Ministry of Higher Education &Scientific Research
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Laser & Optoelectronics Engineering Department

Design and Performance optimization of WDM light wave system using NRZ modulation formatA

project

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By

Fadhel Abbas feddal

Qassim yahya Qassim

Abdulkareem Kadhim Ali

Supervised by

Safa Salam Radhi

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SUPERVISOR CERTIFICATE

We certify that the project entitled "wavelength division multiplexing system" was prepared under my supervision in the Laser and Optoelectronics Engineering Department \ University of Technology, as a partial fulfillment of the requirement of the B.Sc. Degree in Optoelectronics Engineering.

Signature:

Name:

Title:

Date:

DEDICATION

We dedicate this project to God Almighty our creator, our strong pillar, source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program and on His wings only have we soared.

We also dedicate this work to our parents who encouraged us along the way and made sure to encourage on whatever is necessary to finish what we started, God bless you.

We also dedicate our sincere thanks to the greats of the golden age

The master of optics: Al-Hasan bin Al-Haytham.

The master of mathematics: Muhammad ibn Musa al-Khwarizmi.

The master of electronics and communications: Nikola Tesla.

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Abstract

This project discusses data transmission using Wavelength Division Multiplexing (WDM) for four optical channels separated with 100GH_z frequency spacing in a 2.5Gb/s optical transmission system. Non Return to Zero(NRZ) data inputs with laser signal are modulated with Mach-Zehnder modulator (MZM) before being multiplexed. Then, the four channels are multiplexed and sent through a single mode fiber (SMF) with 50km. An optimization scheme for the system was demonstrated with the addition of an optical gain amplifier and an optical filter at the receiver and results are compared to both systems. The simulated transmission system has been analyzed in the basic of different parameters by using OptiSystem simulator, different parameters have been investigated which are output power (dBm), quality factor, bit rate, fiber length, optical spectrum and eye diagram at receiver. Results show a good enhancement in the fiber length and quality of the system where the transmission distance has been twice at the same BER level.

List of Abbreviations

NRZ	non return to zero
SMF	single mode fiber
WDM	wavelength division multiplexing
MZM	Mach-Zehnder modulator
MUX	Multiplexers
de MUX	Demultiplexers
DWDM	Dense Wavelength Division Multiplexing
BWDM	Band Wavelength Division Multiplexing
CWDM	Coarse Wavelength Division Multiplexing
OLT	Optical Line Termination
ONU	Optical Network Unit
PON	Passive Optical Network
GVD	group velocity dispersion
PMD	polarization mode dispersion
SPM	self phase modulation
XPM	cross phase modulation
SBS	stimulated Brillouin scattering
SRS	stimulated Raman scattering
FWM	four-wave mixin

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CHAPTER ONE
INTRODUCTION

1.1 Overview

Communication may be broadly defined as the transfer of information from one point to another. When the information is to be conveyed over any distance a communication system is usually required. Within a communication system the information transfer is frequently achieved by superimposing or modulating the information onto an electromagnetic wave which acts as a carrier of the information signal [1]. Optical communication systems use high carrier frequencies (∼100 THz) in the visible or near-infrared region of the electromagnetic spectrum. They are sometimes called light-wave systems to distinguish them from microwave systems, whose carrier frequency is typically smaller by five orders of magnitude (∼1 GHz). This modulated carrier is then transmitted to the required destination where it is received and the original information signal is obtained by demodulation. Sophisticated techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as microwave and millimeter wave frequencies. However, 'communication' may also be achieved using an electromagnetic carrier which is selected from the optical range of frequencies [2]. Such systems have been deployed worldwide since 1980 and have indeed revolutionized the technology behind telecommunications. Indeed, the light wave technology, together with microelectronics, is believed to be a major factor in the advent of the "information age" [3].

1.2 problem statement

As the optical signal propagates down the fiber, it experience a deterioration in the optical bit stream that affect the performance of the system and reduces the received signal eventually. The aim of any optical system is to reduce the deterioration of the optical signal and increase the quality of the received signal with minimum bit error.

1.3 Aim of the project

1- Study and design a wavelength division multiplexing system(WDM).
2- Optimize the design parameters.
3- Increase the system bit rate and get efficient use of fiber bandwidth.
4- Increase the achievable transmission distance of the system.

5- Study the system performance with the use of eye diagram.

1.4 Scope of Work

The design and optimization of 4-channel WDM system were achieved using optiwave system software, simulation results were drawn compared to the system before and after optimization. At first the optimum power for the predicted system was chosen and then the performance of the system was demonstrated before and after development. Moreover, different factors such as fiber length, bit rate, and quality factor are evaluated and discussed.

1.5 Project Structure

In this project an overview on the optical fiber communication were given in chapter one. Chapter two discusses the theoretical background on the wavelength division multiplexing system and the effect of fiber impairments on system performance. The design of our system is given in chapter three. Finally, chapter four includes the simulation results,discussion and conclusions.

