PERFORMANCE EVALUATION OF OPTICAL ADD DROP MULTIPLEXERS WITH MACH-ZEHNDER INTERFEROMETER TECHNIQUES FOR DENSE WAVELENGTH DIVISION MULTIPLEXED SYSTEM

ОЦЕНКА ХАРАКТЕРИСТИК ОПТИЧЕСКИХ МУЛЬТИПЛЕКСОРОВ НА БАЗЕ ИНТЕРФЕРОМЕТРА МАХА–ЦЕНДЕРА ДЛЯ ВОЛОКОННЫХ СИСТЕМ С ПЛОТНЫМ СПЕКТРАЛЬНЫМ УПЛОТНИТЕЛЕМ

Sanjeev Dewra*, Dr. R. S. Kaler**

* Shaheed Bhagat Singh State Technical Campus-Ferozepur, Punjab, India.
E-mail: neerajsanjeevdewra@rediffmail.com

** Thapar University-Patiala, India.
E-mail: rskaler@yahoo.com

We evaluate the three Mach-Zehnder interferometer (MZI) techniques of optical add drop multiplexer for DWDM system and investigate the impact of crosstalk obtained at 8 × 10 Gbps with 0.1 nm channel spacing. The Dense wavelength division multiplexing (DWDM) transmission with optical add drop multiplexer (OADM) placed at the 35 km point of a 70 km link has been demonstrated. It is also observed that Mach-Zehnder interferometer-Fiber Bragg Grating (MZI-FBG) based OADM and MZI based OADM provide better results with maximum covered distance (150 km) at channel spacing of 0.1 nm and bit rate of 10 Gbps without using Dispersion Compensating Fiber (DCF) and amplifier and the worst case is found with the Mach-Zehnder interferometer-Semiconductor optical amplifier (MZI-SOA) based OADM. It is also found that the MZI Based OADM is cost effective as compared to MZI-SOA and MZI- FBG Based OADM.

Keywords: *Optical Add Drop Multiplexer, Bit error rate (BER), Quality (Q) factor, DWDM system, Channel spacing and Bit rate.*

Submitted 17.01.2013.

1. Introduction

Dense wavelength-division-multiplexing (DWDM) technology is well-known for its dramatic increase in transmission capacity, and its flexibility in optical networking [1]. Optical add-drop multiplexer (OADM) will play a key role in enabling greater connectivity and flexibility in dense wavelength-division multiplexing (DWDM) networks [2]. Crosstalk arises in OADMs through component imperfections and limits the performance of the system [3]. Optical crosstalk at the same wavelength as the information signal is generally referred to as homodyne crosstalk. It is particularly serious because it cannot be removed by filtering [4]. Grating based devices have received a wide popularity over the competing technologies due to their advantages like all fiber geometry, versatility, low insertion loss, high return loss and low cost. Fiber gratings can be used in extremely narrow band filters, fiber lasers, dispersion compensators, wavelength converters, phase conjugators, add/drop multiplexers and wavelength stabilized pump lasers [5]. Many types of OADMs have been demonstrated based on different optical devices. These devices include Mach–Zehnder interferometers (MZIs) which is used to add and drop the channels as described in novel 2 × 2 multi wavelength optical cross connects based on OADM and optical switches [6]. P.T. Neves et al [7]. Investigated an add/drop based in a all fiber Mach- Zehnder Interferometer and two identical fiber Bragg Gratings (MZ-FG) assembled with discrete components with experiments and simulation. The influence of the components parameters on undesirable power return is showed. R.J.S. Pedersen et al [8]. described grating based MZI optical add drop multiplexer might not be limited by the transfer function from the input to the drop port, but rather by the transfer function from the add port to the drop port or the input port to the output port. Mach–Zehnder interferometers with fiber Bragg gratings (MZ-FG) are investigated as promising devices for wavelength-selectable optical add-and-drop multiplexers (OADM). A wavelength reused OADM performance is demonstrated for the first time to our knowledge in a six-channel, 10 Gb/s WDM experiment using a single-stage MZ-FG as reported in [9]. A.M. de Melo et al [10] proposed a modified semiconductor optical amplifier based Mach–Zehnder interferometer (SOA-MZI) setup for high-speed optical time division multiplexing add/drop multiplexing (ADM) operation. It has the property of enabling an independent phase optimization for clear and drop ports simultaneously. P.S Andre et al [11] proposed a tunable OADM based on fiber Bragg gratings (FBG) where the dropped channel is removed by the use of a optical circulator and the added channel is incorporated to the wavelength combo by a passive optical coupler and concluded that the OADM is transparent by design and cost effective due to the use of just one optical circulator. Peng-Chun Peng et al [12] presented and demonstrated two novel optical add-drop multiplexer (OADM) with different self-healing functionalities for reliable wavelength-division-multiplexing networks. Single or multiple failure-link traffics can be bi-directionally restored without the need for wavelength conversion or extra backup fiber links. Kaler et al [13] presented simulation results for DWDM systems with an ultra-high capacity. The impact of signal-to noise ratio (SNR) on parameters such as channel spacing, length of fiber, dispersion, and number of channels has been investigated. Singh & kaler [14-15] simulated 50 nm up and down wavelength conversion for a non-return to zero differential phase shift keying (NRZ-DPSK) signal using four-wave mixing in an optimized semiconductor optical amplifier (SOA) at 10 Gb/s for the first time and investigated sufficient power margin for ten-channels WDM transmission over 68,908 km by using cascaded in-line semiconductor optical amplifier for the differential phase-shift keying (DPSK) modulation format for the first time and used the structural optimization and placement scheme of semiconductor optical amplifiers (SOAs) for long-haul Wavelength Division Multiplexing (WDM) transmission. The SOA model for in-line amplifier has low crosstalk, ASE noise power and low noise figure with sufficient gain. The impact of noise figure, amplification factor, ASE noise power, optical gain and crosstalk with signal input power for the SOA model has been illustrated, which shows that 400 mA is the optimum bias current.

