

Using Wavelength Division Multiplexing (WDM) to Upgrade Infrastructure Optical Fiber Communication Systems

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Abstract

In this paper we optimized optical fiber length in WDM single pulse propagation in single mode fiber (SMF-28). Their results are calculated, tested, and verified using Optisystem7.0 for protect licensed product based company. Only point-to-point optical fiber links are considered in this work. Due to the increasing demand for more bandwidth, optical networks are becoming more and more complex. Over the next few years the growth of existing services and the introduction of new ones will greatly increase traffic in telecommunication networks. Some services, such as normal telephony, will grow slowly, whereas newer services, such as mobile telephony, data and video traffic, will expand very rapidly. Future services will vary widely in terms of the required channel occupancy. Fiber length from (0km-120km), with (bit rate=2.5 Gb/s) are acceptable through (Q-Factor and Min-BER). From actual underground sample optical fiber link about (82km) works in Ministry of Communication in Republic of Iraq, then compares with actual, and practical results in this paper appears acceptable.

Keywords: semaphore, DWDM, nonlinear effects, SBS, SRS, XPM, FWM, and crosstalk.

1. Introduction

The use of light as a communication method dates back to antiquity when define optical communications in a broader way. People had used mirrors, fire beacons, or smoke signals to convey a single piece of information in 1791 Claude Chappe invented the *Semaphore*, which is considered to be the first high-speed

digital communications system. The *Semaphore* was a system which consisted of mechanical arms that was installed on the top of a tower, and operated manually. Using a chain of such devices it was possible to transmit messages over distances of around 150 miles in only 15 minutes. All these inventions can be considered to be the ancestors of modern day optical fiber communications systems.

The emphasis of research can be commonly categorized into two groups. One emphasis is to extend the wavelength range to L-band (1565nm – 1625nm) and S-band (1460nm – 1530nm) to increase the number of channels in WDM. Currently lightwave systems are operating in the conventional wavelength window, known as C-band which is from 1530nm to 1565nm [1].

2. Modulation Format

The capacity of lightwave system, bit rate-distance product, will be improved dramatically using optimal modulation formats compared to non-return to zero (NRZ) format has been the dominant modulation format in fiber-optical communication systems. For convenience refer to NRZ. There are probably several reasons for using NRZ in the early days of fiber-optical communication: First, it requires a relatively low electrical bandwidth for the transmitters and receivers (compared to RZ); second, it is not sensitive to laser phase noise; and last, it has the simplest configuration of transceivers. In recent years, as optical communication is advancing to higher data rates, dense-wavelength division multiplexing (DWDM), and long distance with optical amplifiers, NRZ modulation format may not be the best choice for high capacity optical systems. However, due to its simplicity, and its historic dominance, NRZ would be a good reference for the purpose of comparison [2]. Consequently, non-return-to-zero (NRZ) that has been used for a long time in lightwave system is no more an optimal modulation format in the next generation of lightwave system. A modulation format that is more tolerant to linear and nonlinear impairments is needed.

A long string of ones or zeros contains no timing information since there are no level transitions. However, the use of highly stable clocks increases system costs and requires a long system startup time to achieve synchronization [3]. In addition, spectral efficiency would be improved using optimal modulation format thus more information could be conveyed per wavelength or more wavelengths can be co-propagated over fibers. In economical view, optimal modulation formats will permit service providers to develop their existing lightwave network without overall upgrade and to utilize the most of the existing systems [1].

Thus to save the expenses, in this paper, characteristics of standard single mode fiber (SSMF-28), are taken into concern. Historically, SSMF was the first type to be used in networks and remains the most wide-spread type, representing about

85% of all the fiber in the world. For some time, SMF has met all the transmission requirements, mainly because low loss has been the only issue. However, increasing the bit rate has come up against chromatic dispersion effects at 10Gb/s and above, because SMF has a high chromatic dispersion of 17 ps/nm.km at 1550nm if no compensating elements are added.[4]

3. WDM Optical Communication

Increasing in telecommunications services that demand large amounts of bandwidth. Services such as interactive multimedia, video conferencing and streaming audio have made the capacity of the existing optical fiber systems insufficient. To increase this capacity, time division multiplexing (TDM) has been used traditionally. However, TDM has a few drawbacks. The important is that the existing electronic technology allows multiplexing only up to about 10 Gb/s. Thus; an alternative optical multiplexing technique that avoids the 10Gb/s electronic bottleneck is very attractive. WDM is one such promising technique that can be used to exploit the huge available bandwidth of the optical fiber. Figure (1) illustrates a typical WDM system.

In WDM, the optical transmission spectrum is divided into a number of nonoverlapping wavelength bands, with each wavelength supporting a single communication channel operating at peak electronic speed. Thus, by allowing multiple WDM channels to coexist on a single fiber, the huge bandwidth can be tapped into. WDM is a technique for simultaneous transmission of two or more optical signals on the same fiber. The signals from different sources are combined by a multiplexer and fed into an optical fiber which is the transmission medium. At the receiving end, different signals are separated by a demultiplexer and detected by photodetectors.