CHAPTER TWO
WAVELENGTH DIVISION MULTIPLEXING

2.1 Introduction

Wavelength-division-multiplexing (WDM) technology is now recognized as one of the key technologies in optical communications systems. This is because it has great potential to enhance system design and flexibility.The WDM is the short form of Wavelength Division Multiplexing. This optical multiplexing uses different frequencies at different wavelengths to transmit data separately over multiple channels. The WDM assigns unique frequencies of light having certain bandwidth to different optical signals. The multiplexed wavelengths transmit over a single fiber. At the demultiplexer end, these signals are selected using a tuner of desired bandwidth [2]. Figure 1 demonstrates the concept of WDM.

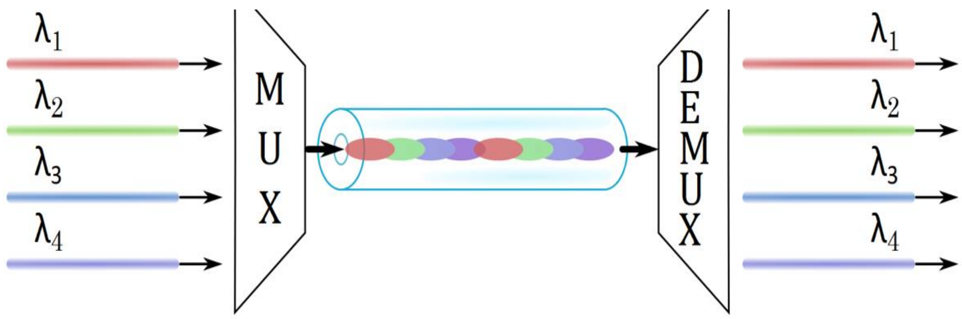

Figure 1: the Schematic diagram of WDM

The concept was first published in 1978, and by 1980 WDM systems were being realized in the laboratory. The first WDM systems combined only two signals. Modern systems can handle 160 signals and can thus expand a basic 100 Gbit/s system over a single fiber pair to over 16 Tbit/s. A system of 320 channels is also present [4].

2.2 Principle of Operation

A WDM system uses a multiplexer at the transmitter to join the several signals together and a demultiplexer at the receiver to split them apart. With the right type of fiber, it is possible to have a device that does both simultaneously and can function as an optical add-drop multiplexer. The optical filtering devices used have conventionally been Etalons (stable solid- state singly-frequency Fabry–Pérot interferometers in the form of thin-film- coated optical glass). As there are three different WDM types, where of one is called "WDM", the notation "xWDM" is normally used when discussing the technology as such[5].

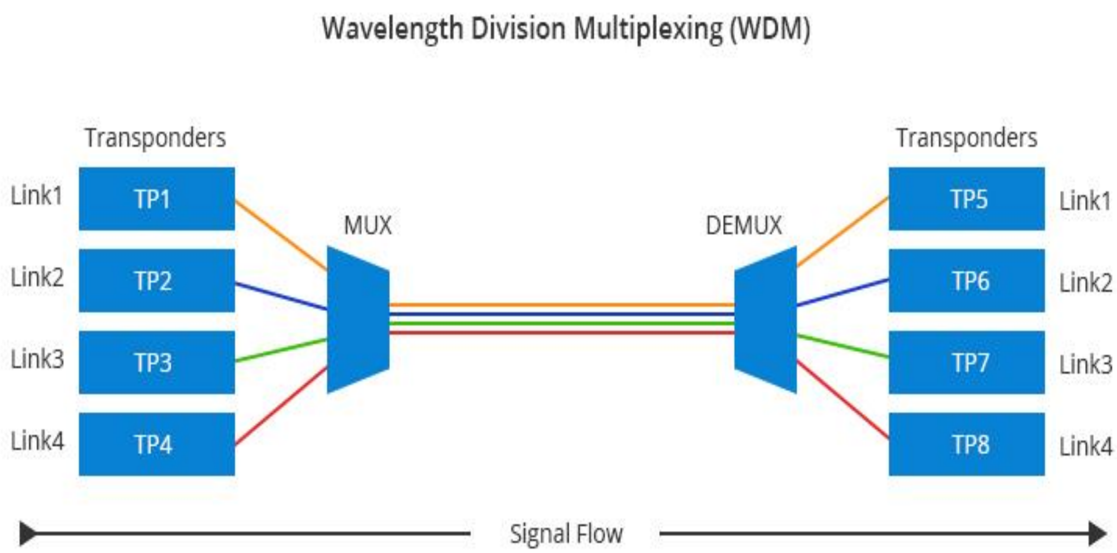

Figure 2: WDM in an optical communication system.

WDM systems are popular with telecommunications companies because they allow them to expand the capacity of the network without laying more fiber. By using WDM and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure without having to overhaul the backbone network. The capacity of a given link can be expanded simply by upgrading the multiplexers and demultiplexers at each end. This is often done by use of optical-to-electrical-to-optical (O/E/O) translation at the very edge of the transport network, thus permitting interoperation with existing equipment with optical interfaces.

Most WDM systems operate on single-mode fiber optical cables which have a core diameter of 9 μm. Certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 μm Early WDM systems were expensive and complicated to run. However, recent standardization, and better understanding of the dynamics of WDM systems have made WDM less expensive to deploy Optical receivers, in contrast to laser sources, tend to be wideband devices. Therefore, the demultiplexer must provide the wavelength selectivity of the receiver in the WDM system.

