

# Optical Time Division Multiplexing (OTDM) and Hybrid WDM/OTDM PON Performance Investigation

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**Abstract** – Every day, the need for high speed reliable data transmission increases more and more. One important option is the passive optical networks which use the optical fiber and provides high data rates and long distance.

This work investigates the performance of a four users Optical Time Division Multiplexing OTDM over different length of single mode fibers SMF for different bit rates. The effect of utilizing Erbium Doped Fiber amplifiers EDFAs was investigated for mitigating effect of performance degradations due to attenuation. In order to increase capacity of the system, A hybrid four Wavelength Division Multiplexing WDM and four OTDM system was proposed Dispersion Compensating Fiber DCF was used for reducing the effect of dispersion distortion. A post dispersion compensation was applied to a four users OTDM each with bite rate of 10 and 40 Gbps in terms of data capacity per Optical Network Unit ONU.

A bit rate of 160 Gbps was obtained from the work with an BER of  $10^{-10}$  over length of 352.89km. The simulation was implemented using optisystem 7 and matlab R2011a.

**Keywords** – OTDM, DWDM, PON, DCF, BER, Q-Factor.

## I. INTRODUCTION

Future multi-terabit/s optical core networks require optical technologies capable of managing ultra-high bit rate OTDM/DWDM (optical time division multiplexing/dense wavelength division multiplexing) channels at 160 Gbit/s or higher bit rates. OTDM (Optical Time-Division Multiplexing) is a very powerful optical multiplexing technique that deliveries very high capacity of data over optical fiber. The basic principle of this technology is to multiplex a number of low bit rate optical channels in time domain. The key functionalities in ultra-high speed network nodes are all-optical wavelength conversion and demultiplexing of OTDM signals. Advanced optical networking techniques (optical add-drop multiplexing and optical routing) are studied in simulations and their performance evaluated considering 160 Gbit/s OTDM/DWDM channels.

Optical time-division-multiplexing (OTDM) is an important technique to overcome the electronic bottleneck and achieve single channel high bit-rate system [1]. The commercially available electronic components are limited to around 10Gb/s data rate. The first 100-Gb/s OTDM transmission experiment over a 36-km fiber link was already reported in 1993, OTDM was first demonstrated as early as 1968, primarily as means to increase the capacity of an optical link. OTDM technologies have made a lot of progress toward much higher bit rates and much longer transmission distance. For example, 160-Gb/s transmission

over a record length of 4320 km and on 2.56-Tb/s transmission over 160-km have been reported [2].

Overall, successful demonstration of OTDM up to 400Gb/s has brightened the future of commercial OTDM. This system has the advantage of operating only on a single wavelength. It is possible of running OTDM on a number of existing WDM channels, which improves the overall data capacity. It is purely digital and compliant with the concepts of all-digital network. With rapid advancement in semiconductor technology and integration techniques, it will eventually make possible to manufacture compact, stable and higher performance components for commercial OTDM system [Jeffrey Huang EE558 Spring 99]. Hybrid WDM/OTDM networks have been proposed to move data between WDM and OTDM networks, and various subsystems have been demonstrated at 40 Gbit/s including WDM-to-OTDM and OTDM to-WDM translators, OTDM transmitters, and OTDM add-drop multiplexers [Lavanya1]. OTDM and WDM are considered as the bases of second generation optical networks. OTDM and WDM can be used within the same network. they are complementary technologies in that a single fiber strand can be transmitting a several WDM signals. OTDM multiplexed data can be contained in each single WDM wavelength can contain. All Optical Network (AON ) uses WDM and OTDM together. AON increases the efficiency and throughput while decreases delay and errors. DWDM takes WDM, one of the second-generation optical network technologies, and takes it further.

This research work investigates the performance of a OTDM-PON and hybrid OTDM/WDM-PON network during the downstream direction. This paper is structured as follows. A brief outline of OTDM in section II. Section III describes the WDM systems. The PON technologies existing in the TDM and OTDM/WDM PON described in section IV. The simulation techniques and the values of the parameters with the results are outlined V. This is followed by Section VI which describes the conclusions of the work.

## II. OPTICAL TIME-DIVISION MULTIPLEXING OTDM SYSTEM

In time-division multiplexing and demultiplexing, each of the baseband data streams is given a series of time slots on the multiplexed channel. A multiplexer (MUX) is responsible of assembling the higher bit-rate bit stream from several baseband streams while a demultiplexer (DEMUX) does the opposite job to reconstruct replica of

the bit streams at the original lower bit rate by separating bits in the multiplexed stream. This technique is applied to optical system to multiplex and demultiplex optical signals as done in electrical systems.

