ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Performance Analysis of Fiber Optics Broadband Communication using OFDM in Ethiopia.

By

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Advisor

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Declaration

I declare that this thesis is my original work, it has not been previously submitted to this University for a degree or other qualification, and all sources of materials used for the thesis have been fully referenced.

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Abstract

Recently, Fiber optics networks become fast growing to give services with high data rate transmission and more reliable networks. One proven solution for improving the reliability of a fiber optics wired channel is to use orthogonal frequency division multiplexing. It is an effective solution to intersymbol interference caused by a dispersive channel.

The focus of the thesis is to investigate performance of fiber optics broadband communication using orthogonal frequency division multiplexing. In this thesis, different types of fibers and their applications, light sources and detectors, some classes of modulation, most wired communication channels advantage and disadvantage and broadband related technologies are discussed.

High band width, low loss, insulation resistivity, highly secured and relation of fiber with other wired medium are discussed. Performance of WDM, DWDM and OFDMidentified by Optisystem software.

Key words: Broadband,DWDM,Fiber Optics, OFDM.

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List of Abbreviations

Abbreviations	Description
ADC	Analog-to-Digital Converter
AWGN	Additive White Gaussian Noise
BER	Bit Error Ratio
BPF	Band Pass Filter
CCDF	Complementary Cumulative Distribution Function
CO-OFDM	Coherent Optical Orthogonal Frequency-Division Multiplexing
CPE	Common Phase Error
DAC	Digital-to-Analog Converter
DDO-OFDM	Direct-Detection Optical Orthogonal Frequency-Division Multiplexing
DFT	Discrete Fourier Transform
DMNG	Digital Mobile News Gathering
DPSK	Differential Phase-Shift Keying
DWDM	Dense Wavelength Division Multiplexing
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulses
ETC	Ethiopian Telecommunication Corporation
FDM	Frequency-Division Multiplexing
FFT	Fast Fourier Transform
GI	Guard Time Insertion
IDFT	Inverse Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
LPF	Low Pass Filter
MCM	Multicarrier Modulation
NRZ	Non-Return-to-Zero
OFDM	Orthogonal Frequency-Division Multiplexing
PAPR	High Peak-to-Average Power Ratio

QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase-Shift Keying
RFI	Radio-Frequency Interference
RZ	Return-to-Zero
S/P	Serial-to-Parallel
SCs	Signal carriers
SNR	Signal to Noise Ratio
VLSI	Very Large Scale Integration
WDM	Wavelength-Division Multiplexing

CHAPTER ONE

INTRODUCTION

1.1 Background

The rapidly changing face of data communications and telecommunications has been a continued growth in the need to transfer enormous amounts of information across large distances. The physical properties of the communications channels limit their ability to carry information in either analog or digital form. The technologies that were used extensively in the past, such as copper cable, coaxial cable and microwave radio for transferring information were, very quickly running out of capacity. The solution to the problems of transmission capacity shortage is fiber optics communication medium because of unlimited bandwidth [5]. Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through optical fibers. The light forms an electromagnetic carrier wave that modulates to carry information. Fiber is preferred over electrical cabling when high bandwidth long distance or immunity to electromagnetic interference are required. Many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals [8, 5] use optical fiber. Fiber optic transmission systems have many advantages over more conventional transmission systems. They are less affected by noise, do not conduct electricity and therefore provide electrical isolation, carry extremely high data transmission rates and carry data over very long distances. Since its invention in the early 1970s, the use of and demand for optical fiber have grown tremendously. With the explosion of information traffic due to the Internet, electronic commerce, computer networks, multimedia, voice, data, and video, the need for a transmission medium with the bandwidth capabilities for handling such vast amounts of information is paramount. Fiber optics, with its comparatively infinite bandwidth, has proven to be the solution.

Broadband also sometimes referred to as “wideband” is the general term used to describe facilities or services that operate at higher frequencies or digital bit rates “data speeds” than are necessary to transmit the human voice. Voice transmission is carried over the telephone network within the frequency range of 300 Hz to 3400 Hz or over digital systems within 64,000 bits per second bandwidth or less which grade transmission is often referred to as “baseband” or “narrowband” [2].

1.2 Problem statement

Recently, the demand for multimedia services like video, audio and data in new generation of internet communication using wireless and wired are rapidly growing. However, providing services with high data rate transmission can be limited by several factors, which imposed high-speed bit rate. Therefore, a main challenge to designing wired communication system is how to obtain higher data rate with reliable communication. To overcome this problem, fiber optics broadband communication is proposed as a powerful technique to improve the reliability of the network as well as improve the limitation of bandwidth especially for users with large data and require high security.

1.3 Objective

1.3.1 General objective:

The main objective of this thesis is to investigate the performance of fiber optics medium for broadband communication using OFDM in Ethiopia.

1.3.2 Specific objective:

- Analysis bandwidth limitation in communication system.
- Studying large data on small bandwidth of fiber optics using OFDM technology.
- Justify the advantages of fiber optics communication over another communication channels.
- Analyzing M- QAM with OFDM for broadband communication.
- Designing communication channel system for fiber optics that able to provide suitable bit-error-rate (BER) performance with QAM modulation
- Investigate the comparative advantage of QAM for OFDM

1.4 Methodology

The following methods will use to achieve the objectives of the research:

- **Literature Review**: Including Reading books, research papers and other information available through the internet those related to the topic.
- **Data collection**: In the telecommunication system, getting the correct and precise data is necessary to do the analysis effectively. In this thesis, we used different sources to collect this data. Ethiopia telecommunication was a main source. They have given technology they used today with fiber optics broadband communication and maximum bit rate can be generated and maximum rate they delivered total length of fiber, type of fiber, number of rate of customer increase. GenerallyEthiopia telecommunication Adama branch and the project office grant access to the infrastructure. This data source used for the analysis and investigation of this thesis.
- **Modeling:** include Faber optics model, the modulation scheme, choosing the channel models and the formulating mathematical expression of fiber optics using orthogonal frequency division multiplexing.
- **Simulation:**Simulating the modeled system with the assumed parameters usingoptisystem software for fiber optics broadband communication using orthogonal frequency division multiplexing.

1.5 Related work

In recent years, innovations in optical fiber technology are revolutionizing world communications to increase the signal reliability and speed without expending additional bandwidth and transmit power. Fiber optics broadband communication system using orthogonal frequency division multiplexing havebeen got attraction in a wide research. Some of the researches proposed to the area of fiber optic systems that related to this work briefly reviewed below.

The available spectrum in fiber is being populated with continued growth of internet traffic driven by bandwidth-hungry applications introduced in [1]. A major contributing factor in the development of new optical systems is the advance in very large scale integration (VLSI) technology, which enables digital signal processing-based receivers at GHz clock speeds. There are many different technics of modulation and multiplexing used in wired and wireless communication system the latest used with fiber optic is orthogonal frequency division multiplexing modulation [1, 2].

The channel limitation for recent multiple input multiple output and large number of user rapidly increase. This bring to new innovation for limitation of bandwidth on existing resource [3, 4,14].

Telecommunication technology is the fast growing serves and world is becoming one house through internet broadband connection. Today large video, audio, and data are transmitted and received. The large signals are carried over medium such as wireless and wired for long and short distance. Fiber optics is the choice current telecommunication technology used throughout the world expressed in [5, 6, 7].

High speed and security is the current focus of telecommunication today the great solution for this problem is fiber optics medium expressed in [8, 9, 10, 11].

World become digitalized the technology and mechanisms that run with this digitalization to perform in quality and optimization of signal process is main attention of researchers. Modulation techniques like quadrature phase shift keying, quadrature amplitude Modulation, and various signal conditioning parameters, like optical signal to noise ratio, bit error rate, chromatic dispersion and signal to noise ratio. Fiber optics capacity today and for future is very high its carrying capacity in frequency range very high in terahertz expressed in [12, 13, 17, 18]

World become one house through internet broadband connection technology the major core for this interconnection is wireless and wired medium. Fiber optics broadband connection is the future on the world and many scholars work with [15, 16,].

Fiber optics broadband communication using orthogonal frequency division multiplexing expressed in [1, 2, 3… 30].

By summarizing all related work with my thesis work on fiber optics broadband communication using orthogonal frequency division multiplexing throughout world, thencontextualizing to our country as well as investigate the performance of fiber optics broadband communication using orthogonal frequency division multiplexing in Ethiopia.

1.6 Contribution

The main contributions ofthe thesis are outlined as follows:

- In Ethiopia Ethernet, broadband communication users are fast growing; as number of user increase rapidly to deliver broadband using copper cable and wireless channel is run out of capacity. Fiber optics broadband communication has unlimited band and very secure.in previous broadband internet is delivered in Kbps and Mbps but the speed is very slow and many times the connection failed. To increase the speed of data; increasing bit rate is the main solution. In this thesis performance and advantage of fiber optics to increase the speed and bit rate wasunder taken.
- Ethiopia today use DWDM for multiplexing and modulation, in this thesis OFDM multiplexing and modulation as well as its performance is undertaken.
- Bandwidth is the major resource and limitation in communication technology. In this thesis, how we use in small bandwidth with large data in Ethiopia context is analyzed.

The advantage of fiber optics over other communication channel and relating with todays' rapidly increasing technology that requires high bandwidth is justified in this study.

1.7 Outline of the Thesis

After the background information about this work is described in chapter one, the remaining chapters organized as follows. Chapter two discuss wired specifically fiber optics and some type and relationship of wired communication medium. Chapter three introduce orthogonal frequency division multiplexing. Chapter four introduce fiber optics broadband design and simulation result.Chapter five introduce conclusion and recommendation future work.

CHAPTER TWO

FIBER OPTICS BROADBAND COMMUNICATION

2.1 Introduction

Nowadays, the world become one house through communication technology. As long as the requirement and its critical use in human daily life increase; ways of information transmission or medium that used to reach information signal from source to destination and vice versa is studied by many scholars. Currently two mediums; wireless and wired are in application that world used for signal transmission. Both have their own advantage and disadvantage as well as limitation. Wired communication has comparative advantage that it is fixed and reliable while the wireless channels are random and unreliable. Wide bandwidth signal transmission with low delay is a key requirement in present day communication. Optical fibers provide enormous and unsurpassed transmission bandwidth with negligible latency and are now the transmission medium of choice for long distance and high data rate transmission in telecommunication networks [17].

The major driving force behind the widespread use of fiber optics communication is its high reliability over long distances, low attenuation, low interference, high security, very high information capacity, longer life span and ease of maintenance. Due to these advantages optical fiber requirement is highly and rapidly increasing consumer and commercial demand for more telecommunication capacity and internet services. With fiber optic technology capable of providing the required information capacity (larger than both wireless connections and copper cable). Advances in technology have enabled more data to be conveyed through a single optical fiber over long distances [18].optical signal processing is more efficient than electrical signal processing.

2.2 The nature of light

The main distinction of fiber optic links is that they use light as the form of energy that they modulate, and they use optical fibers to propagate that energy from the source to the destination. Indeed the main advantage of using light energy for communication is the ease with which light can be modulated with high-speed signals and transported over long distances in an optical fiber with minimal degradation [19]. A desirable feature for future optical networks is the ability to process information entirely in the optical domain for the purpose of amplification, multiplexing, de-multiplexing, switching, filtering, and correlation, since optical signal processing is more efficient than electrical signal processing [17]. In order to understand the nature of optical communications; brief discussion about the nature of light is directive for more detail.

2.2.1 Wave nature

Optical phenomena such as diffraction and interference provide strong evidence for the wave nature of light. The wave theory of light found its most eloquent expression in nineteenth century by James Clerk Maxwell. An elegant consequence of Maxwell's theory is that light is identified as a form of electromagnetic waves, and indeed all-classical optics can be driven from Maxwell's equations. The four equations are;

$$\nabla \times \mathrm{E} = -\frac{\partial \mathrm{B}}{\partial t} \tag{2.1}$$

$$\nabla \times \mathrm{H} = J + \frac{\partial D}{\partial t} \tag{2.2}$$

$$\nabla . D = \rho \tag{2.3}$$

$$\nabla . \mathrm{B} = 0 \tag{2.4}$$

In these equations **E** is the electric field vector, **H** is the magnetic field vector, $\boldsymbol{D}$ is the electric flux density vector, **B**is the magnetic flux density vector, $\boldsymbol{\rho}$ is the charge density, and $\boldsymbol{\nabla}$. From electric field and magnetic field the general wave equation can be derived.

Light waves are transverse electromagnetic waves, which like any other wave can be described by amplitude, frequency, and wavelength.

$$c = \lambda f \tag{2.6}$$

In equation (2.6) $\boldsymbol{c}$is speed of light**,** $\boldsymbol{\lambda}$ wavelength and$\boldsymbol{f}$ frequency. Of the two quantities on the right-hand side of Eq. (2.6), f is determined by the source and, under normal circumstances, remains constant as the wave propagates through various media. In other words, frequency is an inherent property of the light, i.e., a property that is determined by the source and (usually) remainsthe same once the light is generated. Wavelength (λ) changes as the wave goes from one medium to the next. From an optical point of view, a medium is characterized by its index of refraction, **n**. The index of refraction of vacuum is one, but other media have indices of refraction greater than unity. If we represent the vacuum speed of light and wave length by $\boldsymbol{c_0}$and $\boldsymbol{\lambda_0}$, respectively, we obtain $\mathbf{c}=\boldsymbol{c_0}/\mathbf{n}$ and $\boldsymbol{\lambda}=\boldsymbol{\lambda_0}/\mathbf{n}$. In other words, both the speed of light and its wavelength decrease as it enters a medium with an index of refraction of **n**. Therefore, the speed and wavelength are extrinsic properties of light, i.e., properties that are affected by the medium.Various modes of transmission in each region of spectrum is as shown blow by dividing in terms of wavelength and frequency.

From the equation (2.6) frequency and wavelength are inversely proportional due to that as the frequency is increased, the wavelength decreases, and the wave nature of the signals must be taken into account. Optical fibers that are used to guide light waves at much higher optical frequencies are waveguides that enforce boundary conditions on light waves and hence prevent them from scattering in space. Fig. 2.2 blow show the ladder of frequency and wavelength [19].