WDM systems are divided into three different wavelengths patterns: normal (WDM), coarse (CWDM) and dense (DWDM). Normal WDM (sometimes called BWDM) uses the two normal wavelengths 1310 and 1550 on one fiber. Coarse WDM provides up to 16 channels across multiple transmission windows of silica fibers. Dense WDM (DWDM) uses the C-Band (1530 nm-1565 nm) transmission window but with denser channel spacing. Channel plans vary, but a typical DWDM system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 12.5 GHz spacing (sometimes called ultra-dense WDM). New amplification options (Raman amplification) enable the extension of the usable wavelengths to the L- band (1565 nm-1625 nm), more or less doubling these numbers [5].

2.3 Advantages and Disadvantages of WDM

2.3.1 Advantages of WDM

1. Full duplex transmission is possible.
2. Easier to reconfigure.
3. Optical components are similar and more reliable.
4. It provides higher bandwidth.
5. This could be the best approach as it is simple to implement.
6. High security.

2.3.2 Disadvantages of WDM

1. Signals cannot be very close.
2. Light wave carrying WDM is limited to 2-point circuit.
3. Scalability is a concern as OLT (Optical Line Termination) has to have a transmitter array with one transmitter for each ONU (Optical Network Unit). Adding a new ONU could be problem unless transmitters were provisioned in advance. Each ONU must have a wavelength specific laser.
4. Cost of the system increases with the addition of optical components.
5. (WDM in PON:) Inefficiency in BW utilization, difficulty in wavelength tuning, difficulty in cascaded topology [4].

2.4 Multiplexers and Demultiplexers

A Multiplexer is a device that allows one of several analog or digital input signals which are to be selected and transmits the input that is selected into a single medium. Multiplexer is also known as Data Selector. A multiplexer of 2n inputs has n select lines that will be used to select input line to send to the output. Multiplexer is abbreviated as Mux. MUX sends digital or analog signals at higher speed on a single line in one shared device. It recovers the separate signals at the receiving end. The Multiplexer boosts or amplifies the information that later transferred over network within a particular bandwidth and time[6].

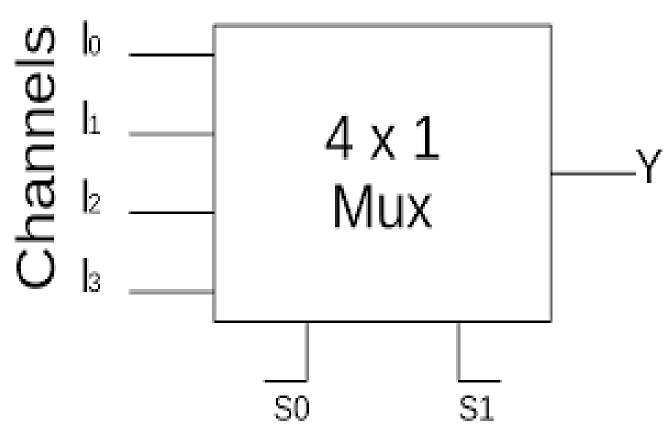

Figure3 : Block diagram of a multiplexer

While a demultiplexer (or DeMUX) is a device that takes a single input line and routes it to one of several digital output lines. A demultiplexer of 2n outputs has n select lines, which are used to select which output line to send the input. A demultiplexer is also called a data distributor. Demultiplexers can be used to implement general purpose logic. By setting the input to true, the DeMUX behaves as a decoder. The reverse of the digital demultiplexer is the digital multiplexer [7]. The action or operation of a demultiplexer is opposite to that of the multiplexer. As inverse to the MUX, DeMUX is a one-to-many circuit. With the use of a demultiplexer, the binary data can be bypassed to one of its many output data lines. Demultiplexers are mainly used in Boolean function generators and decoder circuits. Different input/output configuration demultiplexers are available in the form of single integrated circuits (ICs). Also, the facility of cascading two or more IC circuits help to generate multiple output demultiplexers [8].

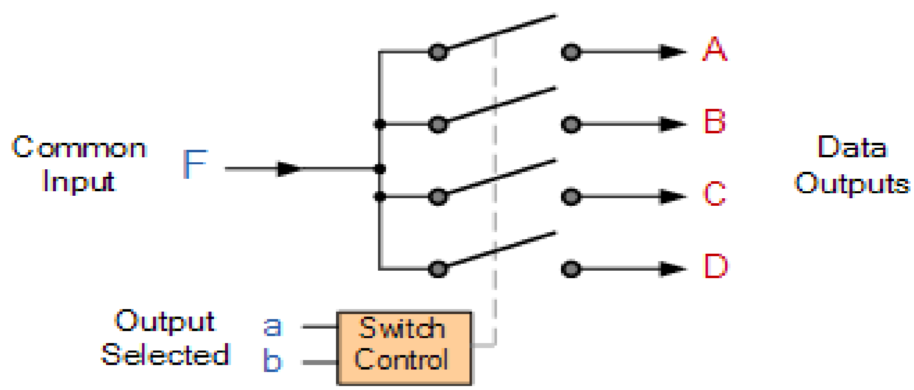

Figure4 : Schematic Diagram of a Demultiplexer.