In Figure (1), a schematic diagram of an  $N$  channel OTDM transmission system is shown. An optical pulse train from a laser diode is splitted into  $N$  paths. In each path, the pulse train is individually modulated by an electrical data signal forming in  $N$  optical RZ format data channels. Each of branches is delayed by a fraction of the clock period and synchronized to allow passive multiplexing to sum up an individual data stream. Here, the multiplexer is most simply implemented using passive fiber couplers with appropriate optical delays between the channels. To avoid crosstalk between these interleaved channels, the laser source must be able to generate optical pulses of duration  $< 1/N$  of the clock period.

To multiplex an optical signal with period  $T$  ps to channel  $N$ , the required time delay for each path is:

$$\Delta\tau_i = i \frac{T}{N} \text{ (ps)} \quad i = 1, 2, \dots, N - 1 \quad [1]$$

Where  $\tau_i$  is the time delay for  $i$ th path. For example, for multiplexing the optical pulse train of 10 Gbit/s to 40 Gbit/s, the period  $T$  is 25 ps, so the time delay is 3.125 ps, and the difference of the fiber length is 0.2 mm. Goal of OTDM is to increase of the aggregate rate  $B_{OTDM} = NB_{ch}$  into the Tb/s-range ( $T \sim 1$ ps). Where,  $N$  is the number of time-channels and  $B_{ch}$  is the channel bit rate.

### III. WAVELENGTH-DIVISION MULTIPLEXING (WDM)

Wavelength-division multiplexing (WDM) gives better utilization of the large bandwidth of optical fiber and can increase the capacity of the cable network. Through WDM, signals from two or more line systems are transmitted over the same fiber [3]. The signal from different sources which combined by a multiplexer and fed into an optical fiber, channels combined are separated in the receiver unit by a demultiplexer and detected by photodetector [3]. The WDM devices at the transmitting unit is essentially a power combining referred to as a multiplexer. The device at the receiver unit is called a demultiplexer and should ideally separate out various channels with negligible loss and signal distortion. a large number of channels can be combined and separated with angularly dispersive multiplexing elements. At the output of the multiplexer, these light rays become co-linear and can be easily launched simultaneously into an optical fiber. At the receiver, a WDM works in exactly in the reverse fashion, directing light beams of various wavelengths from a fiber into their respective channels [3]. A block diagram of an WDM system is shown in Figure (2).

The main goal in any communication system is to increase the transmission distance. Loss and dispersion are the main factor that cause signal degradations and affect fiber-optical communication being the high-capacity develops. It is easy to see that the dispersion become the

major factor that restricts long distance fiber-optical transfers as the bit rate increases [4][ 5].

Several dispersion compensation technologies were proposed [Bo-ning5]. Amongst the various techniques proposed in the literature, the ones that appear to hold immediate promise for dispersion compensation and management could be broadly classified as: dispersion compensating fibers (DCF), chirped fiber Bragg gratings (FBG), and high-order mode (HOM) fiber [6].

Optical amplifiers are used to maintain the correct signal power to keep sufficient signal to noise ratio for acceptable bit-error rate. In such systems, fiber dispersion can be managed in many ways. One method is to balance the average group velocity dispersion in the whole system such that it is zero referred to dispersion management and another is to use soliton transmission techniques.

The third-order dispersion will influence the transmission system seriously as the bit rate of a single exceeds 40 Gbit/s and degrades the system performance. To deal with this problem, one can use DCF to compensate both the second-order dispersion and third-order dispersion of the SMF to extend the transmission distance in the system. The condition for a fiber link containing two kinds of fibers of length  $L_1$  and  $L_2$  to form the dispersion management is [7]:

$$\beta_{21}L_{SMF} + \beta_{22}L_{DCF} = 0 \quad [2]$$

$$\beta_{31}L_{SMF} + \beta_{32}L_{DCF} = 0 \quad [3]$$

Where  $\beta_{2j}$  and  $\beta_{3j}$  are second and third-order dispersion parameters for the fiber of length indicated. The third-order dispersion  $\beta_3$  is decided by:

$$\beta_{32} = \left( \frac{\beta_{22}}{\beta_{21}} \right) \beta_{31} = - \left( \frac{L_1}{L_2} \right) \beta_{31} \quad [4]$$

The resultant length due to use of DCF will be:  
 $L = L_{SMF} + L_{DCF}$  [5]

### IV. PASSIVE OPTICAL NETWORKS PON

During the year 1980's only Passive optical networks (PONs) were developed. Since it is cheap way to implement, PON has received great interest. It is used as a cost effective method for sharing fiber infrastructure to business premises, curb, and home etc. The PON architectures use the passive components, which potentially reduces the cost and maintenance since it is point to multi point transport network.

PONs uses optoelectronics so they characterized to have low power consumption, except laser amplifiers and photo receivers. Gigabit PON GPON has found to improve bandwidth factor by four through maintenance and security issues [8][9][10]. There are several architectures of PON using different modulation schemes like TDM, WDM and hybrid using both TDM/WDM.

The TDM PON is a point to multipoint architecture shown in Figure (3). The packets were broadcasted by the Optical Line Terminal OLT in the downstream direction. It is passed through a 1: N optical splitter and it is extracted by the designated Optical Network Unit ONU.