The WDM scheme increases the transmission capacity of optical communication systems considerably. The two configurations of WDM systems that are possible are the *one-way* and the *two-way*(bidirectional optical fiber) transmission systems as illustrated in Figure (1), while the one-way system requires only one receiver or one transmitter per channel at each end, the two-way system requires both receiver and transmitter at each end of every channel. Optical multiplexers and demultiplexers may be classified into wavelength selective and wavelength nonselective devices. The wavelength selective devices are either active or passive. The active devices are implemented using multi-wavelength light sources or multiwavelength photodiodes [5].

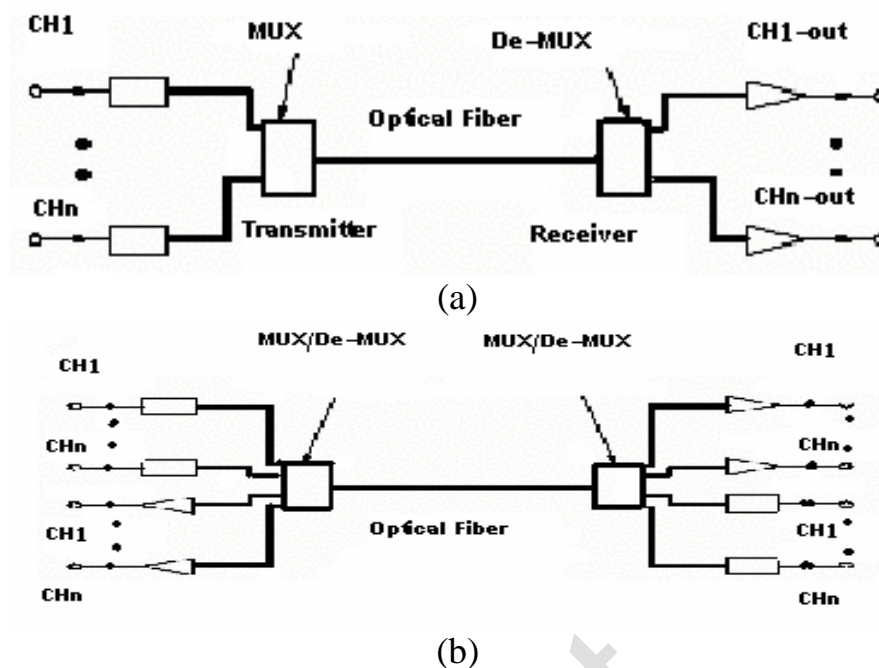


Figure (1)

Two configurations of WDM systems; (a) one-way, and (b) two-way transmission systems using bidirectional optical fiber

It is expected that WDM will be one of the methods of choice for future ultra-high bandwidth multichannel systems. Of course, this could be changed as the technology evolves [6]. Besides the higher capacity, WDM has also some other advantages. One advantage is the easy upgradeability.

While WDM is very attractive, it has some disadvantages also. One such disadvantage is the appearance of fiber nonlinearities. Normally, each channel requires about 1mw, and with the use of multiple channels, several miliwatts are injected into the fiber. Such high powers lead to the appearance of different nonlinear effects in the fiber, such as the Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), Four Wave Mixing (FWM), and the Cross Phase Modulation (XPM). These nonlinear effects lead to the degradation of system performance.

3.1. Channel Multiplexing

Most fiber optical systems are capable of transmitting at rate of more than 1Gb/s. To utilize the system capacity fully, it is necessary to transmit many channels simultaneously through multiplexing. This can be accomplished through time-division multiplexing (TDM) or frequency-division multiplexing (FDM). In the case of TDM; bits associated with different channels are interleaved in the time domain to form a composite bit stream. For example, the bit slot is about 15 ms for a

single voice channel operating at 64kb/s. Five such channels can be multiplexed through TDM if the bit streams of successive channels are delayed by 3 ms .

In the case of FDM, the channels are spaced apart in the frequency domain. Each channel is carried by its own carrier wave. The carrier frequencies are spaced more than the channel bandwidth so the channel spectra do not overlap. FDM is suitable for both analog and digital signals and is used in broadcasting of radio and television channels. TDM is readily implemented for digital signals and is commonly used for telecommunication networks. It is important to realize that TDM, and FDM can be implemented in both the electrical and optical domains; optical FDM is often referred to as WDM.

The lack of an international standard in the telecommunication industry during the 1980s led to the advent of a new standard, it is called the synchronous optical network (SONET) and the later termed the synchronous digital hierarchy or SDH. Optical backbones networks operating at 2.5Gb/s over standard optical fibers[7].The basic building block of the SONET has a bit rate of 51.84 Mb/s. The corresponding optical signal is referred to as OC stands for optical carrier. The basic building block of the SDH has a bit rate of 155.52 Mb/s and is referred to as STM-1, where STM (synchronous transport module). A useful feature of the SONET and SDH is that higher levels have a bit rate that is an exact multiple of the basic bit rate. Table (1) lists the correspondence between SONET and SDH bit rates for several levels [8].