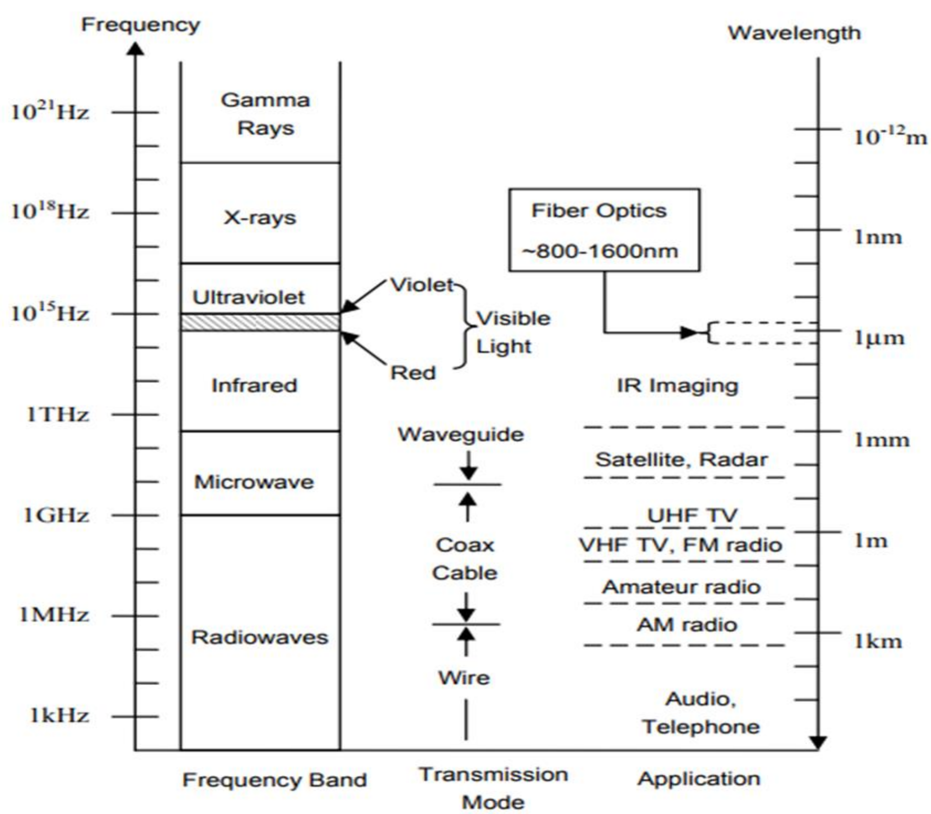


Fig. 2.1 The electromagnetic spectrum [19].

2.3 Elements of a fiber optic link

The building blocks of a typical fiber optic link divided vertically into two domains: a physical layer and a set of data processing layer(s). The processing layers are where complex signal processing functions such as multiplexing and demultiplexing, error detection, routing, and switching take place. The physical layer convert the electrical data to optical data, send the optical signal over the fiber, receive it on the other side of the fiber, and convert it back to electrical data.

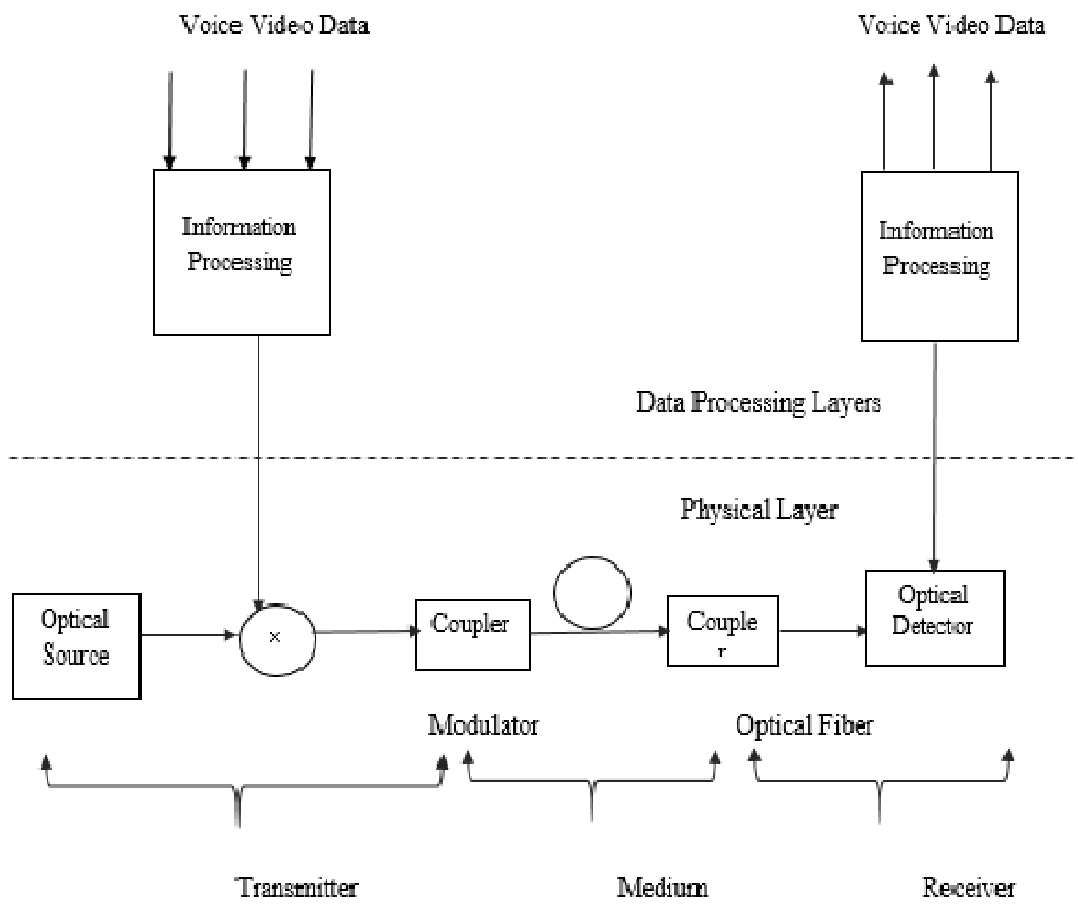


Fig. 2.2 Elements of a typical fiber optic link

2.4 Advantages of optical fiber broadband communication

2.4.1 Enormous potential bandwidth

The optical carrier frequency in the range 10^{13} to 10^{16} Hz (generally in the near infrared around 10^{5} GHz) yields a far greater potential transmission bandwidth than metallic cable systems (i.e. coaxial cable bandwidth typically around 20 MHz over distances up to a maximum of 10 km) or even millimeter wave radio systems (i.e. systems currently operating with modulation bandwidths of 700 MHz over a few hundreds of meters). particularly with dense packing of the optical wavelengths (or, essentially, fine frequency spacing), offers the potential for a fiber information-carrying capacity that is many orders of magnitude in excess of that obtained using copper cables or a wideband radio system.

2.4.2 Small size and weight

Optical fibers have very small diameters which are often no greater than the diameter of a human hair. Hence, even when such fibers are covered with protective coatings they are far smaller and much lighter than corresponding copper cables.

2.4.3 Electrical isolation

Optical fibers which are fabricated from glass, or sometimes a plastic polymer, are electrical insulators and therefore, unlike their metallic counterparts, they do not exhibit earth loop and interference problems. Furthermore, this property makes optical fiber transmission ideally suited for communication in electrically hazardous environments as the fibers create no arcing or spark hazard at abrasions or short circuits.

2.4.4 Immunity to interference and crosstalk

Optical fibers form a dielectric waveguide and are therefore free from electromagnetic interference (EMI), radio-frequency interference (RFI), or switching transients giving electromagnetic pulses (EMPs). Hence the operation of an optical fiber communication system is unaffected by transmission through an electrically noisy environment and the fiber cable requires no shielding from EMI. The fiber cable is also not susceptible to lightning strikes if used overhead rather than underground. Moreover, it is fairly easy to ensure that there is no optical interference between fibers and hence, unlike communication using electrical conductors, crosstalk is negligible, even when many fibers are cabled together.

2.4.5 Signal security

The light from optical fibers does not radiate significantly and therefore they provide a high degree of signal security. Unlike the situation with copper cables, a transmitted optical signal cannot be obtained from a fiber in a noninvasive manner (i.e. without drawing optical power from the fiber). Therefore, in theory, any attempt to acquire a message signal transmitted optically may be detected. This feature is obviously attractive for military, banking and general data transmission (i.e. computer network) applications.

2.4.6 Low transmission loss

Optical fiber cables which exhibit very low attenuation or transmission loss in comparison with the best copper conductors. This feature has become a major advantage of optical fiber communications. It facilitates the implementation of communication links with extremely wide optical repeater or amplifier spacing, thus reducing both system cost and complexity. Together with the already proven modulation bandwidth capability of fiber cables, this property has provided a totally compelling case for the adoption of optical fiber communications in the majority of long-haul telecommunication applications, replacing not only copper cables, but also satellite communications, as a consequence of the very noticeable delay incurred for voice transmission when using this latter approach.

2.4.7 Ruggedness and flexibility

Although protective coatings are essential, optical fibers may be manufactured with very high tensile strengths. Perhaps surprisingly for a glassy substance, the fibers may also be bent to quite small radii or twisted without damage. Furthermore, cable structures have been developed which have proved flexible, compact and extremely rugged. Taking the size and weight advantage into account, these optical fiber cables are generally superior in terms of storage, transportation, handling and installation to corresponding copper cables, while exhibiting at least comparable strength and durability.

These features primarily stem from the low-loss property of optical fiber cables which reduces the requirement for intermediate repeaters or line amplifiers to boost the transmitted signal strength. Hence, with fewer optical repeaters or amplifiers, system reliability is generally enhanced in comparison with conventional electrical conductor systems. Furthermore, the reliability of the optical components is no longer a problem with predicted lifetimes of 20 to 30 years being quite common. Both these factors also tend to reduce maintenance time and costs.

2.5. Comparison of optical fiber and copper cable system

Comparison of wired communication medium of copper and fiber optics summarized in table below.

No.	parameters	Optical fiber	Copper
1	Bandwidth	➢ have enormous bandwidth ➢ transmission speeds up to 40 Gbps operating today ➢ over 100 Gbps is expected in the near future	➢ can carry speeds reaching 1 Gbps ➢ Speeds of 100 Mbps are now quite ➢ Commercial systems are operate up to 1 Gbps.
2	Interference	➢ Completely unaffected by electromagnetic interference (EMI), radio frequency interference (RFI), lightning and high voltage switching. ➢ Do not suffer from capacitive or inductive coupling problems. ➢ If designed correctly, unaffected by nuclear magnetic pulses from nuclear	➢ affected by external interference ➢ affected to varying degrees by EMI and RFI through inductive, capacitive, and resistive coupling ➢ destroyed by nuclear magnetic pulses ➢ emit electromagnetic radiation, which can cause interference to other copper cable-based communications systems ➢ The amount of radiation they emit

		explosions ➢ unaffected by background nuclear radiation ➢ do not emit any electromagnetic interference or radio frequency interference	depends on the magnitude of the signal they are carrying and the quality of the shielding.
3	Electricalc Isolation	➢ Provide complete galvanic isolation between both ends of the cable. ➢ The characteristic of non-conductivity of fibers makes the cables immune to voltage surges ➢ This eliminates interference that may be caused from ground loops, common mode voltages, as well as shifts and shorts in ground potential. ➢ acts like a long opto-isolator ➢ there is no cross talk between cables	➢ Simply working in their designed purpose, provide an electrical connection between both their ends. ➢ susceptible to ground loops, common mode voltages, and ground potential variations ➢ Suffer for potential cross talk problems.
4	Tranismission distance	➢ distances up to 5 km between repeaters are possible ➢ For high-grade commercial systems, distances up to 300 km between repeaters are now readily available ➢ Distances close to 1000 km in feature	➢ Distances upto 2.4 km between repeaters at data speeds of 4 Mbps are commercially available as for twisted cables ➢ Distances upto 25 km between repeaters at speeds of less than 1 Mbps are possible in case of coaxial cables.

5	Size and weight	➢ extremely lightweight and very small in diameter ➢ A four-core fiber optic cable will weigh approximately 240 kg/km and a 36-core fiber optic cable will weigh only about 3 kg more ➢ Cost are generally reduced since they are light in weight and easier to handle.	➢ weigh from 800 k/km for a 36 twisted pair sheathed cable to 5 tons for a kilometer of high quality large diameter coaxial cable
6	Security	➢ impossible to hook across a fiber optic cable and 'bug' the data transmission ➢ The fibers have to be physically tapped to extract the data, which will decrease signal levels and increase error rates, both of which are easily detected ➢ With presently available technology, fiber optic systems are considered highly secure systems.	➢ Tapping into a copper cable transmission system is simply a matter of hooking across the cable with an equivalent high impedance cable ➢ Copper cables are not considered highly secure systems

Table 2.1 relation between fiber optics and copper cable system

CHAPTER THREE

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

3.1 Introduction

Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology, which is now the basis of many telecommunications standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world. OFDM is also the basis of most DSL standards, though in this context it is usually called discrete multitoned (DMT) because of some minor peculiarities.

Orthogonal frequency-division multiplexing (OFDM) belongs to a broader class of multicarrier modulation (MCM) in which the data information is carried over many lower rate subcarriers. Today most new and emerging broadband wired and wireless communication systems used OFDM modulation technique, because it is an effective solution to intersymbol interference caused by a dispersive channel. Modulation and multiplexing are different process modulation is mapping of the information on changes in the carrier phase, frequency or amplitude or combination whereas multiplexing is method of sharing a bandwidth with other independent data channels then OFDM is a combination of modulation and multiplexing. OFDM is a special case of Frequency Division Multiplex (FDM). Fig 3.1 shows the difference between the two as an analogy, a FDM channel is like water flow out of a faucet, in contrast the OFDM signal is like a shower. In a faucet all water comes in one big stream and cannot be sub-divided. OFDM shower is made up of a lot of little streams.

Fig. 3.1 (a) A Regular-FDM single carrier – A whole bunch of water coming all in one stream.**(b)** Orthogonal-FDM – Same amount of water coming from a lot of small streams [10].

3.2Historical Perspective of OFDM

OFDM plays a significant role in the modern telecommunications for both wireless and wired communications. The concept of using parallel-data transmission and frequency-division multiplexing (FDM) was developed in the mid-1960. In a classical parallel-data system, the total signal frequency band is divided into frequency N non-overlapping sub channels. Each sub channel is modulated with a separate symbol, and then the N sub channels are frequency multiplexed. It seems good to avoid spectral overlap of channels to eliminate inter channel interference. However, this leads to inefficient use of the available spectrum.

To cope with the inefficiency, the ideas proposed in the mid-1960s were to use parallel data and FDM with overlapping sub channels, in which each, carrying a signaling rate b, is spaced b apart in frequency to avoid the use of high-speed equalization and to combat impulsive noise and multipath distortion, as well as to use the available bandwidth fully [9].

Figure 3.2 illustrates the difference between the conventional non overlapping multicarrier technique and the overlapping multicarrier modulation technique. By using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize this technique, however, reduce cross talk between SCs, which means that orthogonality needed between the different modulated carriers.The word “orthogonal” indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system.

In a normal FDM system, many carriers are spaced apart in such a way that the signals can be received using conventional filters and demodulators. In such receivers, guard bands are introduced between the different carriers and in the frequency domain, which results in a lowering of spectrum efficiency [9].

It is possible, however, to arrange the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and the signals are still received without adjacent carrier interference. To do this the carriers must be mathematically orthogonal.

The receiver acts as a bank of demodulators, translating each carrier down to dc, with the resulting signal integrated over a symbol period to recover the raw data. If the other carriers all beat down the frequencies that, in the time domain, have a whole number of cycles in the symbol period T, then the integration process results in zero contribution from all of these other carriers. Thus, the carriers are linearly independent (i.e., orthogonal) if the carrier spacing is a multiple of 1/T [9].