The data is sent in the form of packets and each user transmits after a definite time delay. The same time delay is utilized at the destination ONU to distinguish the packets meant for it.

The WDM PONs as shown in Figure (4), has been widely researched as a potential technology. This PON uses multiple wavelengths in a single fiber to multiply the capacity without increasing the data rate. But a single wavelength is assigned for TDM PON. A TDM PON provides moderate bandwidth but more channels [8][11]. The PON architecture consist of a single mode fiber which connects a Central Office CO to the network distribution unit which consist of passive optical splitters or/and Multiplexers and demultiplexer. The Optical Line Terminal OLT housed in the CO contains a set of tunable laser sources or fixed wavelength laser sources used to transmit the downstream traffic to Optical Network Unit ONU. Each user has been assigned a fixed frequency at which the laser operates. The frequency allotment can be permanent or it can be based on the requirement of bandwidth demanded. The data is then given to a multiplexer which combines all the data together and sends it through the optical fiber of lengths varying from 20km to 100km.

The Optical fiber that comes from the central office is connected to a passive WDM Demultiplexer. The function of it is to split the light depending on the wavelength and to transmits the same to the corresponding ONU. The ONU us again an optoelectronic component and converts the light signal to electrical signal and the data is retrieved [8][10].

## V. SYSTEM SIMULATION AND RESULTS

The performance of OTDM system and hybrid OTDM/DWDM system will be evaluated here for different bit rates and lengths of SMF. The proposed 4 users OTDM system is shown in Figure (5). A CW laser diode with a frequency of 193.1 THz is used. The splitter divides the optical power between the four OLTs. Each subsystem included in the OLT consists of a PRBS generator at a specific rate and a RZ Machzehnder modulator. In each branch there is a time delay with time of  $[(1/\text{bit rate}) * i/N]$  where  $i = 0, 1, \dots, N-1$ . So each user capable of transmitting information at a specific time slot. Then combining the output from each user by the optical power combiner and sent throught a single mode fiber SMF. At the end of the SMF of variable length, the multiplexed signal is amplified by an eribuim dopped fiber amplifier EDFA. The emerging signal is splitted and distributed among the ONUs at the receiver side and time delay unit is used at each ONU in order to synchronous with that of the OLT. Each user is allowed to access the network at certain time slot with delay time which limits the throughput of each user. Then, the signal is detected and demodulated at each ONU to extract the original information. Table (1) lists the main parameters and settings of proposed OTDM system.

Figures (6 and 7) shows the Q factor and BER variations of four users OTDM with length of SMF without any

amplification for bit rates of 1, 2.5 and 4 Gbps per user which give total bit rate of 4, 10 and 16 Gbps respectively. Figures (8 and 9) shows the Q factor and BER variations of four users OTDM with length of SMF with EDFA amplifier of 20 dB gain and noise figure of 4 for bit rates of 1, 2.5 and 4 Gbps per user which give total bit rate of 4, 10 and 16 Gbps respectively.

From the results it can be noted that as the bit rate increases the BER reduces for the same length. The use of EDFAs in the work improves the BER since the received optical power increased. For example, at lengths of 20 km, the BER obtained was  $1.16e-18$ ,  $5e-5$  and  $1.3e-13$  for bit rates of 1, 2.5 and 4 Gbps respectively. The BER of  $10^{-9}$  was obtained over a length of 125, 80 and 34.45 km for bit rates of 1, 2.5 and 4 Gbps respectively with the use of EDFA of 20 dB gain.

### Hybrid OTDM/DWDM system

Figure (10) is schematic diagram of a Hybrid OTDM/DWDM PON system which a combination of OTDM and DWDM for increasing the number of users and the rate of transmission of the system. In the above figure, four OTDM systems each with four users so there are sixteen users as a total. The output of each OTDM, which is a time multiplexing of the output of its four OLTs, is at different wavelength and wavelength multiplexed by an WDM multiplexer with four input ports. The output of the WDM is at a bite rate of  $(4*4*\text{bit rate})$ . After passing through the SMF and amplified by the EDFA, the multiplexed signals are demultiplexed by a WDM demultiplexer with four output ports and each wavelength is directed into its OTDM demultiplexing unit. The power of each wavelength is distributed among its four ONU systems in which the signal are detected and demodulated. Table (1) lists the parameters of the four hybrid OTDM/ four WDM system.

Figures (11 and 12) shows The Q factor and BER variations of four users OTDM/ four WDM system with length of SMF with EDFA amplifier for bit rates of 1, 2.5 and 4 Gbps per user which give total bit rate of 16, 40 and 64 Gbps respectivey at the output of DWM multiplexer.

