# Investigation of 2×2 optical cross connect with different Mach-Zehnder Interferometer techniques for optical networks

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In this paper, we investigate the effect of crosstalk of three types of optical cross connects based on Mach-Zehnder Interferometer( MZI), MZI-Semiconductor optical amplifier (SOA) and MZI-Fiber Bragg gratings (FBG) techniques obtained at 4x10 Gbps with 0.1nm channel spacing wavelength division multiplexing transmission with 2x2 optical cross connects using standard single mode fiber. The influence of increase in length of fiber has been investigated to evaluate the performance of optical communication system. It is found that the signal can be transmitted with minimum BER using MZI-FBG based OXC and MZI based OXC up to 80 Km whereas, the MZI-SOA based OXC provides poor performance. The input-output power relationship shows improvement up to -14 dBm approximately in output power for MZI based OXC and MZI-FBG based OXC. It is observed that the MZI Based OXC architecture is cost effective as compared to MZI-SOA and MZI-FBG Based OXC architectures.

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*Keywords:* Optical cross connects, MZI, FBG and SOA

## 1. Introduction

In optical networks using wavelength-division multiplexed (WDM) technology, an optical cross-connect device (OXC) is essential equipment for wavelength add/drop and routing. Transparent to signal format to a certain extent, the OXC's allows the optical network to be reconfigured on a wavelength-by-wavelength basis to interchange and optimize traffic patterns, provide the routing function, facilitate network growth, and enhance network survivability [1]. Future optical transport networks are expected to provide a format-independent (transparent) aggregation, routing and management of signals with distinct center frequencies (wavelengths). This transparent optical networking enables the increased utilization of fiber capacity using wavelength division multiplexing (WDM) and provides improves flexibility of service provision by the network operator [2-4]. One of the most essential enabling technologies for optical networking is the wavelength-selective optical cross connect node (OXN), whose primary function is to crossconnect the constituents of an aggregate WDM signal between any given sets of inter-connected fiber links [5]. The sustainable growth of broadband services critically depends on the availability of agile and future-proof Core and Metropolitan networks. These networks should be service transparent, expandable in terms of the total transported capacity and must be cost-effective. Optical switching is seen as the key enabler for extending the benefits of the optical fiber communications from point-to-point connections towards large scale networks, to satisfy the aforementioned requirements [6, 7]. Such OXC's are characterized by N x N input /output ports and k operating wavelengths. The OXC should be able to optically switch each input channel to any output port. To achieve this objective various schemes have been proposed by different researchers [9] [8]. In practical systems many signals and wavelength channels could influence each other and cause significant crosstalk in the optical cross connect, has probably prevented the use of OXC's in commercial systems [10,11]. Se-Kang Park et al. [12] proposed a multi wav elength bidirectional optical cross connect (B-OXC) structure based on fiber Bragg gratings (FBG's) and polarization beam splitters (PBS's). A 2×2 B-OXC system is implemented using four pairs of short period gratings and two PBS's, in order to experimentally evaluate the performance of the proposed B-OXC system. Rajneesh Randhawaet al. [13] simulated, for the first time, wavelength converter for future broadcast networks at 40 Gbps using low-cost semiconductor optical amplifiers. The performance analysis is carried out for an all-optical frequency converter based on cross-phase modulation in two semiconductor optical amplifiers arranged in a Mach-Zehnder interferometer configuration to evaluate the efficiency of conversion. Ji Wei et al. [14] introduced the model of switch gate based on SOA and a simple theory for the bit error rate (BER) in optical switching networks caused by the crosstalk. The BER has relation with the parameters of SOA in the switch matrix. Rajneesh Kaler et al. [15] demonstrated the quality-of-service offered by the metropolitan area network which is based on optical cross connect (OXC) and arrayed waveguide grating (AWG) demultiplexer operating at 10 Gb/s with 0.1 nm channel spacing for NRZ signal transmission. Dispersion and crosstalk are the main signal-degrading factors arising from the operation of the OXC and the effectiveness of each factor is individually investigated.