2.5 Advantages Of Optical Fiber Communication

Communication using an optical carrier wave guided along a glass fiber has a number of extremely attractive features, several of which were apparent when the technique was originally conceived. Furthermore, the advances in the technology to date have surpassed even the most optimistic predictions, creating additional advantages. Hence it is useful to consider the merits and special features offered by optical fiber communications over more conventional electrical communications.[2].

1- Enormous potential bandwidth.

2- Small size and weight.

3- Electrical isolation.

4- Immunity to interference and crosstalk.
5- Signal security.
6- Low transmission loss.
7- Ruggedness and flexibility.
8- System reliability and ease of maintenance
9- Potential low cost.

2.6 Impairments in Optical Fiber Transmission

The optical fiber is often seen as a perfect transmission medium with almost limitless bandwidth, but in practice the propagation through optical fiber is beset with several limitations especially as distance is increased to multi-span amplified systems. As the transmission systems evolved to longer distances and higher bit rates, the linear effect of fibers, which is the attenuation and dispersion, becomes the important limiting factor. As for WDM systems that transmit multiple wavelengths simultaneously at even higher bit rates and distances, the nonlinear effects in the fiber beginning to present a serious limitation.

The success of high bit rate long haul point-to-point optical transmission networks depend upon how best the linear and nonlinear effects are managed. the various fiber induced impairments and their negative influence in restricting the achievable capacity of the transmission link can be described.

The major linear effects include group velocity dispersion (GVD) of standard single-mode fiber, fiber loss, adjacent channel X-talk, polarization mode dispersion (PMD), accumulated ASE noise, etc. The nonlinear effects on the other hand include self phase modulation (SPM), cross phase modulation (XPM), stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), and four-wave mixing (FWM)[9].

The most effective linear impairments can be classified as follows[9]:

❖ Attenuation :

Attenuation causes the decay of signal strength, loss of light power as the signal propagates through the fiber. Attenuation in optical fibers is caused by intrinsic factors which are scattering and absorption and by extrinsic factors which include stress from the manufacturing process, environmental and physical bending.

❖ Chromatic Dispersion:

Light pulses representing data have a definite spectral width. Because of chromatic dispersion in an optical fiber different wavelength propagate at different speeds thereby resulting pulse reading. If left unmanaged, pulse spreading eventually results in inter-symbol interference when adjacent pulses overlap, leading to errors in the recovery of transmitted bits.

❖ Group velocity dispersion:

Group velocity dispersion (GVD) is the main cause for pulse spreading and thereby introduces the inter-symbol interference in a received signal.

❖ Polarization mode dispersion:

Once dispersion is managed, polarization mode dispersion becomes the most dominant linear effect to limit the channel capacity.

❖ Adjacent channel crosstalk:

Adjacent channel X-talk is very common with all forms of communication system. In dense WDM optical communication system the adjacent channel X-talk is very significant and limits the minimum separation of two adjacent channels with an acceptable penalty. For narrow channel spacing, there is a partial overlap of channels in frequency domain. The effect depends upon large number of parameters such as channel spacing and filtering characteristics of multiplexers and demultiplexers.

CHAPTER THREE

THE DESIGN OF 4-CHANNEL WDM SYSTEM

3.1 Introduction

In order to explore the effect of the impairments in the fiber on the transmitted signal, the NRZ fiber communication system is employed to quantify the quality factor versus the power of the transmitted signal. In addition, the 4-channel WDM system is simulated to investigate the fiber impairments. In this chapter, two experimental setups are described, including the transmitter and transmission link and receiver before and after optimization.

3.2 Transmitter

At first, Figure 3.1 shows the design of a WDM system before optimizing the system, the transmitter section comprises 4 channels separated with 100 GH_z frequency spacing. Each channel consists of a pseudo-random binary sequence (PRBS) that generates random bits according to different operating modes. The bit sequence is designed to approximate the properties of random data, the bit rate of the system was firstly adjusted to 2.5 Gbit/s. After that, the output from the data source is fed to a non-return to zero (NRZ) generator that encoded the signal to trigger the external modulator. A continuous wave laser source produces light with a wavelength of 1550 nm. The Mach Zenhder modulator MZM modulates the NRZ signal on the CW laser to generate the transmitted signal. Using a Mach-Zehnder modulator to modulate the output intensity according to the voltage based on the principle of interferometry, the Mach-Zehnder Modulator was set to an extinction ratio of 30 dB. Then the 4-channels are multiplexed with the use of 4x1 multiplexer in which the four WDM signals are sent through the transmission link.

