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Simulative Investigation of 32x10, 32x20 and 32x40 Gb/s DWDM Systems with Dispersion Compensating Fibers

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Abstract

Dense wavelength division multiplexing (DWDM) is a WDM technology with reduced channel spacing. This technology is really scalable in terms of handling additional wavelengths/users. But the dispersion compensation is a key issue in DWDM at bit rate ≥ 10 Gb/s. Dispersion can be fully compensated by using Dispersion compensating fiber as a compensator. In this paper, the performance of 32 channel DWDM system with post-dispersion compensation using DCF at different bit rates (10, 20 and 40 Gbps) is investigated. The simulation is done in Optisystem simulator. The performance of the simulated system has been investigated in terms of quality (Q) factor and bit error rate (BER).

Keywords: *DWDM (Dense wavelength division multiplexing), dispersion compensation, BER Q-factor*

1. Introduction

In optical fiber communication system, the wavelength division multiplexing (WDM) is one of the efficient techniques used to increase the information carrying capacity. Traditionally, the WDM system have the channel spacing of ≥ 200 GHz, are known as the conventional or coarse WDM system. Then the dense wavelength division multiplexing (DWDM) system was developed, which has the channel spacing of ≤ 100 GHz to enlarge the capacity of optical networks. The transmission in optical communication system is affected by the attenuation, dispersion and fiber non-linearities. The attenuation/losses and non-linearities problems can be overcome by optical amplifiers such as EDFA (Er-doped fiber amplifier), SOA (Semiconductor optical amplifier) and Raman optical amplifiers.

The main goal of every communication system is to increase the transmission distance and speed (data rate). Like other communication systems the optical communication systems also faces problems such as dispersion, attenuation, losses and non linear effects, which degrade its performance. The longer distance an optical pulse goes, the less chance the data can get to receiver end; the faster a pulse is being transmitted, the worse the information can be recognized successfully. This is due to attenuation and the dispersion of propagating light wave. The attenuation effects decreases the signal power and the dispersion effect distorted the shape of the pulse as a lightwave propagating down a fiber. Both attenuation and dispersion also affect repeater spacing in a long distance fiber-optic communication system. The advent of optical amplifiers minimized the attenuation problem significantly. But the dispersion, specially the chromatic dispersion (CD) and polarization mode dispersion (PMD) in single mode fiber, is one of the most severe limiting factors in long distance optical transmission system. If the transmission distance exceeds

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several kilometers, the dispersion can cause intolerable amount of losses and signal distortions, which lead to increase in bit error rate (BER). Therefore, it is necessary to compensate the dispersion by using dispersion compensating techniques such as fiber bragg grating (FBG), dispersion compensating fibers (DCF), optical phase conjugator (OPC), dispersion shifted fibers (DSF), dispersion flattened fibers (DFF) and reverse dispersion fiber (RDF) [1-3].

Dispersion compensating fiber: DCF is the leading technology for dispersion compensation. The idea of using dispersion compensation fiber (DCF) for dispersion compensation was proposed in 1980 but, until after the invention of optical amplifiers, DCF began to be widespread attention and study.

Unlike dispersion-shifted fibers (DSF) and dispersion-flattened fibers (DFF) which are desired to have very small dispersion at 1550 nm, dispersion compensating fibers are designed to provide very large negative dispersion at this wavelength. Optical fibers designed for use at 1300 nm wavelength may be operated at 1550 nm in order to take advantage of lower the fiber attenuation at this wavelength. However, optical fibers at 1550 nm have fairly large positive dispersion which results in signal distortion. To compensate for the accumulated positive dispersion over the length of the link, the fiber is concatenated with a shorter length of a dispersion compensating fiber, which is a single mode fiber with large negative dispersion.

Thus, DCF is an optical fiber, which has a special design that provides a negative dispersion coefficient to compensate for the positive dispersion accumulated over the standard optical fiber.

To achieve a DCF with a high negative dispersion coefficient, manufactures have to manipulate the waveguide dispersion i.e. modify the refractive index profile and the relative index value as may be necessary for a specific application. Most of the dispersion compensating fibers reported in the literature has a single cladding layer. [4-5]

The rest of the paper is organized as: Section 2 presents the literature review. Section 3 discussed the simulation methodology and 4 results and discussion. Section 5 concludes the work.