Till now, works were aimed mainly at studying the feasibility of a DWDM optical system based on an optical add/drop multiplexers, but few works had been carried out to make the comparison among different techniques using OADMs in terms of bit rate, channel spacing, cost and transmission distances. The effect of crosstalk on BER and Q-factor using these techniques has not been analyzed properly. All these measures have been taken in this paper, to have the assessment of signal evolution, as it passes through the 8×10 Gbps Dense wavelength division multiplexing transmission (0.1 nm channel spacing) with OADMs placed at the 35 km point of a 70 km link.

The paper is organized into four sections. Section 1 presents the introduction. Section 2 presents the simulation set-up of the system and the description of its components. Section 3 includes the discussion of the results for the DWDM system based on optical add drop multiplexer with MZI, MZI-SOA and MZI-FBG. Section 4 presents the conclusion about the feasibility of the system.

2. Simulation set up

The simulation setup consists of three stages i.e. transmitter, optical add drop multiplexer and receiver as shown in Fig. 1. As OADM has four ports namely input port, add port, drop port and output port. The simulation was carried out using eight channels. The first channel ch-1 with one frequency is dropped to the drop port and the same frequency is added to the add port.

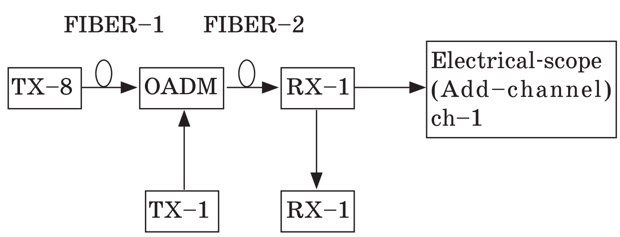

Fig. 1. System Set up.