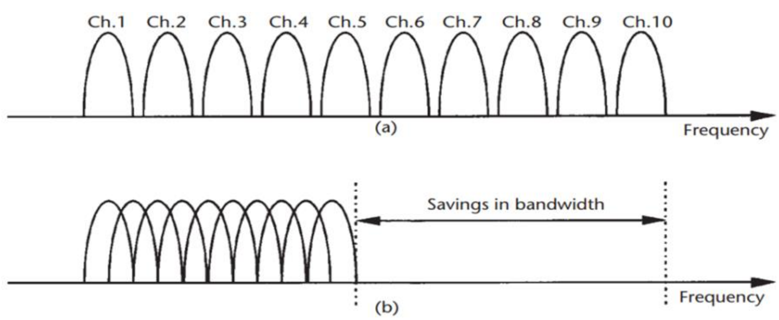


Figure 3.2 Concept of the OFDM signal: (a) Conventional multicarrier techniques (b) Orthogonal multicarrier modulation technique [9].

3.3 Orthogonal Frequency Division Multiplexing Fundamentals

OFDM is a special class of MCM, a generic implementation of which is depicted in Figure 3.3 The structure of a complex multiplier (IQ modulator/demodulator), which is commonly used in MCM systems, is also shown in the figure 3.3. The key distinction of OFDM from general multicarrier transmission is the use of orthogonality between the individual subcarriers.

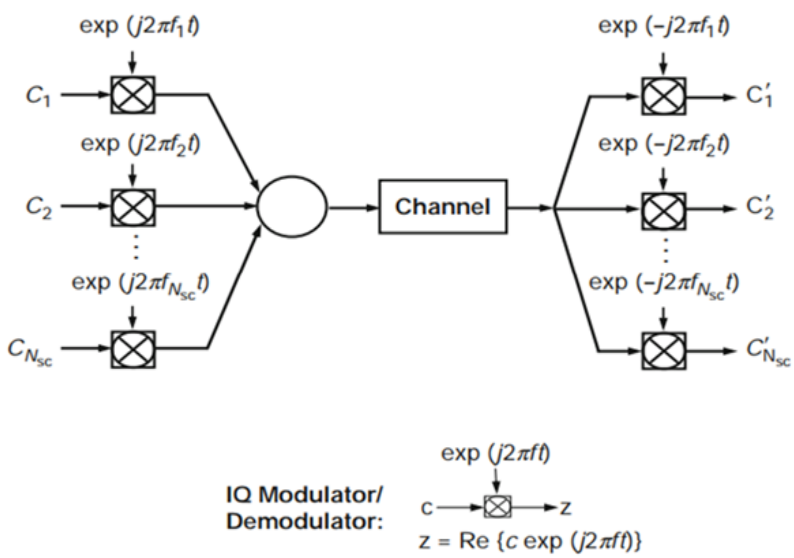


Figure 3.3: Conceptual diagram for a generic multicarrier modulation system [3].

3.2.1 Orthogonality between OFDM Subcarriers and Sub bands

Mathematical equation between subcarrier and sub bunds shown blow.

$$S(t) = \sum_{i=-\infty}^{+\infty} \sum_{k=1}^{N_{sc}} c_{ki} s_k (t - iT_s) \; (3.1)$$

$$s_{k(t)} = \prod(t) e^{j2\pi f_k} t (3.2)$$

$$\prod(t) = \begin{cases} 1, \; (0 < t \le T_s) \\ 0, (t \le 0, \; t > T_s) \end{cases} \; (3.3)$$

Where c_{ki} is the *ith* information symbol at the *kth* subcarrier, s_k is the waveform for the *kth* subcarrier, N_{sc} is the number of subcarriers, *fk* is the frequency of the subcarrier, and *Ts* is the symbol period, $\prod(t)$ is the pulse shaping function. The optimum detector for each subcarrier could use a filter that matches the subcarrier waveform, or a correlator matched with the subcarrier as shown in Fig. 3.3 Therefore, the detected information symbol c'_{ik} at the output of the correlator is given by

$$c'_{ik} = \frac{1}{T_s} \int_0^{T_s} r(t - iT_s) s^* k^{dt} = \frac{1}{T_s} \int_0^{T_s} r(t - iT_s) e^{-j2\pi f_k t} \, dt \;\; (3.4)$$

Where $r(t)$ is the received time domain signal. The classical MCM uses non-overlappedbandlimited signals and can be implemented with a bank of large numbers of oscillators and filters at both transmit and receive ends. The major disadvantage of MCM is that it requires excessive bandwidth. This is because to design the filters and oscillators cost-effectively, the channel spacing has to be a multiple of the symbol rate, greatly reducing the spectral efficiency. A novel approach, OFDM, was investigated by employing overlapped yet orthogonal signal sets [3, 10]. This orthogonality originates from a straightforward correlation between any two subcarriers, given by

$$\delta_{kl} = \frac{1}{T_s}\int_0^{T_s} s_k\, s^* l dt = \frac{1}{T_s}\int_0^{T_s} exp(j2\pi(f_k - f_l)t)\, dt = exp(j\pi(f_k - f_l)T_s)\,\frac{\sin(\pi(f_k - f_l)T_s)}{\pi(f_k - f_l)T_s} \quad (3.5)$$

It can be seen that if the condition

$$f_k - f_l = m\frac{1}{T_s} \quad (3.6)$$

Is satisfied, then the two subcarriers are orthogonal to each other. This signifies that these orthogonal subcarrier sets, with their frequencies spaced at multiples of inverse of the symbol periods, can be recovered with the matched filters in Eq. (3.4) without inter carrier interference (ICI), despite strong signal spectral overlapping.

3.2.2 Discrete Fourier Transform Implementation of OFDM

A fundamental challenge with OFDM is that a large number of subcarriers are needed so that the transmission channel affects each subcarrier as a flat channel. This leads to an extremely complex architecture involving many oscillators and filters at both transmit and receive ends. Weinstein and Ebert first revealed that OFDM modulation/demodulation can be implemented by using inverse discrete Fourier transform (IDFT)/discrete Fourier transform (DFT). This is evident by studying OFDM modulation (Eq. 3.1) and OFDM demodulation (Eq. 3.4). Let's temporarily omit the index i, re-denote N_{sc}as N in Eq. (3.1) to focus our attention on one OFDM symbol, and assume that we sample $s(t)$ at every interval of $\frac{T_s}{N}$. The mth sample of $S(t)$ from Eq. (3.1) becomes

$$s_m = \sum_{k=1}^{N} C_k e^{j2\pi f_k \frac{(m-1)T_s}{N}} \quad (3.7)$$

Using the orthogonality condition of Eq. (3.6) and the convention that

$$f_k = \frac{k-1}{T_s} \tag{3.8}$$

By substituting Eq. (3.8) into Eq. (3.7)

$$s_m = \sum_{k=1}^{N} C_k e^{j2\pi f_k \frac{(m-1)T_s}{N}} = \sum_{k=1}^{N} C_k e^{j2\pi \frac{(k-1)(m-1)}{N}} = \quad \mathfrak{F}^{-1}\{c_k\} \tag{3.9}$$

Where $\mathfrak{F}$ is the Fourier transform, and $m \in [1, N]$. In a similar manner, at the receive end, we arrive at

$$c_k{}' = \mathfrak{F}\{r_m\} (3.10)$$

Where r_m is the received signal sampled at every interval of $\frac{T_s}{N}$ .From Eqs. (3.9) and (3.10), it follows that the discrete value of the transmitted OFDM signal $S(t)$ is merely a simple N-point IDFT of the information symbol c_k, and the received information symbol $c0$ k is a simple N-point DFT of the receive sampled signal. It is worth noting that there are two critical devices we have assumed for the DFT/IDFT implementation: (1) digital-to-analog converter (DAC), needed to convert the discrete value of $S_m$to the continuous analog value of $S(t)$, and (2) an analog-to-digital converter (ADC), needed to convert the continuous received signal $r(t)$to discrete sample r_m. There are two fundamental advantages of DFT/IDFT implementation of OFDM. First, because of the existence of an efficient IFFT/FFT algorithm, the number of complex multiplications for IFFT in Eq. (3.9) and FFT in Eq. (3.10) is reduced from $N^2$to

$$\frac{N}{2}\log_2(N) \qquad (3.11)$$

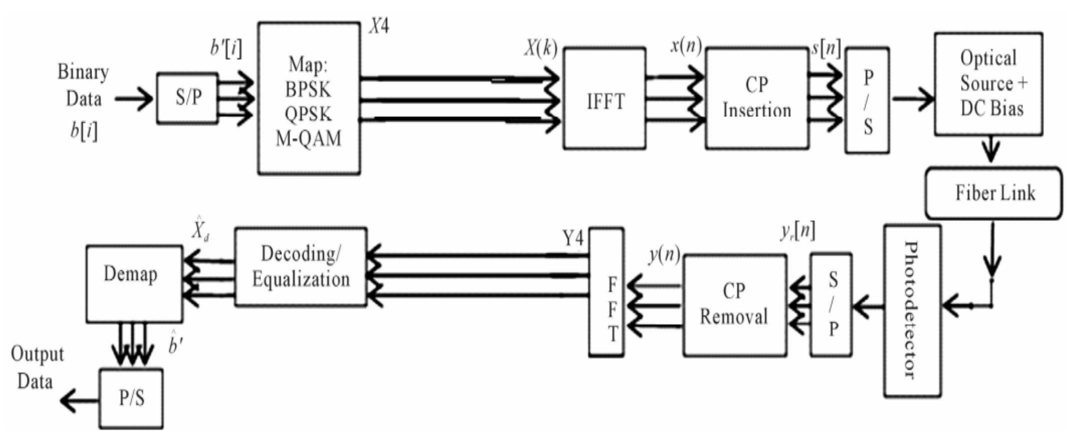


Figure 3.4: Conceptual diagram for OFDM transmitter and OFDM receiver.

3.2.3 Cyclic Prefix for OFDM

Cyclic prefix is an enabling technique for OFDM insertion. The two consecutive OFDM symbols that undergo a dispersive channel with a delay spread of t_d are subcarriers with the fast delay and slow delay spread at td, represented by "fast subcarrier" and "slow subcarrier," respectively. Figure 3.5a shows that inside each OFDM symbol, the two subcarriers fast subcarrier and slow subcarrier are aligned upon the transmission. Figure 3.5b shows the same OFDM signals upon the reception, where the slow subcarrier is delayed by td against the fast subcarrier. By select a DFT window containing a complete OFDM symbol for the fast subcarrier.

It is apparent that due to the channel dispersion, the slow subcarrier has crossed the symbol boundary leading to interference between neighboring OFDM symbols, the so-called ISI. Furthermore, because the OFDM waveform in the DFT window for the slow subcarrier is incomplete, the critical orthogonality condition for the subcarriers (Eq. 3.5) is lost, resulting in an inter-carrier interference (ICI) penalty.

Cyclic prefix was proposed to resolve the channel dispersion-induced ISI and ICI. Figure 3.5c shows insertion of a cyclic prefix by cyclic extension of the OFDM waveform into the guard interval, DG. As shown in Figure 3.5c, the waveform in the guard interval is essentially an identical copy of that in the DFT window, with time shifted forward by ts. Figure 3.5d shows the OFDM signal with the guard interval upon reception. Let us assume that the signal has traversed the same dispersive channel, and the same DFT window is selected containing a complete OFDM symbol for the fast subcarrier waveform. It can be seen from Figure 3.5d that a complete OFDM symbol for the slow subcarrier is also maintained in the DFT window because a proportion of the cyclic prefix has moved into the DFT window to replace the identical part that has shifted out. As such, the OFDM symbol for the slow subcarrier is an almost identical copy of the transmitted waveform with an additional phase shift. This phase shift is dealt with through channel estimation and will be subsequently removed for symbol decision. Now we arrive at the important condition for ISI-free OFDM transmission, given by

$$t_d < \Delta_G \quad (3.12)$$

It can be seen that to recover the OFDM information symbol properly, there are two critical procedures that need to be carried out: (1) selection of an appropriate DFT window, called DFT window synchronization, and (2) estimation of the phase shift for each subcarrier, called channel estimation or subcarrier recovery. Both signal processing procedures are actively pursued research topics, and they are discussed in both books and journals.

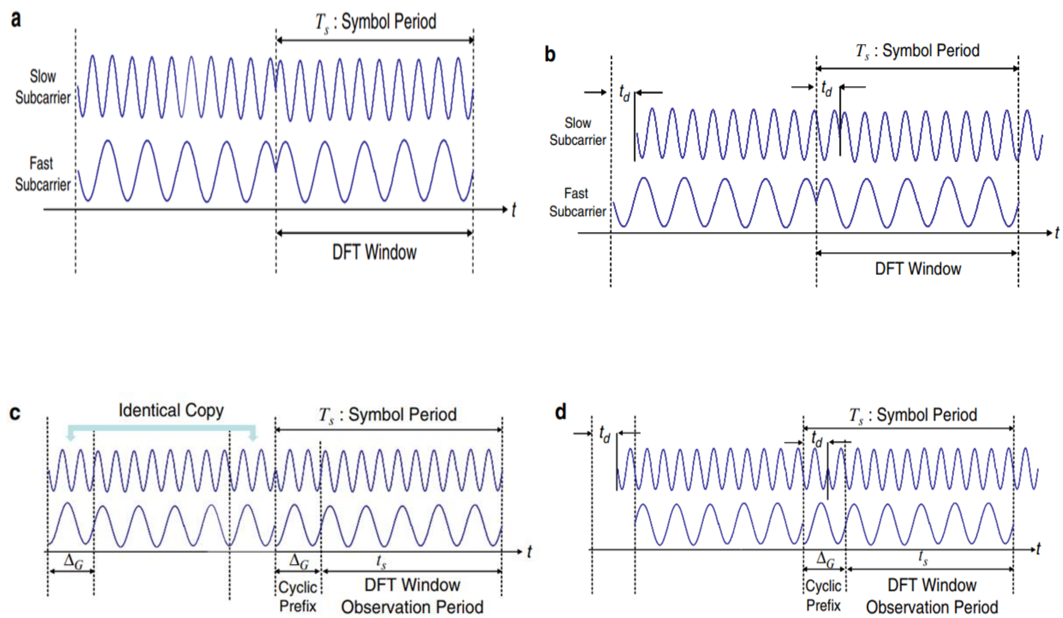


Figure3.5: OFDM signals **(a)** without cyclic prefix at the transmitter, **(b)** without cyclic prefix at the receiver, **(c)**with cyclic prefix at the transmitter, and **(d)** with cyclic prefix at the receiver [19].

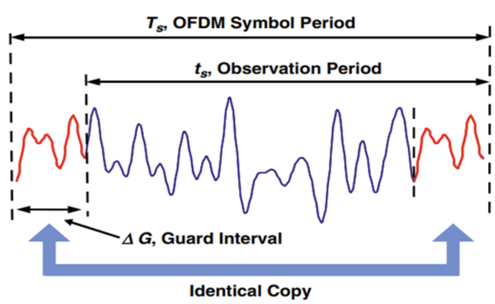


Figure 3.6: The time domain OFDM signal for one complete OFDM symbol.

