PERFORMANCE ANALYSIS AND IMPLEMENTATION OF THREE DIMENSIONAL CODES IN OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM

Thesis submitted in the partial fulfillment of requirement for the award of degree of

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In

Electronics and Communication Engineering

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DECLARATION

I, Minal Garg, hereby certify that the work which is being presented in this thesis entitled "**Performance Analysis and Implementation of Three Dimensional Codes in Optical Code Division Multiple Access System**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Dr. R.S Kaler, Senior Professor ECED & Dean (Resource Planning and Generation).

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

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

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ABSTRACT

Code Division Multiple Access (CDMA) is a “spread spectrum” technology, allowing many users to occupy the same frequency band at the same time. CDMA assigns unique code to each user; it enables many users to transmit at the same time. On the other hand, the optical fiber communications have the high bandwidth, large capacity and having large reliability, to take the full advantage of both of the technologies. CDMA and the optical fiber communication, one of the basic concepts is the idea of allowing several users to transmit data simultaneously over the optical fiber communication channel by simultaneously allocating the available bandwidth to each user, which is called multiple access. There are various multiple access techniques one of them is optical code division multiple access (OCDMA). OCDMA uses various types of the codes like one dimensional, two dimensional and three dimensional. These one, two, three further classified into various types of codes, the basic requirements for any type of the code is that the autocorrelation of that should be maximized and the cross correlation should be minimized. In this report various three dimensional codes are discussed because it gives better performance by spreading in the three dimensions. No doubt that one dimensional codes gives low bit error rate but these possess high temporal length, this temporal length increases as the cardinality increases, in order to overcome this, two or three dimensional codes have been used, but three dimensional codes having high cardinality than two dimensional; means number of users can increases without so much increase in the length of the code. The objective of the thesis is to implement and analyze the three dimensional codes for OCDMA system.

Firstly, presenting the space/wavelength/time single pulse per plane (SPP) codes with direct detection (SPPDD) and these codes are implemented as two dimensional codes by using W^2T scheme in order to avoid the requirements of star couplers and associated hardware. The large code set can be derived using this SPPDD OCDMA code. Analyze these codes by varying the number of space channels (S) and keeping other two dimensions, wavelength (W) and time (T) constant and report that it gives better results when (W>S). For (W≤S) it gives poor performance having large bit error rate**.** In this, by varying the number of space channels and taking the constant value of wavelength and time W=T=4, it is found that the space channels S=2 and S=3 provides better BER rate than other space channels. The performance is compare

by analyzing various parameters like eye diagram, output signal spectrum and BER versus length of fiber, number of users and input power.

Secondly, use the three dimensional (3D) SPPDD codes for data encoding in OCDMA and analyze these three dimensional codes for different data modulation formats. The data modulation format are nonreturn to zero (NRZ) and return to zero (RZ) for space channel S=2 and S=3. The comparison between NRZ and RZ is done by varying the bit error rate (BER) against various parameters like length of fiber, number of users and input power. It is found that OCDMA system with NRZ data modulation format performs better than RZ. In this, take the SPPDD codes with fixed wavelength and time, but varied space channels. As the space channels are varied, the performance of the system is also varied. It gives better performance for (W>S) and shows large BER for (W≤S).

Lastly, a very simple method of optical CDMA encoding known as the spectral Phase encoding in three dimensional OCDMA has been discussed and implemented. The presentation of the system is coherent in nature because in this cohrent OCDMA system a given user's code is generally applied via phase coding. Coherent systems achieve higher performance and having high signal to noise ratio. In this system, choosing the set of hadamard codes which are by nature orthogonal and binary.

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ABBREVIATIONS

1-D	One Dimensional
2-D	Two Dimensional
3-D	Three Dimensional
BER	Bit Error Rate
CDMA	Code Division Multiple Access
FDMA	Frequency Division Multiple Access
FOCDMA	Fiber Optic Code Division Multiple Access
MAI	Multiple Access Interference
NRZ	Non Return to Zero
OCDMA	Optical Code Division Multiple Access
OOC	Optical Orthogonal Codes
RZ	Return to Zero
SPP	Single Pulse per Plane
SPPDD	Single Pulse per Plane with Direct Detection
MPP	Multiple Pulse Per Plane
TDMA	Time Division Multiple Access
WDMA	Wavelength Division Multiple Access

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION TO OPTICAL COMMUNICATION

Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution. Progressing from the copper wire of a century ago to today's fiber optic cable, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas.

Today's low-loss glass fiber optic cable offers almost unlimited bandwidth and unique advantages over all previously developed transmission media. The basic point-to-point fiber optic transmission system consists of three basic elements: the optical transmitter, the fiber optic cable and the optical receiver.

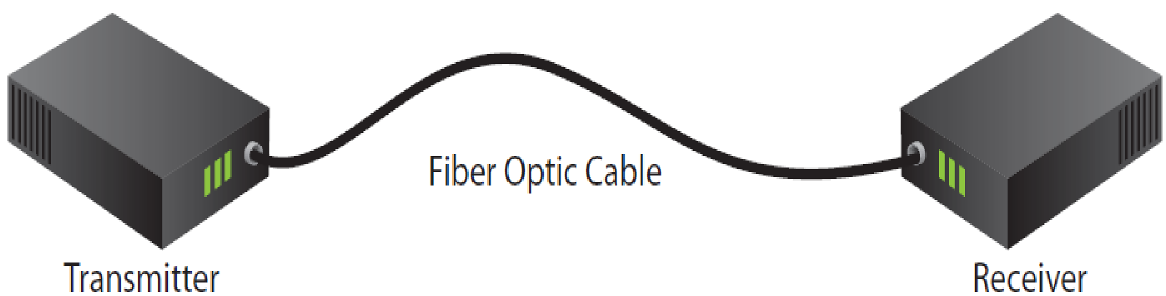


Figure 1.1: Basic Fiber Optic Transmission System [1]

The Optical Transmitter

The transmitter converts an electrical analog or digital signal into a corresponding optical signal. The source of the optical signal can be either a light emitting diode, a VCSEL, or a solid state laser diode. The most popular wave-lengths of operation for optical transmitters are 850, 1310 or 1550 nanometers.

The Fiber Optic Cable

The cable consists of one or more glass fibers, which act as waveguides for the optical signal (light). Fiber optic cable is similar to electrical cable in its construction, but provides special protection for the optical fiber within. For systems requiring transmission over distances of many kilometers, or where two or more fiber optic cables must be joined together, an optical splice is commonly used.

The Optical Receiver

The receiver converts the optical signal back into a replica of the original electrical signal. The detector of the optical signal is either a PIN-type photodiode or avalanche-type photodiode.

1.2 ADVANTAGES OF FIBER OPTIC SYSTEMS

The various advantages of optical fiber are [2]:

1. The ability to carry much more information and deliver it with greater fidelity than either twisted pair wire or coaxial cable.
2. Fiber optic cable can support much higher data rates, and at greater distances, than coaxial cable, making it ideal for transmission of serial digital data.
3. The fiber is totally immune to virtually all kinds of interference, including lightning, and will not conduct electricity. It can there- fore come in direct contact with high voltage electrical equipment and power lines. It will also not create ground loops of any kind.
4. As the basic fiber is made of glass, it will not corrode and is unaffected by most chemicals. It can be buried directly in most kinds of soil or exposed to most corrosive atmospheres in chemical plants without significant concern.
5. Since the only signal in the fiber is light, there is no possibility of a spark from a broken fiber. Even in the most explosive of atmospheres, there is no fire hazard, and no danger of electrical shock to personnel repairing broken fibers
6. Fiber optic cables are virtually unaffected by outdoor atmospheric conditions, allowing them to be lashed directly to telephone poles or existing electrical cables without concern for extraneous signal pickup.
7. A fiber optic cable, even one that contains many fibers, is usually much smaller and lighter in weight than a wire or coaxial cable with similar information carrying capacity. It is easier to handle and install, and uses less duct space. (It can frequently be installed without ducts.)

8. Fiber optic cable is ideal for secure communications systems because it is very difficult to tap but very easy to monitor. In addition, there is absolutely no electrical radiation from a fiber.

1.3 MULTIPLE ACCESS SCHEMES

Optical fibers provide excess bandwidth for multiple access operations, permitting many users to simultaneously communicate over the same medium by partitioning and allocating time, bandwidth, or some other features of the transmitted signal. A multiple access is required for combining and separating traffics on a shared physical medium when the users are not at the same place. There are three major multiple access schemes available, these are:

1. Wavelength Division Multiple Access (WDMA) or (FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)

Traditionally, fiber optic communication systems use either TDMA or WDMA schemes to allocate bandwidth among multiple users [3]. But now days, fiber optic communication system uses CDMA. All these multiple access techniques are explain as follow:

1.3.1 Wavelength Division Multiple Access (WDMA) or (FDMA)

In a Wavelength Division Multiple Access (WDMA) system, bandwidth is divided into number of channels and each channel occupies a narrow optical bandwidth around a center wavelength or frequency [4]. Figure 1.2 shows generalized channel usage by WDMA and WDMA scheme for two users. In this WDMA, the channels are assigned only when demanded by the users. Therefore when a channel is not in use it becomes a wasted resource.

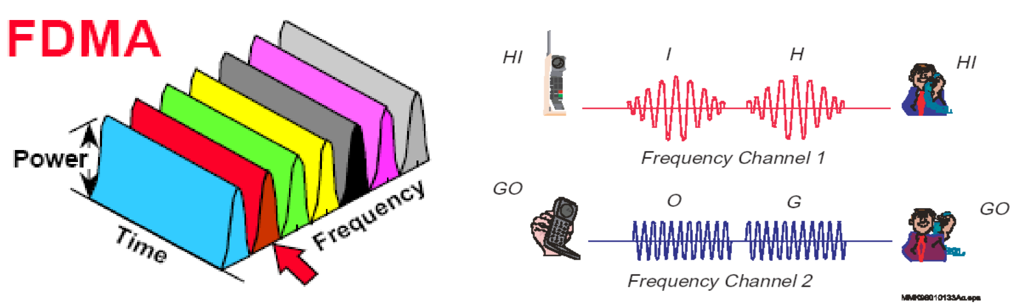


Figure 1.2: Channel usages by FDMA or WDMA [5]

1.3.2 Time Division Multiple Access (TDMA)

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 [6]. In a TDMA system, each channel occupies a pre-assigned time slot, which interleaves with the time slots of other channels. Global Systems for Mobile communications (GSM) uses the TDMA technique. Figure 1.2 shows generalized channel usage by TDMA and TDMA scheme for two users. TDMA requires careful time synchronization since users share the bandwidth in the frequency domain [7].

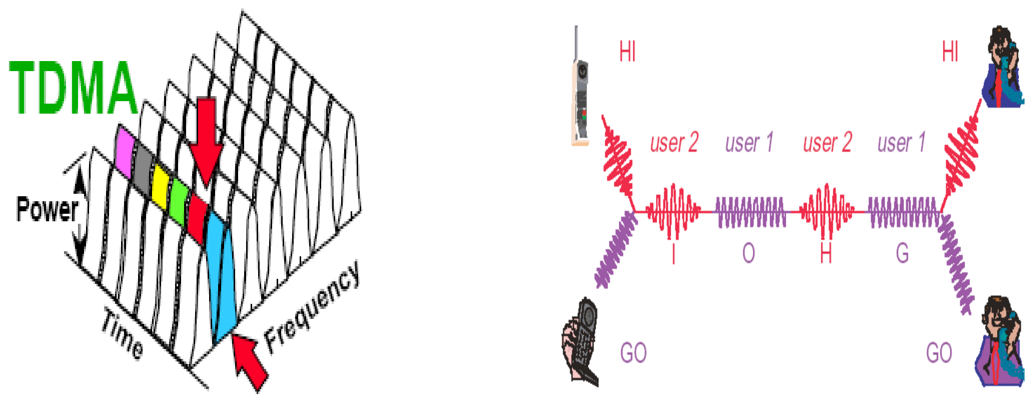


Figure1.3: Channel usages by TDMA [5]

1.3.3 Code Division Multiple Access (CDMA)

Code division multiple access (CDMA) is a form of multiplexing and a method of multiple access to a physical medium such as a radio channel, where different users use the medium at the same time using different code sequences. In CDMA, every user will be allocated the entire spectrum all of the time and CDMA uses unique spreading codes to spread the baseband data before transmission. In optical CDMA, each user is identified by different codes or addresses. In a particular technique, a CDMA user inserts its code or address in each data bit and asynchronously initiates transmission [3]. In Optical CDMA, the field of the optical signal carrying the data exhibits a set of signal processing operation. This modifies it’s time and/or frequency appearance, in a way recognizable only by the intended receiver. Otherwise, only noise-like bursts are observed. The advantages of CDMA include the flexibility in the allocation of channels, the ability to operate asynchronously, enhanced privacy, and increased capacity in bursty-nature networks [3]. Figure1.4 shows CDMA access system and CDMA system for two users.

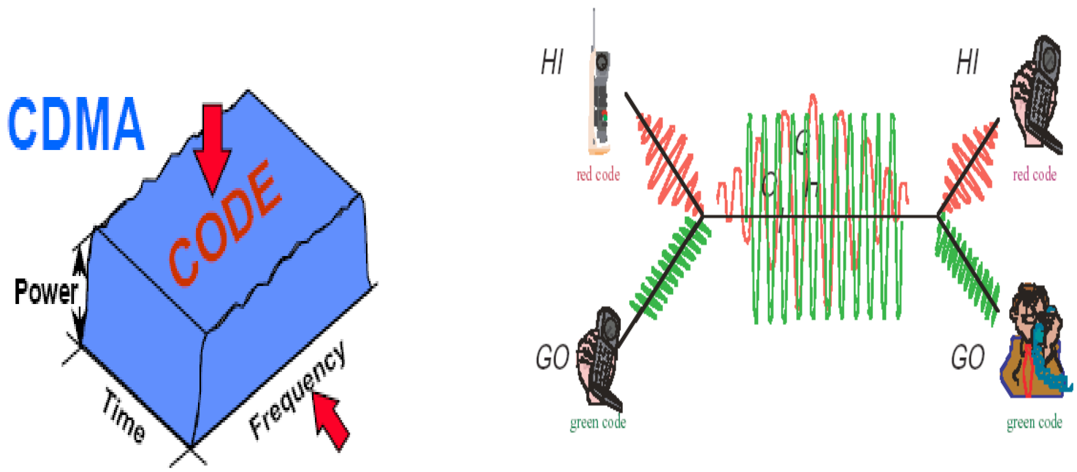


Figure 1.4: CDMA Spreading [5]

The various advantages and disadvantages of these three multiple access schemes are summarized in Table 1.1.

Table 1.1: Comparison of Common Optical Multiple Access Schemes

Comparison of Common optical Multiple Access Schemes	**Advantages**	**Disadvantages**
TDMA	a. Dedicated channels provided b. High throughput c. Deterministic access	a. Accurate synchronization needed b. Not efficient in bursty traffic c. Bandwidth wasted d. Channel not efficiently used e. Performance degrades with the number of simultaneous users `

CDMA	a. Simultaneous users allowed b. Asynchronous access c. No delay or scheduling d. High bandwidth efficiency e. Efficient for bursty traffic. f. Dedicated channels provided	a. Performance degrades with the number of simultaneous users
WDMA	a. Dedicated channels provided b. Simultaneous users allowed c. High bandwidth efficiency d. Simultaneous users allowed	a. Channel crosstalk b. Channel idle most of the time c. Non-linear effects

1.4 OPTICAL CODE DIVISION MULTIPLE ACCESS (OCDMA)

This OCDMA combines the large bandwidth of optical with the flexibility of the CDMA technique to achieve high speed connectivity. In long haul optical fiber transmission links and networks [8], the information consists of a multiplexed aggregate data stream originating from many individual subscribers and normally is sent in a well-timed synchronous format. The design goal of the Time Division Multiplexing (TDM) process is to make maximum use of the available optical fiber bandwidth for information transmission, since the multiplexed information stream requires very high-capacity links. To increase the capacity even further, Wavelength Division Multiplexing (WDM) techniques that make use of the wide spectral transmission window in optical fibers are employed. As an alternative to these techniques in a local area network (LAN), Optical Code Division Multiple Access (OCDMA) has been examined. WDM and TDM system imposes higher cost and complexity in LAN therefore; OCDMA finds its place to conceal the data content in LAN [9]. For long haul, high speed LAN and MAN networks, this OCDMA system is an essential part of the digital communication system [10]. The biggest challenge with optical CDMA system is to maintain the performance of the system and offer high bandwidth in case of high number of users at minimum cost. On the other hand, In OCDMA system the BER degrades by the multiple access interference which comes from all other active users. This in turn ultimately limits the number of active users in a given OCDMA networks.

The various characteristics of OCDMA are summarized in Table 1.2 by contrast with wireless cellular CDMA systems [11] [12]

Table 1.2 Comparison of Optical CDMA with Wireless CDMA

Parameters	Wireless CDMA	OCDMA
1) Carrier	Micro-& millimeter wave Limited availability	Lightwave 4000-70000 GHz
2) Spread/Despread	Frequency Domain	Time Domain
3) Code	Direct Sequence SS Frequency Hopping	Direct Sequence SS Wavelength Hopping
4) Encoding/Decoding	RF Domain	Optical Domain
5) Transmission Medium	Free Space (Air), Non-Dispersive Large Attenuation Linear	Closed-Spaced(Optical Fiber) Dispersive Low attenuation Nonlinear
6) Problems in Propagation	Far-near effect Multipath effect	Dispersion effects Nonlinear effect Interferometric effects

1.4.1 Block Diagram of OCDMA

The aim of Optical Code Division Multiple Access is to take benefits of radio frequency communications. CDMA technique is to share the huge optical bandwidth [13]. The block diagram for optical code division multiple access is shown as below

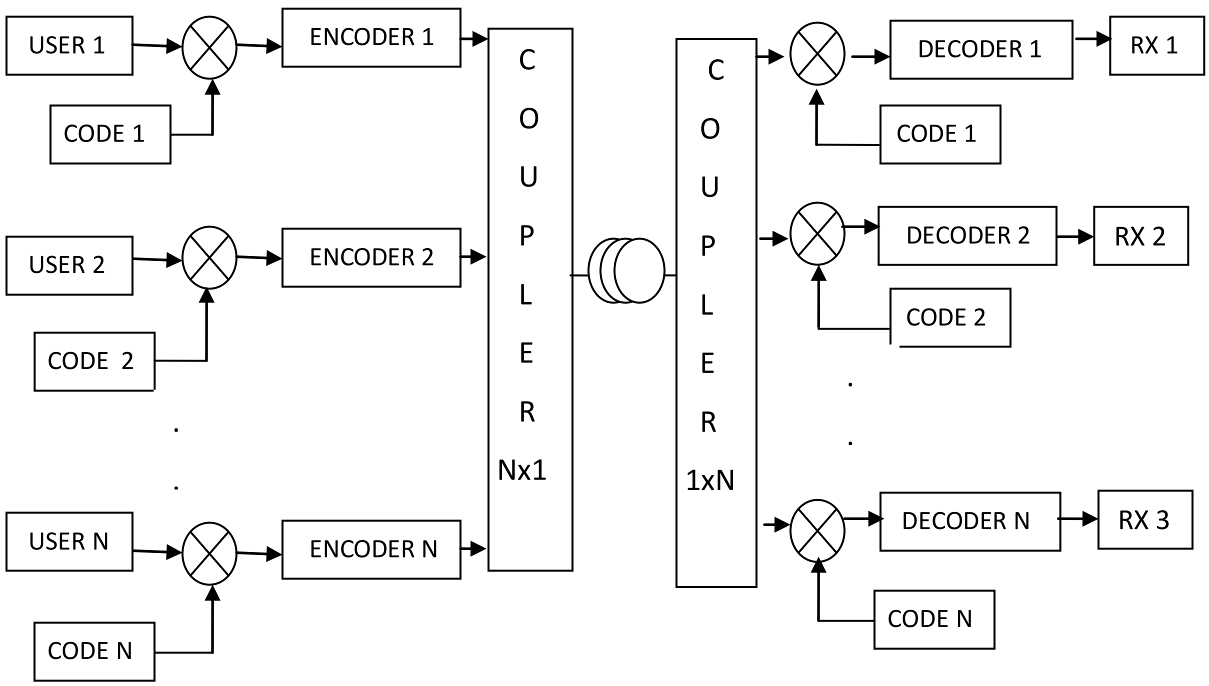


Figure 1.5: Block Diagram of OCDMA

An OCDMA system for each user can be described by a data source, containing the data that will be sent, followed by an encoder and then a laser that maps the signal from electrical form to an optical pulse sequence. At the receiver end, an optical correlator is used to extract the encoded data. Many subscribers transmit data simultaneously. Each user has its own codeword, which is approximately orthogonal to all other code words. The encoded data is send to the Nx1 star coupler, from where the optical channel carries the signal through the optical fiber and couples to a 1xN coupler and broadcast to all nodes. All users encoded data are then added together chip by chip and the result, which is called the superposition, are sent over the channel. The individual receivers consisting of optical correlator continuously observe the superposition of all incoming pulse transmission and recover the data from the corresponding transmitter. This is done by correlation between the incoming signal and stored copies of that user unique sequence. The correlator will give a peak, if the incoming stream of optical pulses contains the unique sequence and the presence of other users will be considered as noise. The decoding process is accomplished by using optical correlation. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independent with no knowledge of the users [14]. The presence of the light pulse represents the binary bit '1'and the absence of the light pulse represents the binary bit '0'

1.4.2 Fundamental Concept of Optical CDMA

High speed can be achieved in optical CDMA by combining large bandwidth of the optical medium with the flexibility of CDMA. CDMA was originally investigated in the context of radio frequency (RF) communications systems and was first applied to the optical domain in the mid 1980 by Prucnal and Salehi [15]. They tried to use the excess bandwidth in single-mode fibers to modulate low-information rate electrical signals into high rate optical pulse sequences to achieve random, asynchronous operation without the need for a centralized network controller.