Each transmitter is composed of data source, NRZ rectangular driver, laser source, optical amplitude modulator. Data source generates a binary sequence of data stream. Data source is customized by baud rate, sequence, logical. Laser block shows simplified continuous wave (CW) Lorentzian laser. The model has eight center emission frequencies, 1 mW CW power, ideal laser noise bandwidth (BW), 10 MHz FWHM (Full width at half maximum) line width and laser random phase. The PRBS of pattern length (2^7–1) used

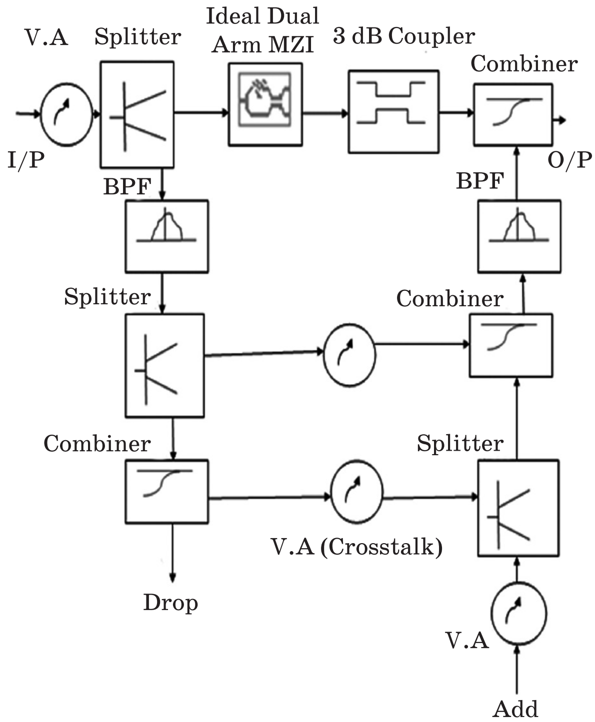

Fig. 2. Structure of OADM based on MZI.

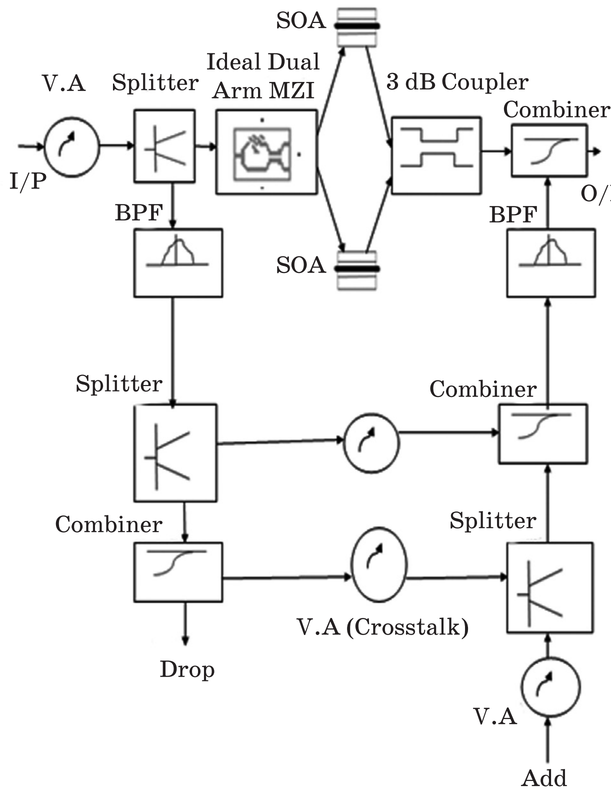

Fig. 3. Structure of OADM based on MZI-SOA.