Table (1)
SONET/SDH bitrates

SONET	SDH	B(Mb/s)	Channels
OC-1	----	51.84	672
OC-3	STM-1	155.52	2,016
OC-12	STM-4	622.08	8,064
OC-48	STM-16	2,488.32	32,256
OC-192	STM-64	9,953.28	129,024
OC-768	STM-256	39,813.12	516,096

3.2 Performance of WDM Systems

In addition to the performance limitations due to nonlinear effects, WDM links require careful consideration of the system operating conditions. Among these are the link bandwidth, optical power requirements for a specific bit- error rate, and crosstalk between optical channels [9]:

- **Link Bandwidth**

If the N transmitters in a WDM link such as shown in Figure (1), operate at bit rates of B_1 through B_N , respectively, then the total bandwidth is

$$B = \sum_{i=1}^n B_i \dots\dots\dots (1)$$

When all the bit rates are equal, then the system capacity is enhanced by a factor N as compared with a single-channel link.

• **Optical Power Requirements for a Specific BER**

At the outputs of the multiplexer, system parameters that need to be considered include the signal level, noise level, and crosstalk. The bit-error rate (BER) of a WDM channel is determined by the optical signal-to-noise ratio (SNR) delivered to the photodetector. The digital receiver performance is governed by bit-error-rate. BER is the probability that a bit is identified incorrectly by the decision circuit of the receiver. In fiber optic communication systems, the error rates usually range from 10^{-9} to 10^{-12} . This value depends on the SNR the receiver. The BER can be calculated from the Q-Factor as shown in [8]

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q}{\sqrt{2}} \right) \approx \frac{1}{\sqrt{2\pi}} \cdot \frac{e^{-\frac{Q^2}{2}}}{Q} \dots\dots\dots (2)$$

$$Q = \frac{I_1 - I_0}{\sqrt{s_1^2 + s_0^2}} \dots\dots\dots (3)$$

I_1 and I_0 are the average values when the bits transmitted are 1 and 0 respectively in the bit stream. s_1^2 and s_0^2 are corresponding variances when 1 and 0 are received.

• **Crosstalk**

The narrow channel spacing in dense WDM link gives rise to *crosstalk*, which is defined as the feed through of one channel's signal into another channel. Crosstalk can be introduced by almost any component in a WDM system, including optical filters, wavelength multiplexers, optical switches, optical amplifiers, and the fiber itself [3].

4. Problem Measurements

The application of the proposed method to calculate the fiber length with certain parameters is carried out. In this paper the accuracy of the proposed method is discussed.

4.1 Experimental Schedule

In Figure (2) shows the layout parameters. From Optisystem 4.0 is a license product of Optiwave Corporation (Canadian based company) [10], the components used in it are shown in below:

1. Pseudo –Random Bit: to generate sequence random bits (0 or 1).

2. Non-Return-to –Zero Pulse Generator (NRZ).
3. Mach Zehnder- Modulator (MZ) has two inputs (optical signal and electrical signal) and one output (optical).
4. Continuous laser diode (CW) to generate optical signals.
5. Wavelength Division Multiplexer (WDM), to multiplexes optical signals. Figure (3) shows the global parameters for the WDM.
6. Optical Fiber to convey optical signals. Figure (4) shows the global parameters for the optical fiber.
7. Wavelength Division Demultiplexer (Demux), to demultiplexe optical signals. Figure(5) shows the global parameters for the WDM Demux.
8. Photodetector Diode Positive Intrinsic Negative (PIN) to translate the optical signal into an electrical signal.
9. Low Pass Bessel Filter has cutoff frequency $=0.75 \times 10$ bit rate.
- 10.Bit Error Analyzer (BER) to monitoring output signals.
- 11.Optical Spectrum Analyzer (OSA), to monitoring output signals after each component.

To optimize the fiber length in 2WDM optical systems will take the real terrestrial infrastructure in Iraq. All calculations depend on some parameters that are related with SMF-28 for example (Bitrate is 2.5 Gb/s , attenuation is 0.2 dB/km , and dispersion is 17 ps/nm.km) [11].