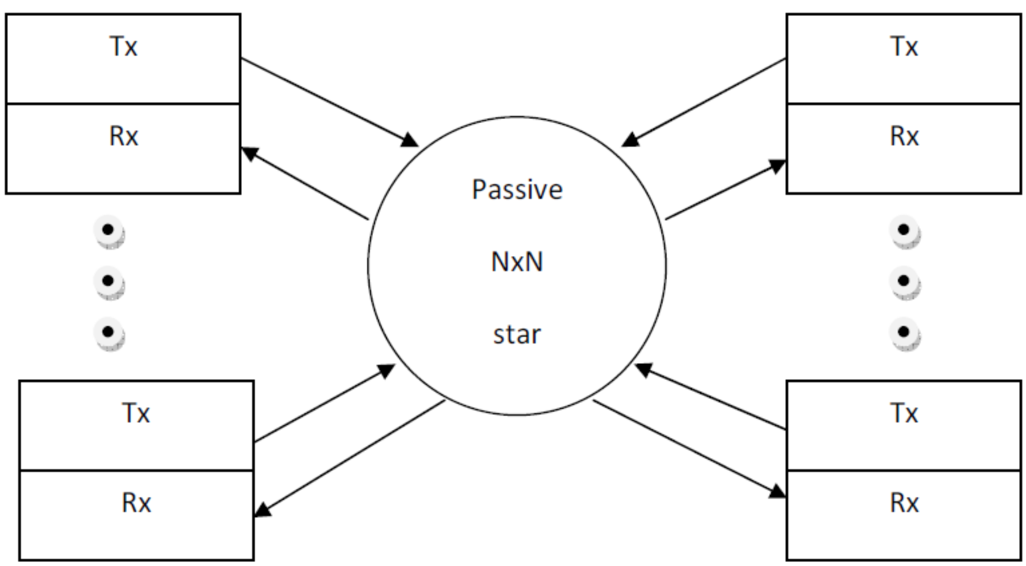


Figure 1.6: A Fiber optic CDMA network using a passive NxN Coupler [13]

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

The OCDMA encoded data is thus sent to the N*N star coupler or 1*N coupler and broadcast to all nodes. A typical fiber optic CDMA system is shown in figure 1.6, where the nodes are connected together through a passive N*N star coupler. At the logical level this configuration is a broadcast -and- select network. The crosstalk between different users sharing a common fiber channel, known as multiple access interference (MAI) is usually the important source of noise in an optical CDMA system, therefore intelligent design of the codeword sequence is important to reduce the contribution of MAI to the total received signal.

1.4.3 Principle of OCDMA

The principle of OCDMA is based on spread-spectrum techniques, which have been widely used in mobile-satellite and digital-cellular communication systems. The concept is to spread the energy of the optical signal over a frequency band that is much wider than the minimum bandwidth required to send the information. For example, a signal that conveys 10^3 b/s may be spread over a 1 MHz bandwidth. This spreading is done by a code that is independent of the signal itself. Thus, an optical encoder is used to map each bit of information into a high rate (longer code length) optical sequence. The CDMA technique has its origin in the spread spectrum (SS) technique. In SS transmission, the input signal is coded in such a way that its spectrum spreads over a much wider range than the original signal. At the receiver, the spreaded signal is decoded and its original form is restored. While despreading the input signal, unwanted noise or intentional jamming signals are spreaded, i.e. though input signal and distortion might carry the same power, the power spectral density of the distortion covers a wider area, thus, enabling the receiver to detect the input signal and noticing some additional, but only weak noise. Furthermore a despreading of the input signal is impossible without exact knowledge of the code sequence, thus increasing the security of the transmission.

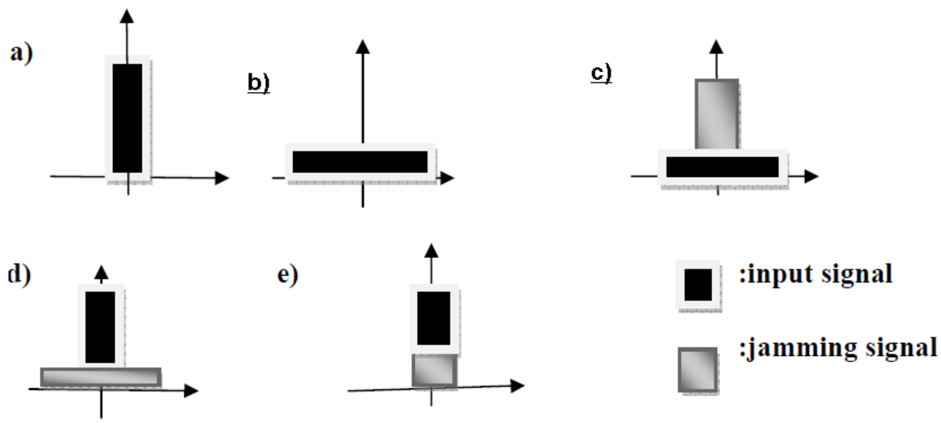


Figure 1.7: Principle of spread spectrum communication [13]

1.4.4 Synchronous and Asynchronous OCDMA

Both synchronous and asynchronous OCDMA techniques have been used. Each of these has its own strengths and limitations [16]. Since synchronous accessing schemes follow rigorous transmission schedule, they produce more successful transmission i.e. higher through puts than asynchronous methods, where network access is random and collisions between users can occur. In applications that require real time transmission, such as voice or interactive video, synchronous accessing techniques are most efficient. When traffic tends to be bursty in nature or when real time communication requirements are relaxed, such as in data transmission or file transfer, asynchronous multiplexing schemes are more efficient than synchronous multiplexing.

1.5 COMPARSION OF SPREAD SPECTRUM TECHNIQUES OF WIRELESS CDMA & OPTICAL CDMA

Wireless CDMA

In spread – spectrum wireless CDMA one uses matched filtering for the detection technique as shown in figure 1.8(a). The data signal is spread by pseudo-noise (PN) code sequence in radio frequency domain and transmitted. The received signal is despread by the matched filtering, followed by narrow bandpass filtering and only desired data is recovered. The ratio of data bit to total bandwidth is defined as processing gain [17]

Optical CDMA

OCDMA draws an analogy from the spread-spectrum wireless OCDMA. By contrast to the frequency spread/despread, the time spread/dispread is adopted in OCDMA as shown in figure 1.8(b). An optical short pulse having much higher frequency spectrum than the data bandwidth, is spread over one bit duration T by the encoding. The decoding time dispreads the encoded signal, reconstructing the original short pulse if the codes between the encoder and decoder match. While, on the other hand unmatched codes remain randomly spread over T after the decoding. Discrimination is achieved by the threshold of the output.

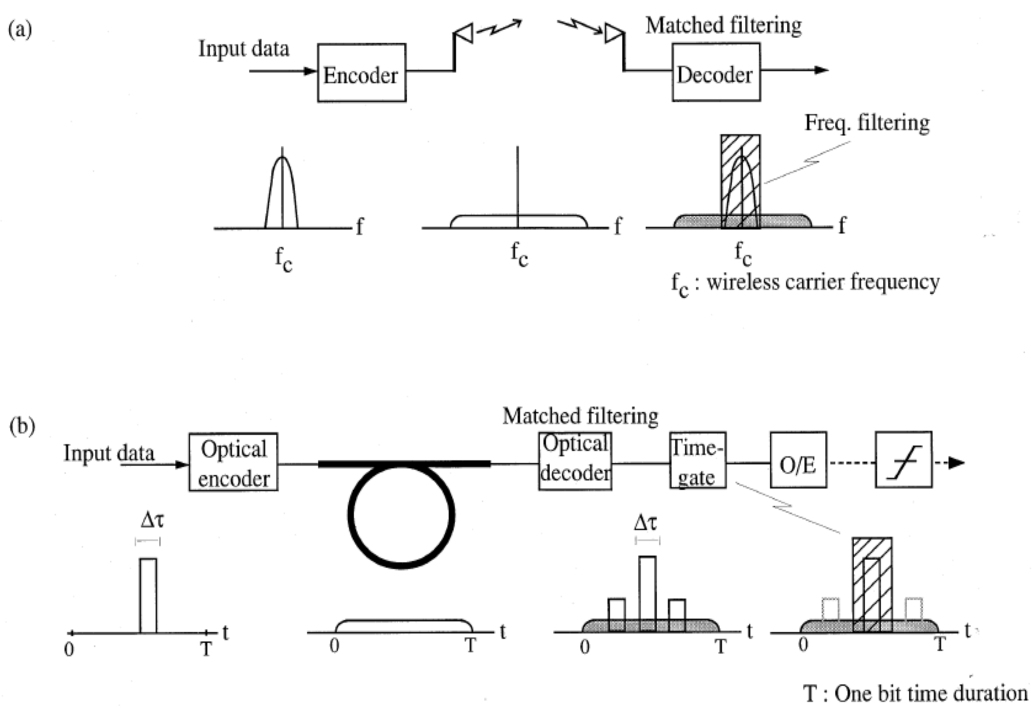


Figure 1.8: (a) Principle of spread spectrum wireless CDMA system on frequency spread/despread basis and (b) Principle of OCDMA system on time spread/despread basis [17]

1.6 ADVANTAGES OF OCDMA

The basic spectral OCDMA architecture naturally possesses a number of desirable advantageous features [13]

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

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

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

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

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

6 Network Control and Management: If the optical codes are designed such that the non-shifted autocorrelation peak is large and the shifted autocorrelation peak is minimized, each receiver is able to operate asynchronously without the need for a global clock signal. Since the number of unique codes is equal to the number of stations on the network, there is no need for a centralized node to arbitrate channel contentions. Adding a new user on an

OCDMA system is as easy as assigning a new code. Unused codes are provided to the new user. If no free codes were available, the system could be upgraded to support more users by increasing the amount of time or wavelength domain spreading. The amount of coding overhead could also be increased if it were being violated .The use of incoherent sources and the spreading of each channel over multiple wavelengths affords spectral OCDMA an inherent tolerance to a variety of imperfections in optical components and the transmission medium such as centre wavelength shifts, slow drop offs at the edges of filters, polarization dependent loss and fiber non-linearities.

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

8 Security: Finally, optical CDMA would offer an advantage that current access networks do not offer: inherent security. Sophisticated encryption is not required because OCDMA is already encoded and does not suffer from the same type of adjacent –channel crosstalk as DWDM i.e. centre wavelength shifts in filters do not results in the accidental reception of someone else's signal. Similarly OCDMA cannot result in the accidental reception of an unwanted channel as could occur with errors in synchronization in TDM. [18]

1.7 DISADVANTAGES OF OCDMA

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

1 Basic limitation: A basic limitation of OCDMA using a coded sequence of pulses is that as the number of user's increases, the code length has to be increased in order to maintain the same performance .Since this leads to shorter and shorter pulses, various ideas for solving this problem have been proposed. Alternatively, frequency domain methods based on spectral encoding of broadband incoherent sources e.g. LEDs or Fabry Perot Lasers have been proposed [18].

2 Cost: The biggest barrier to the wide scale deployment of OCDMA is "cost". Cost not only affects OCDMA rather other multiple access technologies like WDMA also suffers from the same problem. They are also constrained by the need for expensive optical hardware. The need for all optical encoding/decoding hardware and broadband light source for OCDMA makes it much expensive. In OCDMA each bit of information data is encoded by the signature sequence consisting of a number of shorter bits called chips. Each user is assigned one signature sequence called codeword. So the head end of an OCDMA network as well as user terminals would need to be able to generate 2D code words. At the encoder tunable fiber Bragg gratings are used. The tunability is achieved with piezoelectric devices that shift the centre frequencies of the gratings. Hence change the pattern of the code, so in order to avoid this optical hardware is required which is both expensive and bulky. Broadband light source: Filtering the output of a broadband light emitting diode (LED), spectrally slicing the amplified spontaneous emission (ASE) of an EDFA or combining the output of a number of laser diodes tuned to distinct wavelengths generate a broadband light source. Light produced by using laser diode array and the EDFA have the required power but are currently expensive but broadband LED is comparatively cheap, but light generated may not have enough intensity as is required by OCDMA applications.

Remedy to cost problem

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

3 Multiple Access Interference (MAI): The optical CDMA systems suffer from other simultaneous users. As the number of simultaneous users increases, the bit error rate (BER) degrades because the effect of MAIs increases. A critical limitation of OCDMA networks is the reduction of throughput when many users are simultaneously trying to transmit over common medium, thus producing extreme congestion at high network loads [19]. In addition, even if the received optical power is large enough i.e. if the effect of noise is small, the effect of MAIs is constant because the power of the transmitted pulse is equal among all users.

Light pulses transmitted by different users may overlap [20]. As the light source in each transmitter is assumed to be total intensity at a chip is the sum of the intensities of the individual light pulses existing in that chip. The codes are designed to be sufficient different that the probability of mistaking one code for another is very low. However, when many users are transmitting simultaneously, many overlaps may occur. A receiver may then conclude that its target code was sent. As a result, a receiver may incorrectly detect other users codewords, resulting in packet transmission error [21] this phenomenon is known as an error due to multiple access interference (MAI). As more users share the channel simultaneously, the effect of MAI becomes more significant. MAI increases the level of a pulse by integer multiple of the original pulse level. When pulse power is high and the photo detectors are of low noise, MAI is the dominant cause of performance degradation in OCDMA systems.

Remedy to MAI

In order to mitigate MAI several interference cancellation techniques have been proposed aiming at lowering these asymptotic error floors. These interference cancellation techniques are classified into two groups. One is based on the use of properties of modified prime sequence codes and the other is based on the use of optical hard-limiters [22]. Multiple access Interference (MAI) can be minimized by either increasing the code length *N* or choosing codes whose cross-correlations (CCs) are low. Since in the IMDD optical CDMA systems the bit error from a bit “0” to a bit “1” is a major problem, while the bit error from a bit “1” to a bit “0” is rare in absence of the noises caused from a photodiode

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Prior to starting of my thesis, it is important to have a deep understanding on the existing pages of optical OCDMA and its various types of codes used in this OCDMA. The main sources of the information for the dissertation are books, journal, thesis and the internet.

2.2 LITERATURE SURVEY

Sangwook Han [3] examined optical CDMA communication techniques with optical orthogonal codes. Simulations that show the desired properties of theses codes and their use in optical CDMA also reported and demonstrated this OCDMA for two user synchronous channels, for two user asynchronous channels and for K-user synchronous channel. Based on the simulations, they investigate the properties of optical CDMA and probability of error was also evaluated.

István Frigyes [8] showed that as spectrum spreading and CDMA proved themselves as very efficient in radio communication CDMA application in optical communication seems to be reasonable as well. Research in this field started two decades ago or so and is still flourishing. In this paper – after giving a brief listing of relevant concepts in optical communications – concepts of optical spectrum spreading, techniques of temporal and spectral coding was described, possibilities of long-haul application and some networking issues were also discussed.

Shilpa Jindal et al. [9] focuses on the effect of BER of three dimensional OCDMA codes with varying data rates. Performance of the codes has been evaluated in terms of bit error rate and Q factor with 1 gbps, 1.5 gbps, 2 gbps, 2.5 gbps, 3 gbps, 3.5 gbps & 4 gbps systems taking the advantage that light could be propagated in two orthogonal polarization states. It is further shown that 1gbps, 1.5gbps systems have good quality factor or in other words these codes have good performance at lower data rates, as the data rates are increased the Q factor decreases, Simulations were carried out using commercially available simulator from RSoft, OPTSIM.

Jawed A. Salehi [15] derived the bit error rate of the proposed FO-CDMA system as a function of data rate, code length, code weight, number of users, and receiver threshold; and they discuss the performance characteristics for a variety of system parameters. Furthermore, they discuss a means of reducing the effective multiple-access interference signal by placing an optical hard-limiter at the front end of the desired optical correlator. They calculate the performance of the FO-CDMA with an ideal optical hard limiter, and they show that using an optical hard-limiter would, in general, improve system performance.

Ken-ichi Kitayama et al. [17] showed that optical Code division multiplexing (OCDMA) is the other class of multiplexing technique than time division multiplexing (TDM), wavelength division multiplexing (WDM) and space division multiplexing (SDM). OCDM has been proposed in mid 70's. It has been long since OCDMA remains outside the mainstream of research community of optical communication; however, possible scarcity of the wavelength resources in future photonic networks, the simple access protocol as well as versatility of optical codes motivates the recent growth of OCDMA research activities. In this paper, first, fundamentals of OCDMA concept were presented, highlighting optical encoding and optical time gate detection which realize time spreading/despreading.

P. Kamath et al. [21] showed Optical CDMA Local Area Networks allow shared access to a broadcast medium. They demonstrated that every node is assigned an Optical Orthogonal Codeword (OOC) to transmit or receive on. Optical CDMA systems have low throughput under moderate to heavy offered load due to interference between codeword's. Interference Sensing is a media access architecture where nodes on the network sense the amount of interference on the line before transmission. Nodes defer transmissions if there is interference on the line. They discussed and analyze three algorithms for interference sensing. Through simulation it was showed that these algorithms reduce or eliminate throughput degradation at high loads.

E. S. Shivaleela et al. [23] demonstrate that optical CDMA technology is being explored as a multiplexing technology for high speed access networks, with optical fiber as transmission medium and also processing i.e. the spreading/dispreading of the CDMA sequences. For fiber-optic code division multiple access (FO-CDMA) scheme to be a practically implement able one as a high speed access network, two main challenges are, design of (1) codes with high spectral efficiency and cardinality and (2) high speed encoders/decoders which are simple and efficient to implement. As a solution to the first requirement, we have formulated wavelength/time single pulse- per-row (W/T SPR) codes which are energy efficient and of weight/row WP = 1, for a given weight of the code W, in addition have good 1) cardinality 2) spectral efficiency and minimal 3) correlation values, for given wavelength and time dimensions. In this paper, we have simulated W/T SPR network and also Optical orthogonal codes (OOC) network using a commercially available optical simulation package.

J.A.Salehi [24] examined fiber-optic code division multiple access (FO-CDMA) communications techniques. A new class of codes (signature sequences), namely, optical orthogonal codes (OOC's), that are suitable for FO-CDMA were introduced. In an experiment auto and cross correlation property of these codes and their use in FO-CDMA was reported. Furthermore, the concept of optical disk patterns, an equivalent way of representing OOC's was introduced. The optical disk patterns are used to derive the probability density functions associated with any two interfering OOC's. Also presented a detailed study of different interference patterns from which the strongest and the weakest interference patterns were introduced

S. A. Aljunid et al. [25] proposed a new code structure for spectral-amplitude-coding optical code-division multiple-access system based on double weight (DW) code families was proposed. The DW code has a fixed weight of two. By using a mapping technique, codes that have a larger number of weights can be developed. Modified double-weight (MDW) code is a DW code family variation that has variable weights of greater than two. The newly proposed code possesses ideal cross-correlation properties and exists for every natural number. Based on theoretical analysis and simulation, MDW code was shown to provide a much better performance compared to hadamard and modified frequency-hopping codes.

Vishav Jyoti et al. [26] presented the design, implementation and performance analysis of various one dimensional codes in an OCDMA system for different data formats. A number of different codes are used with optical CDMA to improve its error performance. Here, three such codes, optical orthogonal codes (OOC), Walsh Hadamard codes and zero cross-correlation (ZCC) codes have been compared using different data formats, NRZ raised cosine, NRZ rectangular, RZ raised cosine and RZ rectangular. It was found that NRZ raised cosine has the best system performance for all the codes used. After that, the three codes have been compared in terms of the BER, eye diagrams and received optical power using

NRZ raised cosine modulation format. It was analyzed that ZCC codes have zero cross-correlation property. The simulation results revealed that ZCC codes can provide a better BER compared to the OOC and Walsh Hadamard codes and it is most suitable to be employed in the OCDMA systems

J. Singh et al. [27] demonstrates the design of a new family of two-dimensional single pulse per column codes for optical code division multiple access (OCDMA) networks. The 1-D modified pseudo-noise codes have been known to be orthogonal and their generation and system design based on these codes is rather simple. But their performance is limited due to the bandwidth constraints if the code length increases. Hence, using these 1-D modified pseudo-noise codes, modified 2-D pseudo-noise matrix codes (MPMCs) are generated. The system performance was evaluated for two, three and four simultaneous users using the link with all the sources responsible for degradation included: attenuation, chromatic dispersion, non-linear refractive effects, non-linear scattering and four-wave mixing. The effect of the non-linear and lossy dispersive medium over the system performance was shown by plotting the BER with respect to the link length for the systems designed using encoders/decoders based on 1-D modified pseudo-noise codes and our MPMCs. The performance was compared for the two types of codes by finding the crosstalk due to interfering users simultaneously operating in the network.