An elegant way to describe the cyclic prefix is to maintain the same expression as Eq. (2.1) for the transmitted signal $s(t)$but extend the pulse shape function (Eq. 2.3) to the guard interval, given by

$$\pi(t) = \begin{cases} 1, (-\Delta_G < t \leq t_s) \\ 0, (t \leq -\Delta_G, t > t_s) \end{cases} \qquad (3.13)$$

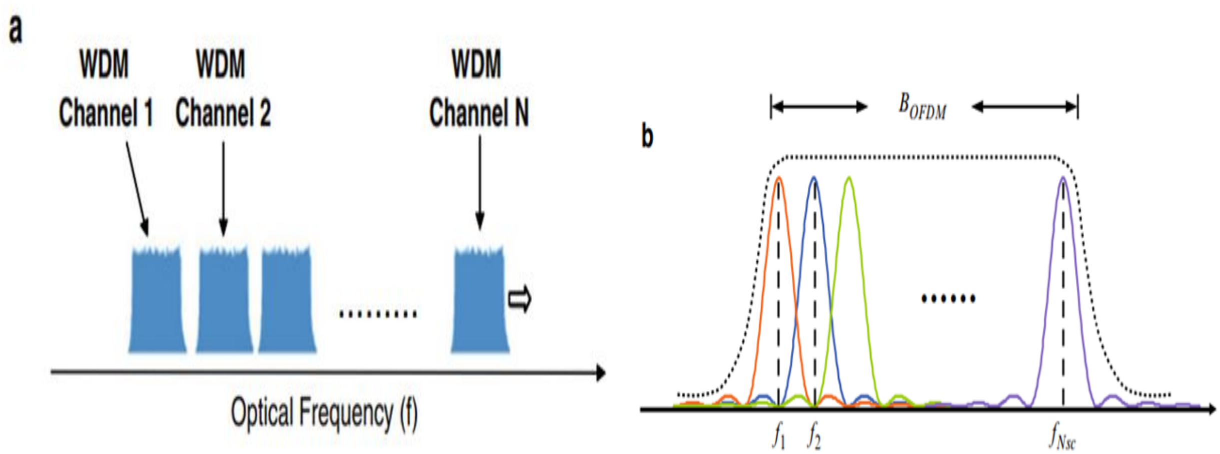
The corresponding time domain OFDM symbol is illustrated in Figure 2.4, which shows one complete OFDM symbol composed of an observation period and cyclic prefix. The waveform within the observation period will be used to recover the frequency domain information symbols.

3.2.4 Spectral Efficiency for Optical OFDM

In DDO-OFDM systems, the optical spectrum is usually not a linear replica of the RF spectrum; therefore, the optical spectral efficiency is dependent on the detailed implementation. In CO-OFDM systems, Nsc subcarriers are transmitted in every OFDM symbol period of Ts. Thus, the total symbol rate R for OFDM systems is given by

$$R = \frac{N_{sc}}{T_s} \qquad (3.14)$$

Figure 3.7a shows the spectrum of wavelength-division multiplexed (WDM) channels, each with CO-OFDM modulation, and Figure 3.7b shows the zoomed-in optical spectrum for each wavelength channel.



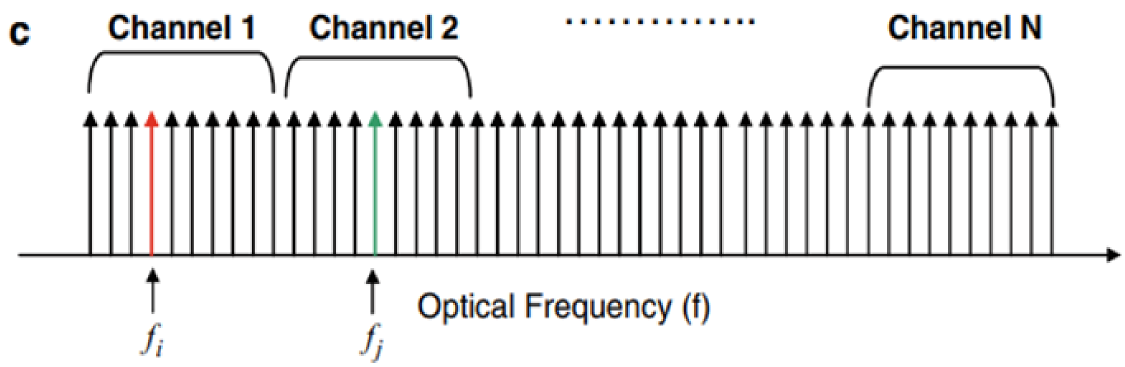


Figure 3.7: Optical spectra for (a) N wavelength-division multiplexed (WDM) CO-OFDM channels, (b) zoomed-in OFDM signal for one wavelength, and (c) cross-channel OFDM (XC-OFDM) without guard band.

Where ts is the observation period (from Figure 3.6). Assuming that a large number of subcarriers are used, the bandwidth efficiency of OFDM is found to be the factor of 2 accounts for two polarizations in the fiber. Using a typical value of 8/9, we obtain the optical spectral efficiency factor of 1.8 Bd/Hz. The optical spectral efficiency gives 3.6 bit/s/Hz if quaternary phase-shift keying (QPSK) modulation is used for each subcarrier. The spectral efficiency can be further improved by using higher order QAM modulation. To practically implement CO-OFDM systems, the optical spectral efficiency will be reduced due to the need for a sufficient guard band between WDM channels, taking account of laser frequency drift of approximately 2 GHz. This guard band can be avoided by using orthogonality across the WDM channels.

3.3.5 Peak-to-Average Power Ratio for OFDM

High peak-to-average-power ratio (PAPR) has been cited as one of the drawbacks of OFDM modulation format. In the RF systems, the major problem resides in the power amplifiers at the transmitter end, where the amplifier gain will saturate at high input power. One of the ways to avoid the relatively "peaky" OFDM signal is to operate the power amplifier at the so-called heavy "back-off" regime, where the signal power is much lower than the amplifier saturation power. Unfortunately, this requires an excess large saturation power for the power amplifier, which inevitably leads to low power efficiency. In the optical systems, interestingly enough, the optical power amplifier (predominately an Erbium-doped-amplifier today) is ideally linear regardless of its input signal power due to its slow response time in the order of millisecond.

Nevertheless, the PAPR still poses a challenge for optical fiber communications due to the nonlinearity in the optical fiber [14–16]. The origin of high PAPR of an OFDM signal can be easily understood from its multicarrier nature. Because cyclic prefix is an advanced time-shifted copy of a part of the OFDM signal in the observation period. The transmitted time-domain waveform for one OFDM symbol can be written as

$$S(t) = \sum_{k=1}^{N_{sc}} c_k \, e^{j2\pi f_k t}, f_k = \frac{k-1}{T_s} \qquad (3.15)$$

The PAPR of the OFDM signal is defined a

$$\text{PAPR} = \frac{max\{|s(t)|^2\}}{\mathrm{E}\{|s(t)|^2\}}, \; t\epsilon[0, T_s] \qquad (3.16)$$

For simplicity, we assume that an M-PSK encoding is used, where $|c_k|$= 1. The theoretical maximum of PAPR is $110\log_{10}(N_{sc})$in dB, by setting $c_k = 1$and $t = 0$. A better way to characterize the PAPR is to use the complementary cumulative distribution function (CCDF) of PAPR, Pc, which is expressed as

$$P_c = P_r\{PAPR > \mathfrak{T}_p\} \qquad (3.17)$$

Namely, $P_c$is the probability that PAPR exceeds a particular value of $\mathfrak{T}_p$.

The following are the most popular PAPR reduction approaches:

PAPR reduction with signal distortion: This is simply done by hard clipping the OFDM signal. The consequence of clipping is increased bit error ratio (BER) and out-of-band distortion. The out-of-band distortion can be mitigated through repeated filtering.

PAPR reduction without signal distortion*:* The idea behind this approach is to map the original waveform to a new set of waveforms that have a PAPR lower than the desirable value, most often with some bandwidth reduction. Distortionless PAPR reduction algorithms include selection mapping, optimization approaches such as partial transmit sequence, and modified signal constellation or active constellation extension [44,45].

3.5 Frequency Offset and Phase Noise Sensitivity

Frequency offset and phase noise sensitivity have long been recognized as two major disadvantages of OFDM. Both frequency offset and phase noise lead to ICI. Because of its relatively long symbol length compared to that of the single carrier, OFDM is prone to both frequency offset and phase noise. However, it is stressed that these two disadvantages obviously have not prevented OFDM from gaining popularity in RF communications. Frequency offset sensitivity can be mitigated through frequency estimation and compensation and phase noise sensitivity is resolved primarily via careful design of RF local oscillators that satisfy the required phase noise specification.

Nevertheless, it is important to understand the impairments from both frequency offset and phase noise. Revisit of the phase noise problem is especially important to optical OFDM, in which the laser phase noise is often relatively large, despite the fact that much research effort has focused on designing lasers specifically for the purpose of low laser linewidth. The impact of laser phase noise on optical OFDM is thus a critical issue, especially for using higher order constellation to achieve high spectral efficiency modulation. An OFDM signal with frequency offset and phase noise can be generalized as

$$r(t) = e^{j\left(2\pi\Delta f t = \phi(t)\right)} \sum_{k=1}^{N_{sc}} c_k e^{2\pi f_k t} + N(t) \tag{3.18}$$

Where Δf is the frequency offset, $\phi(t)$ is the phase noise, $N(t)$ is the additive white Gaussian noise (AWGN). By substituting $r(t)$ in Eq. (3, 4)

$$C_{ki}{}' = \frac{1}{T_s}\int_0^{T_s} r(t) e^{-j2\pi f_k t} dt, f_k = \frac{k-1}{T_s} \tag{3.19}$$

$$C_k{}' = \frac{1}{T_s}\int_0^{T_s} \left\{ e^{j\left(2\pi\Delta f t = \phi(t)\right)} \sum_{k=1}^{N_{sc}} c_k e^{2\pi f_k t} + N(t) \right\} e^{-j2\pi f_k t} dt,$$

$$= \sum_{l=0}^{N_{sc}} c_l \frac{1}{T_s} \int_0^{T_s} e^{j2\pi(f_l - f_k)t + j\left(j2\pi\Delta f_t + \phi(t)\right)} \, dt + n_k = \eta_0 c_k + \sum_{l \neq k} \eta_k - l^{c_l} + n_k$$

$$c_k{}' = \eta_0 c_k + I_k + n_k \tag{3.20}$$

We have defined the ICI coefficient η_m as

$$\eta_m = \frac{1}{T_s} \int_0^{T_s} e^{j\left(2\pi\left(f_m' + \Delta f\right)t + \phi(t)\right)} \, dt, \quad f_m' = \frac{m}{T_s}, m = -(N_{sc} - 1), \dots, o, 1, \dots (N_{sc} - 1) \tag{3.21}$$

$$n_k = \frac{1}{T_s} \int_0^{T_s} N(t) \, e^{-j2\pi f_k t} dt \tag{3.22}$$

$$I_k = \sum_{l \neq k} \eta_{0-l^{c_l}} \tag{3.23}$$

In Eq. (3.18), the first, second, and third term respectively correspond to the signal, ICI, and AWGN. The ICI coefficient $\eta_m$represents the interference between two subcarriers with the index difference of m. The nonvanishingvalue of $\eta_m$signifies the finite ICI as a result of either frequency offset or phase noise.

3.5.1 Frequency Offset Effect

When only frequency offset effect is considered, by setting $\phi(t)$ to zero and carry out the integration in Eq. (3.21).

$$\eta_m = \frac{\sin\left(\pi(m + \delta)\right)}{\pi(m + \delta)} e^{-j\pi(m+\delta)} \tag{3.23}$$

Where $\delta = \Delta f, T_s$ is the normalized frequency offset. Figure 3.8 shows the ICI coefficient η_m when the frequency offset $\delta = 0$ and 0.25. It can be seen that when δ is equal to zero or any integer, the ICI coefficient equals zero or any number of m, which is in essence the orthogonality condition of Eq. (3.5). When δ equals a noninteger value, such as 0.25 as shown in Figure 3.8, there is a residual component of η_m for any number of m, which implies finite interference from one subcarrier to any other subcarrier. The variance of the interference I_m due to frequency offset can be computed as:

$$\sigma_{ICI}^2 = c_c^2 \sum_{m=N_{sc}/2+1, m\neq 0}^{N_{sc}/2} \eta_m^2 \tag{3.24}$$

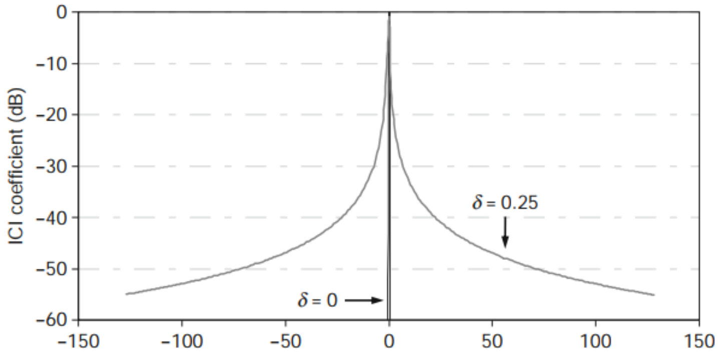


Figure 3.8: Subcarrier index difference, m

The ICI coefficient, η_m, as a function of the subcarrier index difference, m, while varying the frequency offset, δ. The frequency offset is normalized to the subcarrier spacing.