as a data source. The electrical and optical signals from the driver and laser source are passed to the optical amplitude modulator. Modulation driver here generates data format of the type NRZ rectangular with a signal dynamics i.e. low level −2.5 V and high level +2.5 V. The pulses are then modulated using Mach–Zehnder (MZ) modulator. The transmitters are followed by a fiber link of 35 km with dispersion 16 ps/nm/km and core effective area 80×10^{-12} m^2 and an OADM in the circuit which has filter BW 40 GHz, insertion loss 3 dB, bandwidth reference 18 and add/drop frequency 193.15 THz. The OADM crosstalk is varied through parametric run from −90 dB to −10 dB. Further, it is followed by another fiber link of 35 km with dispersion 16 ps/nm/km and core effective area 80×10^{-12} m^2, and the receiver. In MZI based optical add/drop multiplexer, the optical signal pass through the different sections i.e. variable attenuator where 3 dB insertion loss is defined, and are fed to the splitter, ideal dual arm Mach–Zehnder interferometer which has BW 40 GHz, delay (ps) 25 and tuning frequency/wavelength 193.5 THz/1549.32, 3 dB coupler and combiner. The channel which is to be selected from input port passes through splitter, band pass filter which has 15 number of stages, −3 dB two sided BW 40 GHz, splitter, combiner and finally the signal is dropped to the drop port of the OADM. To the add port, the signal passes through variable attenuator where 3 dB insertion loss is defined and are fed to the splitter, combiner, band pass filter and again combiner. Finally the output is taken from output port and crosstalk is defined between add and drop channels by making use of variable attenuator between the propagating signals as shown in Fig. 2. Similarly, in MZI–SOA based optical add/drop multiplexer, two similar SOAs are used in the opposite arms of MZI with 3 dB coupler as shown in Fig. 3. The typical parameters of SOA used in the simulation are as shown in Table 1. The SOAs are used for amplification and attenuation of an optical signal, by turning the gain on and off. This property has a disadvantage for SOA switch- a high additional noise level in the “ON” state caused by spontaneous emission generated in the SOA.

In MZI–FBG based optical add drop multiplexer, two similar ideal FBGs whose reference frequency/wavelength 193.414 THz/1550.000 nm are used in opposite arms of MZI with 3 dB coupler as shown in Fig. 4.

Single receiver is composed of optical raised cosine filter, PIN photodiode and low-pass Bessel filter. PIN photodiode is used to convert the optical signal into electrical signal. Its parameters

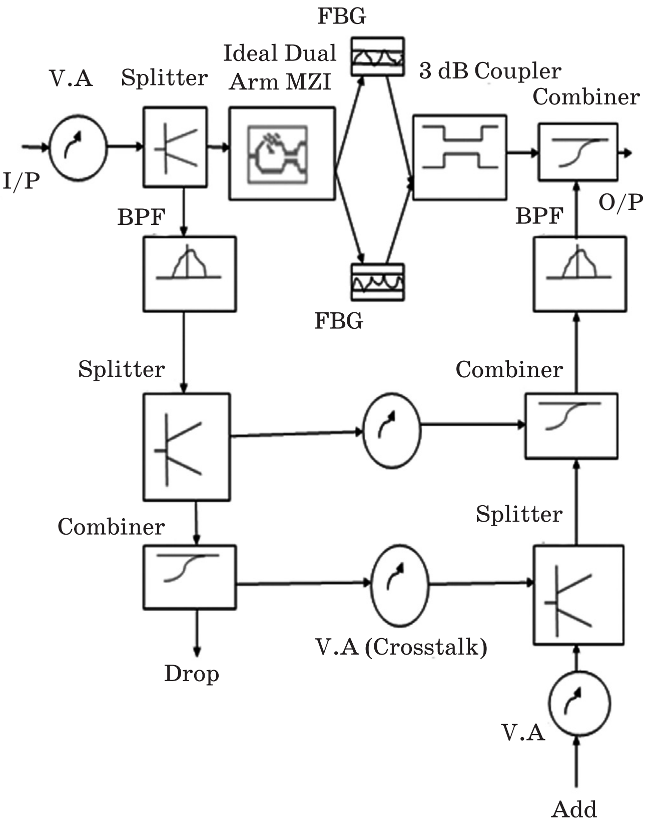

Fig. 4. Structure of OADM based on MZI-FBG.

are 0.7981 quantum efficiency, 1A/W responsivity, and zero dark current. Electrical scope as the measurement component is used to obtain the eye diagram. From the eye diagram, the values of Q factor, BER can be analyzed.