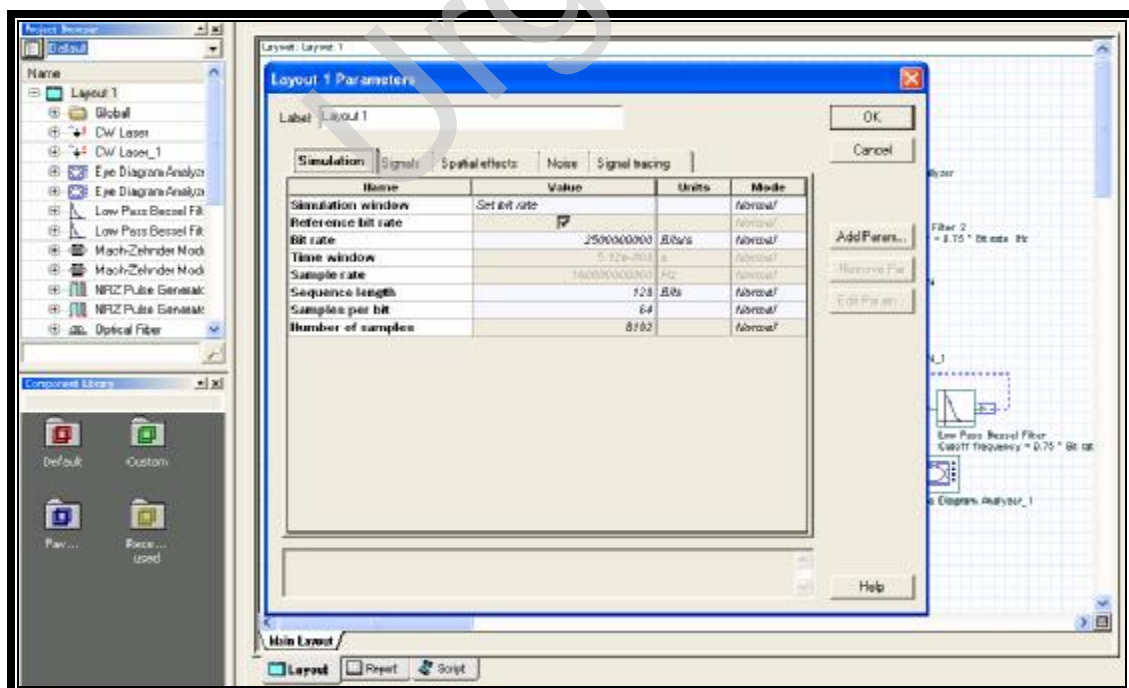


Figure (2): Layout parameters.

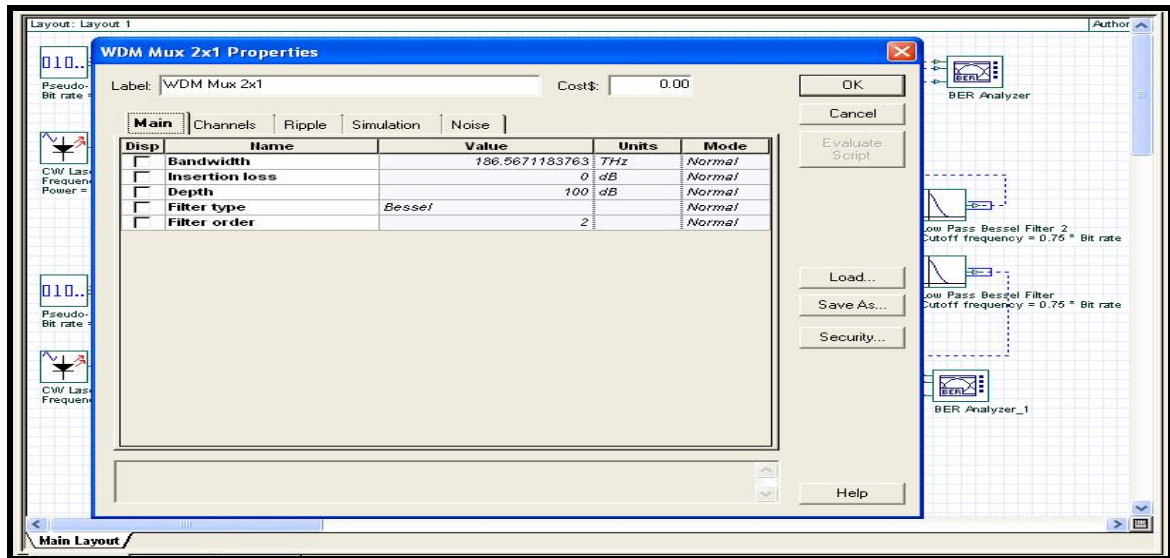


Figure (3): The global parameters for the WDM.

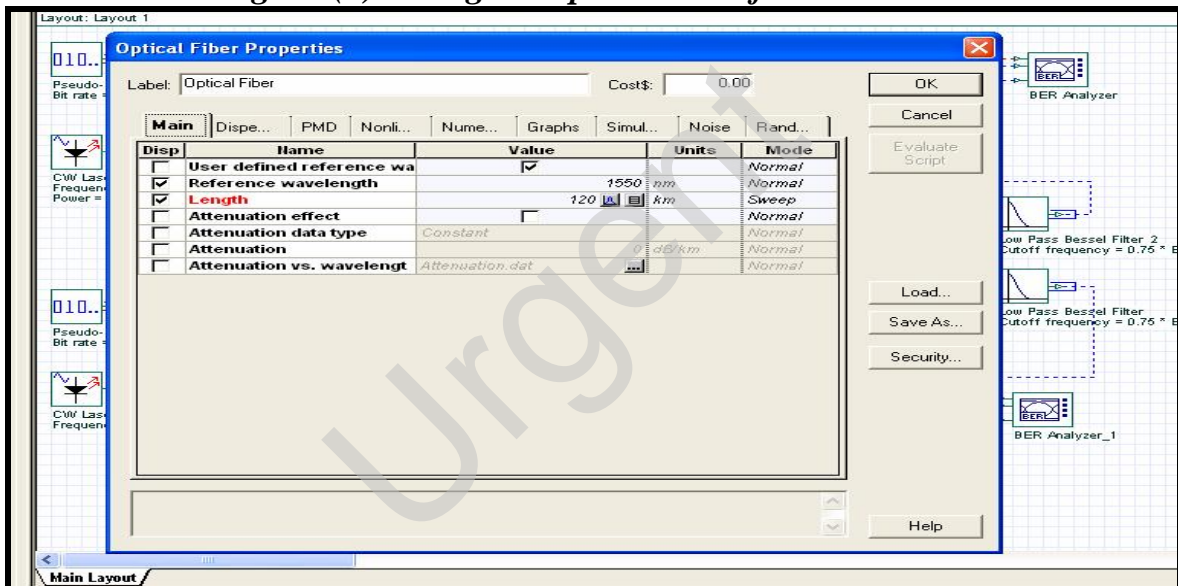


Figure (4): The global parameters for the optical fiber.