Vishav Jyoti et al [28] shows two-dimensional (2D) wavelength/time codes design and implementation. The 2D codes are constructed by a technique based on folding of Golomb rulers. The performance evaluation of OCDMA system based on wavelength/time code has been analyzed by measuring the values of bit error rates and eye diagrams for different number of active users. It is shown that eye opening decreases and BER increases with increase in number of active users. It is also shown that BER further increases with increase in number of active users when number of decoder’s increases on receiver side. Hence, it is concluded that multiple access interference (MAI) is the dominant source of BER and there is graceful degradation in system performance when number of simultaneously active users increases. The received optical power is also measured at different transmission distance. It has been observed that received optical power decreases with increase in length of fiber due to attenuation.

S. Kim et al. [29] presented a new family of space/wavelength/time spread three-dimensional (3-D) optical codes for optical code-division multiple-access (OCDMA) networks. Two types of 3-D codes have been constructed: 3-D codes with single pulse per plane and 3-D codes with multiple pulses per plane. Both codes are based on the prime sequence algorithm and have shown improved performance compared to the previously proposed two-dimensional (2-D) prime code. Effective implementation of the 3-D code has also been proposed. In order to eliminate the requirement of multiple star couplers and associated hardware in space/wavelength/time spread 3-D code based optical networks, a wavelength^2/time scheme has been suggested, in which the periodic property of an arrayed waveguide grating (AWG) is used. It has been shown that the system performance can be maximized for given resources with a proper choice of the wavelength^2/time scheme. Due to the improved performance of the 3-D code and the effective architecture of the wavelength^2/time scheme, the feasibility of the OCDMA network is much enhanced.

J. Singh et al. [30] demonstrates that two-dimensional codes for OCDMA have been shown to be more versatile compared to the one-dimensional codes for their good spectral efficiency as well as better BER performance. The two-dimensional (2-D) codes also benefit from the reduction of the wavelength/time like property over the one-dimensional (1-D) codes. The three-dimensional (3-D) codes are important as these produce a larger code set. In this paper, they present a new family of 3-D single-pulse per plane codes for differential detection (SPDD) for OCDMA systems (based on the 1-D golomb ruler sequences), which achieve good code cardinality and a very high BER performance.

J. Singh et al. [31] demonstrated a new family of three dimensional wavelength/time/space codes for asynchronous optical code-division multiple access (OCDMA) systems with off-peak auto-correlation λ_a=0 and peak cross-correlation λ_c = 1. With wavelengths and time-slots, codes are generated. Antipodal signaling/differential detection was employed in the system. The performance was compared to the two dimensional/three dimensional codes. Arrayed waveguide grating based reconfigurable two dimensional implementation for encoder/decoder was presented.

H. Takahashhi et al. [32] realized the practical wavelength division multiplexing (WDM) systems, a high-performance N x N wavelength multiplexer was introduced that is based on an arrayed-waveguide grating. Its transmission characteristics are theoretically derived and experimentally confirmed. A prototype is constructed using the previously proposed techniques that attain low insertion loss and polarization independent operation. It has 16 channels (N = 16) with a spacing of 0.8 nm, or 100 GHz, in the 1.55-pm band. Frequency relation between input and output ports, free spectral range, and passband width were determined. A demonstration of IM-DD pulse transmission showed that there is no degradation of bit error rate resulting from the finite passband width and crosstalk of the multiplexer. It is confirmed that the multiplexer can realize highly reliable N-channel WDM and WDM-based N x N interconnect optical networks.

M. Othman et al. [33] proposed a detection scheme known as spectral direct detection technique implemented with Fiber Bragg Grating (FBG) act as encoder/decoder. This FBG based is used to encode and decode the spectral amplitude coding namely modified double weight (MDW) code in Optical Code Division Multiple Access (OCDMA). This code is used due to its flexibility where its weight can be any even number that greater than two. Moreover, it can maintain the cross-correlation parameter equal to one. The performance of spectral direct detection technique against AND-subtraction technique which is both implemented with FBG based encoder/decoder was compared via simulation in downstream and upstream access network at point to multipoint configuration. The simulation will be carried out using OptiSystem version 6.0 and the performance is characterized through bit error rate (BER) and power received at various bit rate.

Neetika Soni et al [34] demonstrate a very simple method of Optical CDMA encoding known as the Temporal Phase Encoding and the performance of the system with this encoding technique is evaluated on the basis of number of users, length of the spreading code for 4-phase and 8-phases. Simulation results for the system are presented for upto seven users. Bit error rate curves are plotted with data rate of 1 Gbps. This has been found that performance improves if normalized threshold higher than 0.5 is used.

Xu Wang et al [35] presented a novel reconfigurable time domain spectral phase encoding (SPE) scheme for coherent optical code-division-multiple-access application. In this scheme, the SPE is done in time domain using high speed phase modulator. The time domain SPE scheme is robust to wavelength drift of the light source and is very flexible and compatible with the fiber optical system.

2.3 MOTIVATION

According to the literature survey it has been observed that the type of codes used is a major factor influencing the performance of any OCDMA system. In OCDMA system, we use all 1D, 2D and 3D codes. In 1D codes data is spread either in time [36] or in frequency [37] domain and we find various 1D codes which are : Optical Orthogonal Codes [38], Walsh Hadamard Codes [39], Zero Cross Correlation Codes [40], Prime sequence Codes [16], Modified Prime Sequence Codes [16], New Modified Prime Codes [41] etc. In 1 dimensional OCDMA system, one period of transmission clock is divided into given number of small segments dubbed as time chips and bit '1' is encoded with number of optical pulses spread in the time chips. Among all 1 dimensional families, the optical orthogonal code has lowest out of phase and cross correlation values, both are equal to 1. But there are some drawbacks in 1D code that this 1dimensional optical codes having out of phase autocorrelation cannot be zero because there are multiple optical pulses within one period. The lower limit of out of phase auto correlation in the 1dimensional code is 1, and to achieve as in OOC, the code length increases rapidly as the number of user's increases. In order to overcome the limit of 1dimensional optical codes, 2D can be the best solution which spread either in wavelength/time [42] or in space/time [43] [44] domain. One of the 2D codes is Wavelength hopping time spreading [28]. In 2D OCDMA pulses are placed in different chips is of either different wavelength or different space. The out of phase auto correlation and cross correlation of 2dimensional code families are equal to '0' and '1' respectively. By using another dimension (Space or Wavelength), 2dimensional codes with single pulses per row is achieved and the performance of the 2dimensional OCDMA system is much improved in comparison to the 1dimensional OCDMA system and it also provides larger user code set. But these 2dimensional codes suffer from the impact of timing skew as the time dimension of the code is large. The impact of fiber dispersion on the code performance of the 2dimensional codes have been extensively investigated [45] [46] and it has been shown that these are prone to the problem of timing skew arising in the fiber, if large time dimensions are used for better BER performance and in order to overcome the limit of 2dimensional codes, 3dimensional codes have been used. These 3 dimensional codes have been obtained from 2dimensional codes by adding a third dimension, in which optical pulses are spread in all the three directions. These three dimensional codes can be Space/Wavelength/Time Codes [47], Time/Wavelength/Polarization Codes [48]. The performance analysis of OCDMA system is done by using 3D codes.

2.4 OBJECTIVE OF THESIS

The objectives of thesis are:

- Implementation and analysis of Three Dimensional (3D) space/wavelength/time single pulse per plane code with direct detection.
- Performance analysis of Three Dimensional (3D) single pulse per plane with direct detection (SPDD) code using different data format for OCDMA system
- Implementation of Three dimensional space/wavelength/time OCDMA codes using spectral phase encoding/decoding

2.5 ORGANIZATION OF THESIS

This is divided into six chapters

The first chapter presents a brief introduction of OCDMA system which includes principle of OCDMA and also the comparison of optical and wireless CDMA

The second chapter includes the literature survey of various one dimensional, two dimensional and three dimensional codes for OCDMA system.

The third chapter includes three dimensional space/wavelength/time single pulse per plane code with direct detection (SPPDD), the implementation and analysis of these codes is done by varying one dimension (space) and keeping rest of two dimensions (wavelength and time) constant and find out which channel performs well by observing BER, the eye diagram, input power and output signal

In the fourth chapter, the performance analysis of this three dimensional space/wavelength/time single pulse per plane with direct detection (SPPDD) for different data formats non return to zero (NRZ) and return to zero (RZ) is presented and find out which format gives better results.

The fifth chapter presents the implementation of three dimensional codes using spectral phase encoding/decoding

Finally, the sixth chapter includes the conclusion and the future scope of the work done.

CHAPTER 3

IMPLEMENTATION AND ANALYSIS OF THREE DIMENSIONAL (3D) SPACE/WAVELEGTH/TIME SINGLE PULSE PER PLANE CODES WITH DIRECT DETECTION

In this, I am presenting space/wavelength/time single pulse per plane (SPP) codes with direct detection (SPPDD) and and these codes are implemented as two dimensional codes by using W^2T scheme in order to avoid the requirements of star couplers and associated hardware. The large code set can be derived using this SPPDD OCDMA code. Analyze these codes by varying the number of space channels (S) and keeping other two dimensions, wavelength (W) and time (T) constant and report that it gives better results when (W>S). For (W≤S) it gives poor performance having large bit error rate**.** In this, by varying the number of space channels and taking the constant value of wavelength and time W=T=4, it is found that the space channels S=2 and S=3 provides better BER rate than other space channels. These channels are compared by analyzing various parameters like eye diagram, output signal spectrum and BER versus length of fiber, number of users and input power.

3.1 INTRODUCTION

Ever increasing demand for higher data rates and data security has inspired tremendous interest in optical code division multiple access technology [24]. As the feasibility of multiple access networks increases, OCDMA network's attracts much attention and have been studied by the number of users and it provides bursty, concurrent and asynchronous communication. The main issue of the studies on the OCDMA network is to devise a code set of good performance. The concept of assigning spreading codes to each user in fiber optic communication network is used in OCDMA. In this OCDMA an optical code represents a user address of each transmitted data bit. We can define the optical coding as the process by which the code is inscribed into and extracted from an optical signal. A user transmits an assigned code, whenever a '1' is to be transmitted and does not transmit anything whenever a '0' is to be transmitted [26]. In case of an OCDMA, various different types of codes have been proposed and studied for various OCDMA technologies and found that one dimensional and two dimensional codes having some limitation, that's why three dimensional codes are generally preferable.

J.Singh et al. [30] demonstrated a new family of three dimensional single-pulse per plane codes for differential detection for OCDMA systems (based on the one dimensional golomb ruler sequences), which achieve good code cardinality and a very high BER performance. The BER performance is obtained by using two codes to encode '1' and '0' bits in the encoder and differential detection in the receiver. The comparison of three dimensional SPDD with some of the best reported two dimensional/three dimensional codes.

J. Singh et al. [31] demonstrated a new family of three dimensional wavelength/time/space codes for asynchronous optical code-division multiple access (OCDMA) systems with off-peak auto-correlation $\lambda_a = 0$ and peak cross-correlation $\lambda_c = 1$. With wavelengths and time-slots, codes are generated. Antipodal signaling/differential detection is employed in the system. The performance is compared to the two dimensional/three dimensional codes. Arrayed waveguide grating-based reconfigurable two dimensional implementation for encoder/decoder is presented.

Sangin Kim et al. [29] demonstrated a new family of space/wavelength/time spread three-dimensional (3D) optical codes for optical code-division multiple-access (OCDMA). Two types of dimensional codes have been constructed: three dimensional codes with single pulse per plane and three dimensional codes with multiple pulses per plane. Both codes are based on the prime sequence algorithm. In order to eliminate the requirement of fiber ribbons and multiple star couplers in space/wavelength/time spread 3-D code based optical networks, a wavelength^2/time scheme has been suggested, in which the periodic property of an arrayed waveguide grating (AWG) is used. It has been shown that the system performance can be maximized for given resources with a proper choice of the wavelength^2/time scheme.

Design of one dimensional code is proposed in [49]. The limitation of one dimensional (1D) optical codes is that the out of phase autocorrelation cannot be zero because there are multiple optical pulses within one period. The lower limit of out of phase auto correlation in the one dimensional code is 1, and to achieve as in OOC, code length increases rapidly as the number of user's increases. In order to overcome the limit of 1dimensional optical codes, two dimensional approaches are proposed [28]. These two dimensional codes suffer from the impact of timing skew as the time dimension of the code is large. The impact of fiber dispersion on the code performance of the two dimensional codes have been extensively investigated [45][46] and it has been shown that these are prone to the problem of timing skew arising in the fiber, if large time dimensions are used for better BER performance. In order to overcome the limit of two dimensional codes, three dimensional codes have been proposed.

Till now, the three dimensional SPP codes were implemented using differential detection but now in this paper we implement SPP 3D codes by using direct detection instead of differential detection. In differential detection [3] each user is assigned two codes: one for the transmission of bit '1' and other for the transmission of bit '0' for antipodal signaling but in direct detection, which we use in this paper is ON-OFF keying which means that each user assigned a single code and that code is used for the transmission of bit '1' and this system said to be in 'ON' state, and for the transmission of the bit '0' there is no such code is assigned and this system is said to be in 'OFF' state. In this detection technique only wanted chip in the optical domain is filtered. This detection scheme doesn't need subtraction detection technique at electric side. Therefore, MAI and Phase Induced Intensity Noise (PIIN) will not exist in this detection scheme. Nevertheless, this scheme is only applicable to codes, where the time chips are not overlapped with other time chips of other channels.

This paper is divided into seven subsections: section I gives the introduction of OCDMA and their codes, section II gives brief introduction of three dimensional codes, section III gives an idea to how to design 3 dimensional codes, section IV describes the mathematical representation of the code and section V gives implementation of this 3 dimensional SPPDD code, section VI gives results and discussions and section VII provides the conclusions.

3.2 THREE DIMENSIONAL CODES

Three dimensional codes are the simply extension of the two dimensional codes. These three dimensional codes have been obtained from two dimensional codes by adding a third dimension, in which optical pulses are spread in all the three directions. Various three dimensional codes are available, some of them are:

- Space/Wavelength/Time Codes [47]
- Time/Wavelength/Polarization Codes [48]

The most commonly used three dimensional code is space/wavelength/time because the time/wavelength/polarization codes requires polarization maintaining fiber for the fiber links, the polarization sensitive components are used throughout the link starting from encoder to decoder. This complex polarization control at all stages in the network, making it very complicated and a costly affair. This space/wavelength/time codes are classified as:

- SPP Codes
- MPP Codes

SPP Codes: These codes having single pulse in each dimension or in plane.

MPP Codes: These codes having multiple pulses in all or some dimensions.

By comparing both these codes in [29], found that three dimensional SPP codes offer greater system scalability than the three dimensional MPP codes. By addition of more wavelengths, increases the generated codes in the case of SPP codes only, while MPP codes are upper bounded to the number of time slots. We can say that, for a small number of simultaneous users the three dimensional MPP showed better performance due to dominant effect of increased threshold. The three dimensional SPP code showed lower error probability for large number of the simultaneous users, since the effect of reduced cross correlation probability become dominant. For that reason three dimensional SPP codes are commonly used, these three dimensional SPP codes combines with direct detection technique and that forms SPPDD codes. The SPPDD codes gives much better performance with relatively smaller time chips in the code, and hence less affected by the time skew.

3.3 DESIGN OF THREE DIMENSIONAL SPPDD CODE

The SPP with direct detection code words (SPPDD) are the three dimensional matrices with a single '1' element per plane with the three dimensions: wavelengths, time-chips and the space channels and hence are the W x T x S (Wavelength x Time x Space Channels) codes. The '1' chips in the code denote that an optical pulse is to be transmitted over the optical channel in the corresponding time slot over the respective wavelength. In order to design the three dimensional SPP code the concept of Golomb ruler is used [30]. Golomb rulers are the binary sequences of 1's and 0's such that the distances between any two 1's in the ruler are non-repeating. This property can be used in deriving the orthogonal user codes from them.

Method for generating complete code set

Two-dimensional optical codes based on Golomb rulers (known for their pseudo-orthogonal properties because of the distances among any two 1's in the Golomb ruler are non-repeating integers) have been proposed by Mendez et al. [50]. The SPPDD codes based on Golomb rulers are generalized and can be derived for any weight (order of the Golomb ruler) and satisfy the off-peak auto-correlation of '0' and cross-correlation constraint of '1'. An SPPDD code based on Golomb ruler [2 4 5 8] of order '4' is derived as shown in figure.3.1 [30]

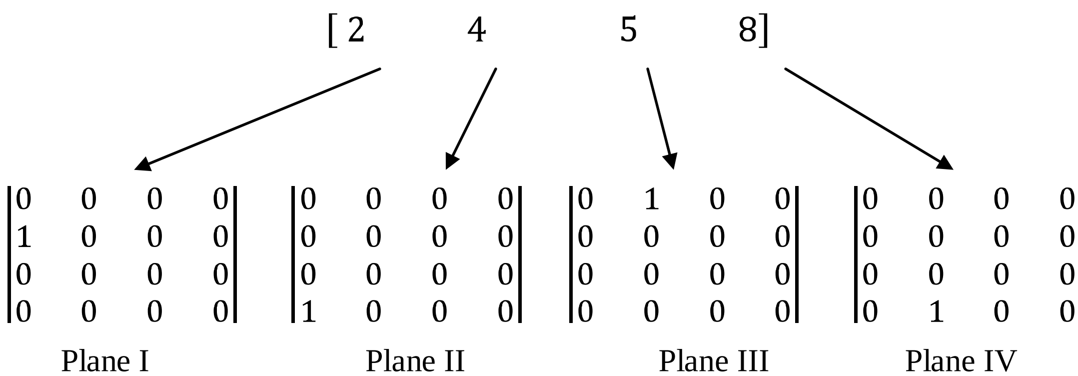


Figure 3.1: An example of the 3-D SPPDD code of weight = 4 based on Golomb ruler [2 4 5 8] of order 4. It shows four planes each of weight one [30].

The code has a weight '4' and the same number of planes. The entries of the ruler are shown as the positions of 1's in the respective planes of the code. As each plane has only a single '1', these codes are single-pulse per plane codes. Once the number of space channels selected (equal to the order of the Golomb ruler or the code weight), the minimum value of (W x T) required for a code, (W x T) min, such that the code satisfies the peak cross-correlation constraint of '1', is selected to be (2 x (value of the last element in the Golomb ruler)) [30]. The flexibility in choosing the matrix dimensions can further ease and modify the encoder/decoder design as per our preferences (as W x T = 16, can be implemented as 4x4 or 8x2). (W x T) dimension e.g. using the ruler [2 4 5 8], can be taken as a divisible value so that its factors form the two dimensions W and TS of a matrix. Taking W x T = 16 (also shown in figure 3.1), the code is derived by writing the matrices each containing one pulse. These matrices form the planes of the SPPDD code shown in figure 3.1 with each plane containing a single pulse. The three dimensional code shown in figure3.1can also be represented as shown in figure 3.2 [30].