Where δ_c^2 is the variance of the transmitted information symbol for each subcarrier. Assume that the interference is also AWGN. The effective SNR γ' is given by

$$\gamma' = \frac{\eta_0^2 \delta_c^2}{C_{ICI}^2 + \delta_w^2} \tag{3.25}$$

2.5.2 Phase Noise Effect

Phase noise has been extensively studied since OFDM began to be incorporated into the standard. Equation (3.21) becomes

$$\eta_m = \frac{1}{T_s}\int_0^{T_s} e^{j\left(2\pi' f_m t+\phi(t)\right)}dt\,, \qquad f'_m = \frac{m}{T_s}, m = -(N-1), \dots, 0, \dots, N-1 \tag{3.26}$$

Denote $\eta_0 = |\eta_0|e^{j\phi_0}$. ϕ_0 is also called the common phase error (CPE).Substituting Eq. (3.26) into Eq. (2.20) and making some simple rearrangements, we derive

$$c_k^{\sim} = c'_k e^{-j\phi_0} = |\eta_0|c_k + e^{-j\phi_0}\sum_{l\neq k}\eta_k - l^{C_l} + e^{-j\phi_0}n_k \tag{3.27}$$

Where $c_k^{\sim}$is the received information symbol after removing the common phase error. It can be seen that the phase noise has two major effects. First, CPE,ϕ_0, rotates the entire constellation. This can be estimated and the skewed constellation can be rectified through simple collective rotation as shown in Eq. (3.27). Second, ICI impairment, which is the second term in Eq. (3.27), is manifested by the nonvanishing terms of $\eta_0$or nonzero m. To assess the ICI impairment of phase noise, we make a further assumption that the phase noise $\phi(t)$observes the Wiener process, such that

$$\mathrm{E}\left[\left(\phi(\tau - t_0) - \phi(t_0)\right)^2\right] = 2\pi\beta\tau \tag{3.28}$$

Where E[ ]is the ensemble average, and β is the laser linewidth or, more precisely, the combined linewidth including both transmit and receive lasers. By denote$|\eta_0| = \alpha + \zeta$, where $\alpha = \langle|\eta_0|\rangle$, and ζ is the residual amplitude noise for each OFDM symbol. From Eq. (3.27), the SNR of $c_k^{\sim}$can be represented as

$$\gamma' = \frac{\alpha^2\sigma_k^2}{n^2 + n_p^2} \tag{3.29}$$

Where σ_k^2 and n_k^2 k are respectively the variance of the signal and AWGN noise for the kth subcarrier, and $n_p^2$is the variance for the noise including ICI and the amplitude fluctuation of the $|\eta_0|$. $\sigma_k^2$of 1 is assumed for simplicity. From Eq. (3.27), n_p^2can be expressed as

$$n_p^2 = \mathrm{E}[\zeta^2] + \mathrm{E}\left[\sum_{l\neq k}|\eta_{k-l}|^2\right] \tag{3.30}$$

Denoting $a_1 = [|\eta_0|^2]$, then

$$\mathrm{E}[\zeta^2] = \mathrm{E}[|\eta_0|^2] - (\mathrm{E}[|\eta_0|])^2 \ = a - a^2 \qquad (3.31)$$

It also written that

$$\mathrm{E}\left[\sum_{l\neq k}|\eta_{k-1}|^2\right] = 1 - \mathrm{E}[|\eta_0|^2] = 1 - a_1 \tag{3.32}$$

Therefore, the effective SNR impaired by the phase noise becomes

$$\gamma' = \frac{a^2}{\gamma^{-1} + 1 - a^2} = \gamma \frac{a^2}{1 + (1 - a^2)\gamma} \tag{3.33}$$

$$\gamma = \frac{\delta_k^2}{n_k^2} \tag{3.34}$$

Where γ is the SNR without phase noise impairment. The SNR penalty or reduction from the phase noise-free system in decibels is thus

$$\Delta\gamma(dB) = 10.\log_{10}(\gamma') - 10.\log_{10}(\gamma) = 10.\log_{10}\left(\frac{a^2}{1 + (1 - a^2)\gamma}\right) \tag{3.35}$$

$\Delta\gamma(dB)$can be also interpreted as the additional SNR needed to achieve the same effective SNR or BER.

CHAPTER FOUR

SIMULATION RESULT, ANALYSIS AND DISCUSSION

4.1 Introduction

Today Ethiopian communication system like fixed telephone, mobile phone and broadband Internet delivered by Ethiopian Telecommunication Corporation. Both wireless and wired communication channels rapidly growing. The requirement of broadband for daily life of human being is became critical.

Internet broadband communication by wired is in two way copper cable and fiber optics; depending on the capacity and future communication growth of broadband copper is running out of capacity. Fiber optics is the main solution for the future because it has unlimited bandwidth to carry large data and go long distance with minimum loss. ETC has introduced optical fiber cable in around 1988 for inter exchange link in Addis Ababa and its application as transmission media has extended in other areas outside the capital.

In fiber optics different types of multiplexing and modulation to map message signal on carrier among them wave length decision multiplexing, frequency division multiplexing and time division multiplexing. This all have their advantage and disadvantage and currently most publicized are FDM and WDM in fiber optics communication. In this thesis orthogonal frequency division multiplexing is the major target and the current Ethiopian broadband communication that use DWDM are compered.

The frequency, speed and wave length have mathematical relationship that show one is depend on other but in communication system when we use parameter selection as central focus in operation and system setting one is more advantageous then other based on environment and technology we use.

Fiber optics broadband communication is the future world inter communication with minimum limitation and innumerous advantage. Both frequency and wave length division multiplexing are major modulation and multiplexing techniques.

In this chapter, the simulation result is presented to investigate the performance of fiber optics broadband communication using orthogonal frequency division multiplexing described in previous chapter. The evaluation of the performance carried out using Optiysystem software with QAM modulation scheme.

4.2 Adama city fiber optics broadband user current situation.

Total coverage of fiber	80Km
Number of broadband user currently	4000
Rate of increase currently	150 per month
Types of fiber	Single mode
Technology used	Digital
Modulation type currently	DWDM
Maximum capacity today delivered	400Mbps

Table 4.1 data from Adama Ethiopian Telecommunication station

4.3 Fiber optics attenuation per kilometer

Wavelength (nm)	Maximum Value (dB/km)
1310	0.33 - 0.35
1383	0.31 -0.35
1550	0.19 - 0.20
1625	0.20 - 0.23

Table 4.2 range of fiber optics wavelength and attenuation per kilometer from ITU.

4.4 Simulation parameters for OFDM

NO.	Parameters	value
1	Data rate	40Gbps
2	Wavelength	1550nm
3	SMF length	80Km
4	SMF attenuation	0.2dB/Km
5	CW laser frequency	193.1THz
6	CW laser line width	0.1MHz

7	CW laser desperation	16.75pd/nmKM
8	Gain	35dB
9	Cyclic prefix	16
10	FFT	64
11	M-QAM	
12	Maximum possible subcarrier	1024
13	Subcarrier point	512
14	Subcarrier location	257
15	16-QAM	7.5GHz
16	EDFA optical Fiber gain	0.2dB/KM
17	Photo detector central frequency	193.1THz
18	Software1	Optiysystem 15

Table 4.3 simulation parameter and value

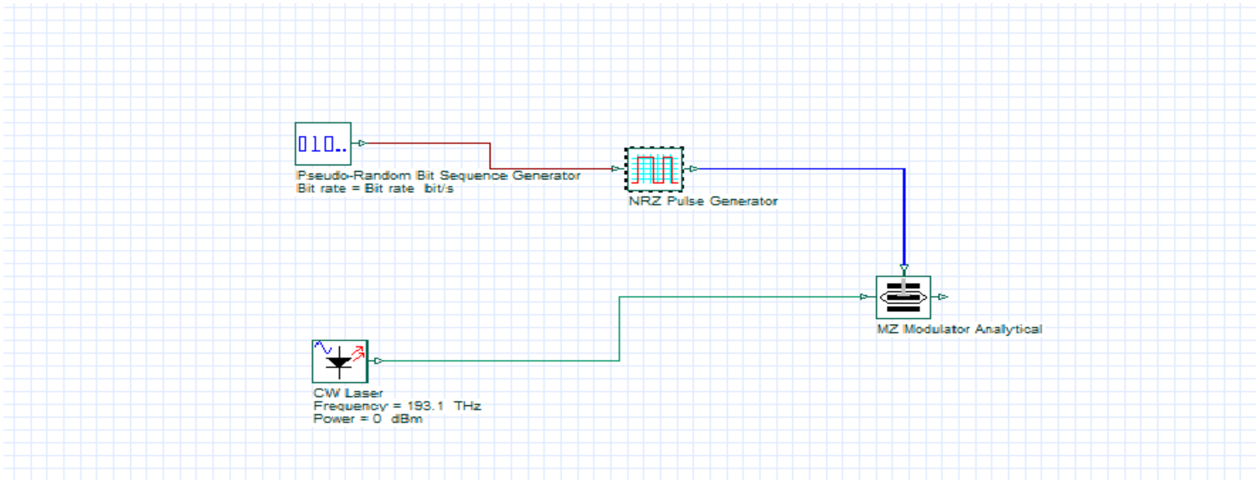
4.5 Attenuation Vs wavelength

Range(nm)	Ref. λ(nm)	Max.α Difference (dB/km)
1285-1330	1310	0.03
1525-1575	1550	0.02

Table 4.4averagerange of fiber optics wavelength and attenuation per kilometer from ITU.

4.6 Optiysystem transmission fiber optics design

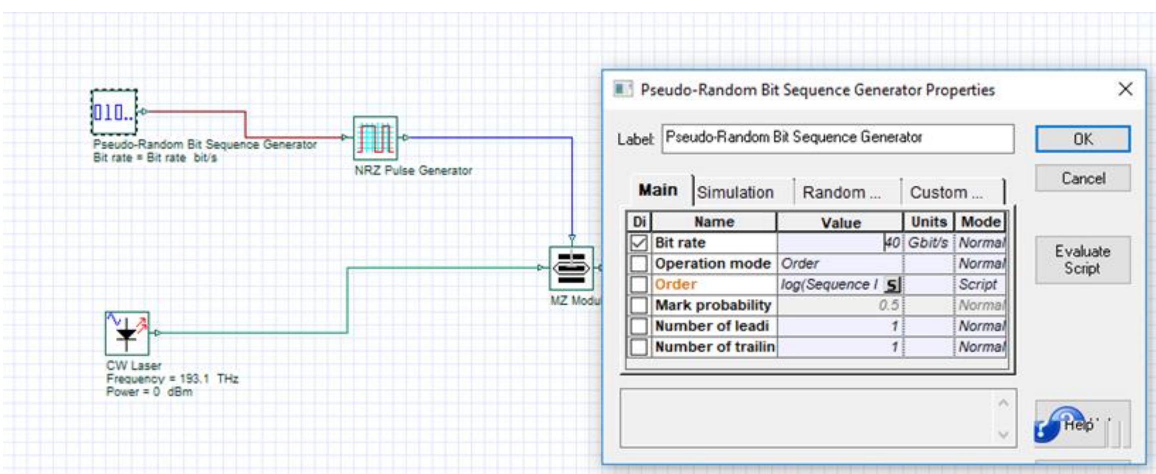
Fiber optic communication use light to carry message signal for that electrical to optical conversion take place in MZ modulator. The two input electrical source and optical source as well as transmitter simulation parameters are shown below. At the transmitter bit sequence generator used generate digital electrical signal that been message signal as the requirement data rate amount. In this thesis 40Gbps is considered to be implement in the simulation by considering the broadband data speed of Ethiopia deliver is in Mbps not in Gbps. After digital signal that required to be transmitted is generated it need pulse shaping to do that NRZ pulse generator is followed. Another component that is main in the transmitter side is optical source generator named as CW laser. Three optical source generators are there LED, LASER and DFB among these thee CW laser is selected for this simulation because it is used for long distance strong emission to reach the distance required. The main thing happen core of the simulation is to be proceed to the next step is electrical to optical conversion is performed at transmitter by MZ modulator. By connecting these all together the required signal is generated to be loaded on fiber optics. The two figure blow shows how to connect each component one with another component by keeping its compatibility. The first figure show how connection undertake. The second one show how parameter select value for simulation.



optical transmitter by optiysystem

Figure. 4.1 optical source, electrical source, NRZ pulse generator and MZ modulator at transmitter

From the above figure each components have their own value diferent option are there from that values and options the user select in the form of figure blow. when chosing bit rate value doublecling clicking on the compone and select the parameter bit rate as shown figure blow in this simulation 40Gbps that selected in table 4.3 above choosed and ready to the next proccess as shown in figure 4.2 blow.

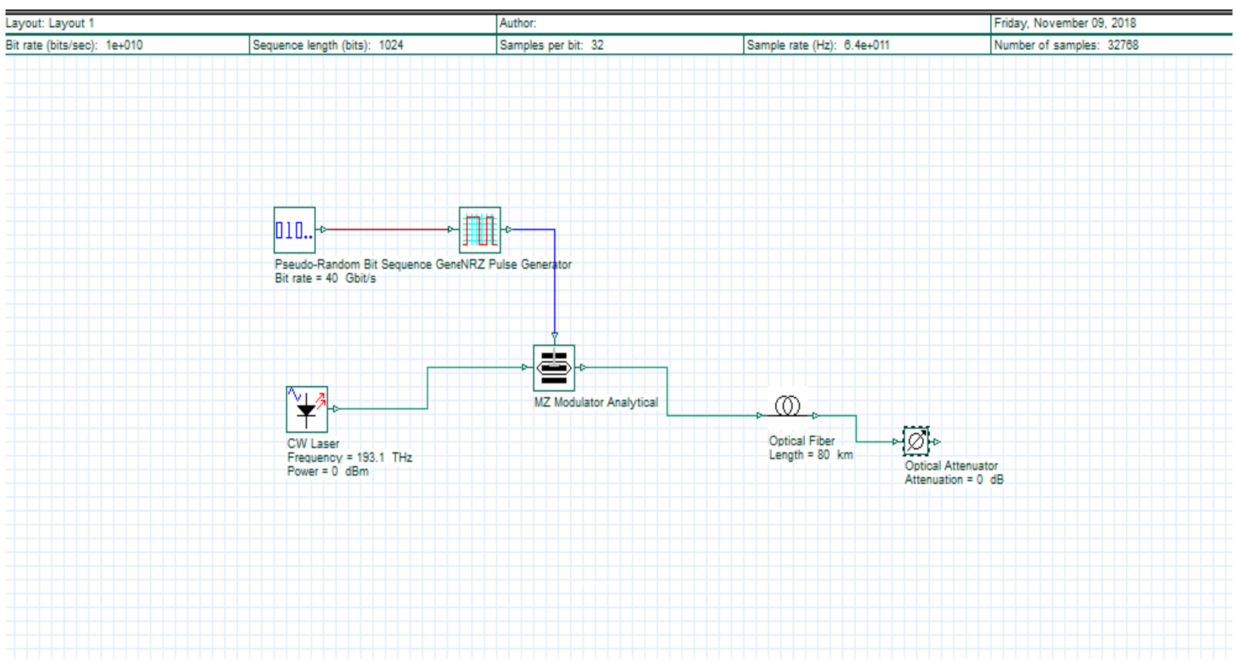


Tx simulation parameter

Fig. 4.2 selection of parameter and value for parameter.

4.7 Optisystem transmission channel

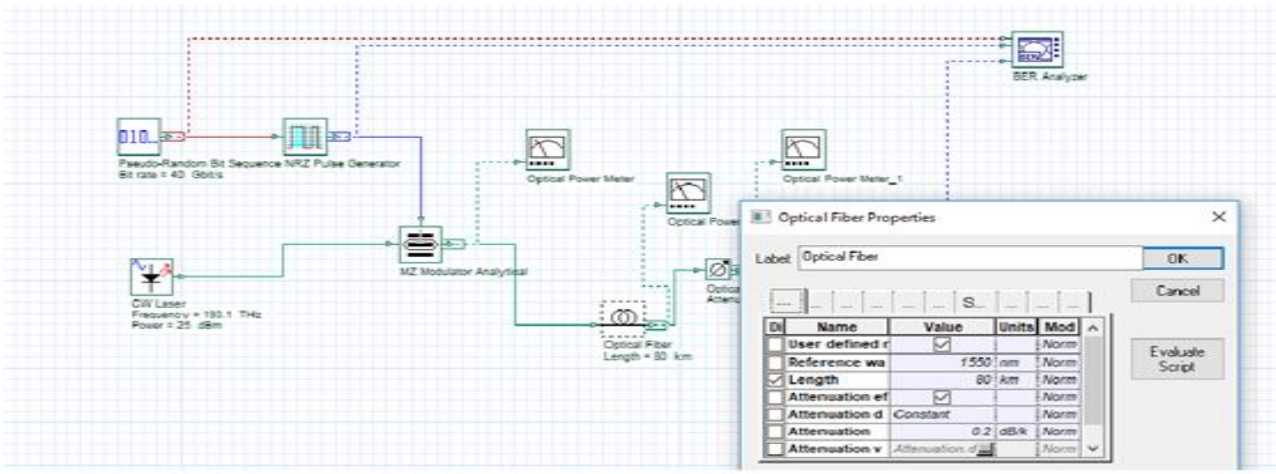
Fiber optics that carry the message using light is connected to optical source and carry message to destination. The simulation parameters of fiber optics and values shown blow. Length of fiber optics and type fiber used in the simulation is consider here. As shown blow the length of fiber is 80Km, type of fiber optics used is single mode fiber, attenuation per Km is 0.2Db/Km. Fiber optic carry the massage signal in the form of light wave and send to receiver. After its parameter value selected optical fiber connected to MZ modulator directly. Since optical fiber support light pulse the digital signal that converted from electrical to light is propagate in the fiber. This shows that one of the advantage of fiber optics that signal loss is not much as that of transmitting by electrical form is confirmed.



optical communication channel by optiysystem

Fig. 4.3 fiber optics channel and tranmitter connection.