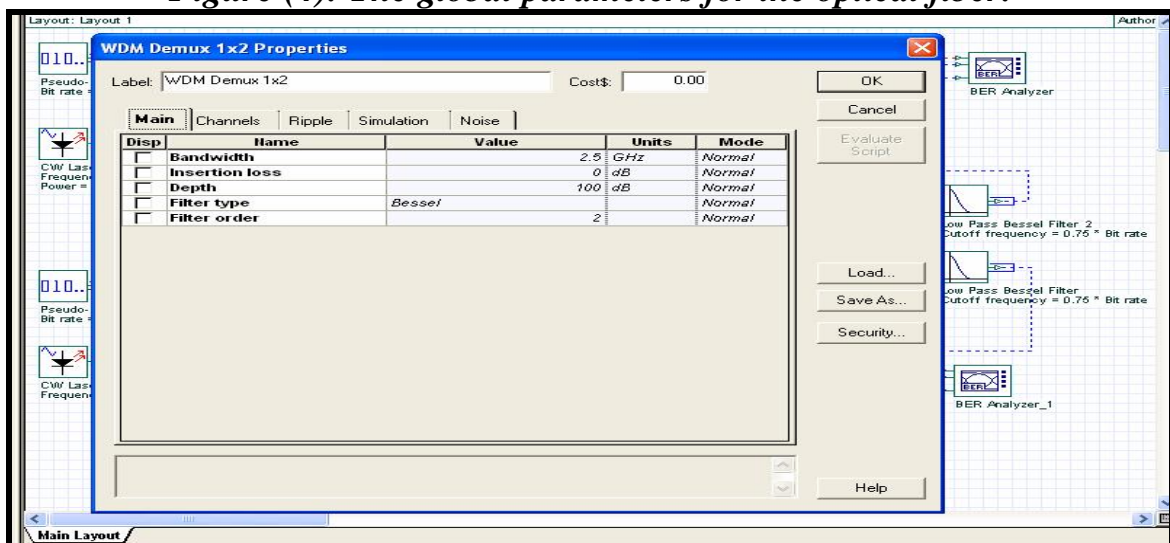


Figure (5): The global parameters for the WDM Demux

4.2 System Implementation Test Layout

To find the optimum fiber length the Optisystem 7.0 is used Figure (6) is use to test parameters that be list in previous section.