2. Literature Review

M. I. Hayee and A. E. Willner [5] analyzed 10 Gb/s non dispersion managed and dispersion managed wavelength division multiplexed systems which use the pre compensation, post compensation **a**nd dual compensation of each channel to mitigate dispersion and nonlinear effects. They observed that the dual compensation method gives the minimum penalty for each dispersion managed WDM systems. Furthermore, they have found that the optimal amount of pre or post compensation depends upon the specific dispersion map used in the wavelength division multiplexing (WDM) system.

Fariborz Mousavi Madani and Kazuro Kikuchi [6] investigated the performance limit of 10, 20, and 40 Gb/s WDM systems employing the higher order DCF by extensive computer simulations. They have realized that in conventional long distance wavelength-division multiplexed (WDM) dispersion-managed transmission systems, since both the dispersion-shifted fiber (DSF) and the standard single-mode fiber (SMF) have positive dispersion slope, perfect dispersion compensation can be achieved only for a single wavelength channel. In contrast, WDM dispersion managed systems comprised of a SMF followed by a higher order dispersion compensation fiber (DCF) with opposite second and third-order dispersions can clear out this drawback.

J.-J. Yu, Kejian Guan, Zhenbo Xu and Bojun Yang [7] analyzed the effects of different compensation ratios with dispersion post-compensation on nonlinear signal channel and WDM systems with 10 Gb/s NRZ per channel. Post dispersion compensation enhanced the performance of the nonlinear single channel system and the nonlinear WDM system. But the enhanced distance of the nonlinear WDM system was not as obvious as that of the single channel transmission system, because the cross phase modulation effect played an important role in the nonlinear WDM system. The numerical results showed that in order to achieve good performance, the length of DCF should be precisely selected.

R. S. Kaler [8] investigated the 16 channel WDM systems at 10 Gb/s for the various optical amplifiers and hybrid amplifiers. The performance has been investigated on the basis of transmission distance and dispersion and the performance of optical amplifiers was evaluated using the power level, eye patterns, BER measurement, eye opening and Q factor. EDFA and SOA have been investigated independently and further compared with hybrid optical amplifiers like RAMAN-EDFA and RAMAN-SOA. It was observed that hybrid optical amplifier RAMAN-EDFA provides the highest output power (12.017 and 12.088 dBm) and least bit error rate (10^{-40} and 9.08×10^{-18}) at 100 km for dispersion 2 ps/nm/km and 4 ps/nm/km respectively.

Gurinder Singh, Ameeta Seehra and Sukhbir Singh [9] analyzed the use of RZ super Gaussian pulse inputs for different WDM systems such as conventional WDM, dense and ultra dense WDM systems, employing dispersion compensating fibers (DCFs). They investigated the performance of pre, post and symmetrical dispersion compensation methods and the performance of these three techniques is compared for different WDM systems having a channel spacing of 200 GHz, 50 GHz and 25 GHz, respectively. The pulse width and the order of the RZ super Gaussian pulse were varied to evaluate the performance at 40 Gb/s. It is observed that for coarse or conventional WDM system with 200 GHz channel spacing, pulse width is to be taken between 5 ps and 10 ps with minimum BER at 10 ps. For 50 GHz channel spacing, pulse width of 5 ps and 7.5 ps is preferred. Also for 25 GHz channel spacing, pulse width of 5 ps and 7.5 ps is preferred. The symmetrical compensation is recommended for use over other compensation techniques and 3rd order RZ super Gaussian pulse at 40 Gb/s is useful instead of 1st and 2nd order RZ super Gaussian pulses to get minimum BER.

R. S. Kaler, A.K.Shrama and T.S.Sharma [10] presented simulative results for DWDM systems using NRZ format with ultra high capacity upto 1.28 Tb/s and spectral efficiency 0.4 b/s/Hz. They investigated the impact of signal to noise ratio on channel spacing, dispersion, length of fiber and number of channels.