3.3 Transmission Link

The transmission link comprises a standard single mode fiber SMF of 50km modeled with an attenuation coefficient α of 0.2 dB/km, chromatic dispersion coefficient of 16.7 ps/nm/km, an effective area of 80 μm^2. The signal is then demultiplexed and sent to the receiver section

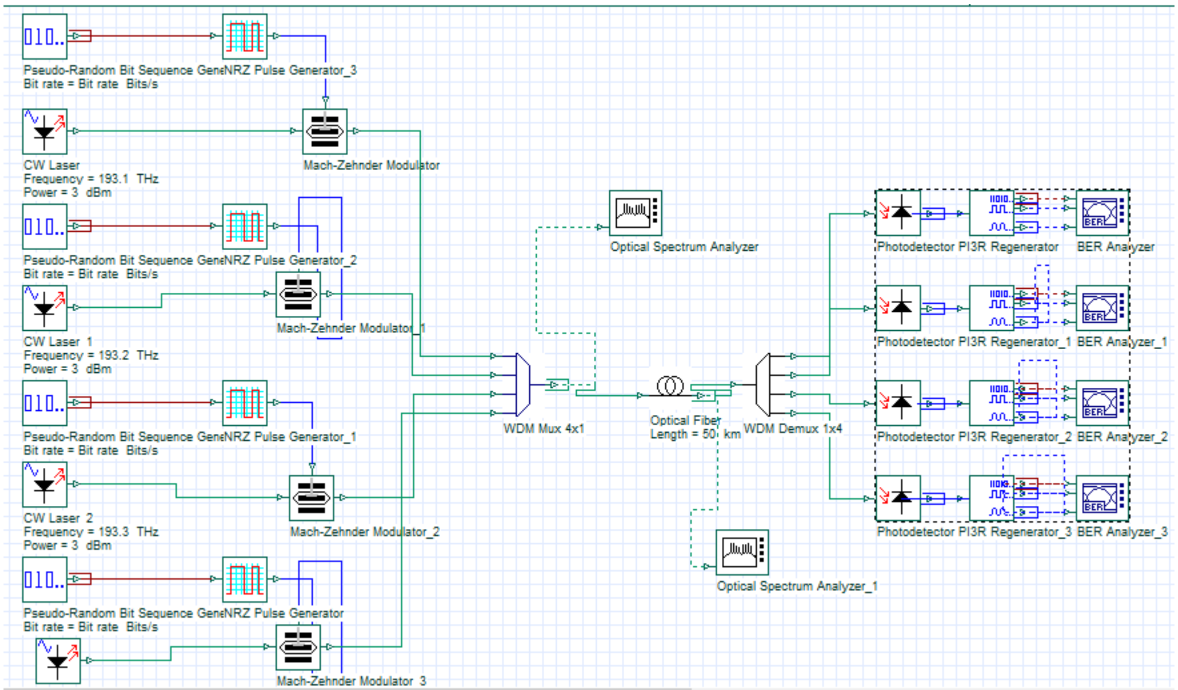

Figure 3.1 the WDM system before optimization

3.4 Receiver Section

In receiver section, after passing through a demultiplexer, Photodiode is used for optical to electrical conversion. The use of a BER Analyzer to Measures the performance of the system based on the signal before and after the propagation. The 3R regenerator used to generate an electrical signal, by using the 3R Regenerator, there is no need for connections between the transmitter and the BER Analyzer. This is especially important for WDM systems, where you have multiple transmitters, receivers and BER Analyzers.

The second part of the design is shown in Figure 3. 2. After doing some optimization to the system.

The addition of an optical amplifier at the end of the SMF to reboost the signal. In addition to the circuit in Figure 3.1, a Bessel filter and an optical amplifier are used at the receiver for each channel the use of Bessel filter is a kind of analog linear filter with a flat group/phase to the fullest extent, which keeps the waveform of the filtered signal in the passband. With a frequency band of 40 GHz. While the use of an Optical Amplifier to reboot the signal at the receiver. An optical amplifier is a device that receives some input signal and generates an output signal of higher optical power.