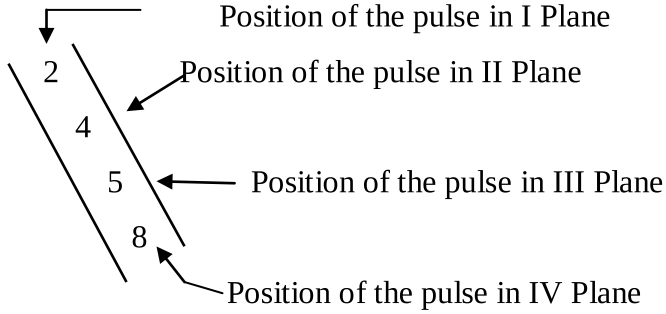
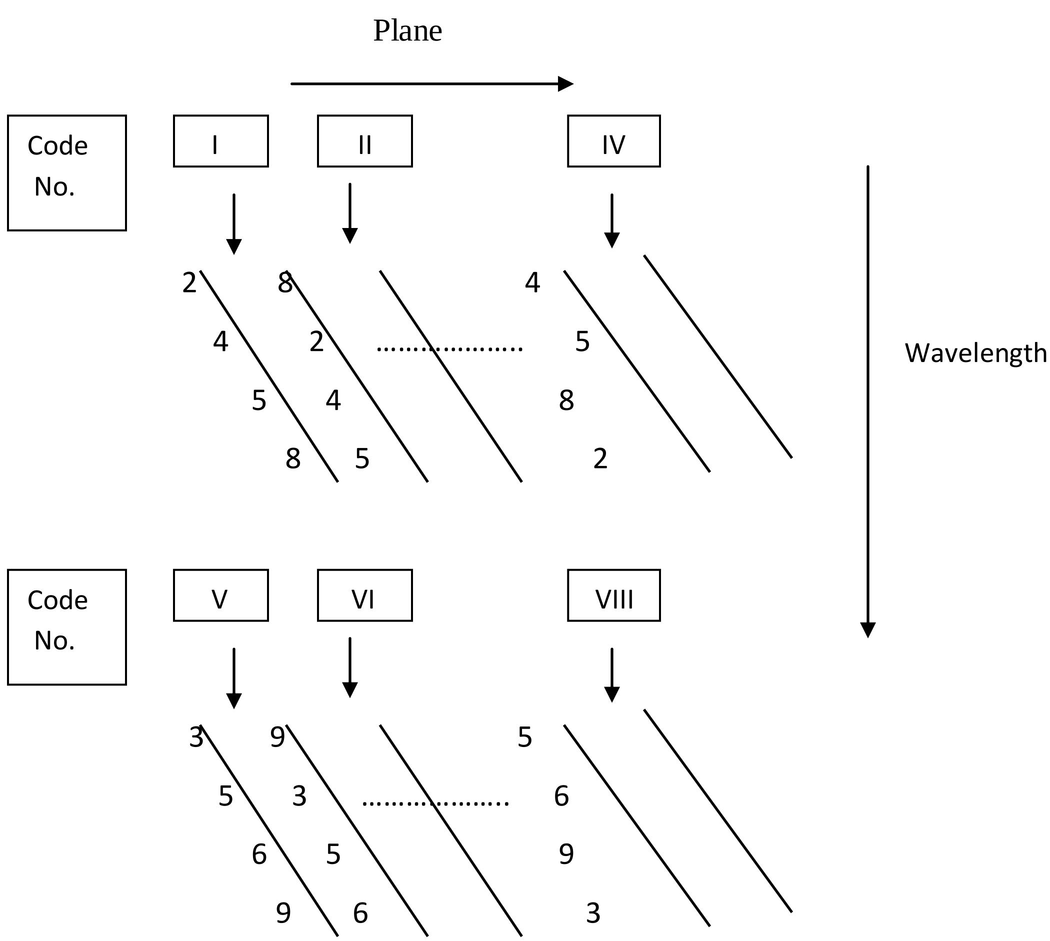


Figure 3.2: Representation of the pulses in the SPPDD code [30]

The procedure for generation of the complete code set from the code 1 is explained in figure 3.3. As shown in the figure, the complete set of codes is generated by applying row-shift operation in downward direction and the plane-shift operation in the horizontal direction [30]



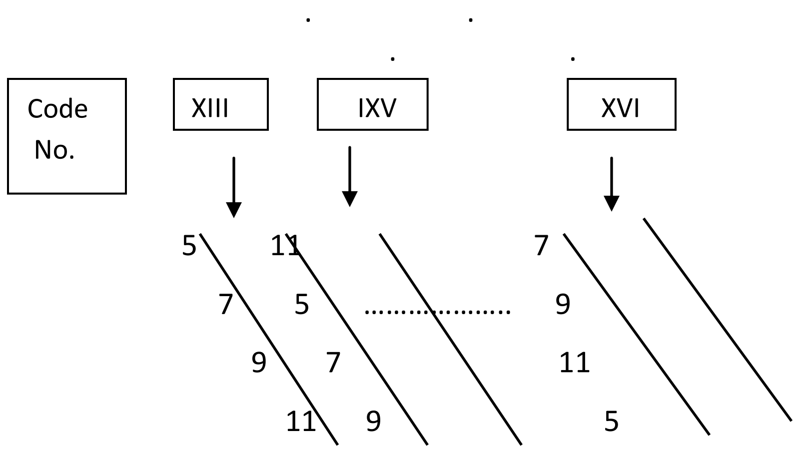


Figure 3.3: Procedure for generating the complete code set of 3-D SPPDD codes [30]

Hence the total number of the three dimensional SPPDD codes generated is equal to (W x S) and the total number of supported users are half of the total codes generated i.e. (W x S)/2

3.4 MATHEMATICAL REPERSENTATION OF THE CODE

A (W x T x S) SPPDD code is generated by a row shift of s_s and a plane-shift of p_s, using a Golomb ruler [g1 g2 g3 g4] can be mathematically represented as shown in figure 3.4 [30]

$$\text{Code} = \begin{array}{l} (g1 \oplus \text{mod } (W^*T)\ s\_s)\ \Theta\ P\_s \\ \quad (g2 \oplus \text{mod } (W^*T)\ s\_s)\ \Theta\ P\_s \\ \qquad (g3 \oplus \text{mod } (W^*T)\ s\_s)\ \Theta\ P\_s \\ \qquad\quad (g4 \oplus \text{mod } (W^*T)\ s\_s)\ \Theta\ P\_s \end{array}$$

Figure 3.4: Mathematical representation of a SPPDD code based on golomb ruler [g1g2g3g4] and generated using a downward row-shift s_s and a plane-shift p_s for a golomb ruler of order ‘4’ [30].

where [g1 g2 g3 g4] is the Golomb ruler of order 4; mod(W * T) represents modulo (W x T) addition; s_s is the row- or wavelength- shift downwards; and s_s ϵ[0,W-1]; W is the number of wavelengths used which is equal to the number of rows in the code; 'Θ'represents plane-shift operation and p_s is the plane-shift; where p_s ϵ [0, S-1] and S is the number of planes or the space channels.

Generalizing, a code designed using a golomb ruler [g1 g2. . . gn], is given by:

$$(gn + s\_s) mod\,(W * T)\ \ \Theta\, P\_s$$

The code set size of the three dimensional SPPDD codes, i.e. (W x S), increases with the increase in wavelengths and the space channels.

3.5 IMPLEMENTATION OF THREE DIMENSIONAL SPPDD CODES

In order to implement this 3dimensional codes multiple star couplers and associated hardware are required, this makes the system complicated. In order to overcome this limitation W^2T scheme (using AWG based encoder/decoder and tunable filters) can be used for the 2 dimensional implementation of the three dimensional codes [31], which removes the requirement of star couplers and associated hardware. AWG based [32] 2dimensional implementation is shown in [50]. For this purpose code is written as (W x S) x T, where the number of wavelengths now are (W x S). In this, we can construct W^2T code only if (W>S) and during this condition it provides lower bit error probability. As the (W≤S), the bit error probability increases [46], this is proved by implementation of W^2T scheme in Rsoft Optsim. Block Diagram and the simulation setup for the implementation of three dimensional codes are as follow:

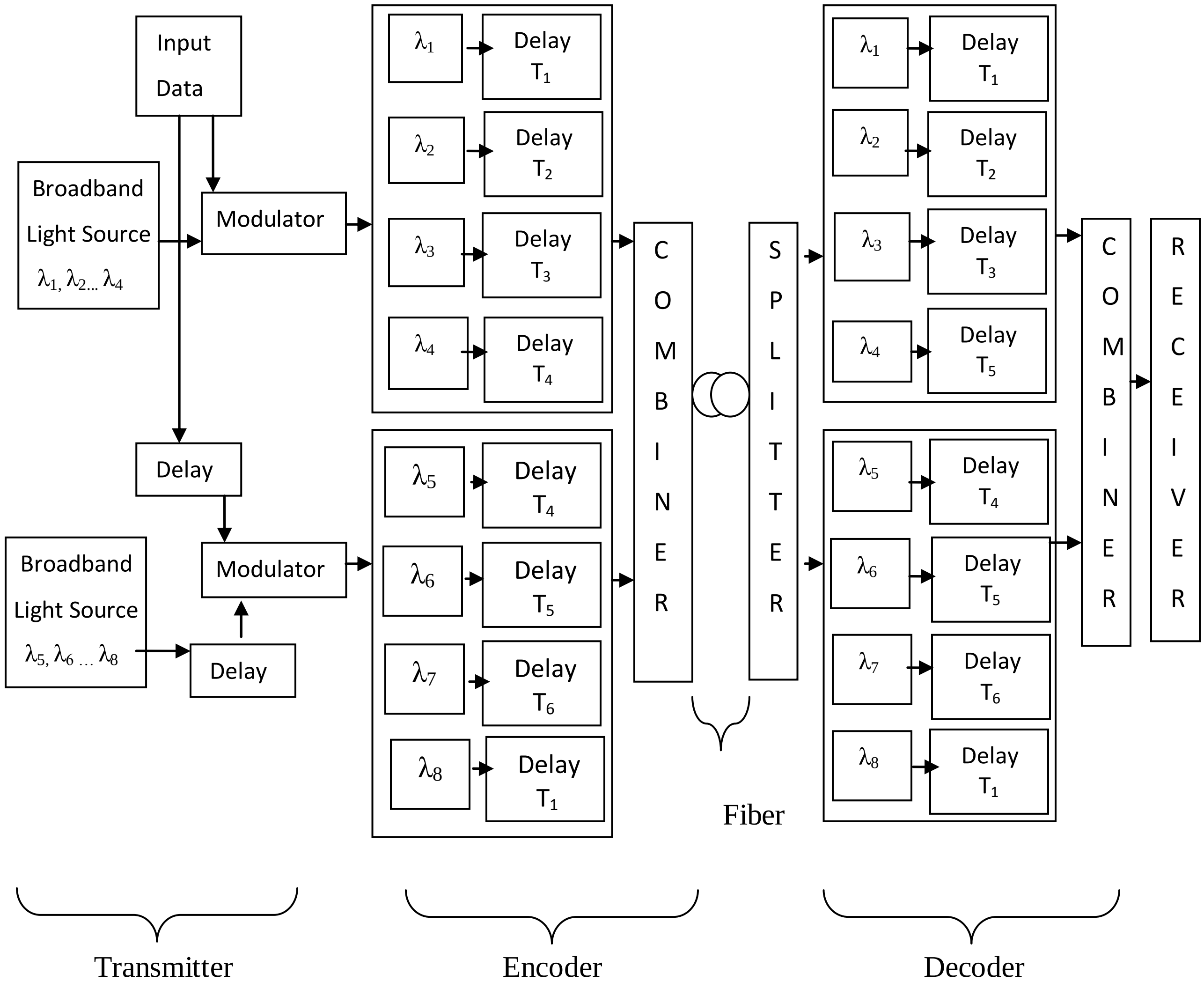


Figure 3.5: Block Diagram for the implementation of 3D codes.

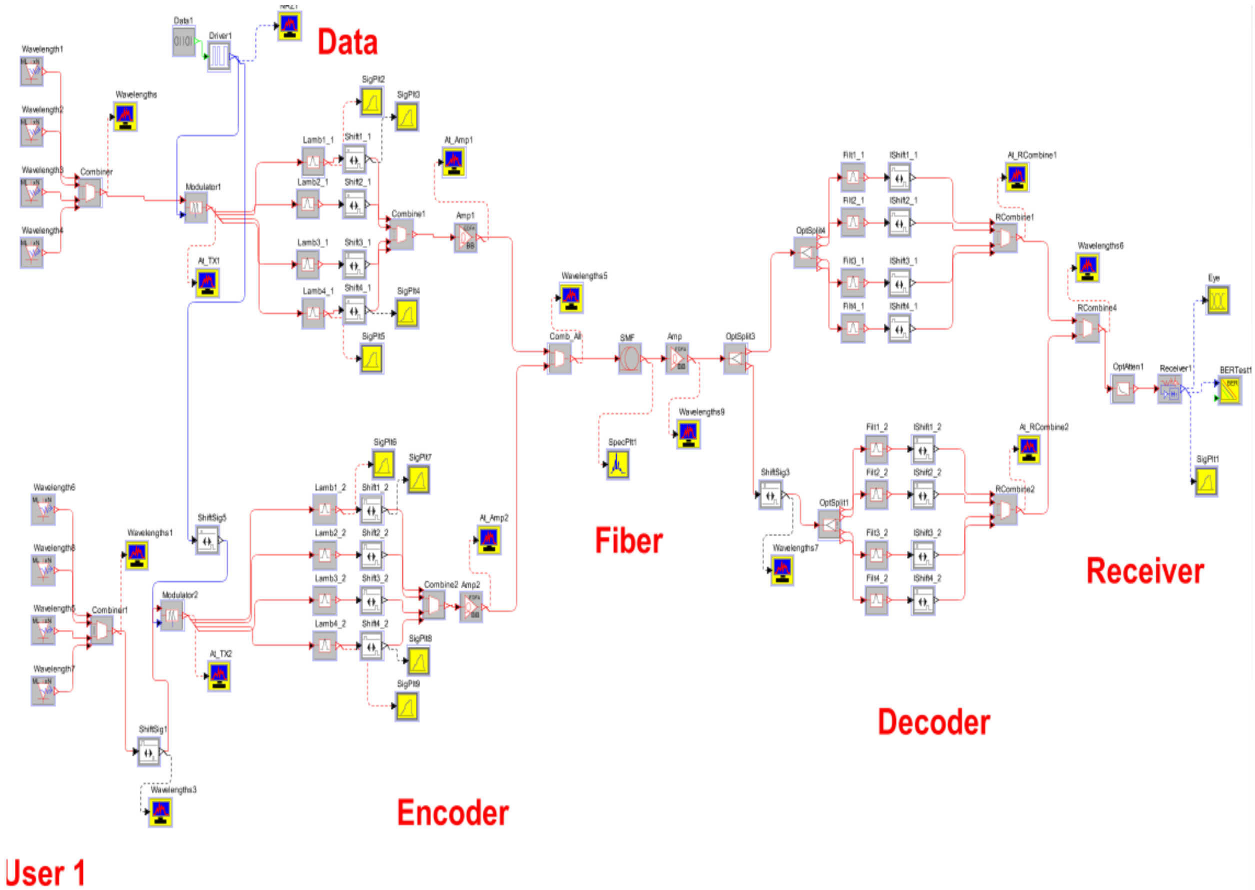


Figure 3.6: Simulation Setup for the implementation of 3D codes

The values of space, Wavelength and time are known from the construction of the SPPDD codes. If we find S=2, W=4 and T=4 the block setup and the simulation setup for 3dimensional OCDMA system is shown in figure 3.5 & 3.6 respectively. This simulation setup works on the bit rate 2.5Gbps. The total number of the available wavelengths is given by (W x S) Now, here the total number of wavelengths becomes 8 and we are having two space channels and each space channel is having four wavelength that depends upon the available number of time slots or delays. Four wavelengths of one space channel are multiplexed to form broadband source, the next four wavelengths of the second channel is delayed by some value this delay works as a function of AWG because we are having only 4 time slots or delay units. The output of the multiplexer is given to the optical input of the modulator, another input to the modulator is the data. A PN sequence is generated in the form of logical data from the PN sequence generator. The logical data is converted into electrical data through the NRZ driver. In second channel this data is also delayed by same delay value as per given to the wavelength and this data is fed into the electrical input of the modulator. The modulator modulates the light according to the input data. After the modulator, encoder is placed to encode the data this encoder encoded the data in time and wavelength domain, encoding in space domain is already done at transmitter. So the output of encoder gives spreading of the data in all the three dimensions. After that SMF is used. At the receiver, decoder is implemented by inverting the encoder and negative delay also given to the wavelengths of second channel at decoder. After that, receiver is placed which will convert the optical signal into electrical one. Eye diagram analyzer, BER tester and electrical signal plotter is used to analyze the various outputs.

3.6 RESULTS AND DISCUSSION

We implement these 3-dimensional codes in Optsim for different values of space, wavelength and time combinations and particular combination of S, W and T is compared to others. Firstly, by varying the space channels and keeps W and T constant we will find that which space channel performs well and gives better results. The comparison of varying space channel setups for S=2, S=3, S=4 and S=5 is done by varying the length of fiber against BER, by varying the number of users against BER, by varying the input power against BER and also can be done by observing the input data, output signal and the eye diagram of the output at receiver. Eye diagram analyzer is used for the eye diagram, BER tester is used to measure the BER of the received signal and electrical signal plotter is used to take the received electrical signal.

Figure 3.7 shows that as the lengths of the fiber varied BER is also varied, and the BER increases as the length of the fiber increases. By varying the length of the fiber for all the space channels S=2,S=3,S=4 and S=5, correspondingly BER rate is measured and compares this varied length of the fiber versus BER for all the space channels and find out that which space channel provides better result. By observing this graph, we find out that the space channel S=2, S=3 gives better BER above optimized value 10^{-9}.

Figure 3.8 shows the plot of BER against the number of users, as the numbers of users vary correspondingly BER is vary and BER increases with increase in number of users. By varying the number of users for all the space channels S=2, S=3, S=4 and S=5, correspondingly BER is measured and compares this varied no of users versus BER for all the space channels and find out that which space channel provides better results. By observing this graph, we find out that the space channel S=2 and S=3 gives better results as compare to others.

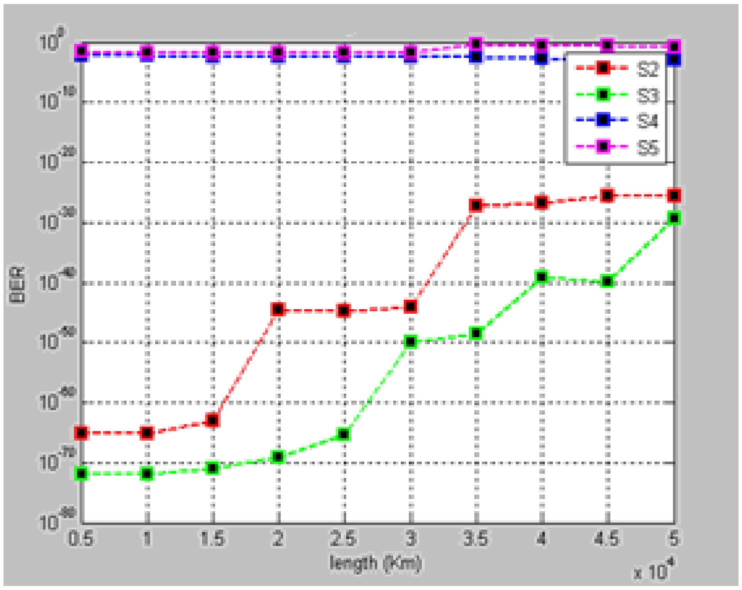


Figure 3.7: BER versus length of the fiber

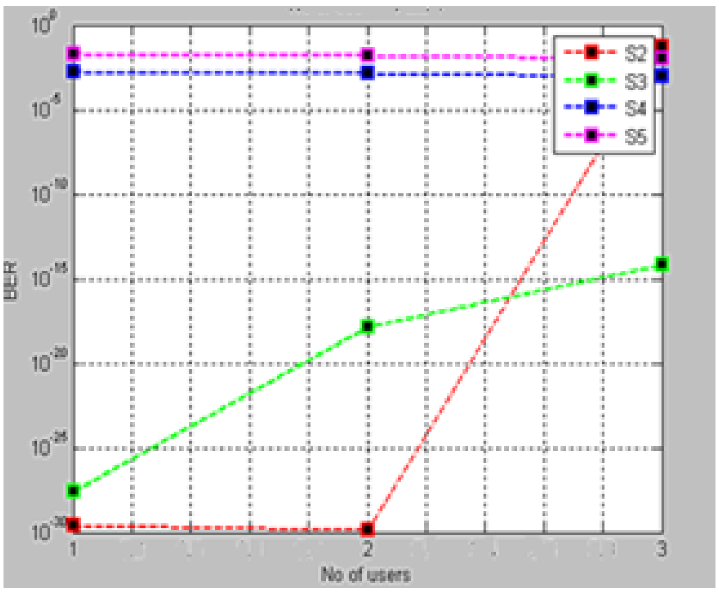


Figure 3.8: BER versus number of user

Figure 3.9 shows the plot for BER versus input peak power, in this case as the peak power increases the BER rate of the system decreases. Varying the peak power for all the space channels S=2, S=3, S=4 and S=5 correspondingly varying BER is measured and compare the peak power versus BER curves of all the channels and find out that which space channel performs better. By observing this graph, we find out that space channel S=2 and S=3 performs better.

Figure 3.10 shows the input data signal in the NRZ format that is given at the input of the modulator the modulator modulates the data signal by using optical input as carrier.