Table 1. Parameter of SOA

BIAS current (mA)	100
Amplifier length (10^{-6} m)	300
Active layer width/thickness (10^{-6} m)	1.5/0.15
Confinement factor	0.35
Spontaneous career lifetime (ns)	0.3
Transparency Carrier Density NO (cm^{-3})	1×10^{18}
Material gain constant	3×10^{-16}
Line width enhancement factor	3
Material loss (dB)	10.5
Input/output insertion loss (dB)	3

3. Results and discussions

To illustrate the performance of three MZI-Techniques, Quality factor and BER are recorded at first channel of the DWDM system obtained at 8×10 Gbps and 0.1 nm channel spacing Dense wavelength division multiplexing transmission with optical add/drop multiplexers. Fig. 5 shows the Q-factor with crosstalk plot of add Channel ch–1 (193.15 THz) detected at output port. It is evident that in cases of MZI based OADM and MZI-FBG based OADM for add Channel, as we are increasing the value of crosstalk from –90 dB to –10 dB, the Q-factor of optical signal decreases from 18.14 to 15.08 dB and from 18.13 to 15.74 dB respectively. But in case of MZI–SOA based OADM, the Q-factor remains at 6.02 dB. Fig. 6 shows the BER with crosstalk plot of frequency 193.15 THz (ch–1) at output port (add). It is observed that the BER for MZI-FBG based OADM and MZI based OADM, increases from 2.67×10^{-16} to 5.83×10^{-9} and from 2.69×10^{-16} to 8.66×10^{-10} respectively as the crosstalk level increases from –90 dB to –10 dB, and these BER values are less than the one for the third technique. In case of MZI–FBG based OADM, while inducing a grating directly into the core of the fiber leads to low insertion loss. As for MZI–SOA based OADM, SOAs have more insertion losses and nonlinear effects such as cross gain modulation, cross phase modulation, wavelength conversion and four wave mixing. Therefore it is the worst case. Our results are in coincidence with the previous results Karfaa et al [16] where they analyzed the effects of crosstalk in an array waveguide grating add/drop router on the performance of WDM networks. It was then reported that in the presence of crosstalk from –55.4 dB to –54 dB with add/drop channels the BER is more i.e. 10^{-10} to 10^{-11}. Here in this paper at crosstalk of –20 dB with add/drop channel,

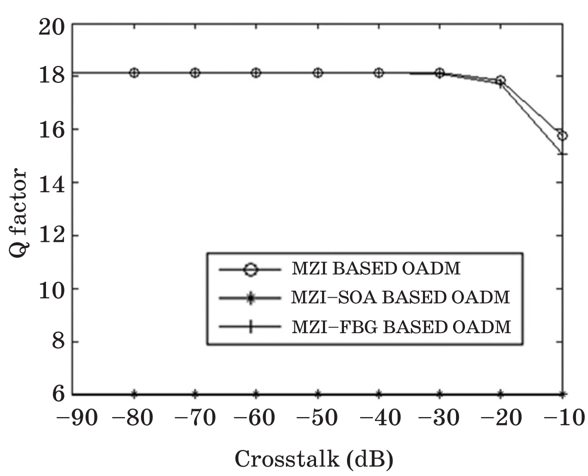

Fig. 5. Q-factor v/s Crosstalk plot of add channel at frequency 193.15 THz (ch–1) for 70 km.

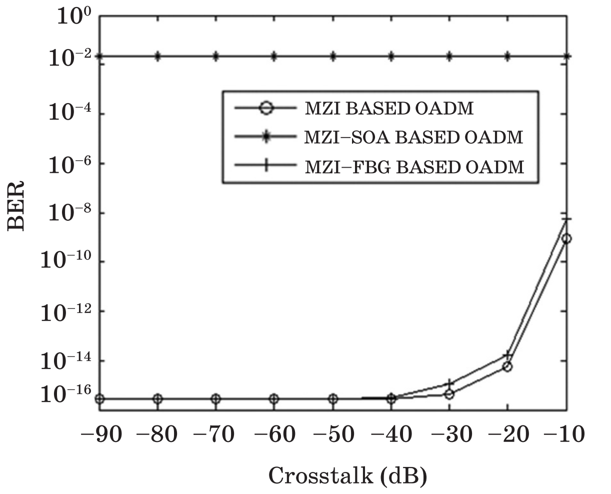

Fig. 6. BER v/s Crosstalk plot of add channel at frequency 193.15 THz (ch–1) for 70 km.