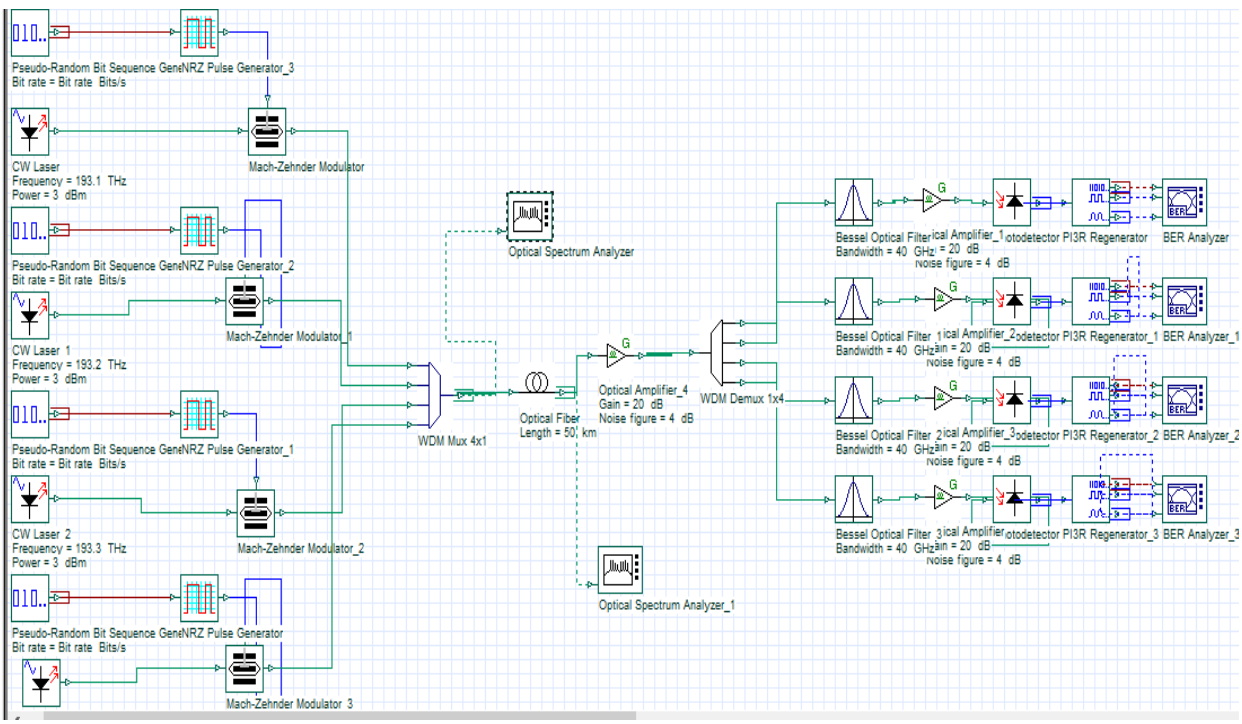

Figure 3.2 WDM system after optimization

Chapter four

RESULTS AND DISCUSSION

4.1 Introduction:

In this chapter, the performance of the receiver in the 4-channel WDM system is demonstrated by simulation and compared before after system optimization. Simulation results are achieved by using optisystem software. Different parameters such as, lunched power,quality factor, eye diagram and optical spectrum are studied.

4.2 Results And Discussion:

Figure (4.1) shows the influence of the fiber impairments on the performance of WDM optical fiber communication system. The results are achieved at a transmission distance of 50 km and a bit rate of 2.5GB/s. The results are obtained by varying transmitted power from 0dBm to 9dBm. Generally, the Q factor increases gradually with increasing transmitted power. It reaches its maximum value at power 7dBm. With increasing power beyond optimum power (7dBm), the quality factor is decreased. This decrease is due to the increase in the nonlinearity of SPM, XPM with increasing intensity of electric field.

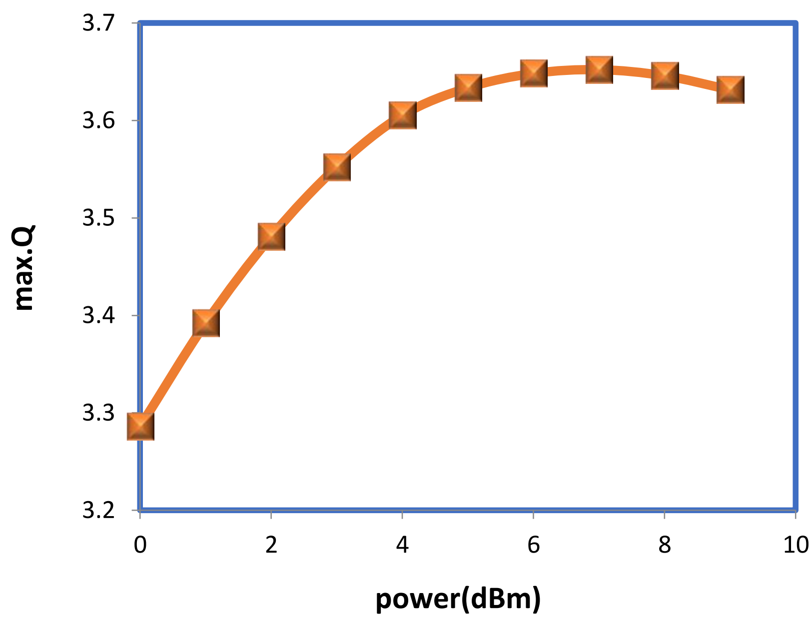

Figure (4.1): The variety of quality factor against lunched power.

To investigate the transmission performance of the conventional 4-WDM system, the transmitted power is set to optimum power (7 dBm) and bit rate at 2.5GB/s. The transmission distance versus the quality factor is plotted as shown in Figure (4.2). The fiber length is changed from 10 km to 90 km. It can be observed that the quality factor is decreased with increasing transmission distance due to interaction the transmitted signal with the dispersion and nonlinearity effects. At 80km the quality factor achieved is about 10. while Figure (4.3) shows similar behavior for the system after optimization. The results are achieved by adjusting the transmitted power to 7 dBm. However, the quality factor is better than that for the conventional system where the distance has been increased by more than 100%. Achieveing 200km with an acceptable quality of about 10.