### Dispersion compensation and OTDM

At high bit rates, the dispersion becomes the main limiting factor that affecting the system performance. Figure (13) shows OTDM system with dispersion compensation application for bit rates of 10 and 40 bit/sec for each of the four users i.e. the total rates are 40 and 160 Gbit/sec. dispersion compensation fiber DCF was used as a solution for reducing the dispersion effects. For 10 Gbps, Figure (14) shows the BER variations of four users OTDM system versus distance using only EDFA amplifier while Figure (15) demonstrates the BER variations of 40 Gbps four users OTDM system versus distance using only EDFA amplifier. The BER of  $10^{-9}$  is obtained at a distance of 5.7 km for 10 Gbps OTDM system while it was at 730 meter for 40 Gbps OTDM system.

In order to increase the length of the link, a DCF was applied to system as shown in Figure (13). The parameters of the DCF are listed in Table (1). Figure (16) illustrates the performance of the 10 Gbps OTDM system with DCF and EDFA amplifier and Figures (17) illustrate that of the

40 Gbps OTDM system. The distance at which the BER is  $10^{-9}$  becomes 202.32 km for 10Gbps rate and 182.367km for the 40Gbps systems. This length represent the length of both the SMF and DCF fibers.

**160 Gbps OTDM signal transmission over 352km**

In Figure (18), a schematic of a four users OTDM each with 40 Gbps i.e. resultant rate after multiplexing is 160 Gbps is shown. It uses three spans. Each span has length of 117.63km so the total length is 352.89km. The BER obtained at the receiving end was  $3.42e-10$  which is in the acceptable zone. The setting of the system is as listed in Table (1).

**VI. CONCLUSIONS**

The proposed 160 Gbps OTDM access network was designed using four users each transmitting at 40 Gbps has been successfully evaluated in this research work. The system operated over a distance of 352.89km with a BER of  $10^{-10}$ .

In OTDM, the performance depends on both bit rate and length of the fiber as the bit rate increased the BER of the system decreased. The use of the EDFAs enhances the system performance and the link length as shown in the figures.

Results simulated using optisystem have confirmed that the use of WDM PON network increases the net bit rate over that of TDM PON networks.

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**AUTHOR'S PROFILE**



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Obtained his B.Sc. (Electronic and Communications Engineering) from Baghdad University\ Baghdad\Iraq in 1996, and M.Sc. (Electronic and Communications Engineering/Laser Applications) from Baghdad University\ Baghdad\ Iraq in 2001. He is an Instructor Electronic and Communications Engineering Department(College of Engineering)\ Baghdad University. His current research areas include Optical Fiber Communications and Wireless Communications, Error Correcting Codes and MC-CDMA.

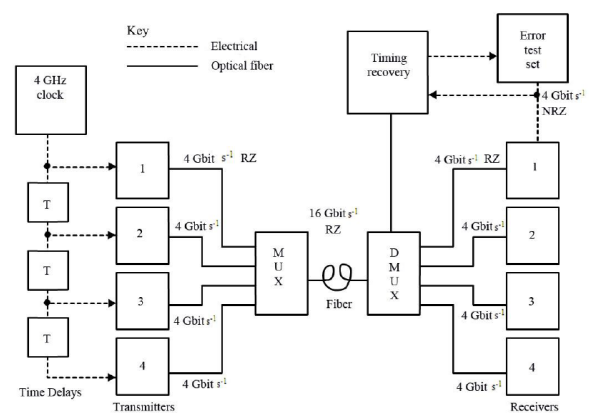


Fig.1. A block diagram of Optical Time Division Multiplexing OTDM

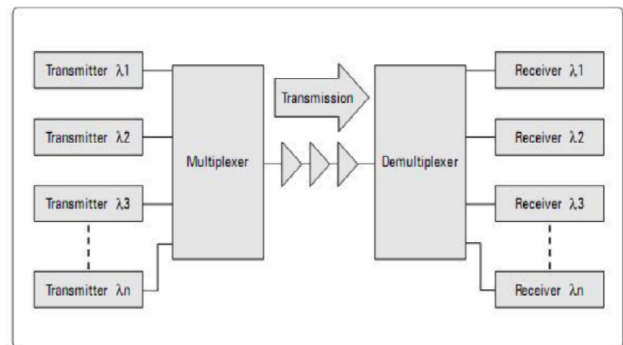


Fig.2. A block diagram of Wavelength Division Multiplexing WDM system.