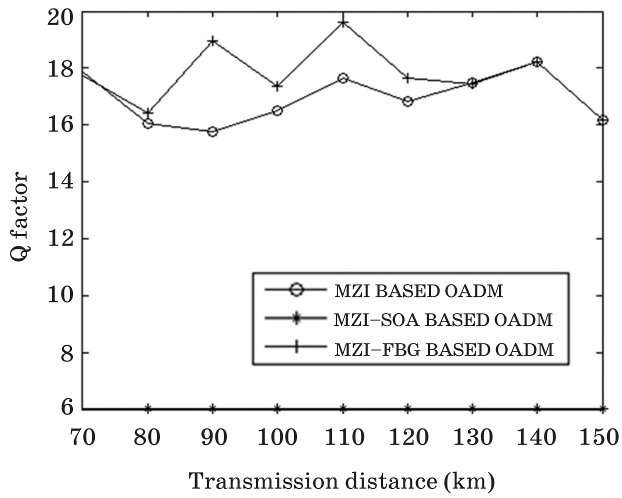

Fig. 7. Q-factor v/s Transmission distance plot of add channel at frequency 193.15 THz (ch–1) at –20 dB crosstalk.

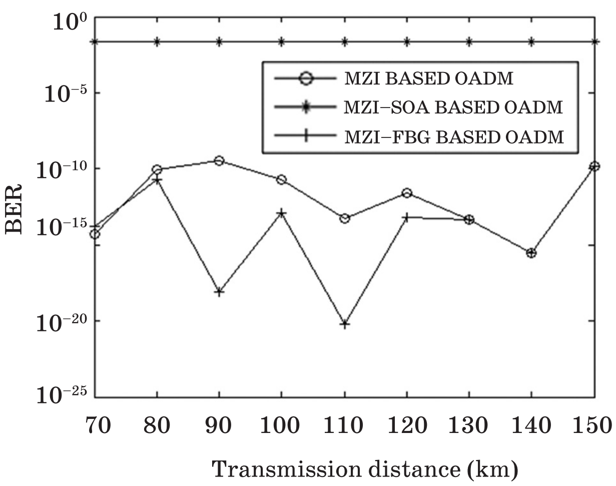

Fig. 8. BER v/s Transmission distance plot of add channel at frequency 193.15 THz (ch-1) at -20 dB crosstalk.

the BER reported is low i.e 5.47×10^{-15} and 1.58×10^{-14} with MZI based OADM and MZI-FBG based OADM techniques.

For comparison we also conducted a transmission over 70 to 150 km at 0.1 nm channel spacing for 10 Gbps without dispersion compensated fiber (DCF). Fig. 7 & 8 show that as the transmission distance increases from 70 to 150 km, the degradation of BER and Quality factor occurs. Degradation occurs due to continuous raise in ASE as the span distance increases, also reported in [17].

The variation in Quality factor of three MZI techniques for given transmission distance at channel spacing 0.1 nm & –20 dB crosstalk for 10 Gbps are following: from 17.86 to 16.19 dB for MZI based OADM, from 17.72 to 16.19 dB for MZI-FBG based OADM and remains at 6.02 dB for MZI-SOA based OADM as shown in Fig. 7.

The graph between the bit error rate (BER) and transmission distance at the fiber link is shown in Fig. 8. For MZI based OADM & MZI-FBG based OADM, the BER is low and these OADM designs indicate best performance as compared to MZI-SOA based OADM.

It is observed that at the transmission distance of 150 km, MZI based OADM & MZI-FBG based OADM provide both acceptable BER about (1.38×10^{-10}) & also Q factor as (16.19 dB). After this distance the performance is degraded.

Furthermore, we investigate the performance of three MZI techniques at different bit rates varying from 5 to 40 Gbps. In this system 0.1 nm channel spacing is used to achieve better results.

Fig. 9 shows the variation of Quality of the signal as a function of bit rate of individual channel among 8 channels.

From Fig. 9 it is observed that again MZI based OADM & MZI–FBG based OADM provide better Quality factor (17.86 dB) & (17.72 dB) for 10 Gbps bit rate.