In this paper, we have analyzed three basic architecture of MZI based OXC. Type-I is MZI based OXC, Type-II is MZI-FBG based OXC and Type-III is MZI-SOA based OXC. The Type-I consists of a two 3 dB coupler, connected by two interferometer arms. In MZI a light beam is first split into two parts by 3dB coupler and recombined by another 3dB coupler. On recombination at the coupler, if the two paths are of equal length, then the phases are equal. The MZI is attractive because of its simplicity and flexibility. The same is reported [16] as an electro optic 2×2 switch based on integrated Mach-Zehnder interferometer. Larger switches can be realized by integrating several 2×2 switches on a single substrate. In Type-II, two identical FBGs are integrated within the arms of couplers, a fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelength of light, called as Bragg wavelength and transmits all others. Fiber Bragg gratings (FBG's) have the advantage of inherent high wavelength selectivity, low insertion loss, high reflectivity, etc. The same is described [17] as a novel architecture of 2×2 multi wavelength optical cross connects based on optical add/drop multiplexers and optical switches. In Type-III, two identical SOAs are placed at the respective arms of coupler and two 3-dB optical couplers are employed at the input and the output to complete the interferometric arrangement [18]. A semiconductor optical amplifier can be employed for a simple but effective way of switching by splitting an optical signal with a 3 dB splitter, after which this signal is attenuated in one arm and amplified in the other arm, since the splitter losses and additional losses can be compensated by the SOA. 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; it is having high additional noise level in the "ON" state caused by spontaneous emission generated in the SOA.

Till date, work is done on studying the feasibility of a WDM optical system based on an optical cross connects with the acceptable BER ($<10^{-9}$) and with crosstalk of less than -100dB [15] but very less work has been carried out to design the cost effective system based upon optical cross connects using different techniques. The effect of crosstalk on BER 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 cross connects in 4×10 Gbps wavelength division multiplexing (WDM) transmission with 0.1nm channel spacing.

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

## 2. System set up

The simulation set up consists of three stages i.e transmitter, 2×2 an optical cross connect and receiver as shown in Fig. 1. As optical cross connect has two input ports A, B and two corresponding output ports C, D. Four channels (Tx) with different center frequencies are fed to the each input port. Each transmitter is composed of data source, NRZ rectangular driver, laser source and optical amplitude modulator. Data source generates a binary sequence of data stream. Data source is customized by baud rate, sequence type. Laser block shows simplified continuous wave lorentzian (CW) laser. The model has four center emission frequencies, 1mW CW power, ideal laser noise B.W, 10 MHz FWHM (Full width at half maximum) line width and laser random phase. The output from the driver and laser source is 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 and high level +2.5. The pulses are then modulated using MZ modulator at 10Gbps bit rate. The transmitters are followed by a fiber i.e standard single mode fiber of dispersion 16 ps/nm/km, an EDFA in the circuit which has a fixed output power type 6.025dBm, flat gain shape and maximum small signal gain of 35 dB in both input ports. An attenuator is used in the circuit to provide the power difference of 3dB at input ports. The optical cross connects based on MZI, MZI-SOA, MZI-FBG are used in the system. The optical cross connect has the filter roll off 0.2 dB, insertion loss 3dB, channel spacing 0.1nm, center frequency is 193.1THz, filter bandwidthof 50 GHz, insertion loss switch 0.5 dB and crosstalk is from -30 dB to -5dB. In Type-I, the optical signal passes through variable attenuators, demultiplexer, realistic optical switches and multiplexers. The variable attenuator is having 3 dB insertion loss. The optical demultiplexer section consists of raised cosine band pass filter with each channel passes the optical signal to the realistic optical switch i.e. 2×2 four optical cross connects. Further, the optical multiplexer combines all the optical signals and passes to the output ports as shown in Fig. 2.

Each realistic optical switch i.e.2×2 OXC, consist of variable attenuators, optical splitters and combiners. The optical cross connects are assumed to be in bar state for all types of architecture. The signal is fed to variable attenuator having 0.5 dB insertion loss and another pair of variable attenuators are used to define the crosstalk between the signals. After defining the crosstalk, the signal passes through optical splitters and combiners. At the output stage MZI switch is used where two 3 dB couplers are used as shown in Fig. 3. In Type-II, two identical ideal FBG's whose reference frequency / wavelength 93.414THz/1550.000 nm, are integrated in opposite interferometer arms as shown in Fig. 4. Similarly in Type-

III, in place of FBGs, two identical SOA's are used in the opposite interferometer arms as shown in Fig. 5. Typical values of SOA are used in the set up as shown in Table 1.