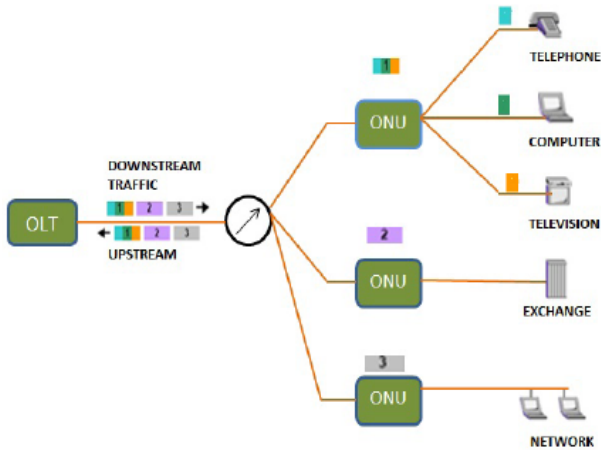


Fig.3. TDM PON Model

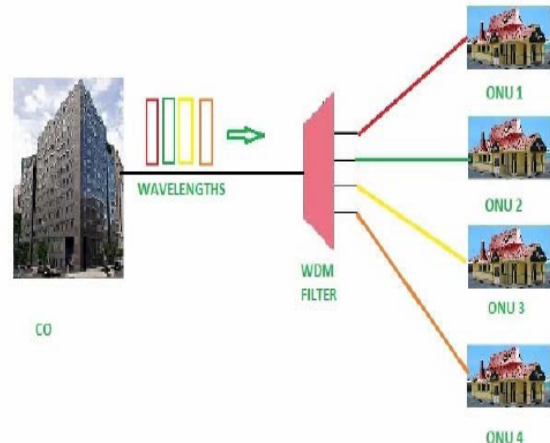


Fig.4. WDM PON Model

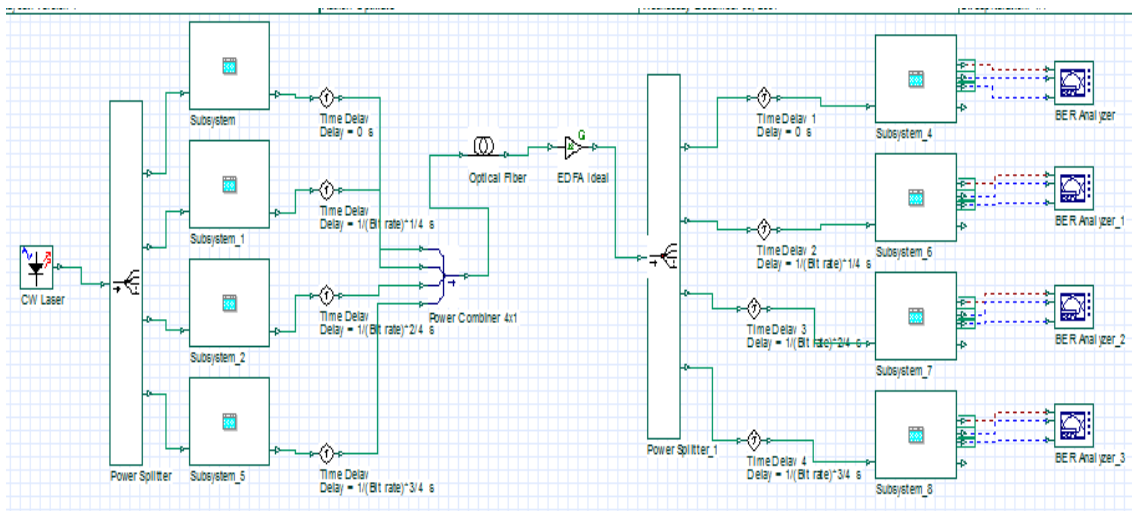


Fig.5. Proposed OTDM four users system

Table 1: Lists the main parameters and settings of proposed OTDM system

Parameter	SMF	DCF
Fiber loss dB/km	0.2	0.2
Dispersion (ps/nm.km)	16.75	-95
Second order dispersion parameter (ps <sup>2</sup> /km)	-20.79	117.9
Third order dispersion parameter (ps <sup>3</sup> /km)	0.1	-0.567
Bit rates (Gbps)	1, 2.5, 4, 10 and 40	
Operating frequency (THz)	193.	
Signal format	NRZ	
Photodiode quantum efficiency	1	
Receiver filter bandwidth	0.65*bit rate	
EDFA gain (dB)	20	
Amplifier noise figure (dB)	4	
WDM multiplexer and Demultiplexer		
Frequency spacing (GHz)	100	
Bandwidth (GHz)	10	