Jyoti Choudhary, Lalit Singh Garia and Rajendra Singh Shahi [11] analyzed 16 channels DWDM optical communication system for different dispersion compensation schemes pre, post and mix dispersion compensation scheme using DCF using different modulation system NRZ, CS-RZ, DRZ and MDRZ at different bit rates 10 Gb/s, 20 Gb/s and 40 Gb/s. They observed that at high bit rate MDRZ format gives better performance than others and found that mix- dispersion compensation scheme shows better performance as compare to other schemes on the basis of Q factor, bit error rate (BER) and eye opening over 50 km of single mode fiber (SMF) and 10 km of dispersion compensating fiber (DCF).

Simranjit Singh, Amanpreet Singh and R.S. Kaler [12] investigated 16 × 10, 32 × 10 and 64 × 10 Gb/s WDM lightwave system using optical amplifiers (RAMAN, EDFA and SOA) with and without non-linearities. Both the cases with and without nonlinearities were implemented to compare optical amplifiers by varying transmission distance (40-200 km) and dispersion (2–10 ps/nm/km) in the term of output power, BER, Q factor and eye closure. It was concluded that when the dispersion was 2 ps/nm/km and the number of channels were less, then SOA provide better results but as the number of channels increases, it degraded the performance because gain saturation problem arises. When dispersion is increased from 2 to 10 ps/nm/km, EDFA provides better results than SOA in the term of BER and output power, but it shows non-uniform gain spectrum. It has been also observed that the RAMAN amplifier provides good results for L band amplification and gain flatting issue because it can substantially reduce the impact of fiber nonlinearity.

Abdel Hakeim M. Huseina [13] investigated the spectrum sliced dense wavelength division multiplexed (DWDM) passive optical network as a power efficient and cost effective solution for optical access networks. The high speed DWDM system has been realized and investigated for 32 channels with data rate up to 3 Gbps using broadband ASE source (LED). The 3 Gb/s signals both non-return-to-zero (NRZ) and return-to-zero (RZ) were demonstrated in 40 km optical fiber link with BER < 10^{-12}. The results obtained here demonstrate that DWDM is well suited for Fiber-to-the-Home network.

In this paper, the work has been extended and investigated the 32 Channel DWDM system at different bit rates (10, 20 and 40 Gb/s) for 80 km of SMF and 10 km of DCF. The number of spans taken to be 2 i.e. the total length of the link is 180 km.

3. Simulation Setup

The 32 channel DWDM system with DCF is designed and simulated in Optisystem simulator software. The parameters in Table 1 are used for the simulated system and Table 2 described the fiber parameters. “Figure 3” shows the block diagram of simulation setup. Transmitter section consists of 32 transmitters that have equally spaced emission frequency range form 191-194.1 THz, i.e. the channel spacing is 100 GHz. Each transmitter section consists of bit sequence generator, NRZ pulse generator, CW laser and Mach-Zehnder (M-Z) modulator. Optical multiplexer that has 32 input ports is used to combine the signals and transmits over the single fiber link. EDFA is used in the system to compensate for the attenuation losses. Optical channel consists of 80 km of SMF and 16 km of DCF. The optical spans taken to be 2 i.e. the total length of the link is 180 km. Post-compensation scheme is used to compensate for the dispersion using DCF i.e. the DCF is placed after the SMF to compensate for the positive dispersion accumulated over the length of SMF.

The transmitter section block diagram is shown in “Figure 1”.

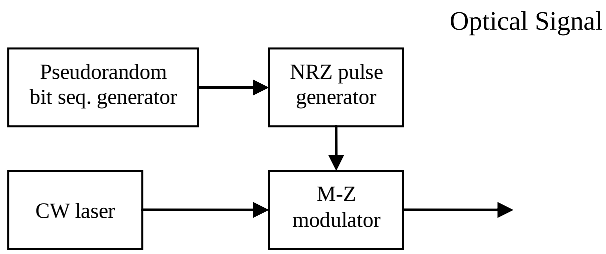


Figure 1. Block Diagram of Transmitter Section

The receiver section consists of optical demultiplexer, PIN photodiode, low pass Bessel filter and 3R regenerator. Signals are demultiplexed /separated by optical demultiplexer that has 32 output ports and detected by PIN photodiode. The block diagram of receiver section is shown in “Figure 2”.