In Figure 4.4 below, the fiber optics simulation parameter like wave length1550nm,fiber optics length 80Km and attenuation 0.2dB/Km is shown with total components.

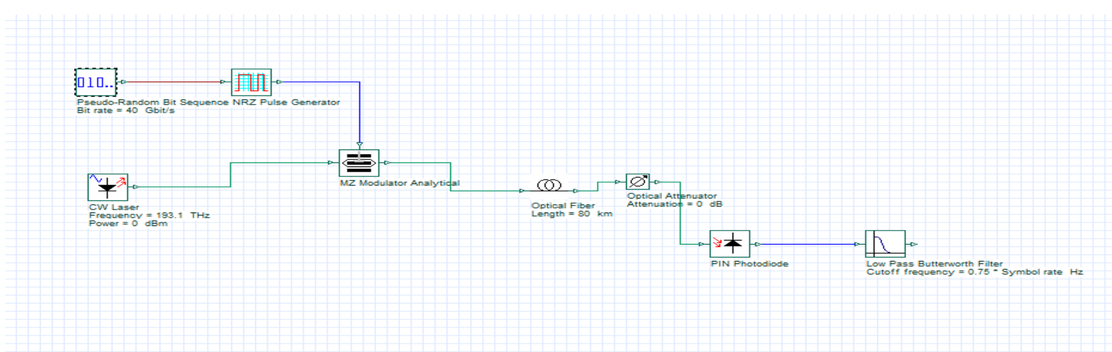


optcal fiber simulation parameter

Fig. 4.4 Fiber optics transmitter, medium and simulation parameter.

4.8 Optisystem receiver

At receiver side signal that carried by fiber optics in light or optical form is converted to electrical by PIN photo diode. The main operation of PIN photo diode is receiving optical pulse from fiber optics and convert it back to electrical. Because the customer material support electrical signal and in digital form. The figurer blow show the design and ways of connection each component from transmitter to receiver. After optical to electrical by PIN photo diode then final signal output is electrical. Figure blow shows some Simulation results at receiver.

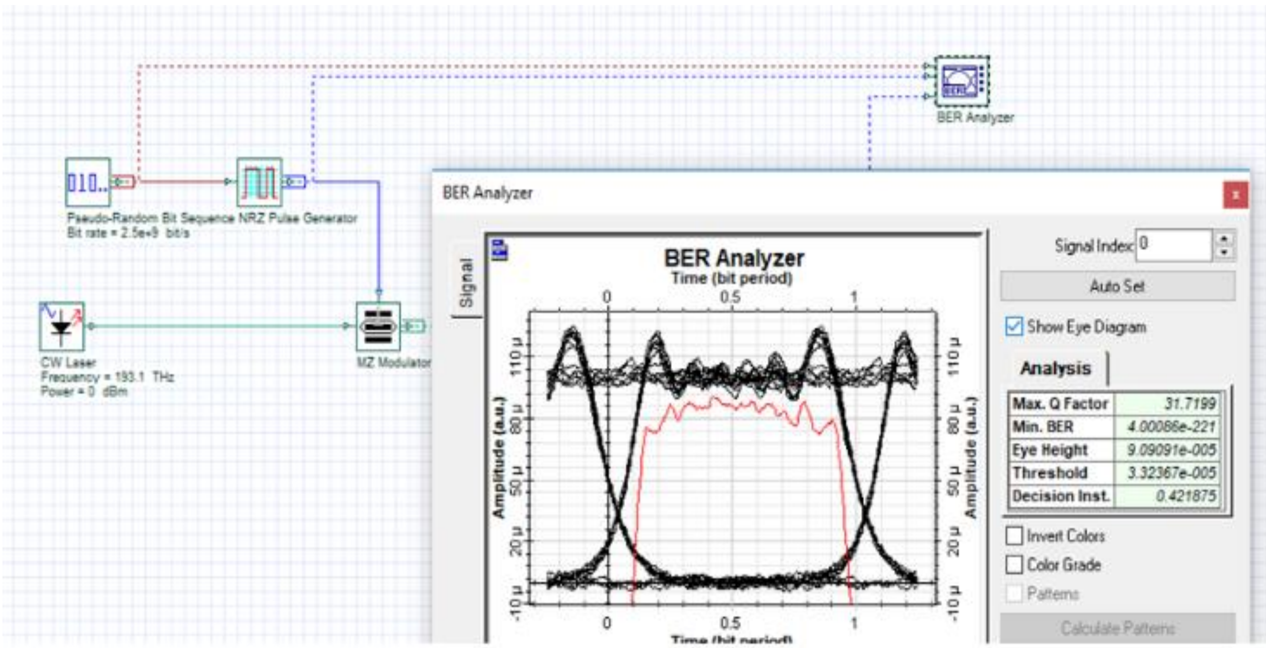


optical full channel reciever

Figure 4.5 optisytem full channel model from transmitter to receiver

The quality factor or Q-factor of BER shown by eye diagram in figure 4.6 blow.the eye diagram give as the maximum value at which signal is good. In this simulation the area at where eye diagram wide is indicate the quality of signal. The value indicate the horizontal line of frequency from 0 to 1 Hz and vertical value wave length 10 to 80 micro meter is where Q- factor is good and signal strength reach its peak.

Maximum Q-factor 31.7199 at frequency 0.5Hz and wave length 50 micro meter.

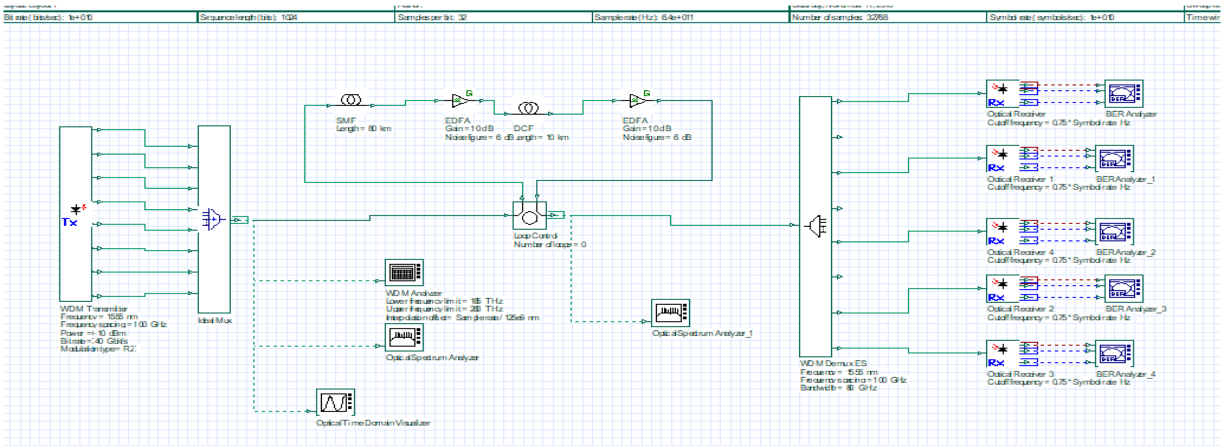


BER analyzer

Figure. 4.6 Transmitter, medium, receiver and BER simulation result.

4.9 Dense wavelength division multiplexing

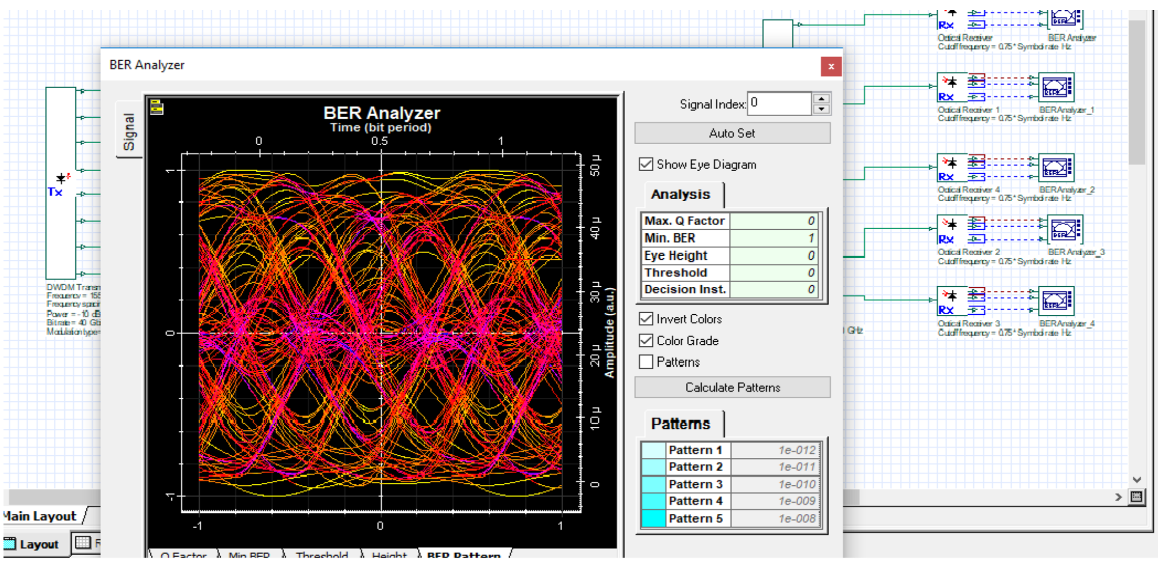
DWDM modulation techniques used to modulate signal using wavelength of different light colors. WDM transmitter blow multiplex the signal in to eight to transmit the source signal by dividing into eight. To do so transmitter WDM use wave length 1555nano meter, frequency 100 GHz, power 10dBm and the transmitted signal selected for this simulation is 40Gbps bit rate. The simulation and how it work is shown blow. Components used in the simulation are DWDM transmitter, Ideal Mix, SMF 80Km, 2EDF 5Km, DCF10Km, DWDM Demux ES and simulation indicator components.Generally the figure 4.7 blow show full DWDM communication channel with eight multiplexer.



DWDM for optical tranismision

Figure 4.7 Eight DWDM optical communication design

The eye diagram simulation result below shows the maximum and the minimum wave length in which the signal run. As the amplitude indicates wave length between 10 to 40 in average and min BER is 1 and those other related to eye diagram is zero.



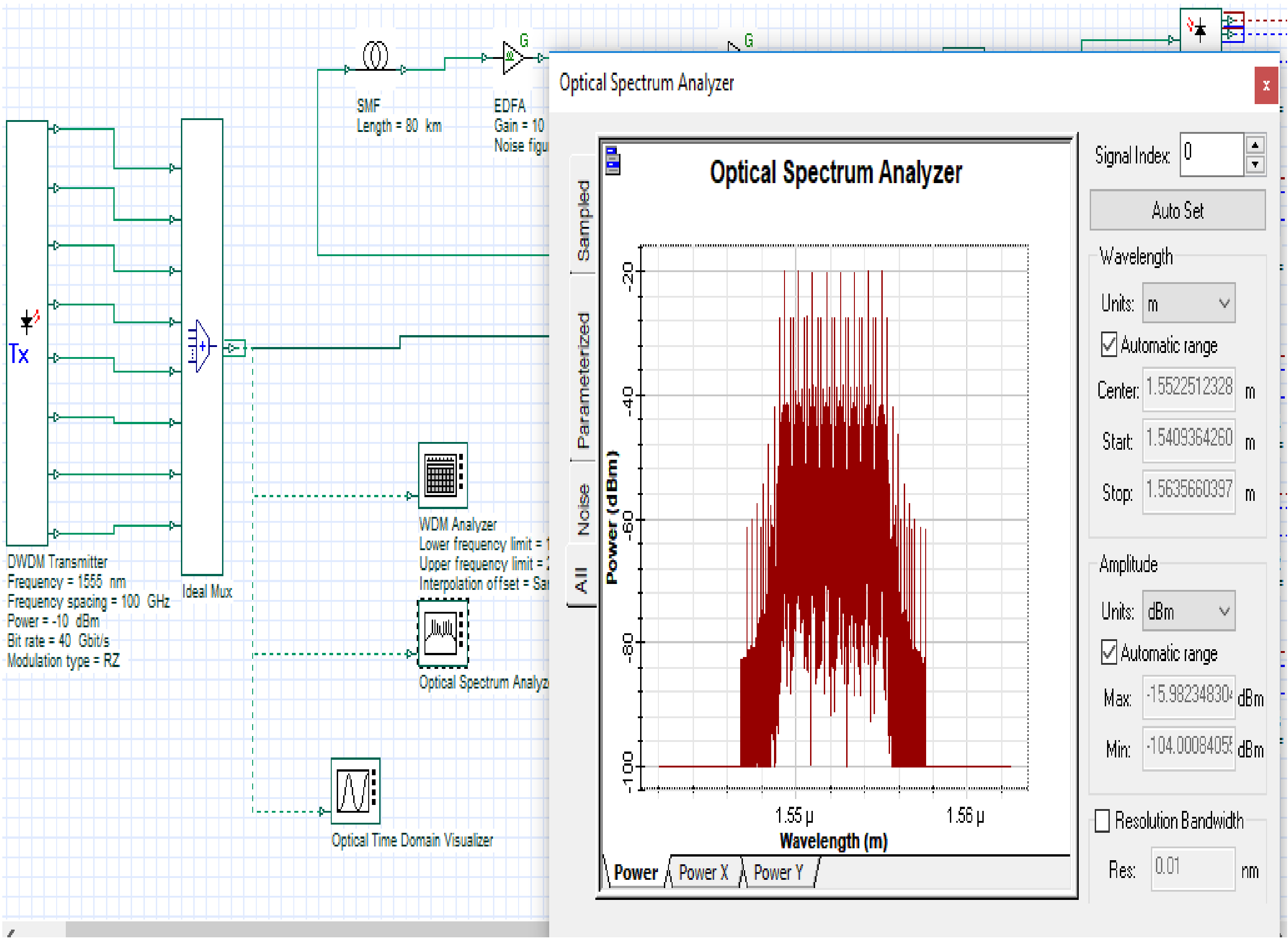
DWDM BER Analyzer

Fig.4.8 optisystem DWDM parameter design and BER simulation result

4.9.1 DWDM BER Analyzer and Optical Spectrum Analyzer

Simulation results of optical spectrum anylizer indicate different value at diffirent wave langth.