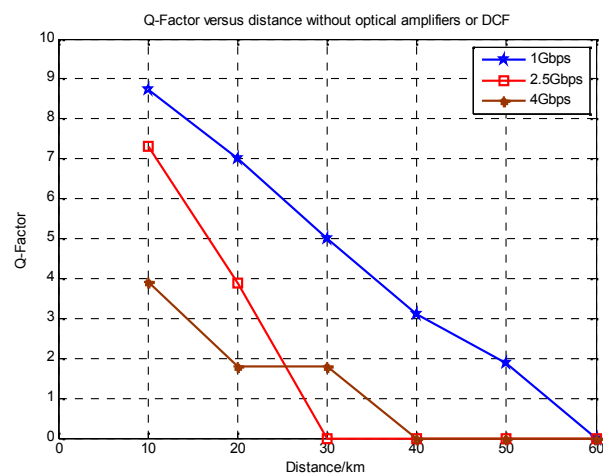


Fig.6. Q-Factor versus distance without optical amplifiers or DCF

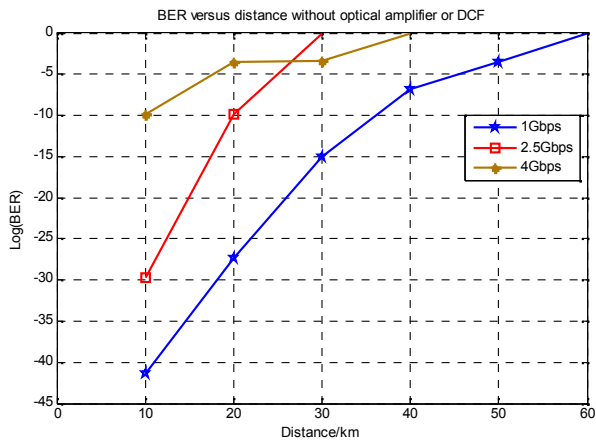


Fig.7. BER versus distance without optical amplifier or DC

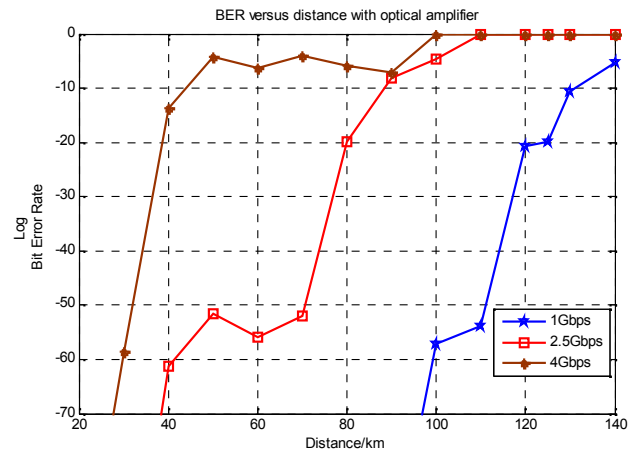


Fig.9. BER versus distance with optical amplifier.