The variation in BER as a function of bit rate is as shown in Fig. 10.

From Fig. 10 it is observed that again MZI based OADM & MZI-FBG based OADM provide acceptable BER (5.47×10^{-15}) & (1.58×10^{-14}) for 10 Gbps bit rate.

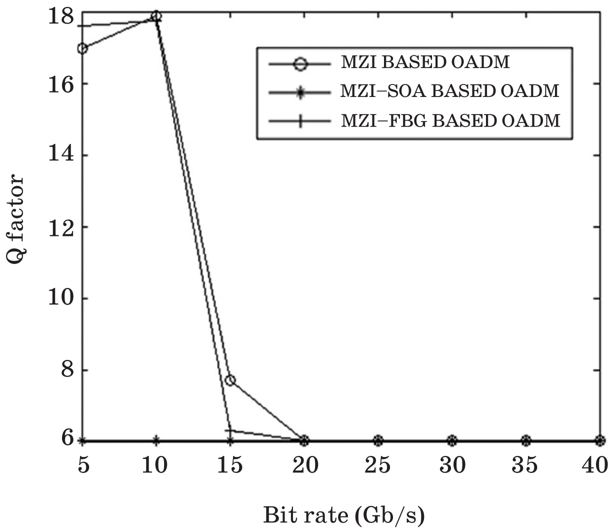

Fig. 9. Q-factor v/s Bit rate plot of add channel at frequency 193.15 THz (ch–1) & –20 dB crosstalk for 70 km.

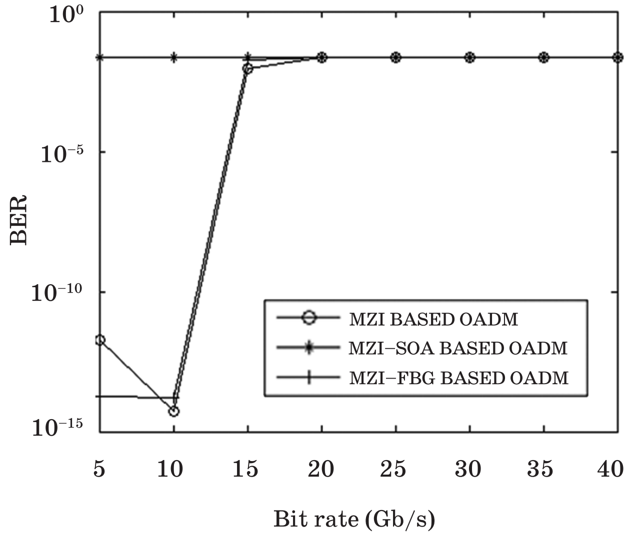

Fig. 10. BER v/s Bit rate plot of add channel at frequency 193.15 THz (ch–1) & –20 dB crosstalk for 70 km.

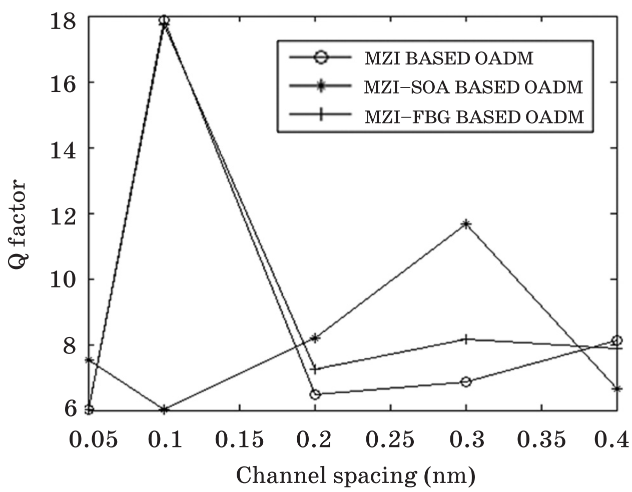

Fig. 11. Q-factor v/s Channel spacing plot of add channel (ch–1) at –20 dB crosstalk & 10 Gbps bit rate for 70 km.