As the simulation indicate the maximum power is between the wavelangth of 1.552 , it is high tripping signal is between 1.5409m and 1.563m aproxmetly. From this the maximum power and minimam power depend on wave langth. In this simulation minimum power -104.0008 and maximum -15.98 in dBm .

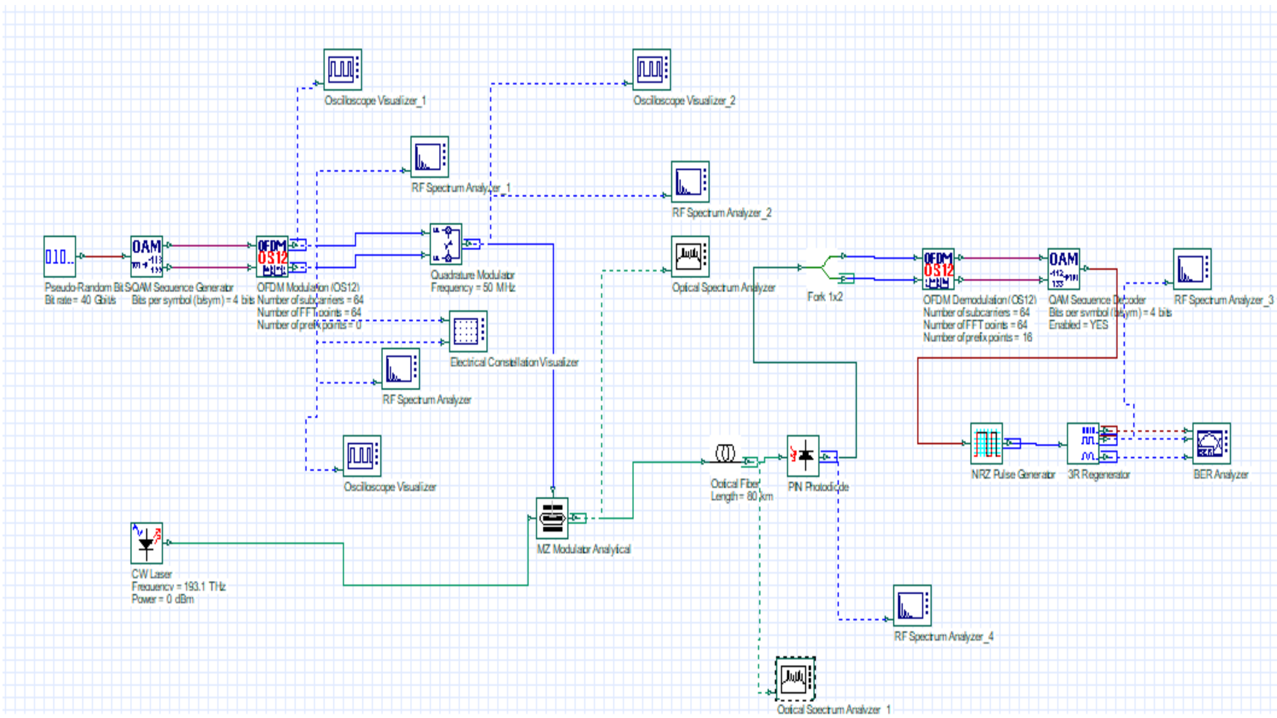


spectrum Analyzer

Fig. 4.9 simulation of DWDM by BER and Optical Spectrum Analyzer.

4.10 OFDM modulation and OFDM demodulation

Simulation design of OFDM modulation and demodulation. Components of OFDM optical communication and how it work is shown in figure blow. OFDM modulator with different M-QAM at transmitter and OFDM demodulator of different M-QAM at receiver are indicated in the following simulation result. By changing the value of M the maximum power at which the signal attains is varied. This mean that



ofdm in/out

Figure 4.10 OFDM full design

In the above design, the Quadrature Amplitude Modulation (QAM) is implied to modulate the signal at the transmitter. The input data are needed to be mapped and modulated after generation. The 4-QAM, 16-QAM and 64-QAM modulation are considered for this case. The power spectrum density of 40 Gbps data which are modulated at 4-QAM, 16-QAM and 64-QAM are shown in figure 4.8, 4.9and 4.10. As expected, the power of signal increases as the number of modulation format increases. The maximum signal power of 4-QAM is -10 dBm, the maximum power of 16-QAM is -5 dBm and signal power of 64-QAM is 0 dBm as shown below.

M-QAM	Speccttral efficiency in dBm

64-QAM	0
16-QAM	-5
4-QAM	-10

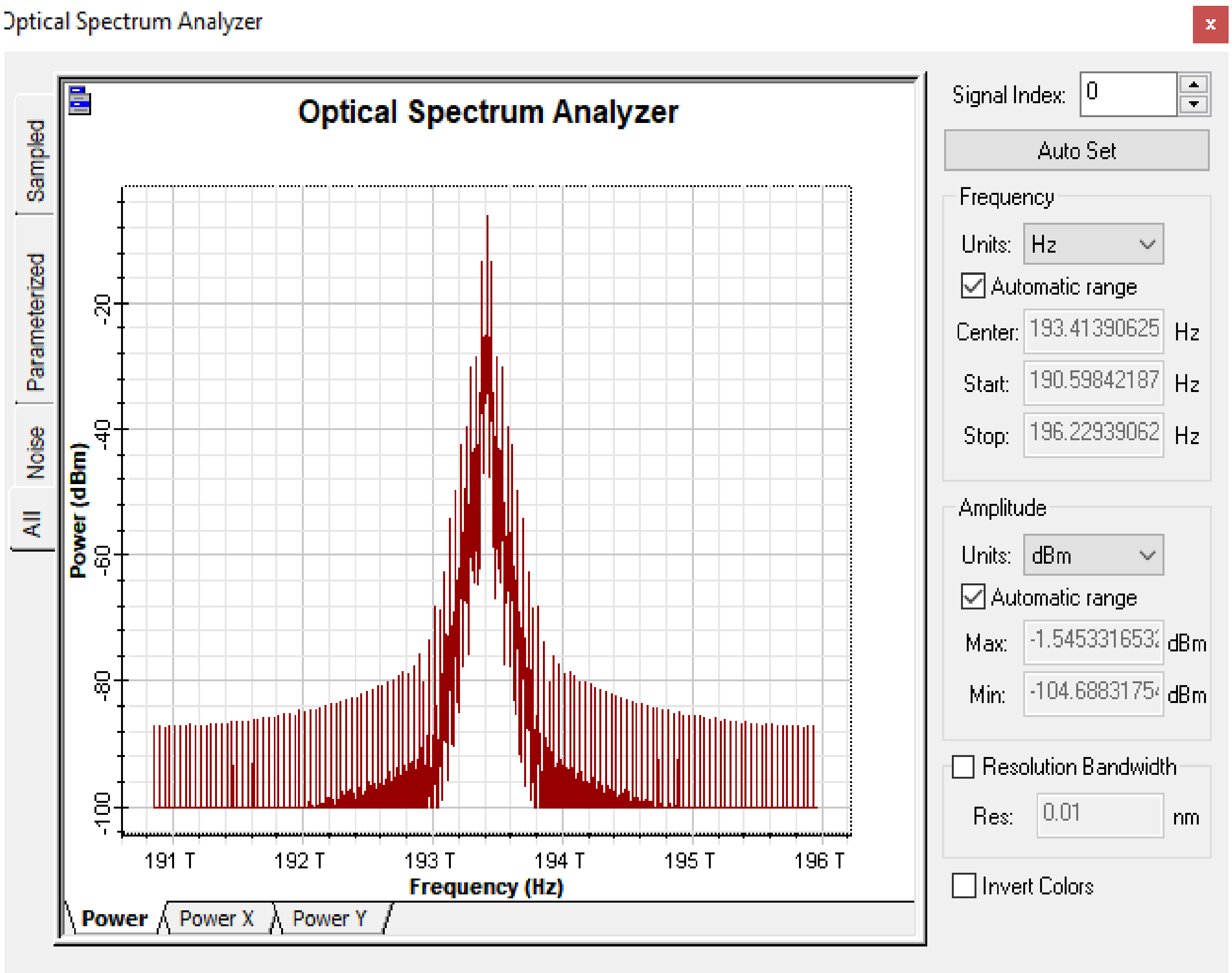


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Figure 4.11 ower spectrum density of 4-QAM

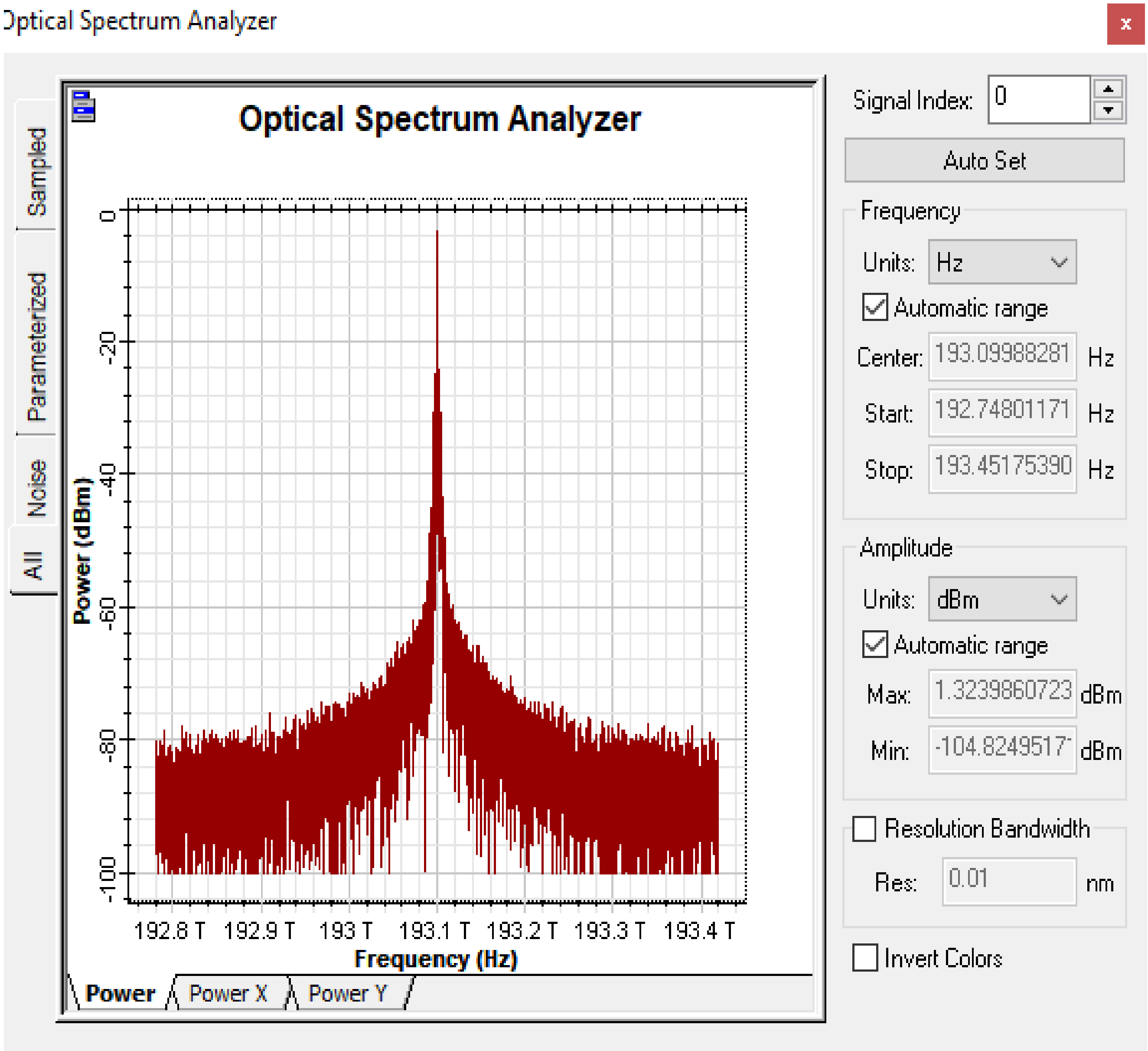


Figure 4.12Power spectrum density of 16-QAM.