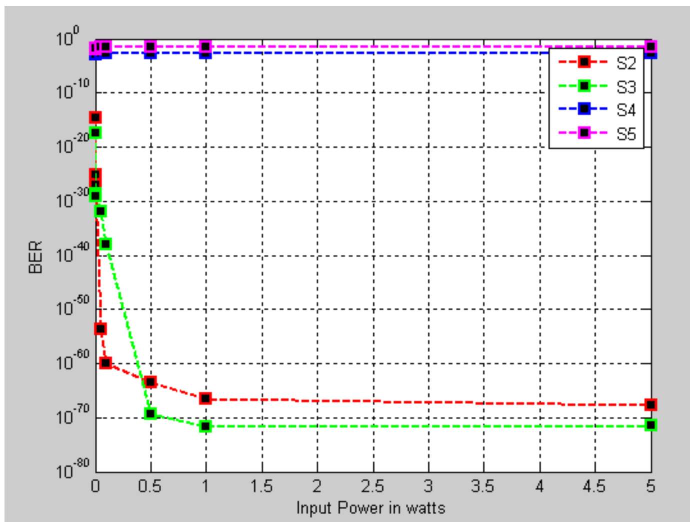


Figure 3.9: BER versus Input Power

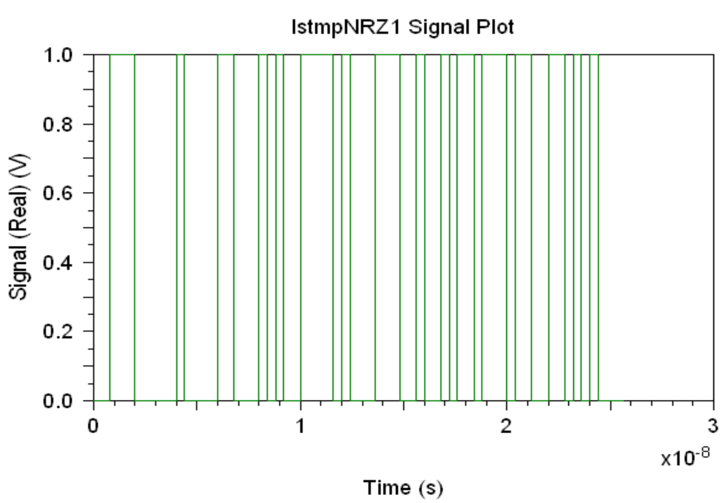


Figure 3.10: Input data signal

Figure 3.11-3.14 shows the eye diagram taken for different values of space channels S=2, S=3, S=4 and S=5 with standard single mode fiber of length 60 km. It can be seen from these diagrams as the number of space channel increasing eye opening is considerably decreasing and found that for space channel S=2 and S=3 gives maximum opening of eye with less distortions as compare to others.

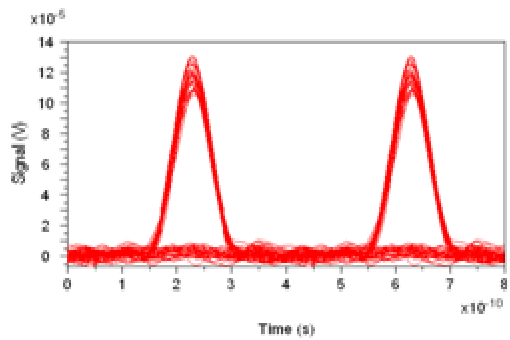


Figure 3.11: Eye diagram for S=2

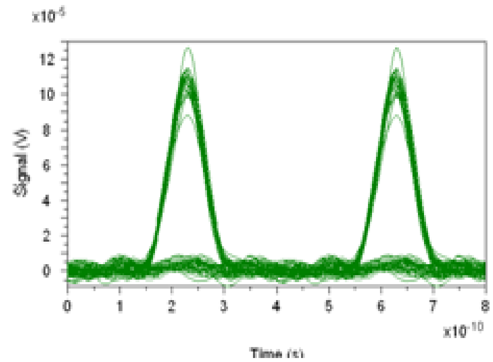


Figure 3.12: Eye diagram for S=3

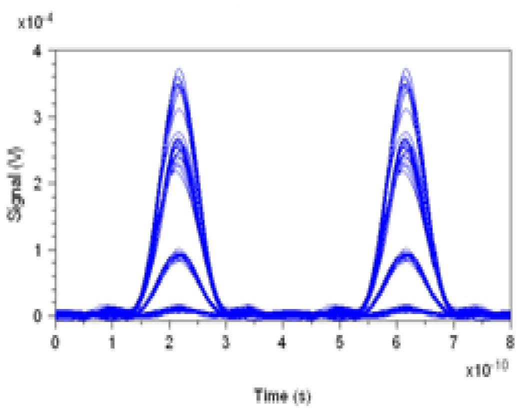


Figure 3.13: Eye diagram for S=4

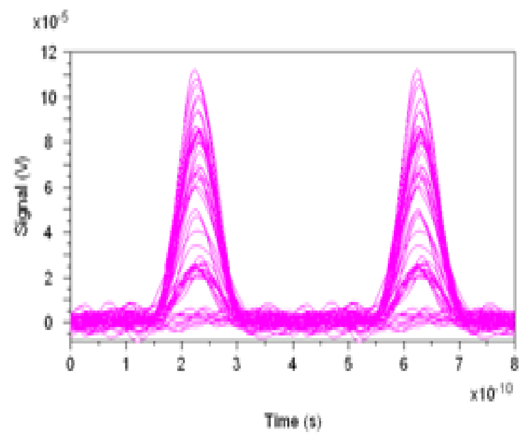


Figure 3.14: Eye diagram for S=5

Figure 3.15-3.18 shows the output signal at receiver for different number of space channels. By observing all these output signals for S=2, S=3, S=4, S=5 we find out that for S=2 and S=3 gives better signal at output with less distortion as compare to other channels.

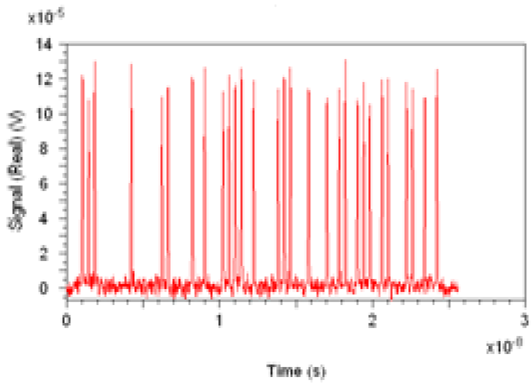


Figure 3.15: Output signal at receiver for S=2

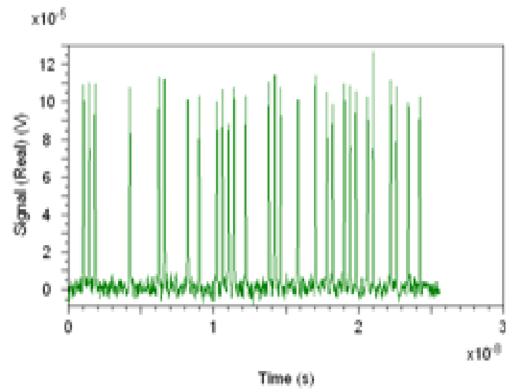


Figure 3.16: Optical signal at receiver for S=3

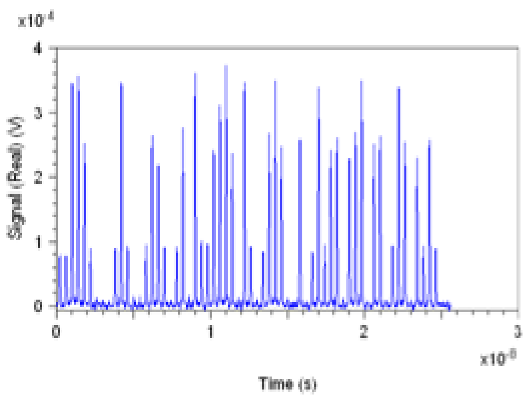


Figure 3.17: Output signal at receiver for S=4

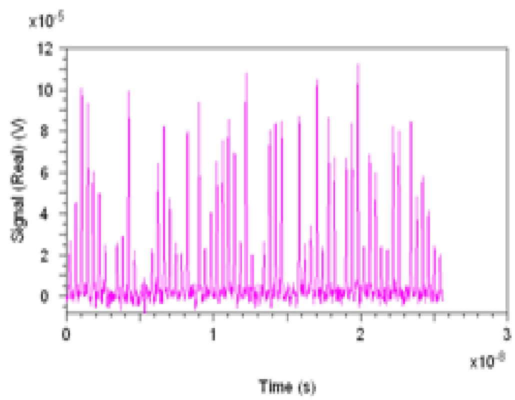


Figure 3.18: Output signal at receiver for S=5

3.7 CONCLUSION

Three dimensional codes are most preferable over one and two dimensional codes. The three dimensional SPPDD codes having three dimensions: space/wavelength/time, in order to implement these SPPDD codes multiple star couplers and associated hardware are required. To eliminate this requirement, two dimensional implementation of three dimensional codes is done using W^2T scheme, where total number of wavelengths are (W x S). By varying the number of space channels of three dimensional we conclude that the system shows better performance when (W>S) condition, while (W≤S) shows poor performance. In this chapter, it is found that the space channels which shows better performance are S=2 and S=3 for W=T=4.

CHAPTER 4

PERFORMANCE ANALYSIS OF 3-DIMENSONAL SINGLE PULSE PER PLANE WITH DIRECT DETECTION (SPPDD) CODE USING DIFFERENT DATA FORMAT FOR OCDMA SYSTEM

In this, I am using three dimensional (3D) SPPDD codes for data encoding in OCDMA and analyze these three dimensional codes for different data modulation formats. The data modulation format are nonreturn to zero (NRZ) and return to zero (RZ) for space channel S=2 and S=3. The comparison between NRZ and RZ is done by varying the bit error rate (BER) against various parameters like length of fiber, number of users and input power. It is found that OCDMA system with NRZ data modulation format performs better than RZ. In this we take SPPDD codes with fixed wavelength and time, but varied space channels. As the space channels are varied, the performance of the system is also varied. It gives better performance for (W>S) and shows large BER for (W≤S).

4.1 INTRODUCTION

Optical Code division multiple access (OCDMA) is one of the upcoming technology for future multiple access networks [24]. We can say that OCDMA is a spreading technique in which assigning a code to each user in fiber optic communication. A '1' is transmitted by the user in the form of an assigned code and '0' by means of no transmission [28]. Optical CDMA can operate asynchronously, without centralized control, and it does not suffer from packet collisions [3]. Two main factors to be consider regarding codes are the nature of codes and type of codes. The nature of codes in OCDMA system means that whether codes used are unipolar and bipolar. In bipolar (-1, +1) codes, both the positive and negative logic are used to encode the data bit'1' and zero logic level is used to encode the data bit '0'. In OCDMA system, unipolar codes are used to transmit the information and optical power cannot be negative. The type of codes in OCDMA system can be one dimensional, two dimensional and three dimensional, out of these three types of codes- three dimensional codes are generally preferable due its performance [29]. Generally used 3D code is space/wavelength/time code with single pulse per plane with direct detection (SPDD). In

OCDMA system, the system performance is determined by the bandwidth efficiency of the optical codes which is closely related to the error probability behavior of optical codes in multiple user circumstances as well as code set size dependence on code length and also on the modulation format of the input data. Moreover, there are two possible modulation formats, nonreturn-to-zero (NRZ), in which a constant power is transmitted during the entire bit period, and return-to-zero (RZ), in which power is transmitted only for a fraction of the bit period [51], in intensity-modulated direct-detection (IM/DD) optical communication systems. The NRZ pulses have a narrow optical spectrum. The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference between the pulses. The narrow spectrum of NRZ pulses yields a better realization of dense channel spacing in DWDM systems. The RZ pulse shape enables an increased robustness to fiber non-linear effects and to the effects of polarization mode dispersion (PMD) [52].

M. I. Hayee et al. [51] compares the nonreturn-to-zero (NRZ) with return-to-zero (RZ) modulation format for wavelength-division multiplexed systems operating at data rates up to 40 Gb/s. They find out that in 10–40-Gb/s dispersion-managed systems (single-mode fiber alternating with dispersion compensating fiber), NRZ is more adversely affected by nonlinearities, whereas RZ is more affected by dispersion. In this dispersion map, 10 and 20-Gb/s systems operate better using RZ modulation format because nonlinearity dominates. However, 40-Gb/s systems favor the usage of NRZ because dispersion becomes the key limiting factor at 40 Gb/s.

Vishav Jyoti et al. [26] showed the implementation and performance analysis of various one dimensional codes in an OCDMA system for different data formats is presented. A number of different codes are used with optical CDMA to improve its error performance. Here, three such codes, optical orthogonal codes (OOC), Walsh Hadamard codes and zero cross-correlation (ZCC) codes have been compared using different data formats, NRZ raised cosine, NRZ rectangular, RZ raised cosine and RZ rectangular. It is found that NRZ raised cosine has the best system performance for all the codes used. After that, the three codes have been compared in terms of the BER, eye diagrams and received optical power using NRZ raised cosine modulation format.

J. Singh et al. [31] demonstrated a new family of three dimensional wavelength/time/space codes for asynchronous optical code-division multiple access (OCDMA) systems with off-peak auto-correlation λ_a=0 and peak cross-correlation λ_c = 1. With wavelengths and time-slots, codes are generated. Antipodal signaling/differential detection is employed in the system. The performance is compared to the two dimensional/three dimensional codes. Arrayed waveguide grating-based reconfigurable two dimensional implementation for encoder/decoder is presented.

Various 3D codes for the OCDMA systems are proposed and one of them performs well is 3D SPPDD [30] code and this code is analyzed for different space channels and find out only those channels are suggested to use which fulfill (W>S) condition and if we use W=4, it provides channel S=2 and S=3 are better the comparison of NRZ and RZ format for both of the channels.The NRZ and RZ modulation formats for three dimensional codes is not compare by anyone till now. Now, we present this comparison for different data modulation, for 3D single pulse per plane with direct detection (SPPDD).

The organization of this paper is as follow: This paper is divided into different sections. Section I gives the introduction about OCDMA and its codes, Section II provides the analytic model for 3D codes, Section III provides the simulation setup for 3D codes, section IV provides the performance analysis of OCDMA system using 3D codes for different data formats and section V gives the conclusions.

4.2 ANALYTICAL MODEL

Three dimensional code words are represented by the 3-D matrices that have binary (1or 0) values for their elements. Single pulse per plane 3D code having a single ‘1’ element per plane with the three dimensions: wavelengths, time and the space channels and hence are the (Wavelength x Time x Space Channels) codes. Each element represents whether the corresponding point in 3D conceptual space is occupied by optical pulse or not. The ‘1’ chips in the code denote that an optical pulse is to be transmitted over the optical channel in the corresponding time slot over the respective wavelengths and ‘0’ represents transmitting nothing.

Now, we define 3D code mathematically, A (W x T x S, $C_{w,}$ $\lambda_{a,}$ λ_c) represents 3D code, C is a set of binary (0,1) here (S x W x T) is a three dimensional matrices, C_w is a code weight and $\lambda_{a,}$, λ_c represents the auto-correlation and cross correlation of the code respectively.

The code auto-correlation and cross-correlation constraints for a general 3-D SPP code family are defined below [29]:

Auto-correlation constraint: For a 3D SPP code Y (W, T, S)

Auto-correlation,

$$RY,Y = \sum_{l=0}^{W-1}\sum_{m=0}^{T-1}\sum_{n=0}^{S-1} yl,m,n\; yl,m(n \oplus t)$$

$$such\ that\ RY,Y = Code\ weight \quad for\ t = 0$$

$$\leq \lambda a \qquad for\ 1 \leq t \leq S-1$$

Cross-correlation constraint: For any two 3D SPP codes Y&Z (W, T, S)

Cross-correlation,

$$RY,Z = \sum_{l=0}^{W-1}\sum_{m=0}^{T-1}\sum_{n=0}^{S-1} Zl,m,n\; Zl,m(n \oplus t)$$

$$such\ that\ RY,Z \ \leq \lambda c \quad for\ 0 \leq\ t \leq S-1$$

In the above definitions, non-negative integer's λ_a and λc are the peak out-of-phase auto correlation and the peak cross-correlation values; $\oplus$ denotes modulo-n addition. The cross correlation constraint guarantees asynchronous operation of the 3D code based system. Hence use of direct detection with 3D optical SPP codes improving the bit error rate performance and provides larger code set.

4.3 SIMULATION SETUP

The simulation setup for OCDMA system, implementing 3D SPPDD codes for space channel S=2 and S=3 with constant value of W=T=4 is shown in figure 4.1 and in figure 4.2 respectively. As S=2, there are two space channels and each channel is having four wavelengths, then the number of wavelengths becomes 8. As S=3, there are three space channels and also each channel is having four wavelengths, then the number of wavelengths becomes 12. Total number of wavelengths are determined by (W x S). For S=2 there are total 8 wavelengths and these wavelengths are ranging from 1550 nm to 1552.8 nm. For S=3 there are total 12 wavelengths and these wavelengths are ranging from1550 nm to 1554.8 nm. Each wavelength differs from another wavelength by .4 nm. These setups having chip spectral width (.01 nm). The random input data bit sequence is generated at the rate of 2.5 Gbps, after that coded light signal modulates the input data. The modulator is driven by the modulator driver which decides the input data format and the modulator uses in both setups is Machzender. The input data format can be NRZ or RZ. The modulated data is encoded in the encoder, that spreads the data in both wavelength and time domain because encoder consists of filter and time delays. Outputs of all encoders of space channels combine and sent to the single mode optical fiber of length (60 km). All the dispersion (1.312e-6 m) and non linear effects are activated and specified according to the typical industrial values to simulate the real environment as close as possible. After that decoder is placed which decodes the data, it is just the inverse of the encoder and then receiver is placed, this receiver consists of photodiode and filter, this photodiode is use to convert the optical signal to electrical and the filter used is low pass Bessel filter. In these setups direct detection technique is used at receive means that only single code is given to each user for the transmission of ‘1’. At the end, BER tester, eye diagram analyzer and electrical power meter are placed to measure BER, pattern of eye diagram and the received power respectively.