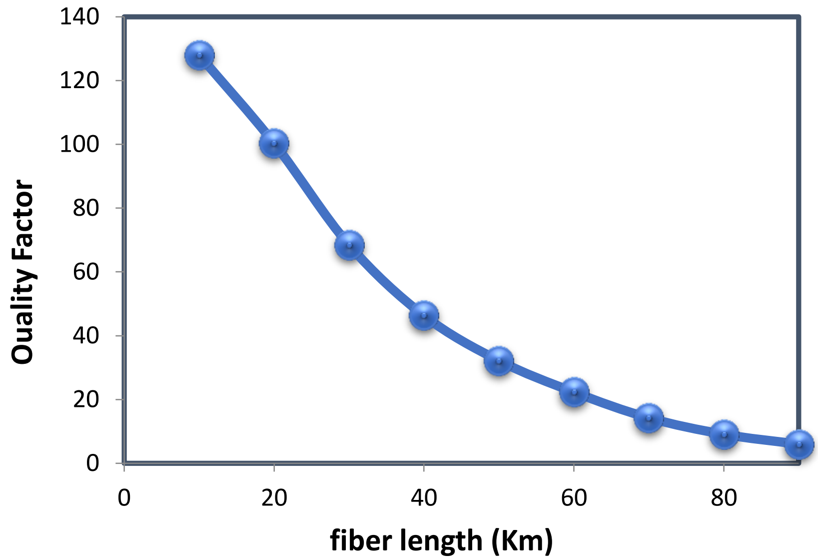

Figure (4.2) the quality factor against fiber length for the WDM system before optimization.

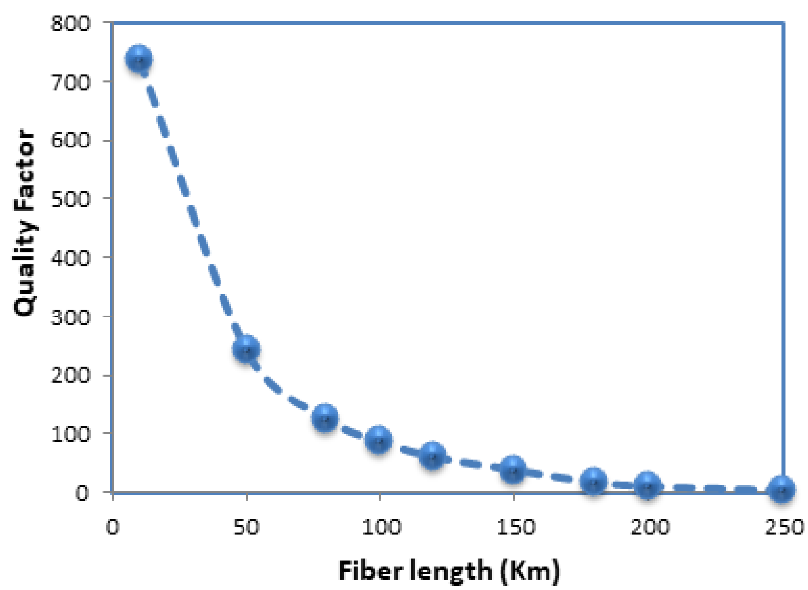

Figure (4.3) the quality factor against fiber length for the WDM system after optimization.

The effect of bit rate on the performance of the system is studied by plotting quality factor against bit rate the range of 2.5GB/s - 10GB/s. Figure (4.4) depicts the results for the NRZ system at the optimum power of 7dBm and transmission distance of 50 km. It can be seen that the quality factor decreases gradually from about 241 at 2.5Gbit/s to less than 4.7 at 10 G bit/s.

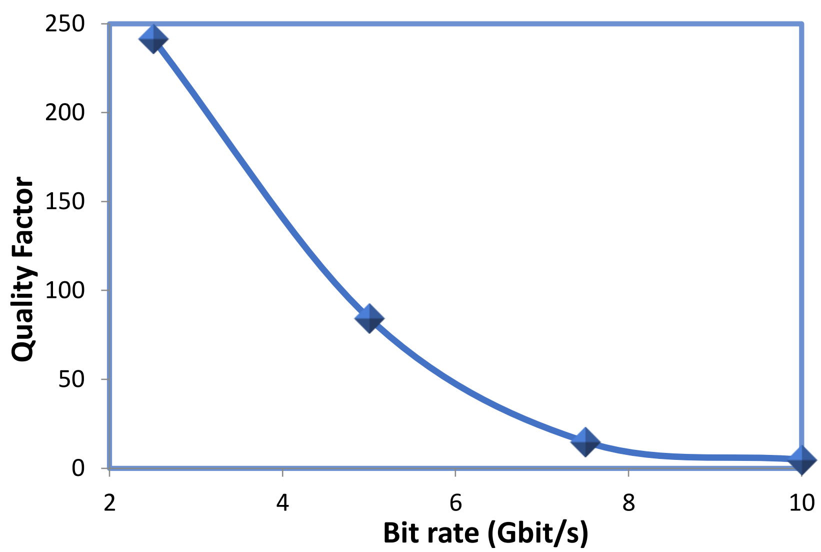

Figure (4.4) the Quality factor with bit rate using NRZ after optimization at power7 dBm

The eye diagram of the NRZ modulation for the received channels is demonstrated and compared in figure (4.5) for the WDM system before and after optimization , it can be seen that the eye diagram becomes undistorted and the eye opening increases both horizontally and vertically due to the effect of nonlinearity impairments such as XPM.