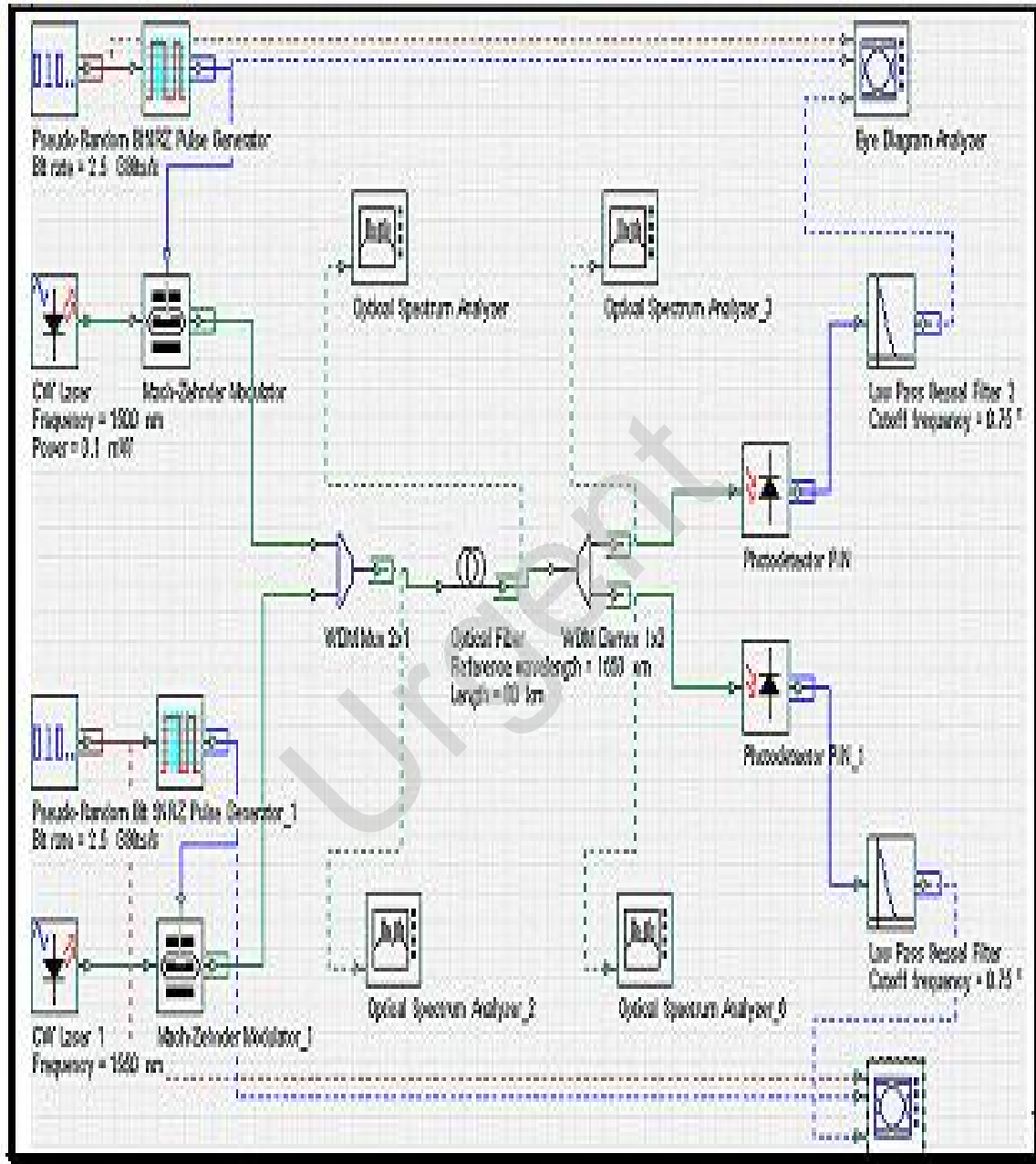


Figure (6): The system test layout.

In fact, to ensure results are acceptable we used (Optisystem 7.0) to test, and certificate our results.

5. Results

The output results from this simulation for (12 iteration) in fiber length from 0 km to 120 km are shown in Table (2) shows these results depends on ITU-652 standard.

Table (2)
Wavelengths= (1500nm-1550nm) optimization, and bitrate=2.5Gb/s.

ITERATIO N No.	FIBER LENGTH (Km)	WAVELENGT H (nm)	MAXQ - FACTOR $Q = \frac{I_1 - I_0}{\sqrt{S_1^2 + S_0^2}}$	MIN-BER $BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q}{\sqrt{2}} \right) \approx \frac{1}{\sqrt{2p}} \cdot \frac{e^{-Q^2}}{Q}$
1	0	1500	9.0384	5.96e-020
	0	1550	9.39251	2.15e-021
2	10.9	1500	8.968	1.05e-019
	10.9	1550	9.38650	2.28e-021
3	21.8	1500	9.10469	3.02e-020
	21.8	1550	9.37791	2.48e-021
4	32.7	1500	9.15937	1.85e-020
	32.7	1550	9.36623	2.77e-021
5	43.6	1500	9.23974	8.53e-021
	43.6	1550	9.35190	3.17e-021
6	54.5	1500	9.13748	2.25e-020
	54.5	1550	9.33498	3.72e-021
7	65.4	1500	9.08726	3.59e-020
	65.4	1550	9.31535	4.48e-021
8	76.3	1500	9.04212	5.45e-020
	76.3	1550	9.29208	5.58e-021
9	87.2	1500	9.31766	4.14e-021
	87.2	1550	9.26713	7.05e-021
10	98.1	1500	9.15073	2.03e-020
	98.1	1550	9.23963	9.12e-021
11	109	1500	9.03985	5.66e-020
	109	1550	9.20923	1.21e-020
12	120	1500	9.01144	7.31e-020
	120	1550	9.17712	1.64e-020

From Table (2), and Figures (7 to 14) shows the Max Q-factor, and Min-BER the wavelengths are equal to 1500nm and 1550nm, and bitrate is 2.5Gb/s as eye diagram for different optical fiber length equal to (98.1km and 120km). We can obtain the following conclusions: (i) with the same input power the eye diagram is

very good, conclusion (ii), is easy to understand, because when the optical fiber length is increase the nonlinearity phenomena is effects with degrade the system performance, and conclusion (iii) when compared with the underground sample optical fiber link about 82km works in Ministry of Communication in Republic of Iraq they are acceptable without using any additional components e.g.,(repeaters, amplifiers,).

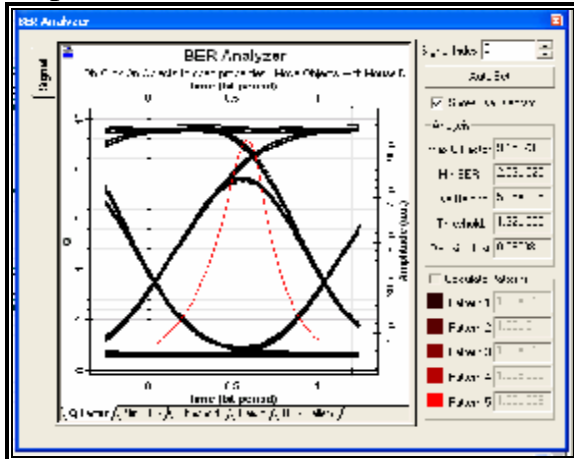


Figure (7) :Q-factor for fiber length = 98.1km, wavelength =1500nm, and bitrate =2.5Gb/s.