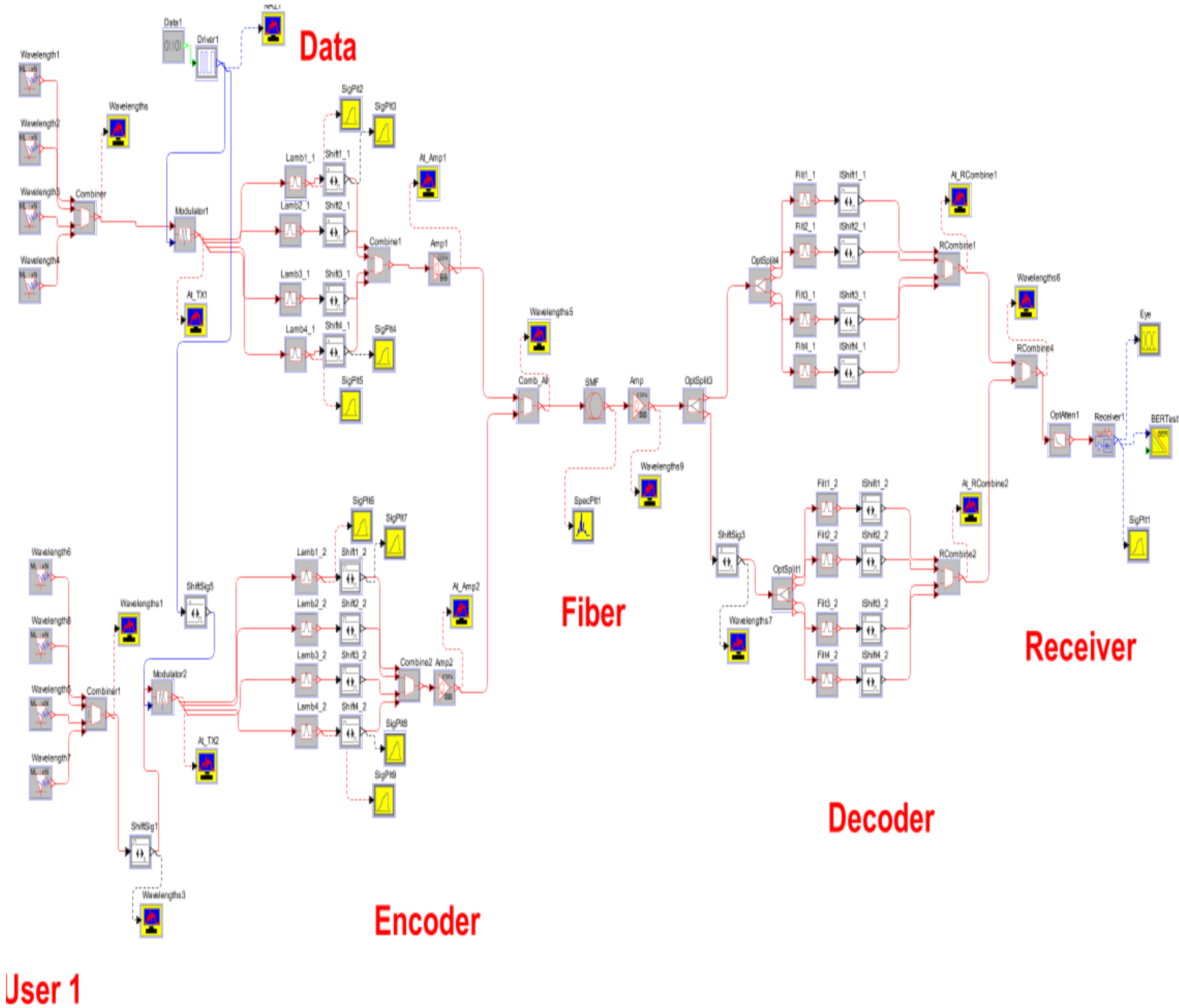


Figure 4.1: An OCDMA system implementing 3D codes for S=2

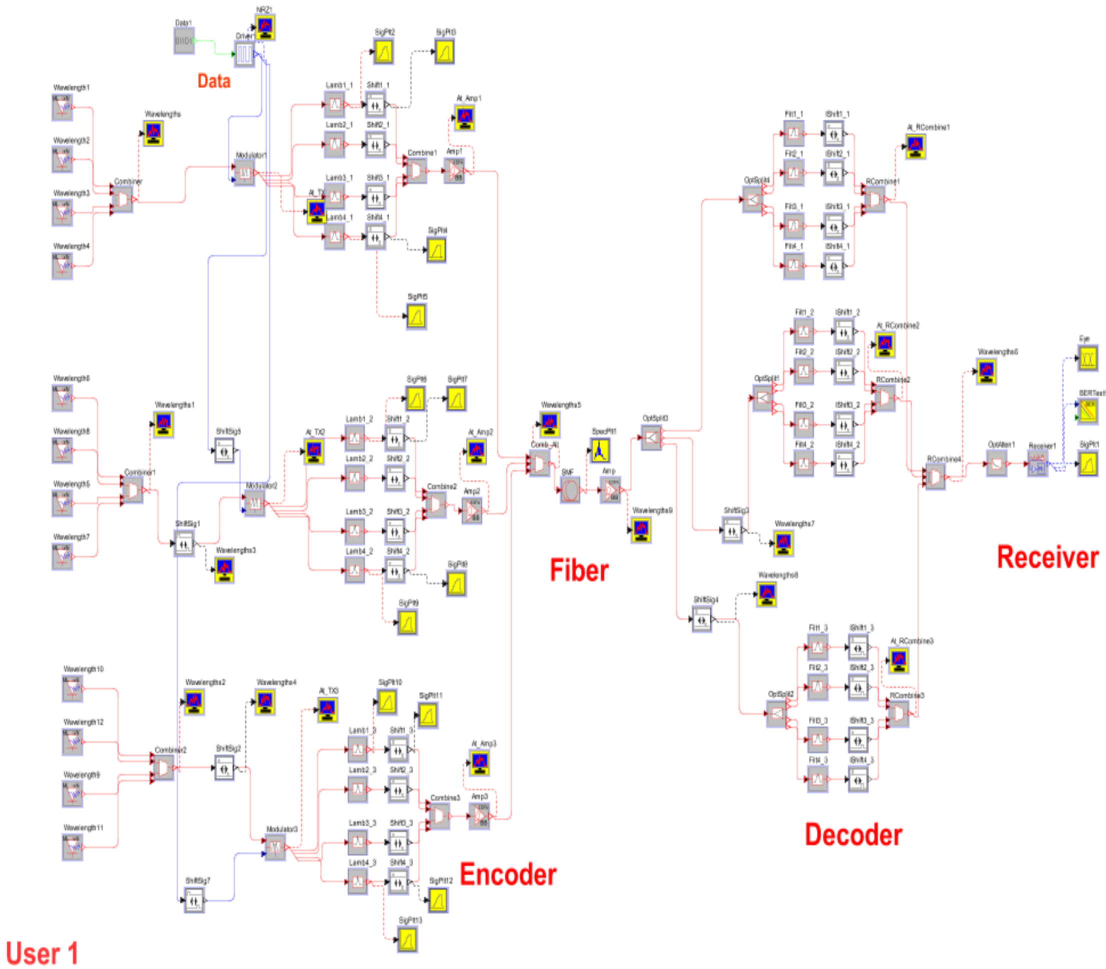


Figure 4.2: An OCDMA system implementing 3D codes for S=3

4.4 RESULTS AND DISCUSSION

In this we compare the modulation data format NRZ and RZ for both S=2 and for S=3. Using simulation setup for NRZ and RZ differently, find out the BER against variation in length, number of users and input power and also determine the output signal at receiver, input data signal and eye diagram. Compare the results of NRZ and RZ in channels S=2 and S=3 and find out which modulation format gives better results.

Figure 4.3-4.4 shows that as the length of the fiber varies, correspondingly BER is varied and BER increases with increase in length of the fiber. Firstly, BER is obtained for nonreturn to zero (NRZ) data format and then with return to zero (RZ) data format for S=2 and S=3. Figure 4.3 is for space channel S=2 and figure 4.4 is for space channel S=3. By observing both the graphs, we find out that NRZ data format provides better BER as compare to RZ.

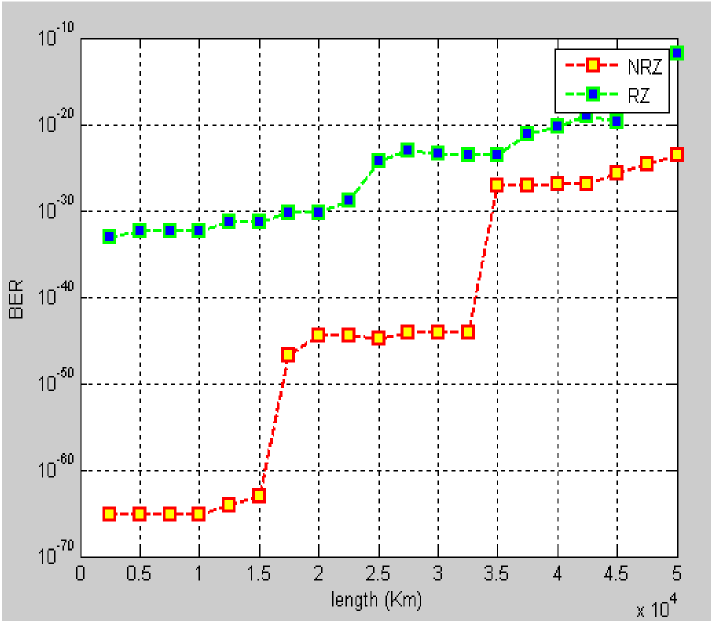


Figure 4.3: Comparison of NRZ or RZ for BER versus length of the fiber for S=2

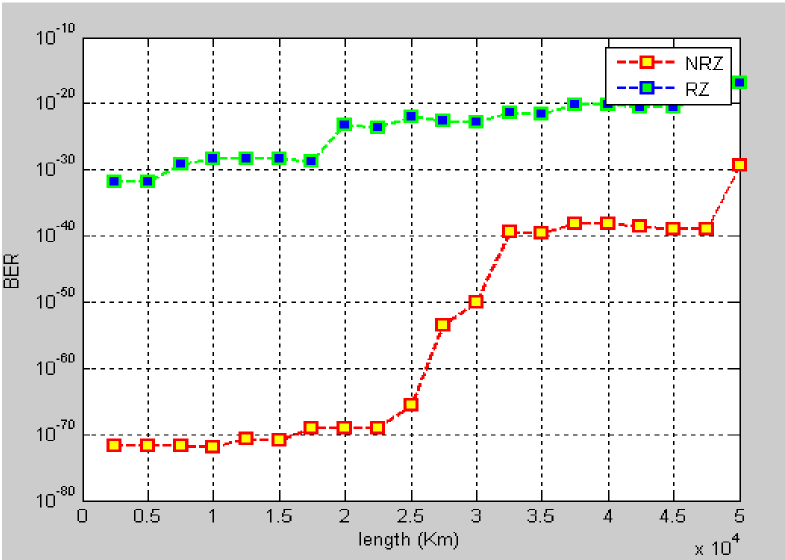


Figure 4.4: Comparison of NRZ or RZ for BER versus length of the fiber for S=3

Figure 4.5-4.6 shows that as the number of users varies correspondingly BER rate is also varied, firstly BER is obtained for nonreturn to zero (NRZ) data format and then with return to zero (RZ) data format for S=2 and S=3, Figure 4.5 for space channel S=2 and figure 4.6 for space channel S=3. By observing these graph we, find out that NRZ data format provides better BER as compare to RZ.

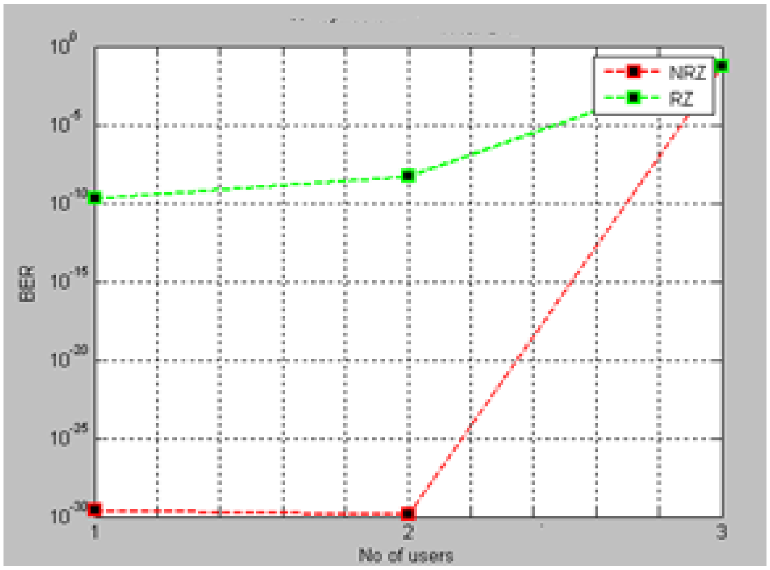


Figure 4.5: Comparison of NRZ or RZ for BER versus number of users for S=2

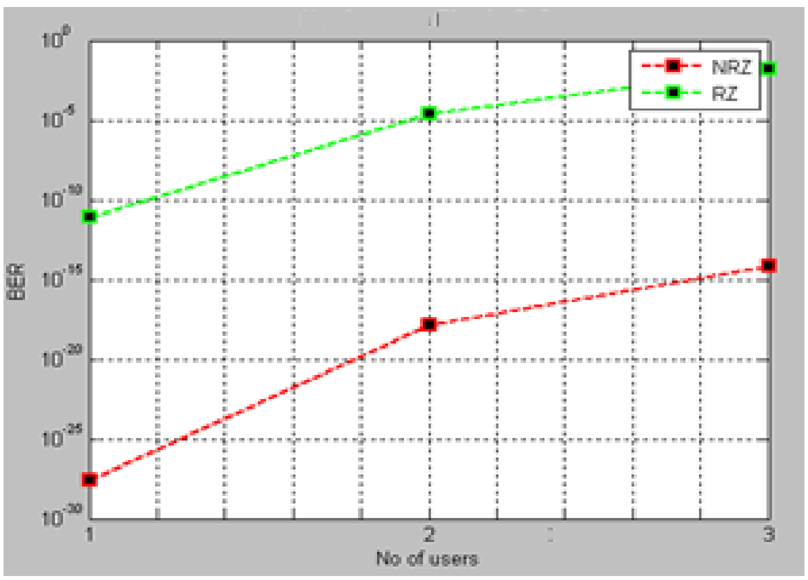


Figure 4.6: Comparison of NRZ or RZ for BER versus number of users for S=3

Figure 4.7-4.8 shows that as the peak input power of the system varied correspondingly BER rate is also varied, BER is increases with increase in the input power. BER is obtained for nonreturn to zero (NRZ) data format and then with return to zero (RZ) data format for S=2 and S=3. Figure 4.7 is for S=2 and figure 4.8 is for S=3. By observing these graphs, we find out that for NRZ data format in both the figures provides better BER as compare to RZ.

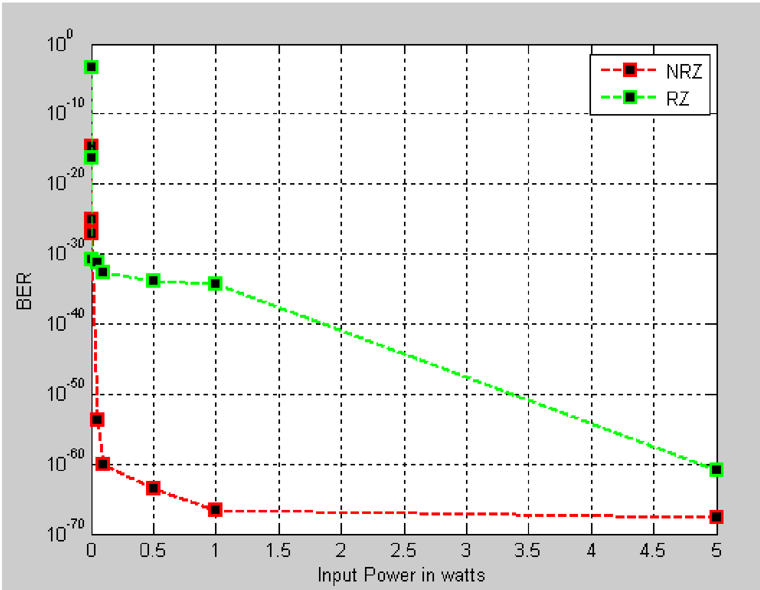


Figure 4.7: Comparison of NRZ or RZ for BER versus input power for S=2

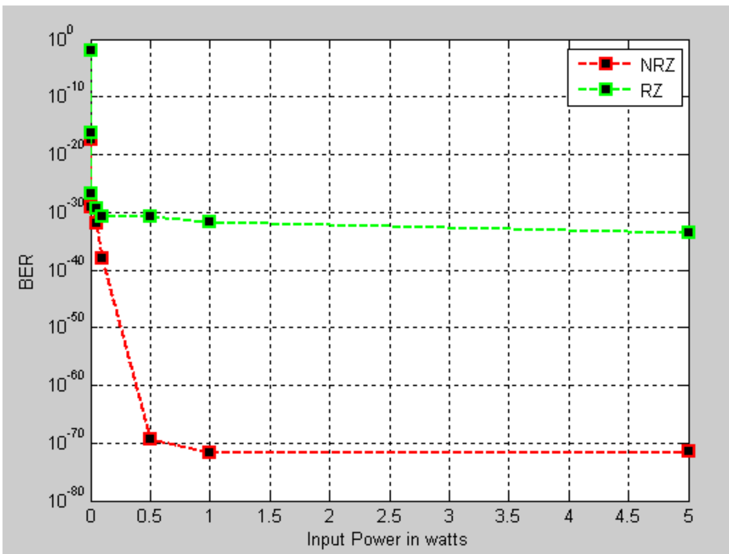


Figure 4.8: Comparison of NRZ or RZ for BER versus input power for S=3

Figure 4.9-4.10 shows the input data in NRZ format and in RZ format here figure 4.9 shows signal in NRZ format and figure 4.10 shows signal in RZ format

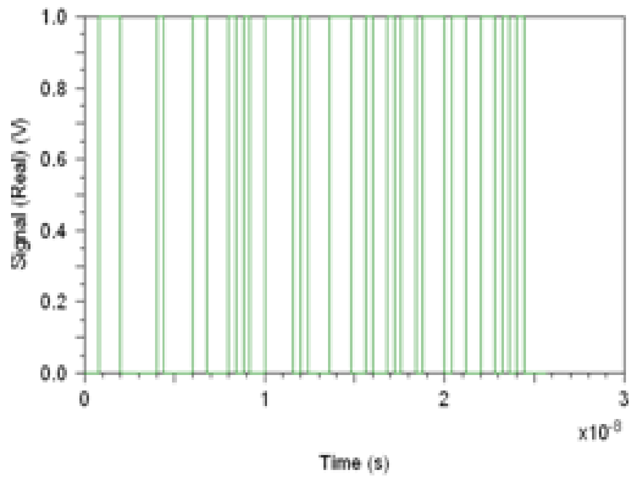


Figure 4.9: Input signal in NRZ format

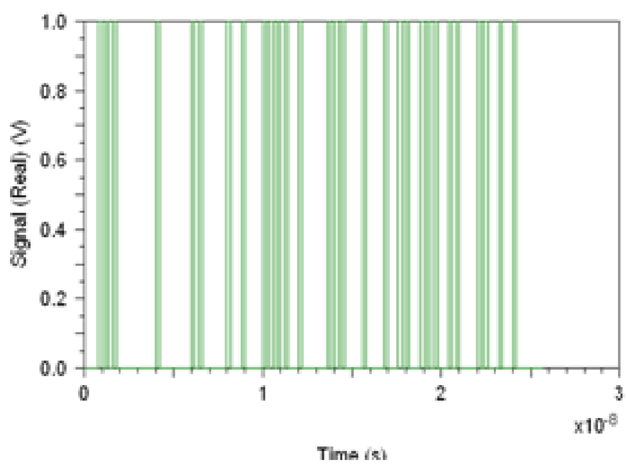
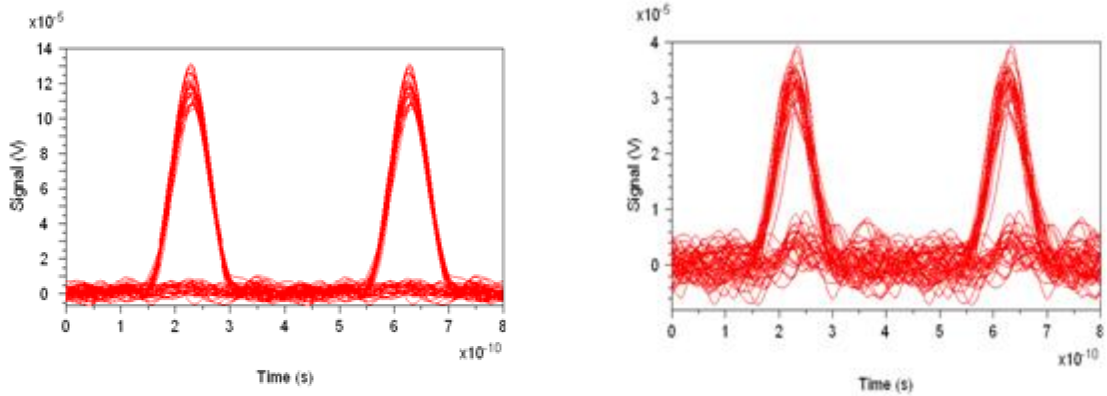


Figure 4.10: Input signal in RZ format

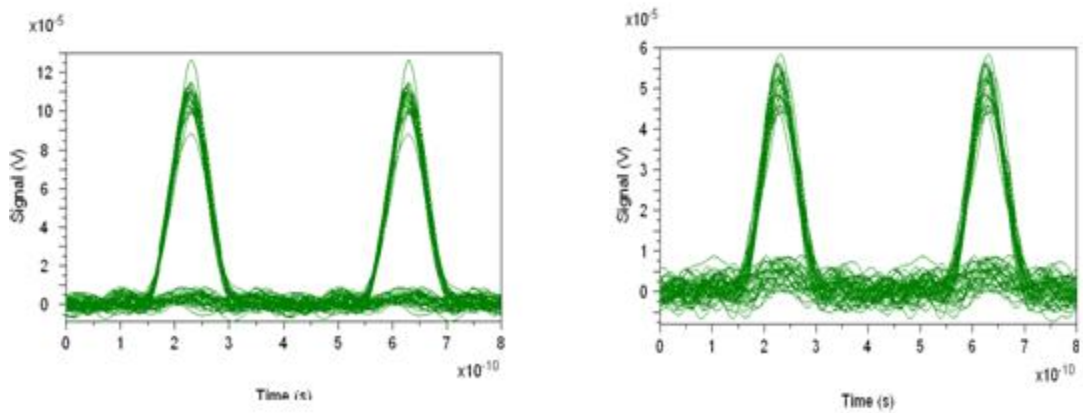
Figure 4.11 shows eye diagram for NRZ and RZ format for S=2 in 11(a) and in 11(b) respectively and by observing these diagrams we find that figure 4.11(a) for NRZ format gives maximum eye opening and less distortion than RZ format in figure 4.11(b).



(a) (b)

Figure 4.11: Eye diagram at channel S=2 for different data modulation (a) for NRZ and (b) for RZ

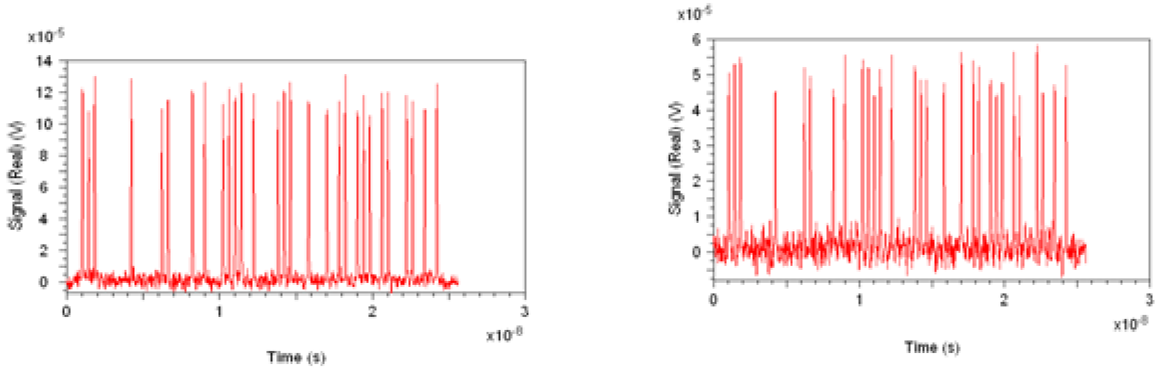
Figure 4.12 shows eye diagram for NRZ and RZ format for S=3 in figure 4.12(a) and in 4.12(b) respectively and by observing these diagrams we find that figure 4.12(a) for NRZ format gives maximum eye opening and less distortion than RZ format in figure 4.12(b).