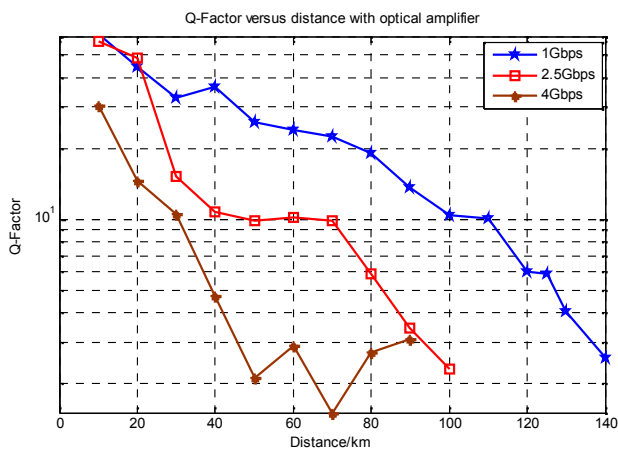


Fig.8. Q-Factor versus distance/km with optical amplifier

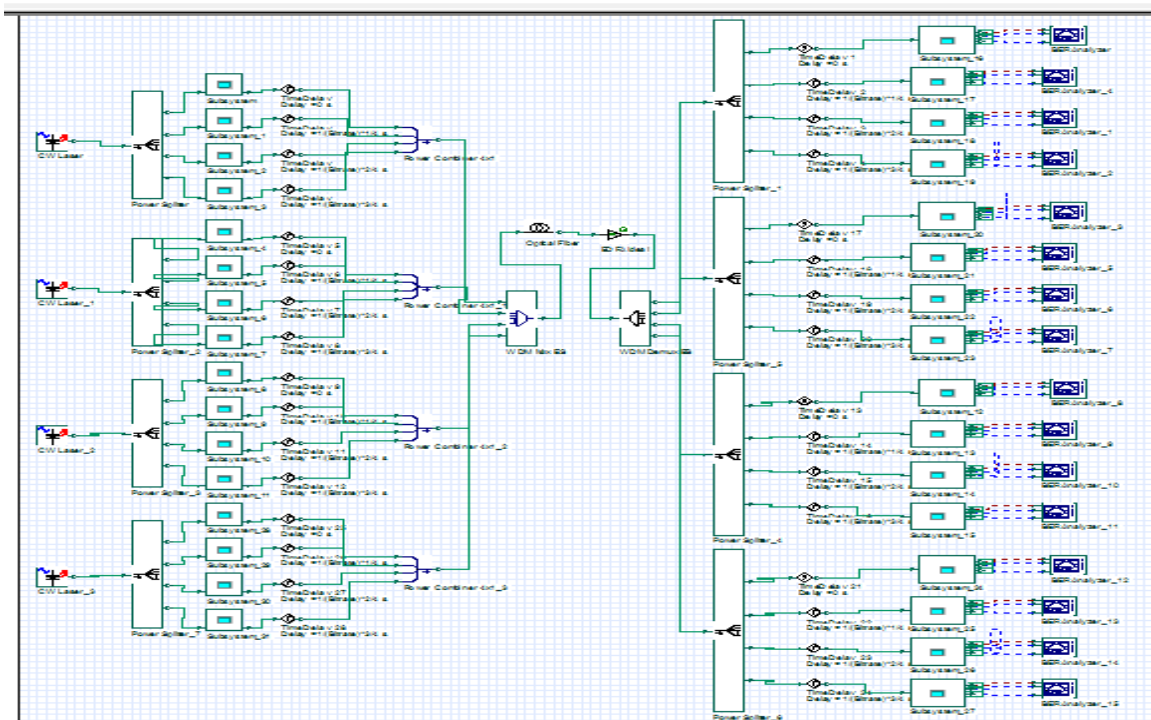


Fig.10.

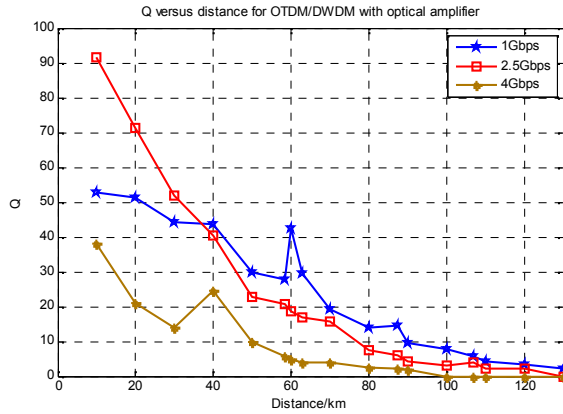


Fig.11. Q versus distance for OTDM/DWDM with optical amplifier

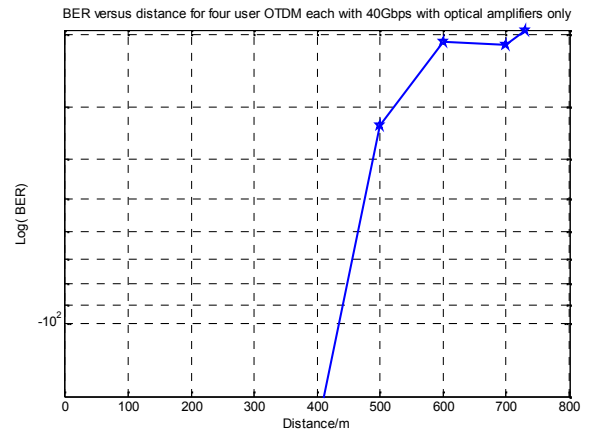


Fig.15. BER versus distance for four user OTDM each with 40Gbps with optical amplifiers only

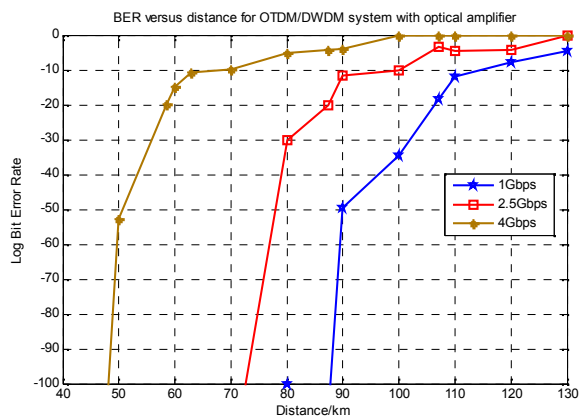


Fig.12. BER versus distance for OTDM/DWDM system with optical amplifier.

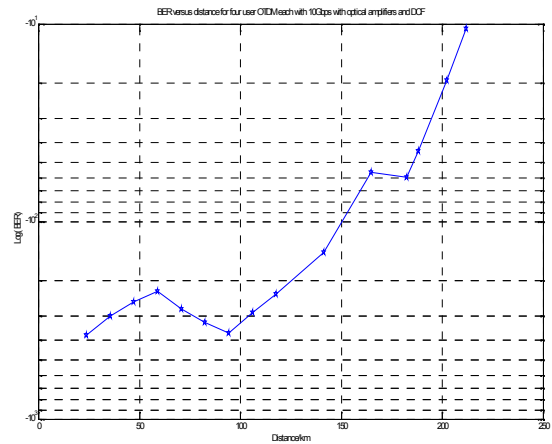


Fig.16. BER versus distance for four user OTDM each with 10Gbps with optical amplifiers and DCF.