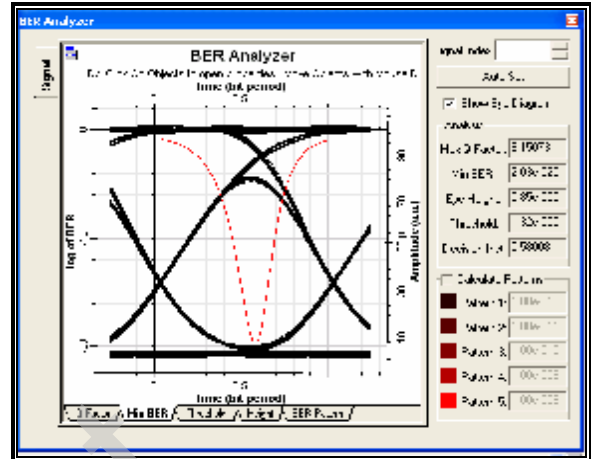


Figure (8): Min -BER for fiber length = 98.1km, wavelength=1500nm, and bitrate =2.5Gb/s.

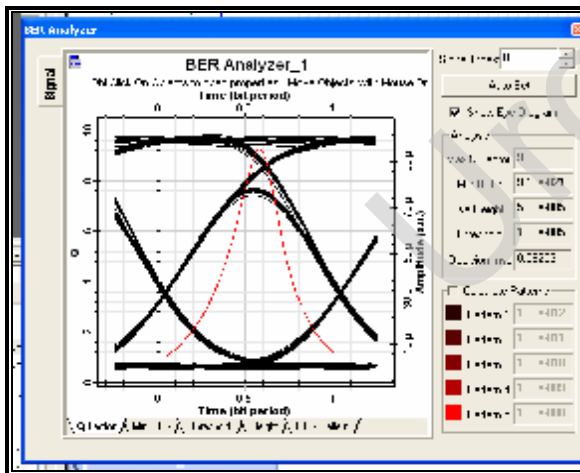


Figure (9): Q -Factor for fiber length =98.1km, wavelength =1550nm, and bitrate = 2.5Gb/s.

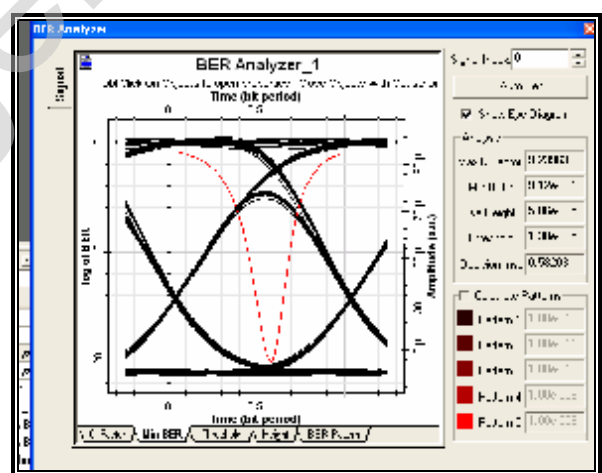


Figure (10): Min- BER for fiber length =98.1km, wavelength =1550nm, and bitrate = 2.5Gb/s.

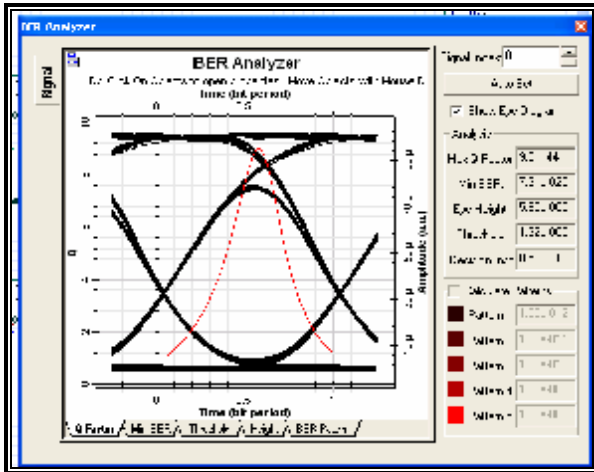


Figure (11): Q- factor for fiber length =120 km, Wavelength =1500nm, and bitrate=2.5Gb/s.