(a) (b)

Figure 4.12: Eye diagram at channel S=3 for different data modulation (a) for NRZ and (b) for RZ

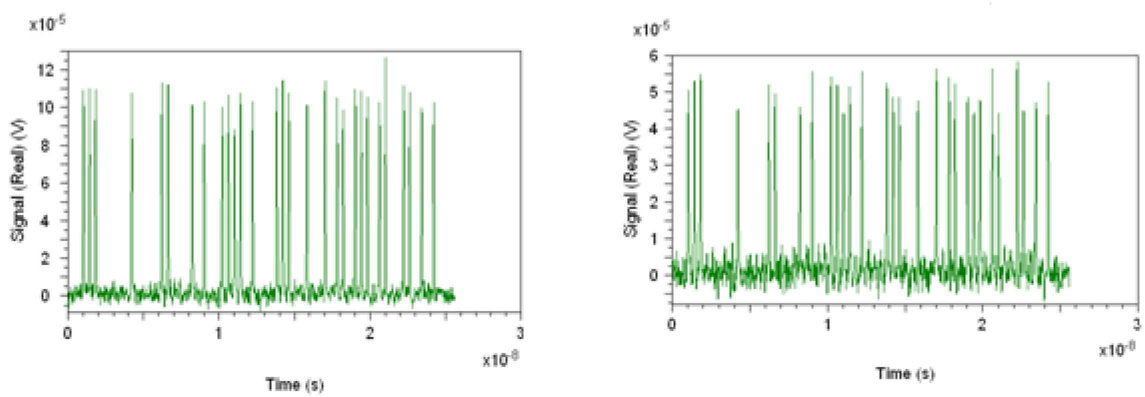
Figure 4.13 shows output signal at receiver for NRZ and RZ format for S=2 in figure 4.13(a) and in figure 4.13(b) respectively and by observing these diagrams we find that figure 4.13(a) for NRZ format provides better signal output with less distortion than RZ format in figure 4.13(b).



(a) (b)

Figure 4.13: Output signal at receiver for channel S=2 for different data modulation a) NRZ and b) RZ

Figure 4.14 shows output signal at receiver for NRZ and RZ format for S=3 in figure 4.14(a) and in 4.14(b) respectively and by observing these diagrams we find that figure 4.14(a) for NRZ format provides better signal output with less distortion than RZ format in 4.14(b).



(a) (b)

Figure 4.14: Output signal at receiver for channel S=2 for different data modulation a) NRZ and b) RZ

4.5 CONCLUSION

In this chapter, the design implementation and performance analysis of 3D codes in OCDMA system for different data formats is presented. The comparison of data formats NRZ and RZ for space channel S=2 and S=3 is done. It is shown that the NRZ has lowest BER value and better system performance as compared to RZ. Hence, NRZ data modulation format can be recommended for 3D codes and for the larger distance in OCDMA at higher bit rates.

CHAPTER 5

IMPLEMENTATION OF THREE DIMENSIONAL SPACE WAVELENGTH /TIME OCDMA CODES USING SPECTRAL PHASE ENCODING/DECODING

In this, a very simple method of optical CDMA encoding known as the spectral Phase encoding in three dimensional OCDMA has been discussed and implemented. The presentation of the system is coherent in nature because in this cohrent OCDMA system a given user's code is generally applied via phase coding. Coherent systems achieve higher performance and having high signal to noise ratio. In this system we have choosen the set of hadamard codes which are by nature orthogonal and binary.

5.1 INTRODUCTION

As far we know that, CDMA system has been productively and extensively used in wireless domain, this successful and widespread use of CDMA has renewed interest in exploring its use in optical domain, which, however, presents different set of challenges [53]. The CDMA technique is based on the concept of spreading the spectrum of narrowband message over a much wider frequency spectrum by means of digital code [54,55]. OCDMA is a technique where different codes are assigned to different users. Each user data bit is spreaded according to the code allotted to it. Due to spreading, the transmitted signal arrives at the receiver as the noise like signal and message recovery is impossible unless the original code is known. The decoder performs the correlation operation to recover the original signal where the decoder having the same code as transmitted by the transmitter, will get the sharp auto correlation peak while for the other decoders the output will be pseudorandom noise. Optical CDMA systems can be divided into two broad categories based on the way in which a particular user's code is applied to the optical signal. These classifications include: Coherent CDMA and Incoherent CDMA In a coherent CDMA system, a given user's code is generally applied via phase coding of the optical signal field, which is often derived from a highly coherent wideband source, such as mode locked laser or phase locked laser. The receiver for a coherent CDMA system relies on a coherent reconstruction of the signal field to recover the decoded user's data. In this the signals are bipolar in nature. Coherent systems achieve higher performance than incoherent ones but require high precision control of the optical path within the encoder and decoder [36]. In contrast, an incoherent OCDMA system typically relies on amplitude-modulated codes rather than directly manipulating the optical pulse. Also, the receiver is based upon an incoherent decoding and recovery process. A number of incoherent OCDMA system architectures utilize wideband incoherent sources, such as broadband amplified spontaneous emission source, while other incoherent architectures utilize coherent laser sources as a part of their implementation. The main advantage of coherent OCDMA system is low signal to noise interference ratio. Though in 80's most of the work in OCDMA dealt with incoherent optical codes. However, with the advancement in optical device technology, coherent optical codes come into picture as phase encoding becomes possible commercially. OCDMA offers the several advantages: (i) all optical processing; (ii) fully asynchronous transmission; (iii) low: (iv) soft capacity on demand; (v) potential security; (vi) quality of service control.

Neetika Soni et al [34] demonstrate a very simple method of Optical CDMA encoding known as the Temporal Phase Encoding and the performance of the system with this encoding technique is evaluated on the basis of number of users, length of the spreading code for 4-phase and 8-phases. Simulation results for the system are presented for upto seven users. Bit error rate curves are plotted with data rate of 1 Gbps. This has been found that performance improves if normalized threshold higher than 0.5 is used.

S. Etemad et al [56] presents an initial feasibility demonstration of a WDM-compatible Optical-CDMA system using 16 phase-locked laser lines within an 80 GHz tunable window as frequency chips and an ultrahigh frequency resolution phase shifting encoder/decoder.

Xu Wang et al [35] presented a novel reconfigurable time domain spectral phase encoding (SPE) scheme for coherent optical code-division-multiple-access application. In this scheme, the SPE is done in time domain using high speed phase modulator. The time domain SPE scheme is robust to wavelength drift of the light source and is very flexible and compatible with the fiber optical system.

This paper is divided into four subsections: Section I gives the introduction about OCDMA, section II provides the technology which we use, section III explains the simulation setup of the system, section IV gives the results and discussions of the system and section V gives the conclusion

5.2 KEY TECHNOLOGY

In coherent OCDMA, encoding and decoding are performed either in temporal domain or in spectral domain. This temporal OCDMA performs the coding in time domain, by using very short optical pulses, using optical delay lines to compose the coded optical signal [57]. In spectral OCDMA the phase or intensity of the spectral content of broadband optical signal is spread by using phase or amplitude masks. The phase encoding scheme of phase – encoded OCDMA is presented in the figure 1. The phase code employed in the spectral phase-encoded OCDMA system is a pseudo-random code. The SPC-OCDMA system requires a broadband multi- wavelength source. The stream of phase locked laser pulses is then modulated with the user's data which is equivalent to spectral broadening of discrete spectral components generated by the phase locked laser. After data modulation, signal is sent into a spectral phase encoder, which applies a particular OCDMA phase code to the spectrum. Each user is assigned one set of N element spectral phase codes [58]. Once the signal has been encoded, it can be passively combined with other OCDMA signals, each of which have their own unique spectral phase codes but overlap completely in frequency domain. In order to recover a particular OCDMA user's signal at the receiver end of the system, a spectral phase decoder is first employed. Physically, it is nearly identical to the spectral phase encoder located at the transmitter, but it has conjugate spectral phase mask. After the spectral phase decoding, it is necessary to remove the multi-user interference noise resulting from the undesired OCDMA users. The desired user's data signal can be recovered through data demodulation and detection. Here, in this system we have choosen the set of hadamard codes which are by nature orthogonal and binary. The generated codes are then converted to phase codes by assigning to -1's and 1's phase shifts of '0' and 'π'. This choice of hadamard codes is based on the goal of high spectral efficiency with minimal multiuser interference (MUI). Unlike many optical coding schemes that have been proposed, ours offers true orthogonally in the sense that MUI is zero at the time that the decoded signal is maximum.

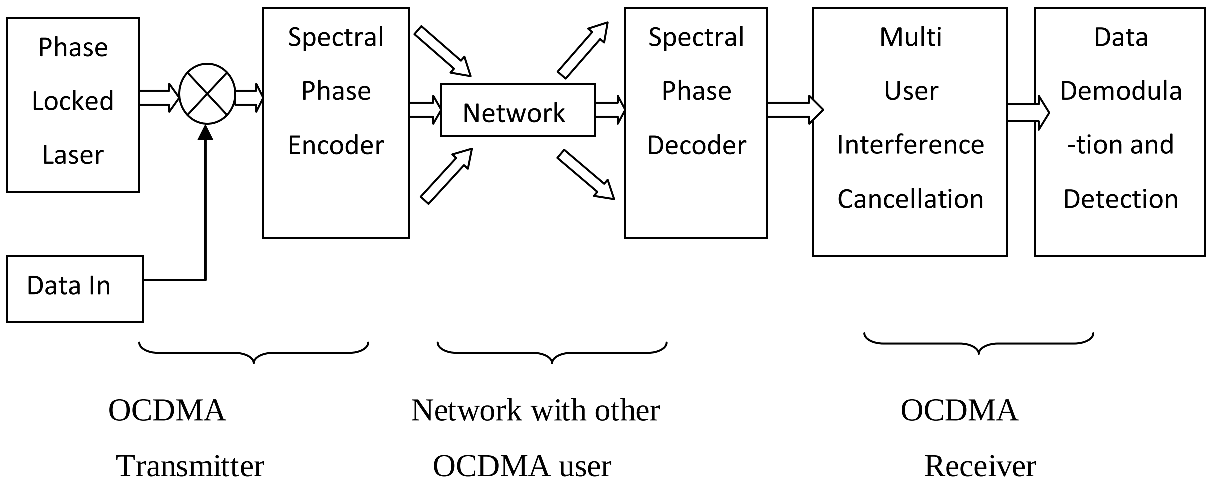


Figure 5.1: Block Diagram of Spectral Phase Encoding/Decoding

The encoding is done to the broad spectrum of the optical pulse and different spectral component having different phase shift. The decoding is to give inverted phase changes to different spectral components by the proper decoder with a harmonizing phase shift pattern compared to encoder [35].

5.3 SIMULATION SETUP

The simulation setup for optical CDMA is implemented phase coding by constructing a matched encoder decoder pair from the hadamard 16 code set and this setup operates on 2.5 gbps. For the demonstration purposes we consider three users only and all these three users having different codes. Firstly there are lasers which are equally spaced within 40Ghz tunable window as frequency slots and producing a continuous wave optical signal, which combines to form broadband signal. In this setup we are considering two space channels and each space channel is having three equally spaced lasers. Here, we use an amplitude modulator which modulates the light and data signal and this modulator is used in both the channels but in second channel both the inputs of the modulator are delayed by some time. The modulated signal is given to the encoder, in encoder there is a WDM-DEMUX which demultiplexes WDM channels. It is a galaxy which contains optical bandpass filters, an ideal attenuator and a logical fork to split the signal and this splitted signal is encoded and then transmitted through optical fiber having length 10km, group refractive index 1.47 and the dispersion of the fiber is $16x10^{-6}$ s/m^2 after that signal goes to combiner from the combiner signal is splitted to the decoder of each channel. Here in second channel negative delay is given to compensate the output. Decoding is accomplished by using optical power splitter which equally splits the incoming signal on each output port and using matched complementary codes at OCDMA decoder, for the binary hadamard codes used here, these codes having its own compliment and consequently both encoder and decoder are identical. The desired decoded signal can be eaisly separated from all other users at reciever

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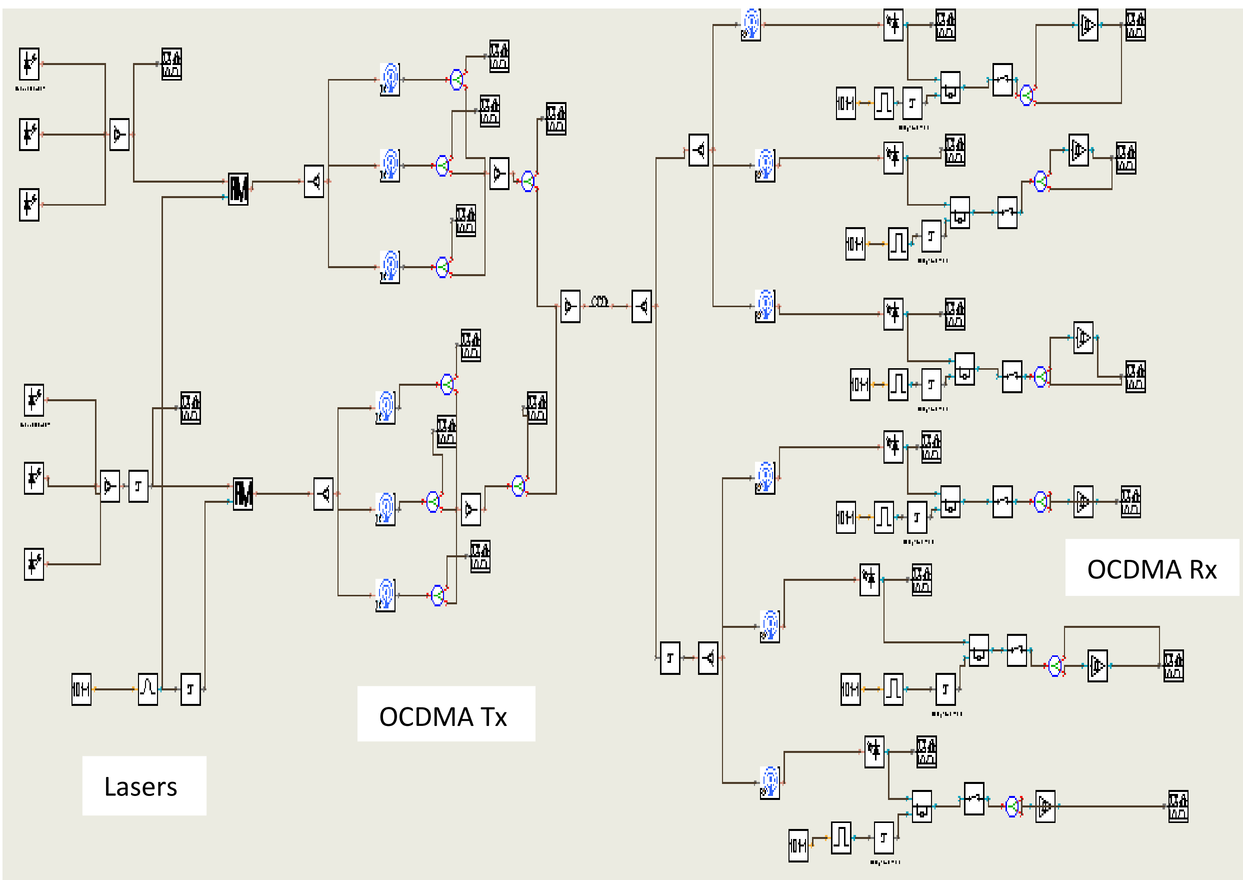

Figure 5.2: Simulation Setup for the implementation of 3D codes by using spectral phase Encoder/Decoder

5.4 RESULTS AND DISCUSSION

As we implement three dimensional space/wavelength/time, in which we use two space channels. The input given to second space channel are delayed from first space channel by some time unit.

Figure 5.3 & 5.4 represents the signal which is transmitting through channel 1 and channel 2 respectively.

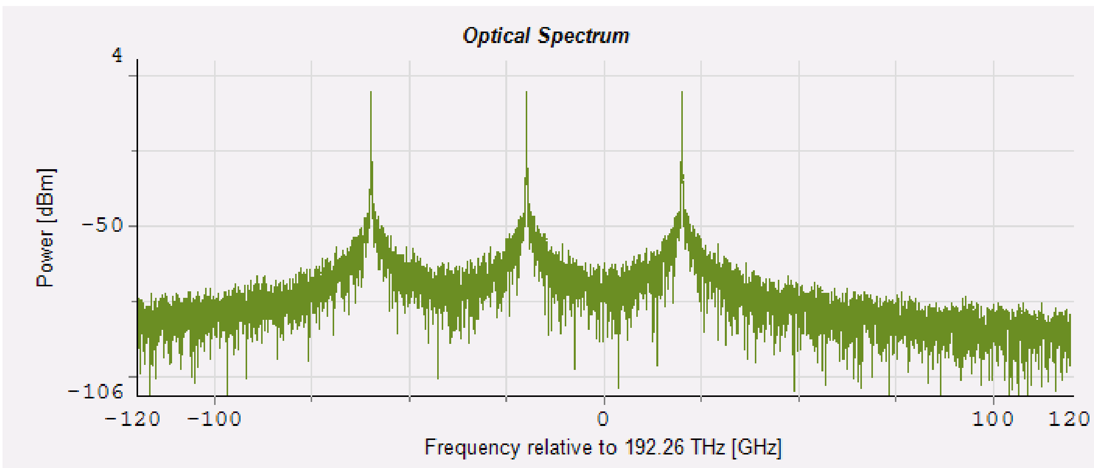

Figure 5.3: Signal transmitting through channel 1

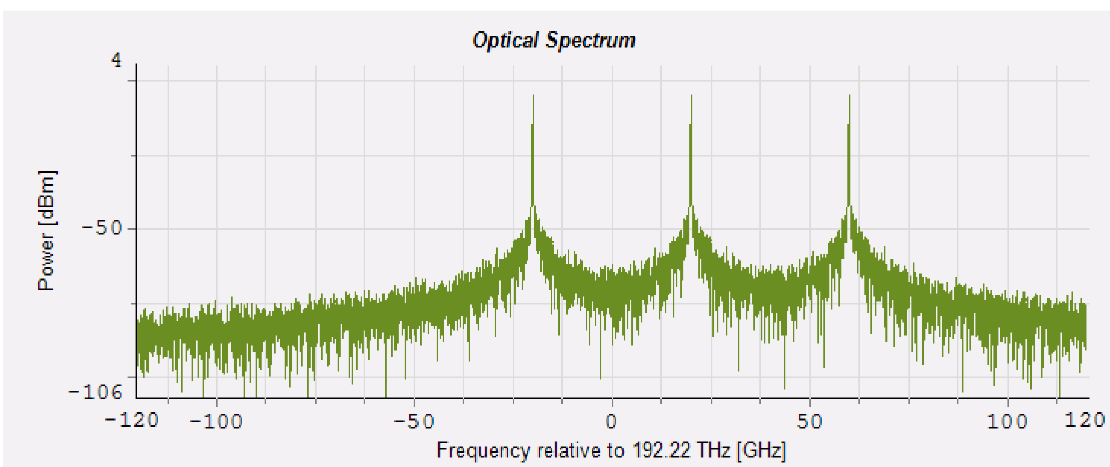

Figure 5.4: Signal transmitting through channel 2

Figure 5.5, 5.6 & 5.7 represents the encoded signal of three users depending upon the codes applied. Figure 5.5 is the encoded signal corresponding to the code 1, figure 5.6 is the encoded signal corresponding to the code 2 and figure 5.7 is the encoded signal corresponding to the code 3.

