and security. It provides high noise tolerance.

A highly spectral-efficient transmission technique based on optical code-division multiplexing (OCDM) is investigated in this work.It has been demonstrated that properly designed fiber optical CDMA using Fuzzy Logic Generator is more robust to the effect of non-linearity in terms of bit-error –rate performance.We have demonstrated that OCDMA system using Fuzzy Logic Generator has improved the performance of the system by means of various graphs and diagrams such as Signal Plots,Wavelength spectrums,Eye diagrams,BER Tester Eye Decision diagrams,Auto correlation diagrams.

Two cases have been considered ,without fuzzy and with fuzzy.First the cases have been considered for the no. of users equal to 1 and then for the no. of users equal to two. Fuzzy Logic generator accepts V_π and R_{on}/R_{off} and generates I/I_0 in a non – linear fashion. Such fuzzy logic augmented OCDM has shown better performance which is quite evident from various diagrams of BER Tester Decision Eye Diagrams, BER Tester Eye Lids Diagram, Eye Diagrams and autocorrelation Diagrams.

CONCLUSION AND FUTURE SCOPE

Optical transmission systems have to meet the rapid increase in the demand of data bandwidth and spectral efficiency. OCDM multiplexing technique is different from optical time-division multiplexing and wavelength-division multiplexing (WDM). OCDM provides asynchronous transmission, secure communication, soft capacity on demand, and high degree of scalability. We have experimentally demonstrated a highly spectral efficient OCDM system using Fuzzy Logic generator. This system results in a considerable performance improvement as compared to the conventional systems.The proposed system offer a larger flexibility and bandwidth for transmission.

Over the past decade ,considerable progress has been made in the field of fibre-optic.The rapid progress in this field suggests that in upcoming years ,the complexity of integrating optical signal –processing devices will not be the overriding criterion for the selection of one optical multiple access scheme over another. The OCDMA technology is well suited to increase the capacity and the number of users of bursty networks.It's performance can be further enhanced by using the Fuzzy Logic generator as proposed in this work.A multitude of different application spaces can be benefitted from this system ,such as passive optical networks(PON),local and metro area networks,free space optics, and interconnects for computing.

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2. Park E.,Mendez A.J.,Garmire E.M., "Temporal/spatial optical CDMA networks-design, demonstration, and comparison with temporal networks," ***Photonics Technology Letters, IEEE,*** Volume 4, Oct 1992.

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APPENDIX 1
PUBLICATIONS FROM THIS RESEARCH WORK

"Performance Analysis and Improvement of Optical CDMA using Fuzzy Logic Generator", has been accepted for the **WASET Conference** (World Academy of Science, Engineering and Technology) 2008 VIENNA - AUSTRIA.