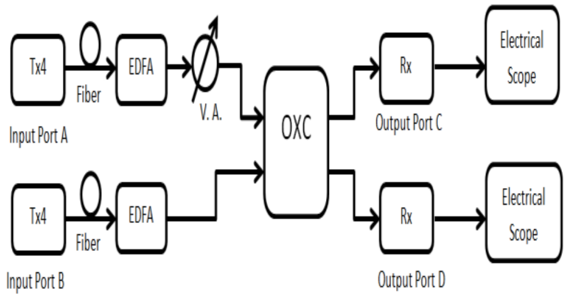


*Fig. 1. System Set up*

The receiver section is composed of optical raised cosine filter, PIN photodiode and low-pass Bessel filter. Optical filter component implements a raised cosine transfer function filter having band pass filter synthesis, raised cosine exponentis1, raised cosine roll off is 0.5 dB, center frequency is 192.95 THz and B.W is 60 GHz.PIN photodiode is used to convert the optical signal into electrical signal. Its parameters are reference frequency/wavelength193.0 THz/1553.32 nm, quantum efficiency is 0.7979, responsivity is 0.999A/W and dark current $I_d$ is Zero. Electrical filter at the receiver side is implemented by single pole low-pass. The filter has single pole in number and has pole frequency 10GHz. Electrical scope as the measurement component is used to obtain the eye diagram. From the eye diagram, the values of BER can be analyzed.

*Table 1. Parameters of SOA*

| | |
|---|---|
| Bias current (mA) | 100 |
| Amplifier length ($10^{-6}$ m) | 300 |
| Active layer width ($10^{-6}$m) | 1.5 |
| Active layer thickness ($10^{-6}$m) | 0.15 |
| Confinement factor | 0.35 |
| Spontaneous career lifetime (ns) | 0.3 |
| Transparency Carrier Density (cm^-3) | $1\times10^{18}$ |
| Material gain constant (cm^2) | $3\times10^{-16}$ |
| Line width enhancement factor | 3 |
| Material loss (dB) | 10.5 |
| Input insertion loss (dB) | 3 |
| Output insertion loss (dB) | 3 |