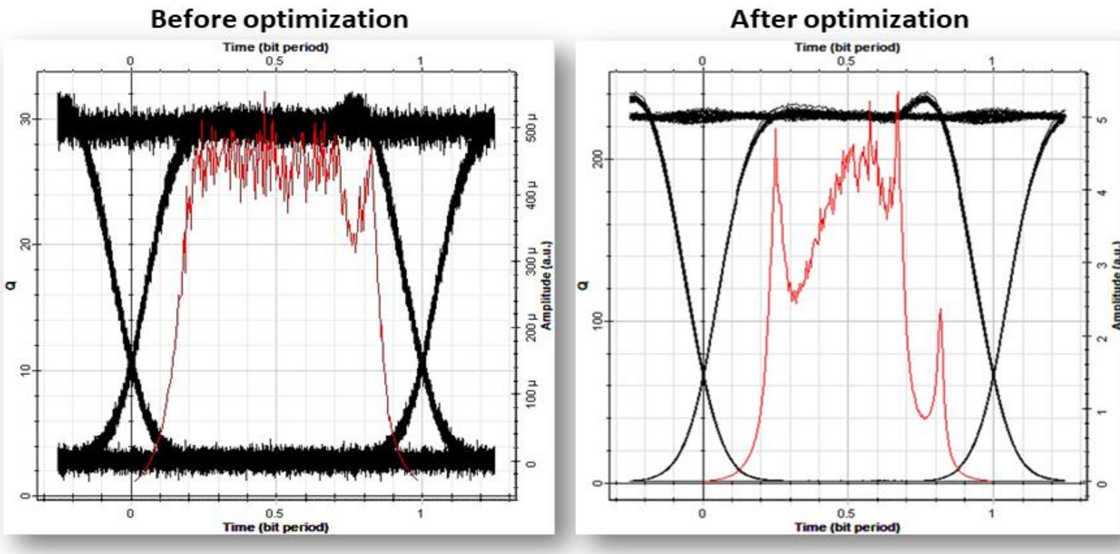

Figure (4.5): the eye diagram for the system before and after optimization at 50km fiber length.

Figure (4.6) shows the optical spectrum before and after fiber link for the four wavelength (1552.5,1551.7,1550.9 and 1550.1) µm separated with a frequency spacing of 100 GH_z , it can be seen that the power has been decreased by about 10dBm due to the existence of nonlinearities (peaks generated by FWM) that distort the signal and decrease the power reaching the receiver consequently.

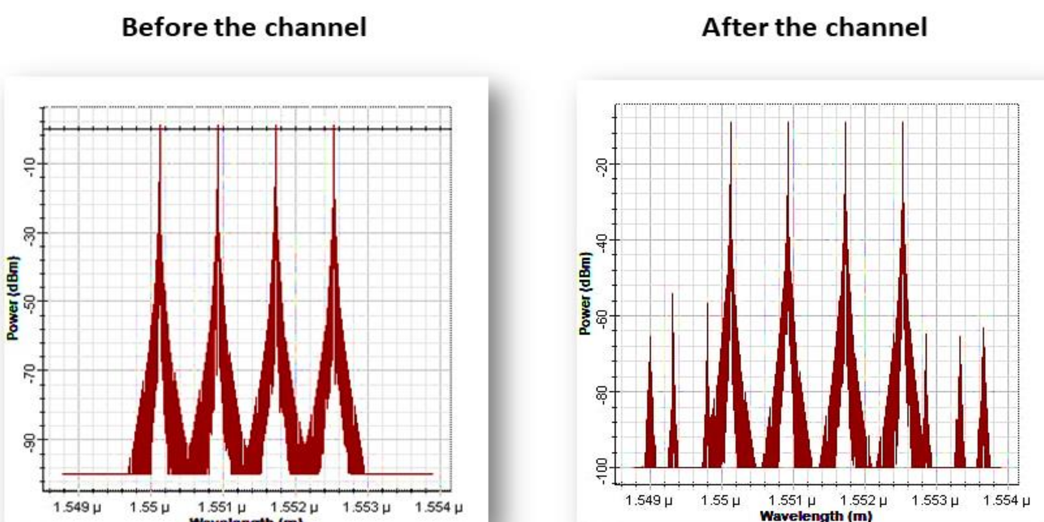

Figure (4.6): the output spectrum of NRZ format for the 4-signals WDM before and after the channel.

4.3 Conclusions:

- This project has investigated and studied the design and implementation of a4 channels WDM optical communication system. The performance in demonstrating with a NRZ coding format and bit rate of 2.5Gb/s.
- system Optimization has been utilized with the addition of optical filters and gain amplifiers, results are compared before and after optimization.
- Results show that the transmission distance has been increases significantly after optimization where the fiber length has been maximized by100%
- The bit rate for the system has been increased from (2.5 to10)Gb/s
- The overall performance has been enhanced where better quality factors are achieved.

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