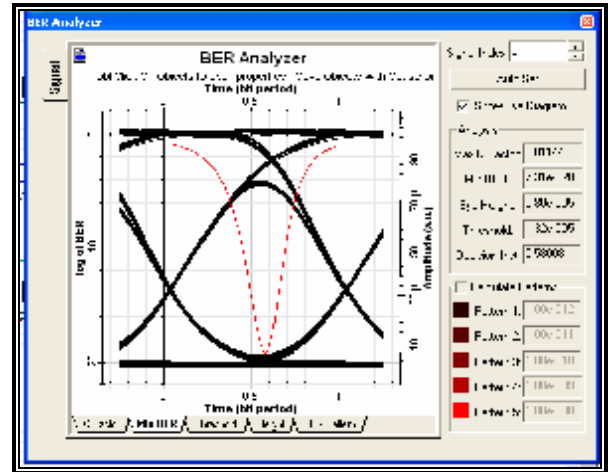


Figure (12): Min- BER for fiber length =120 km, wavelength=1500nm, and bitrate=2.5Gb/s.

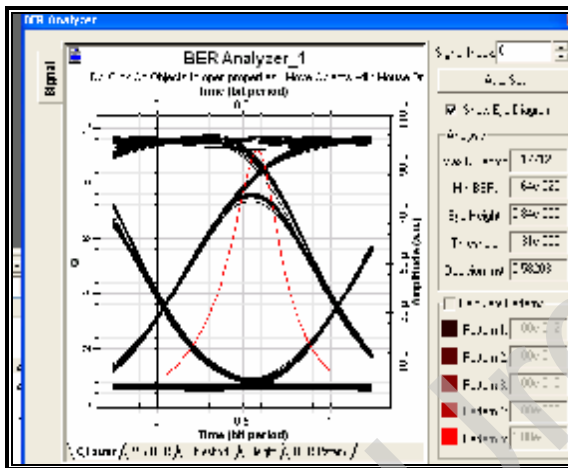


Figure (13): Min- BER for fiber length =120 km wavelength =1550nm, and bitrate=2.5Gb/s.

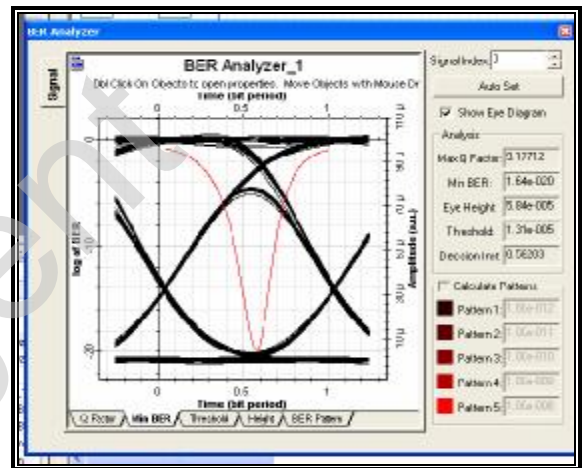


Figure (14): Min-BER for fiber length=120 km, wavelength =1550nm, and bitrate=2.5Gb/s.

Finally, in case the bitrate is equal to 2.5Gb/s from these results the WDM can be use in any two or more exchanges when distance between them is less than 120km. without repeaters and without other new components.

6. Conclusion and Future Works

These results are valuable for improving system performance by increasing transmitting datarate, and then the number of channels or users in the fiber optic system, and

- In WDM system, the effects of various users on the performance of the user of interest can be separated.
- When knowing the statistical nature of the input signals of the interfering users in multi-users (WDM) systems, an optimal detector can be design for removing the interchannel interference at the receiver.

The WDM seems attractive in the optical communications industry for a number of reasons:

1. By increasing the per channel rate, can be achieve the same capacity with fewer components.
2. Fewer components and fewer channels result in increase system reliability, survivability, and reduce operational expenses. There is less equipment to be monitored and less number of wavelengths needs to be restored.

Minimizing the probability of error for the whole network is of interest, and the system performance is optimized for all users and channels in the network, and:-

- The use of wavelength for add-drop multiplexing and routing in networks are also an attractive feature in WDM.
- Use WDM reduction cost.
- Minimizing the probability of error for the network is of interest for all users and channels.
- Use add-drop multiplexing and routing in communication.
- To reduce problem nonlinearity can be use soliton fiber.
- Use of the (Split-Step Fourier Transform) SSFT method, to predicting the optical pulse phenomena in nonlinear dispersive fibers, it is useful for improving existing system performance of designing new systems.

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الملخص باللغة العربية

تم في هذا البحث عمل مفاضلة على طول الليف البصري ذي النمط الواحد (٢٨) في مازج ثنائي للأطوال الموجية المقسمة . وقد تم حساب النتائج واختبارها وتحقيقها في الإصدار السابع للمنتج الكندي لتصميم واختبار الأنظمة الضوئية. وتم اختيار النموذج (نقطة- إلى - نقطة) لرابط الليف البصري ودعت الحاجة لذلك من الزيادة المستمرة في الحصول على معدل نقل بيانات عالي في الشبكات والاتصالات الضوئية حسب أطوال المسافات (٠ كم إلى ٢٠ كم) ومعدل إرسال بيانات (٢,٥ غيغا بت/ثانية) . ومن خلال مقياس معامل النوعية ومقياس أقل خسارة في معدل نقل البيانات وجدت هذه الأطوال مناسبة لتطبيقها على منظومة الاتصالات الضوئية التي تعمل في وزارة الاتصالات العراقية بين أي بدالتين تعملان بنظام (ISDN).