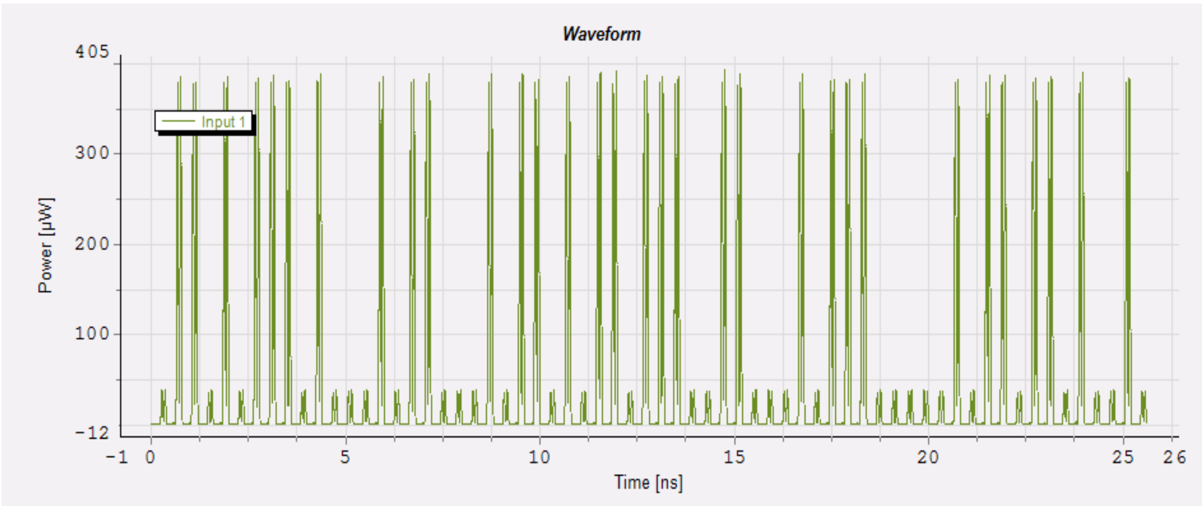

Figure 5.5: Encoded signal for code 1 of channel 1

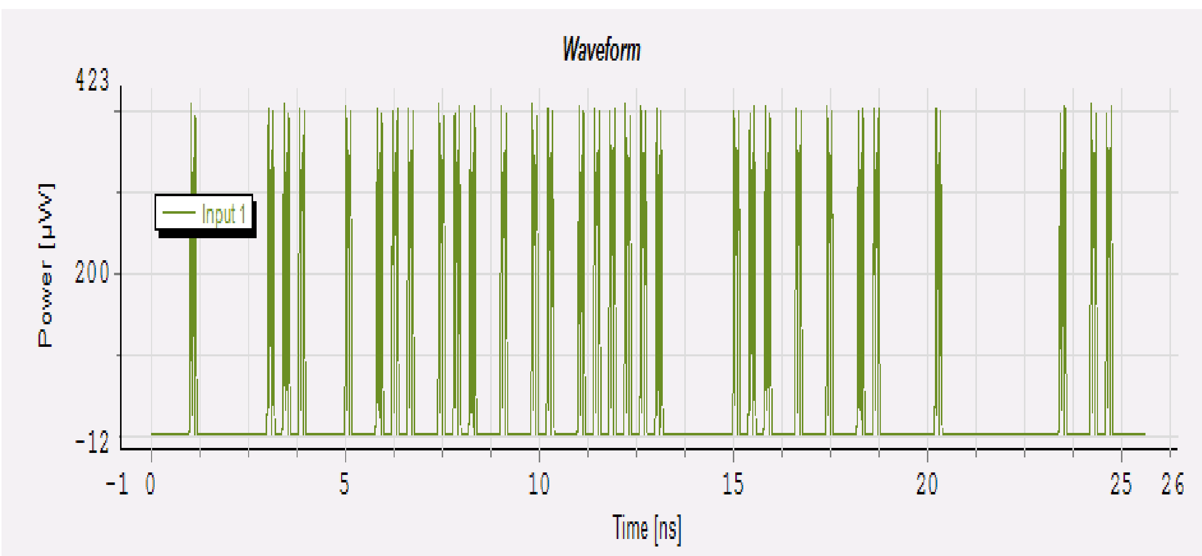

Figure 5.6: Encoded signal for code 2 of channel 1

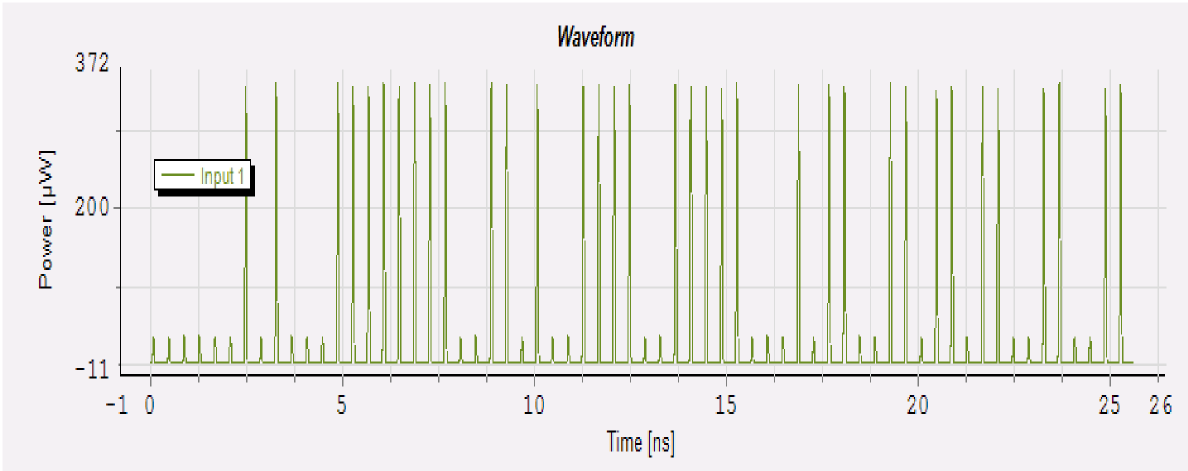

Figure 5.7: Encoded signal for code 3 of channel 1

After encoding, the encoded signals of all the users are combined and then transmitted through the fiber, the combined encoded signal is shown in figure 5.8

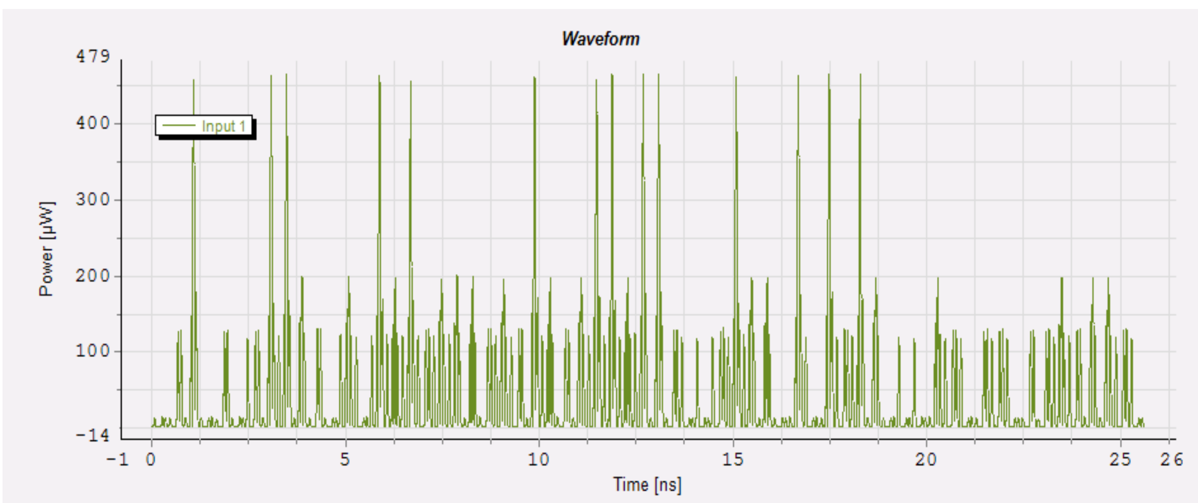

Figure 5.8: The Combined Encoded Signal of Channel 1

Figure 5.9, 5.10 & 5.11 represents the encoded signal of three users depending upon the codes applied of channel 2. Figure 5.9 is the encoded signal corresponding to the code 1, figure 5.10 is the encoded signal corresponding to the code 2 and figure 5.11 is the encoded signal corresponding to the code 3.

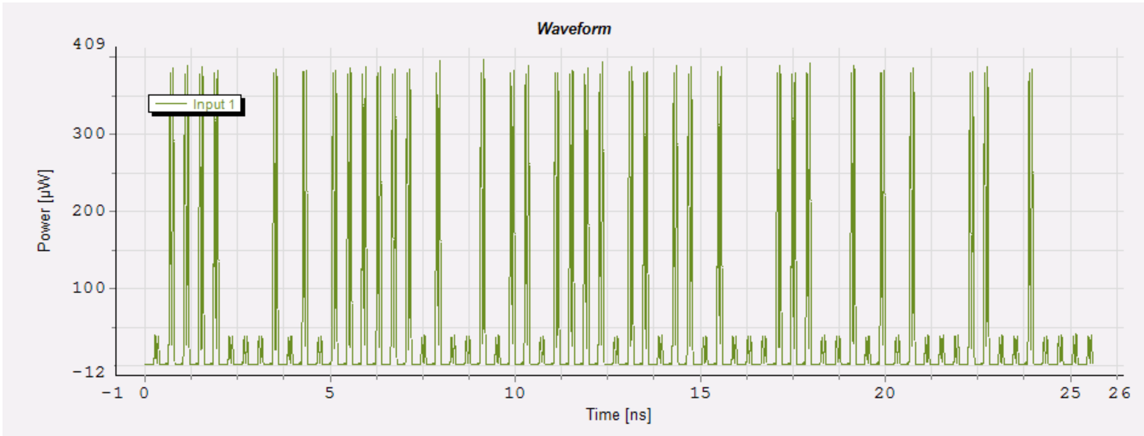

Figure 5.9: Encoded signal for code 1 of channel 2

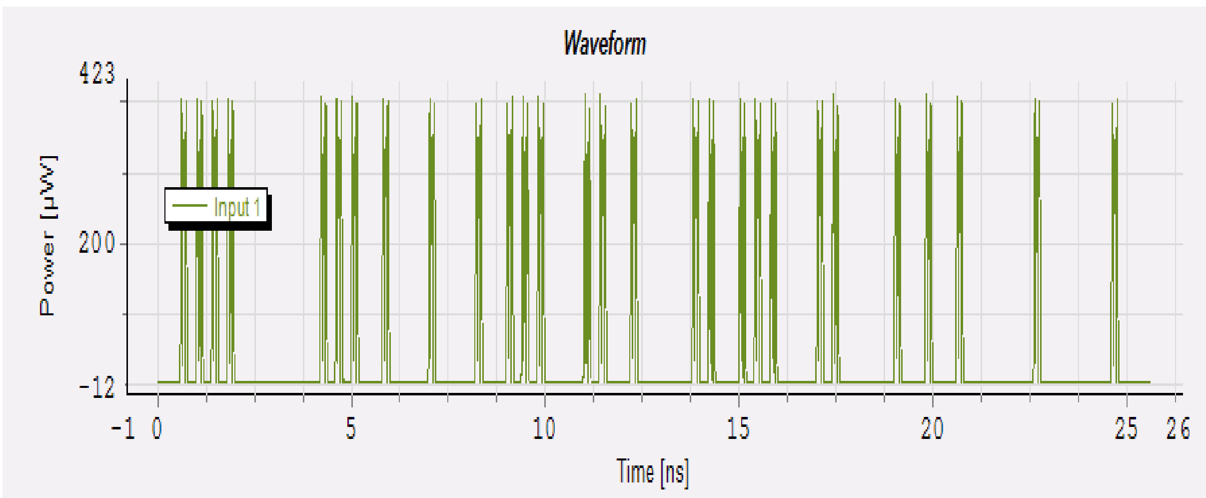

Figure 5.10: Encoded signal for code 2 of channel 2

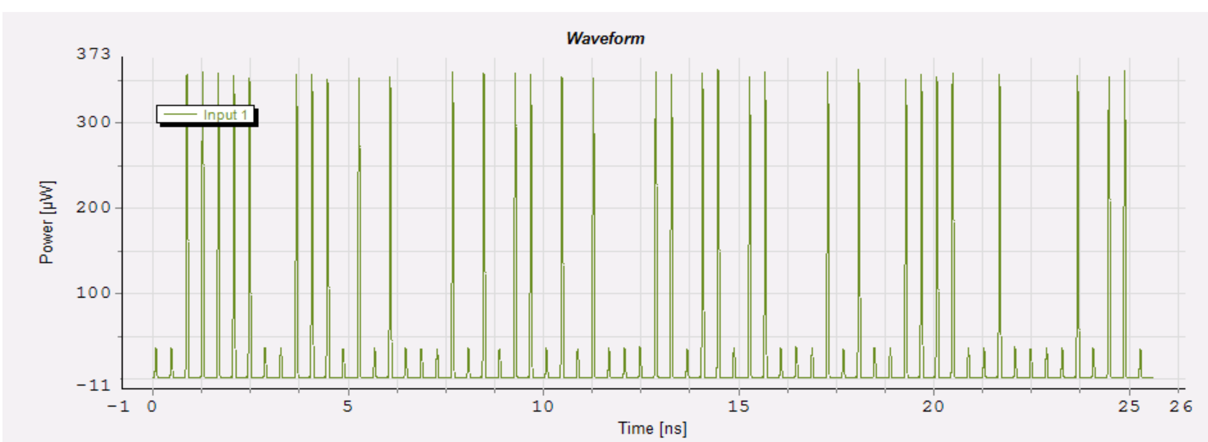

Figure 5.11: Encoded signal for code 3 of channel 2

After encoding of channel 2, the encoded signals of all the users are also combined and then transmitted, the combined encoded signal is shown in figure 5.12. the encoded signal of both the channels are also combined and then transmitted through optical fiber.

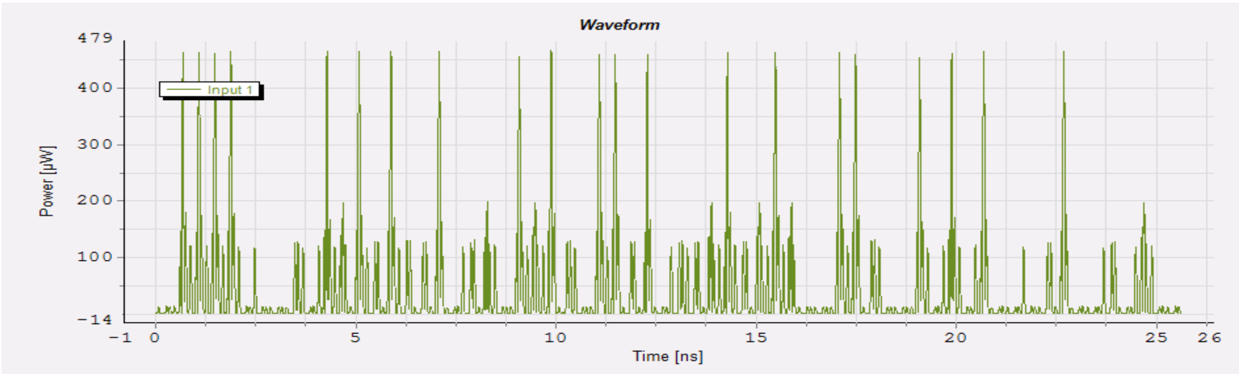

Figure 5.12: The Combined Encoded Signal of Channel 2

At the receiver, decoder is used which is exactly complementary of encoder. Figure 5.13 represents the decoded signal of user 1 and figure 5.14 represents the electrical spectrum of decoded signal

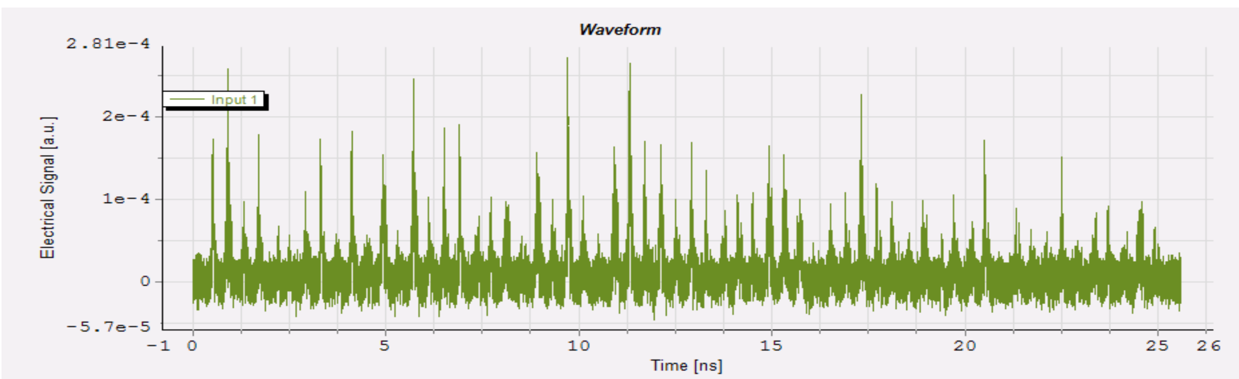

Figure 5.13: Decoded Signal of User 1

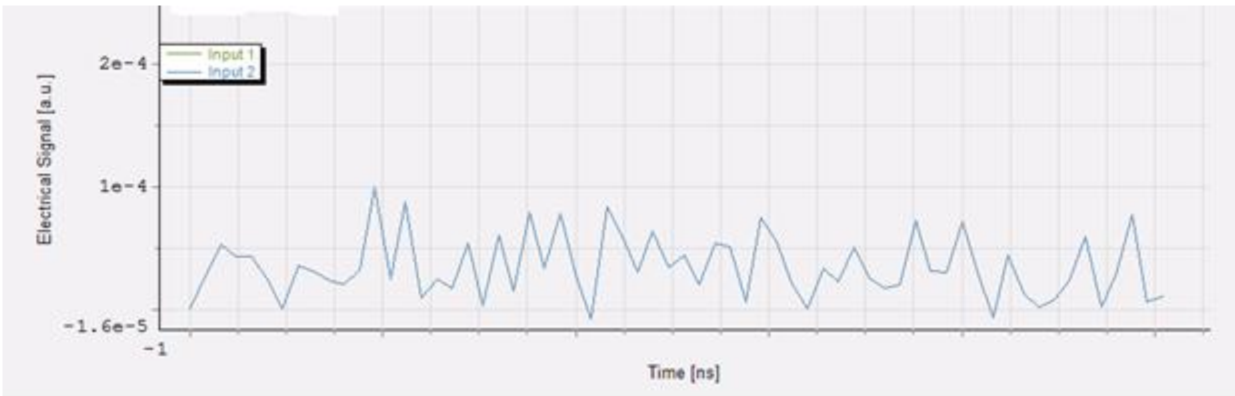

Figure 5.14: Electrical Spectrum of Decoded Signal

5.5 CONCLUSION

In this chapter, the spectral phase encoding is discussed and demonstrates the implementation of three dimensional space/wavelength/time by using spectral phase encoding/decoding which uses the unique codes. In this system we find that encoder provides the different-different phase shifts to different spectral components. The decoder provides the inverted phase change of different spectral components with balancing the phase shift pattern of the encoder.

CHAPTER 6
CONCLUSION AND FUTURE SCOPE

This chapter provides a summary of the findings of the study which has been done so far. Also in this chapter the scope for further research in OCDMA is given.

6.1 CONCLUSION

In the first objective of the thesis, it is found that the three dimensional codes are most preferable over one and two dimensional codes. The three dimensional SPPDD codes having three dimensions: space/wavelength/time, in order to implement these SPPDD codes multiple star couplers and associated hardware are required. To eliminate this requirement, two dimensional implementation of three dimensional codes is done using W^2T scheme, where total number of wavelengths are (W x S). By varying the number of space channels of three dimensional we conclude that the system shows better performance when (W>S) condition, while (W≤S) shows poor performance. In this, it is found that the space channels which shows better performance are S=2 and S=3 for W=T=4.

The second objective of thesis is to analyze the performance of three Dimensional (3D) single pulse per plane with direct detection (SPDD) code using different data format for OCDMA system. In this, the design implementation and performance analysis of 3D codes in OCDMA system for different data formats is presented. The comparison of data formats NRZ and RZ for space channel S=2 and S=3 is done. It is concluded that the NRZ has lowest BER value and better system performance as compared to RZ. Hence, NRZ data modulation format can be recommended for 3D codes and for the larger distance in OCDMA at higher bit rates.

In the third objective of the thesis the spectral phase encoding is discussed and demonstares the implementation of three dimensional space/wavelength/time by using spectral phase encoding/decoding which uses the unique codes. In this system we find that encoder provides the different-different phase shifts to different spectral components. The decoder provides the inverted phase change of different spectral components with balancing the phase shift pattern of the encoder.

6.2 FUTURE SCOPE

In this thesis, the work is done on three dimensional space/wavelength/time codes and these codes are analyzed only by varying the space channels and keeping other two dimensions constant. The variations in wavelength and time dimension have not been considered in this work. The present work can be enhanced for variation in wavelength and time dimension.

Moreover, multiple access interference is the main limiting factor for OCDMA system. It increases with increase in number of users. Further work can be done to find the techniques to mitigate the effect of MAI.

This OCDMA system can also be applied to various applications like wireless optical CDMA, in data networks, in multimedia transmission, in radio over fiber network, in LAN and LAN interconnection for hostile environments and in future access networks. So, the combination of both OCDMA and WDMA and OCDMA system with passive and active access networks can be studied further.

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