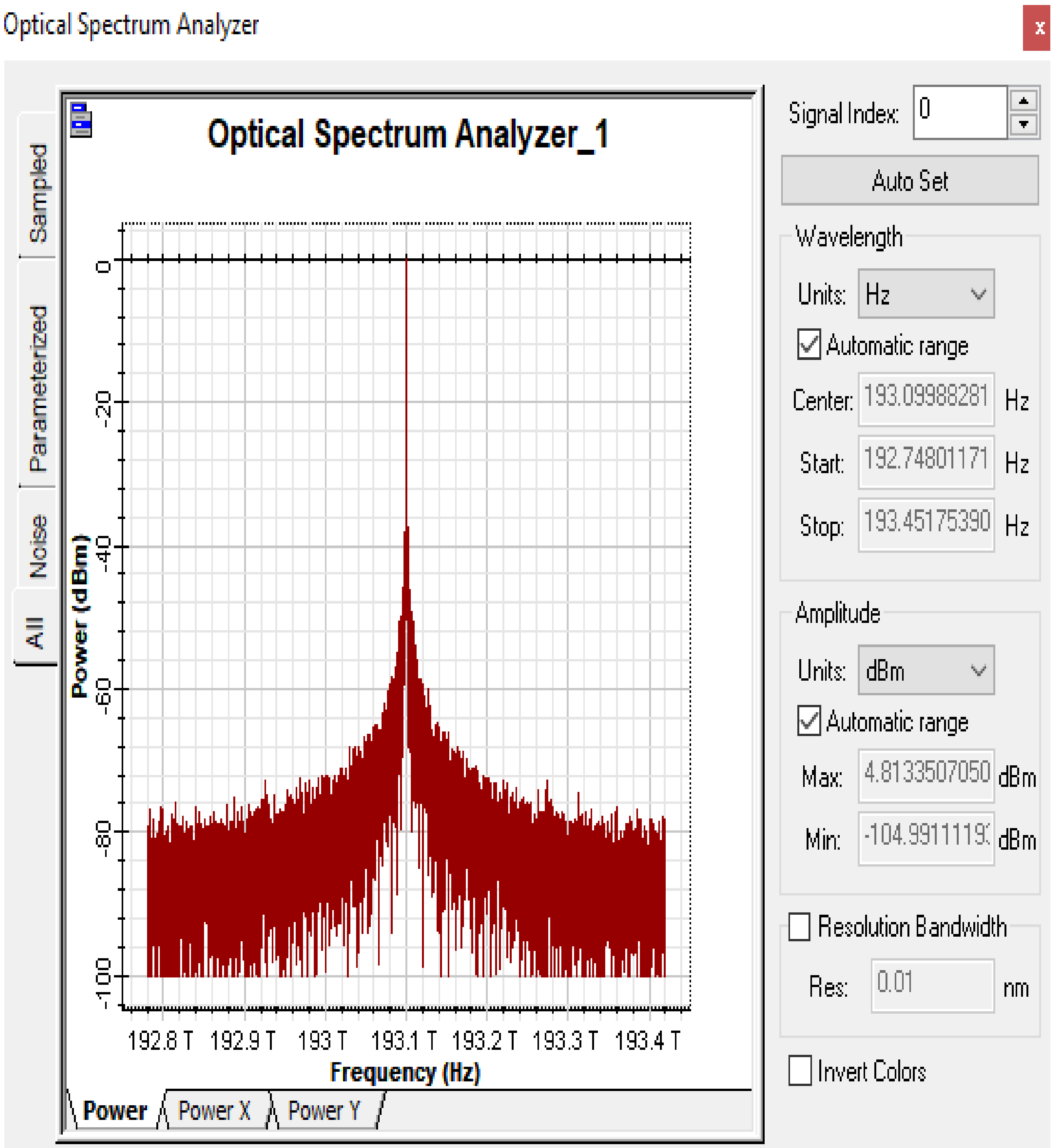
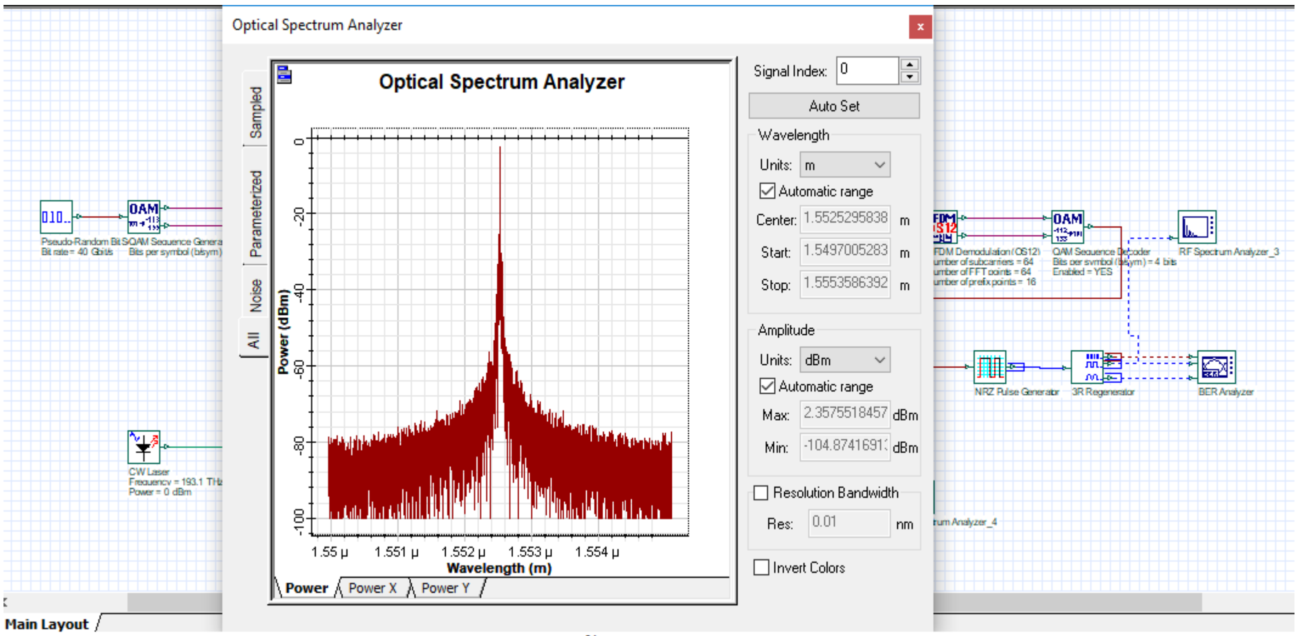


Figure 4.13 Power spectrum density of 64-QAM.

Figure below 4.14 shows spectrial power with relation to wave langth. From simulation result it atian it is maximum power at the wave length of 1.5525295 micro meter. The peack power at the centerl wave langth is 2.357dBm. the avarege power befor and after peck power is between -100dBm and -80dBM this shows that the chromatic dispersion that is maximum in DWDM is less in OFDM broadband communication.



ofdm r3

Fig 4.14 OFDM optical spectrum analyzer

Performance of signal of OFDM Vs DWDM strength shown table below.

Wave length(µm)	OFDM (dBm)	DWDM (dBm)
Min 1.5409	-104.87	-104.00
max 1.5635	2.35755	-15.98
Cen. 1.5525	0	-20

Table 4.5 power spectral efficiency of OFDM and DWDM

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION FOR FUTURE WORKS

5.1 Conclusion

In this thesis, the performance of fiber optics broadband communication using OFDM advantage over other broadband communication is investigated. This investigation has shown the potential benefits of fiber optics transmission usingOFDM rather than DWDM to achieve improved performance in power spectrum efficient.

Thepower spectrum efficiency performances of OFDM and DWDM were compared by using Optisytem simulation result. According to results have been done in chapter four; all OFDM multiplexing and modulation have better performance than DWDM. As result shows, OFDM broadband communication hasbetter performances than DWDM broadband communication. This is occurredBecause of the consumed bandwidth by OFDM is less than DWDM.

The comparative performances of OFDM and DWDM are concluded optical spectrum analysis as follows. OFDM reach its maximum power 2.3dBm at value of wave length 1.552529 micro meter where as DWDM reach its maximum power of -15.98dBm at value of wave length 1.552529 micro meter. As the result shows OFDM is highly effective power than OFDM at approximately the same wave length value.

5.2. Recommendation for Future Works

- In this thesis, the optical spectrum efficiency was considered for simulation over

Optisytem. The performance of the systems can be measured by other parameter.

- For all networks, only single mode fiber have been assumed. Multi-mode can be implemented to evaluate the overall system performance.

- Only QAM modulation technique assumed in this work. Other modulation schemes can also be used toinvestigate the system performance.

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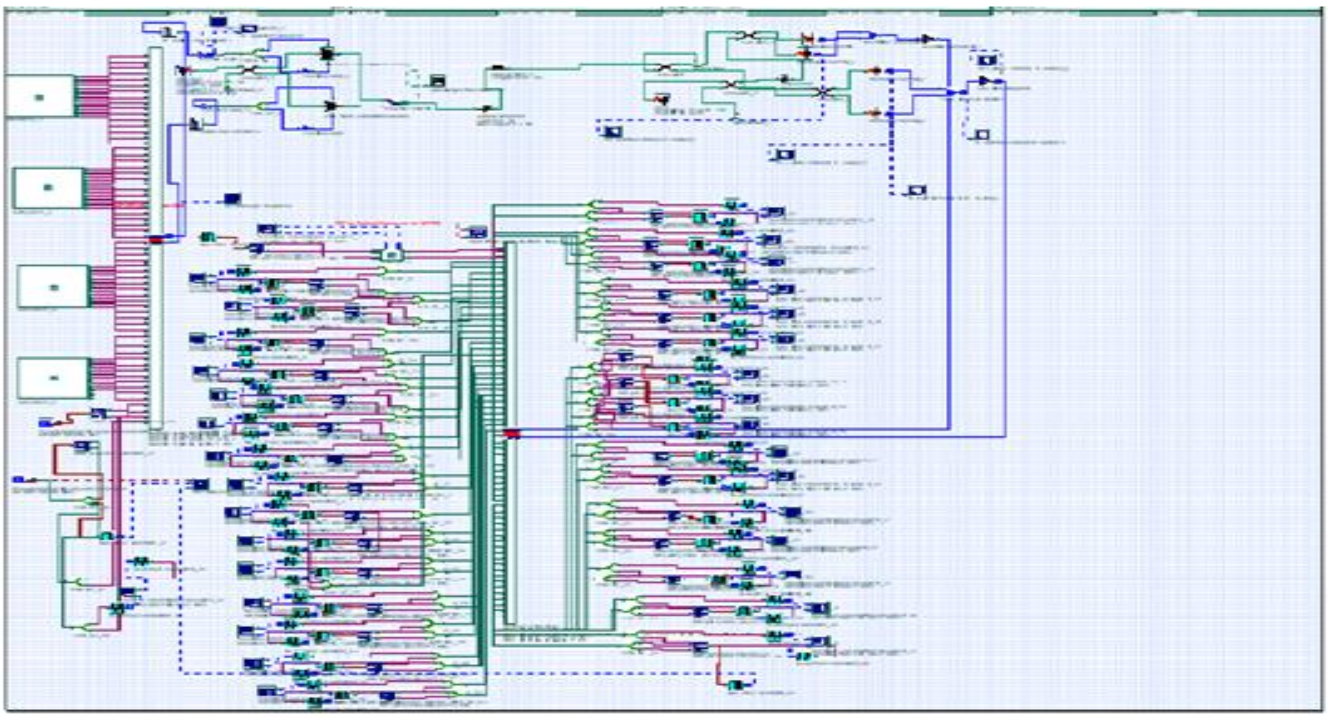
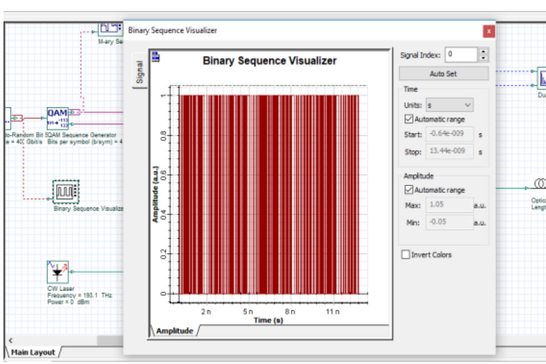
APPENDIX

Optisystem Simulation Block Diagram

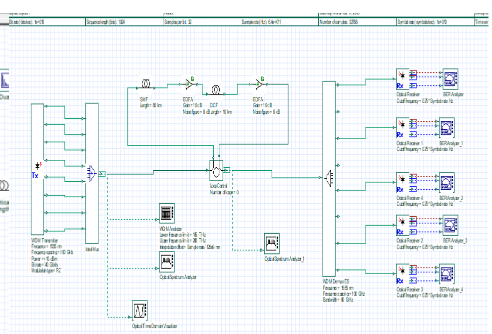
This appendix summarize transmitter, channel, receiver, DWDM and OFDM



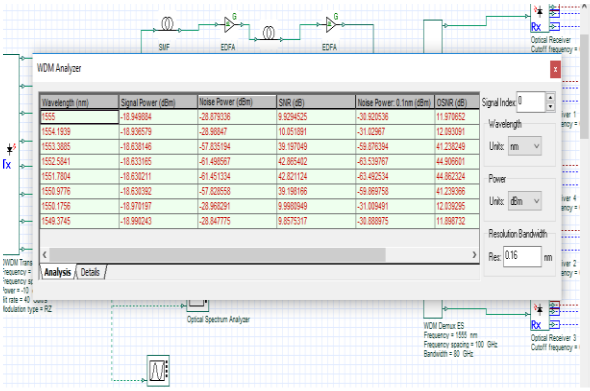
dwdm complex design



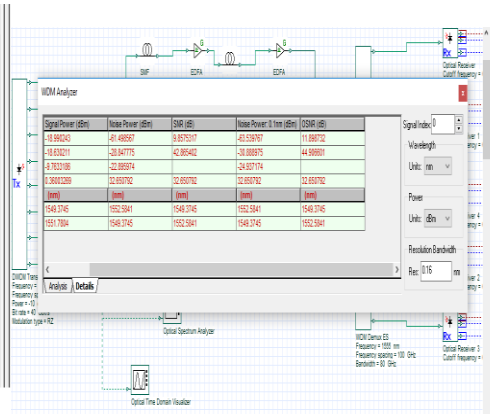
BSV Tx



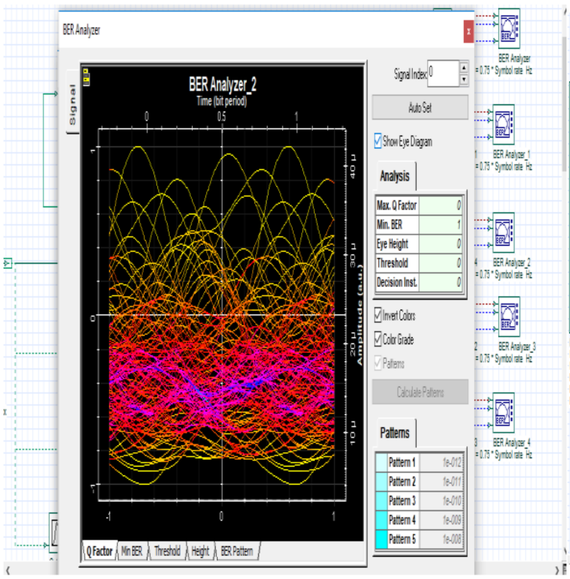
DWDM for optical transimision



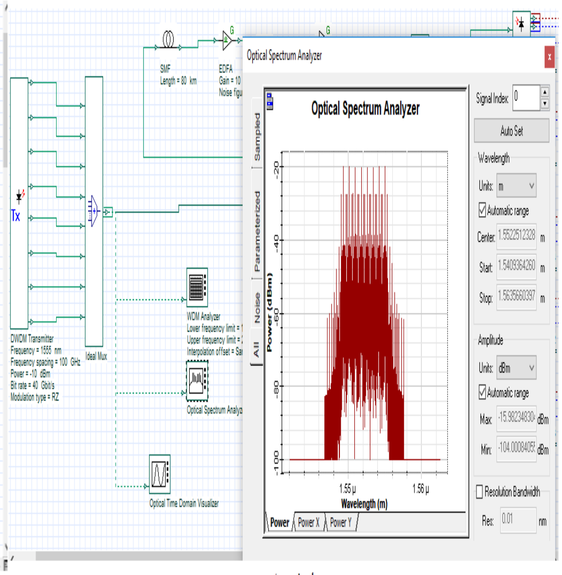
simulation of WDM analyzer



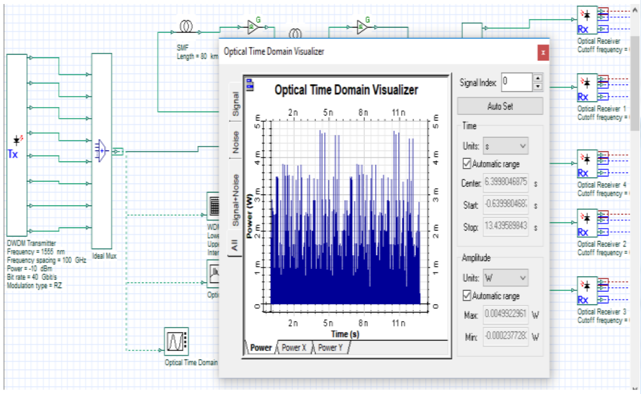
WDM Analyzer detail



Analyzer Q-Factor



spectrum Analyzer



DWDM Optical Time Domian Visualizer