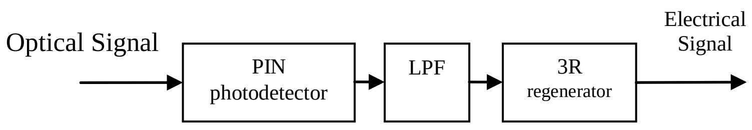


Figure 2. Block Diagram of Receiver Section

The block diagram of simulation setup of the 32 channel DWDM system is as shown in “Figure 3”.

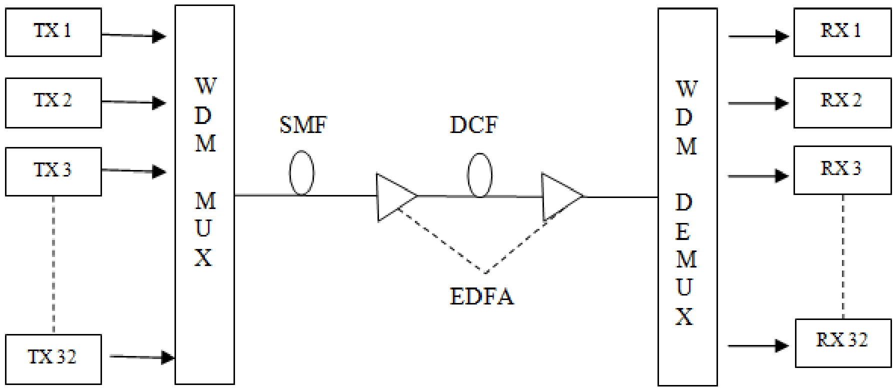


Figure 3. Block Diagram of 32 Channel DWDM System Using Post-Dispersion Compensation Technique

Table 1. Simulation Parameters

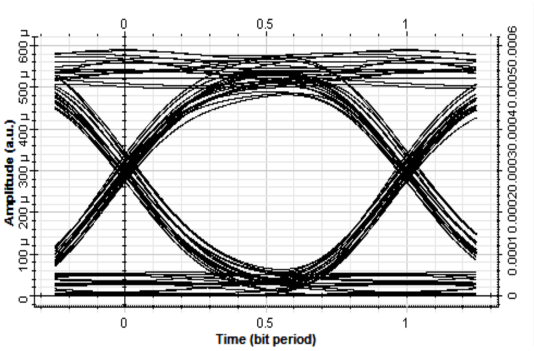
Parameters	Value
Data rates	10, 20, 40 Gb/s
Sequence length	64
Samples per bit	256
Central frequency of first channel	191 THz
Channel spacing	100 GHz
Capacity	32x40 Gbps

Table 2. Fiber Parameters

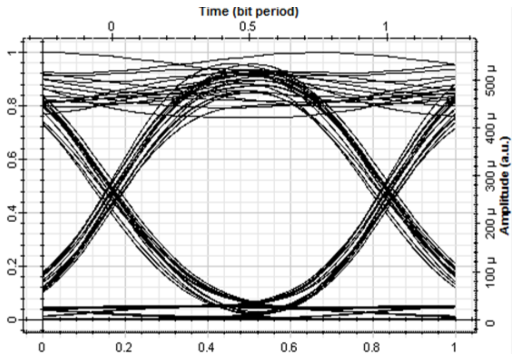
Parameters	SMF	DCF
Length (km)	80	16
Attenuation (db/km)	0.2	0.6
Dispersion (ps/nm/km)	17	-80
Dispersion slop (ps/nm^2/km)	0.08	0.3
Differential group delay (ps/km)	0.5	0.5
PMD coefficient (ps/nm)	0.5	0.5

4. Results and Discussion

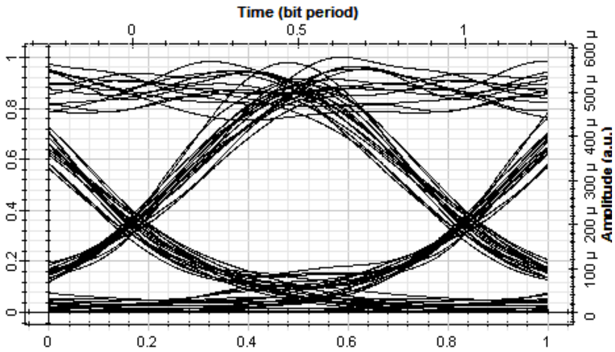
The simulation is carried out to evaluate the performance of post-dispersion compensation technique using DCF on 32 channel DWDM system at different data rates (10 Gb/s, 20 Gb/s and 40 Gb/s). The performance at different data rates is investigated in terms of bit error rate (BER) and Q-factor (db). The eye diagrams for the first user and last user at frequencies 191 THz and 194.1 THz for 10, 20 and 40 Gb/s are shown in “Figure 4”.