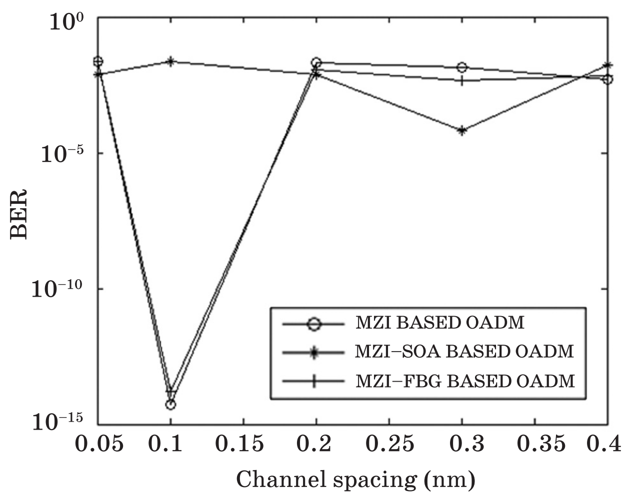

Fig. 12. BER v/s Channel spacing plot of add channel (ch–1) at –20 dB crosstalk & 10 Gbps bit rate for 70 km.

The variation in Q factor & BER as a function of channel spacing is as shown in Fig. 11 & 12. The figure shows optimization of MZI based OADM and MZI–FBG based OADM with channel spacing. It is observed that the system has been optimized at 0.1 nm for various parameters like insertion loss, interferometer bandwidth, delay, tuning frequency, coupling ratio, band pass filter no. of stages, –3 dB two sided bandwidth of band pass filter, FBG reference frequency and crosstalk as shown in table 2. If we change these parameters, the system can be optimized for other channel spacing. However the system parameters could not be optimized for less than 0.05 nm due to the cross phase modulation and four wave mixing effects. Such optical fiber nonlinearities lead to inter channel crosstalk which occurs due to less channel spacing and further reduces the quality of the optical signal. It can be seen that again MZI based OADM & MZI–FBG based OADM provide acceptable Q factor & BER for 0.1 nm channel spacing.

The cost of the system depends upon the number of equipments used i.e. the optical layer equipment and the equipment of system higher layer. The structure of MZI based OADM is simple and cost effective since it requires less number of components as compared to other techniques as shown in table 3.

Table 2. Optimized Parameters

Insertion loss	3 dB
Interferometer bandwidth	40 GHz
Interferometer Delay	25 ps
Interferometer tuning frequency	193.5 THz
Coupling Ratio	50:50
Band pass filter no. of stages	15
−3 dB two sided bandwidth of band pass filter	40 GHz
FBG reference frequency	193.414 THz
Crosstalk	−20 dB

Table 3. Number of Components Required

Components	MZI based OADM	MZI-FBG based OADM	MZI-SOA based OADM
V.O.A	4	4	4
B.P.F	2	2	2
Ideal dual arm MZI	1	1	1
Splitter	3	3	3
Combiner	3	3	3
3dB Coupler	1	1	1
SOA	–	–	2
FBG	–	2	–

MZI-FBG and MZI-SOA based OADM structures require incorporation of FBG's and SOA's, which increase both the complexity and cost of the design as compared to MZI based OADM structure.

4. Conclusion

We evaluate the three MZI techniques of optical add drop multiplexer for dense wavelength division multiplexed system and investigate the impact of crosstalk obtained at 8×10 Gbps with 0.1 nm channels spacing with optical add drop multiplexer (OADM) placed at the 35 km point of a 70 km link. With respect to the crosstalk performance in a transmission system, MZI based OADM & MZI-FBG based OADM are found to have the best performance among the three techniques in the terms of Quality factor and bit error rate, We report the maximum distance of 150 km achieved by MZI based OADM and MZI-FBG based OADM at acceptable BER (1.38×10^{-10}) and Quality factor (16.19 dB). It is also noted that the MZI based OADM system has low cost as compared to other techniques. Furthermore, the simulation results have shown that the maximum acceptable BER and Q factor are achieved for 0.1 nm channel spacing and 10 Gbps bit rate DWDM system with MZI based OADM & MZI-FBG based OADM.

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