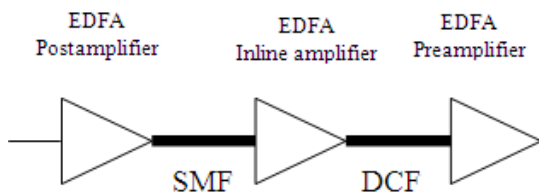


Fig.13

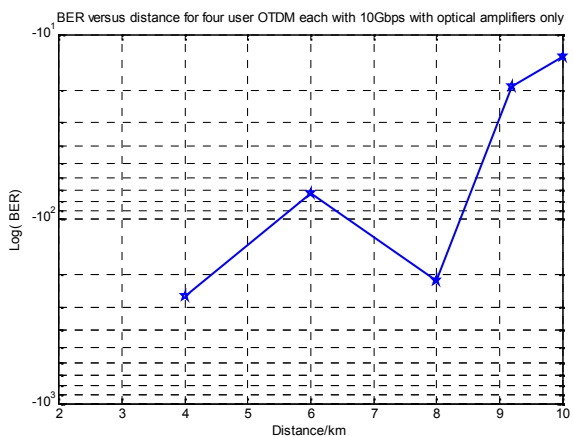


Fig.14. BER versus distance for four user OTDM each with 10Gbps with optical amplifiers only

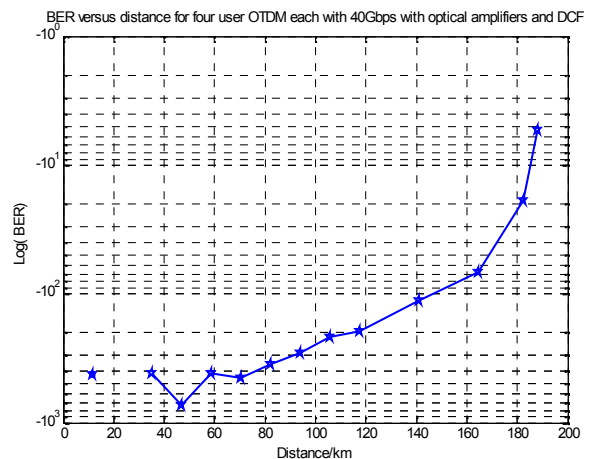


Fig.17. BER versus distance for four user OTDM each with 40Gbps with optical amplifiers and DCF

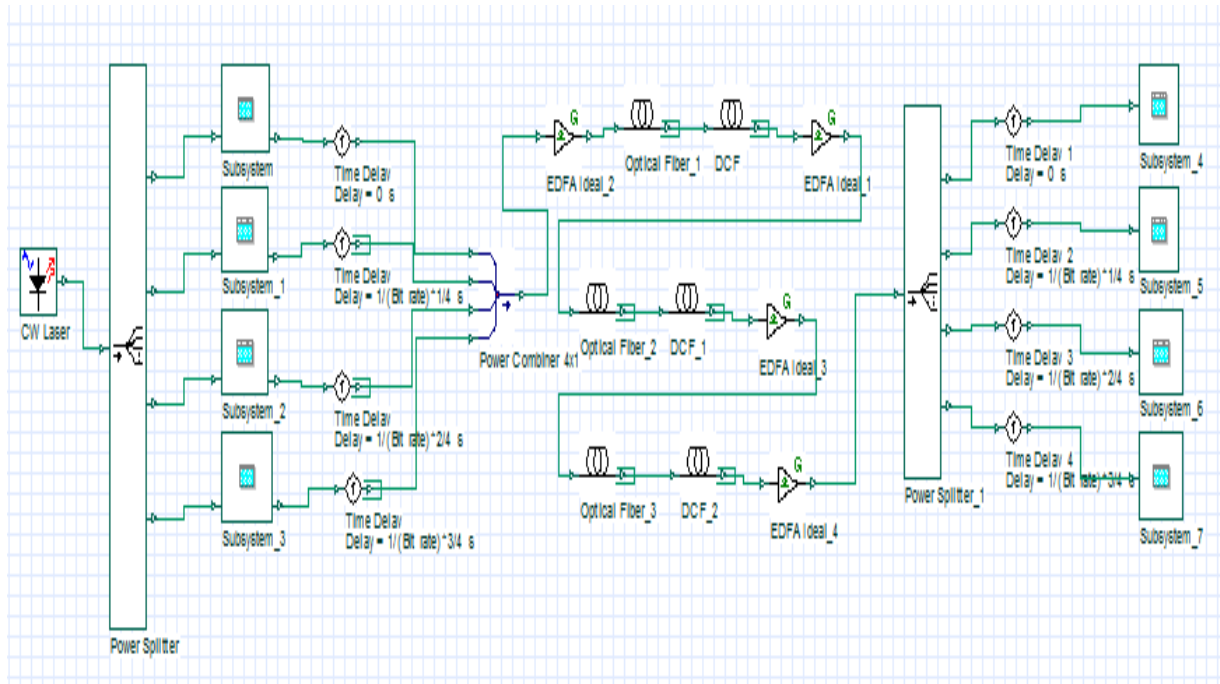


Fig.18. 160 Gbps OTDM over 352.89km.