(a) 32x10Gb/s



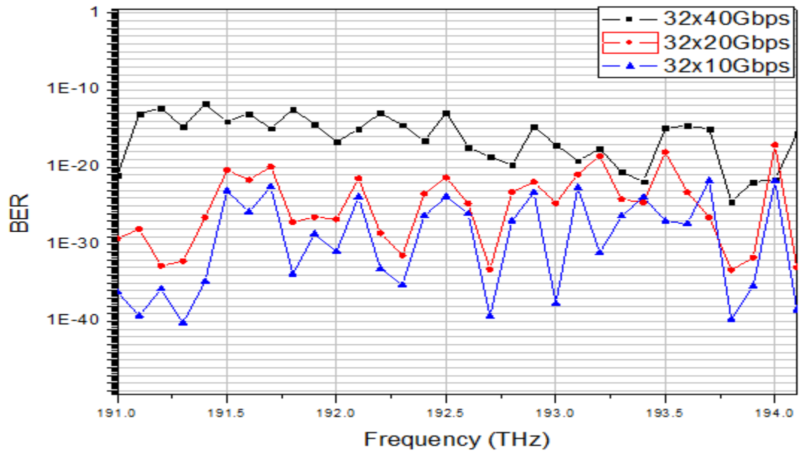
(b) 32x20Gb/s



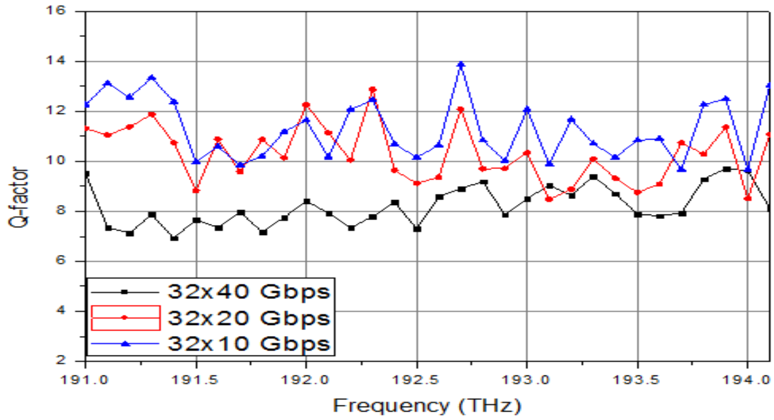
(c) 32x40Gb/s

Figure 4. Eye Diagrams at Different Data Rates for First User (191 THz)

The graphs of BER and Q-factor for 32 users i.e. at different frequencies for the different data rates are shown in “Figure 5”.



(a) BER for 32 users at different freq.



(b) Q-factor for 32 users at different freq.

Figure 5. Graphs of BER and Q-factor for 32 Users at Different Bit Rates

5. Conclusion

In this investigation, the performance of post-dispersion compensation technique using dispersion compensating fiber (DCF) on 32 channel DWDM system at different bit rates (10 Gb/s, 20 Gb/s and 40 Gb/s) is evaluated. The channel spacing of 100 GHz is used in this system with the central frequency of first channel is 191.0 THz and of last is 194.1 THz. The performance of simulated system has been investigated in terms of BER and Q-factor as shown in graphs above. From the simulation results, it has been observed that the average minimum BER for all the 32 channels is 10^{-32}, 10^{-28} and 10^{-19} at 10, 20 and 40 Gb/s respectively and the average maximum Q-factor for all 32 channels is 11.31, 10.5 and 9.65 at 10, 20 and 40 Gb/s respectively. Thus, the simulation results show that the DWDM systems have good performance, low bit error rate and fully exploit the high speed, if the dispersion compensating fibers (DCFs) are incorporated in the system as the dispersion compensation technique.

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