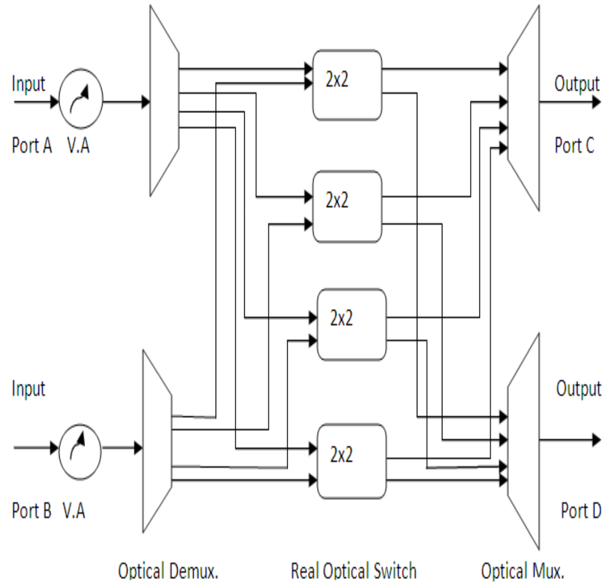


*Fig. 2. Structure of OXC*

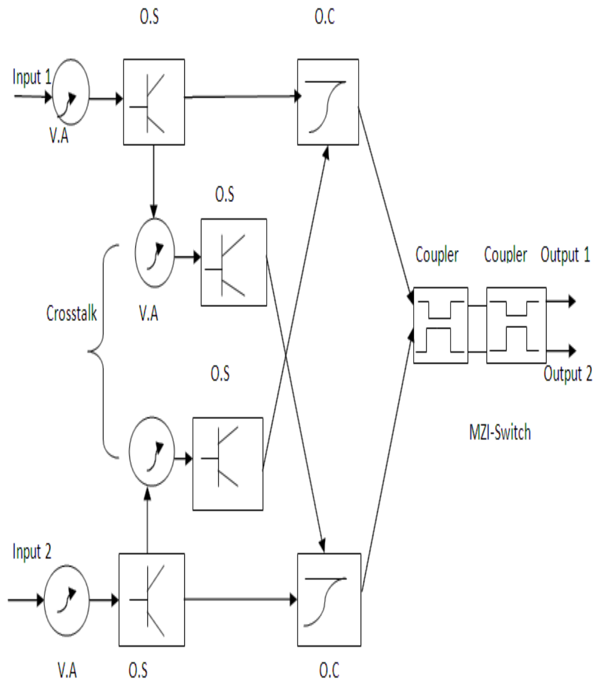


*Fig. 3. Real optical switch (2x2) based on MZI*

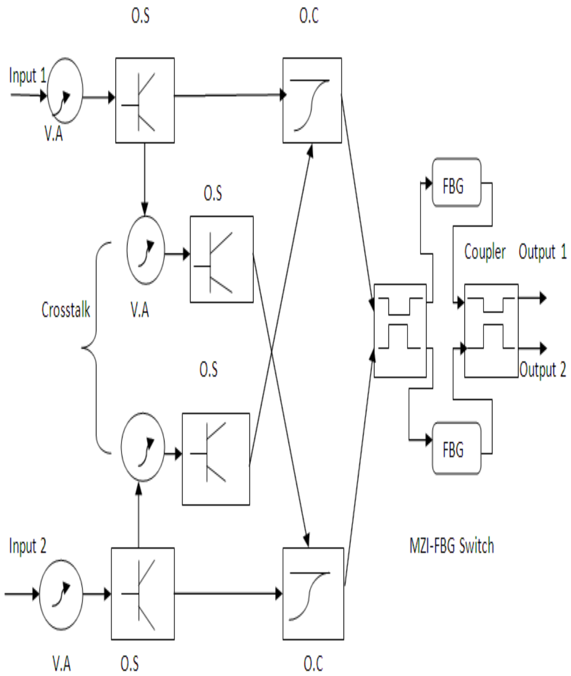


*Fig. 4. Real optical switch (2x2) based on MZI-FBG*

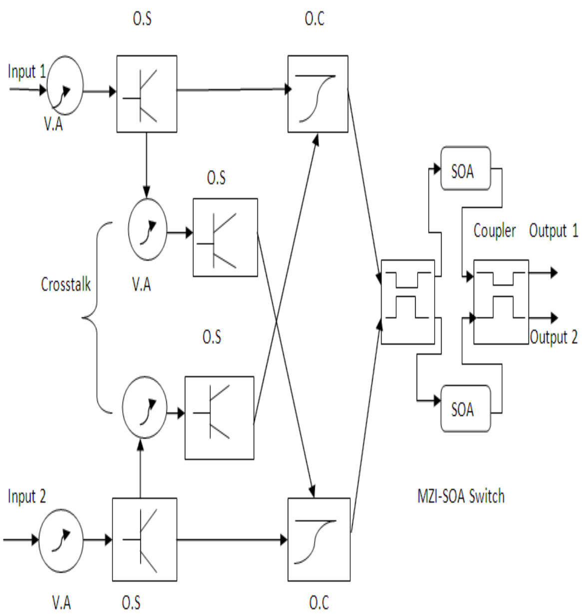


*Fig. 5. Real optical switch (2x2) based on MZI-SOA*

### 3. Resuts and discussion

The results on different aspects of optical cross connects based on three techniques are obtained at 4×10 Gbps and 0.1nm channel spacing wavelength division multiplexing (WDM)transmission with 2×2 optical cross connects using standard single mode fiber are shown in Fig. 6 to Fig. 11.

Fig. 6 and Fig. 7 shows BER versus Crosstalk plot at output port C& output port D with channel frequency of 192.95THz (ch-1). It is observed that the BER for Type-I and Type-II increases as the crosstalk level increases from -30 dB to -5dB for 80Km distance as compared to Type-III. As in case of Type-II, while inducing a grating directly into the core of the fiber leads to low insertion loss but in case of Type-III, SOA's have more insertion losses and nonlinear effects therefore it is the worst case. Our results are in coincidence with the results of Rajneesh Kaler et al. [12]where they analyzed the performance of metro WDM network based on an optical cross connects and arrayed waveguide grating demultiplexer with the same bit rate and channel spacing. It was then reported that at -30dB Crosstalk, the BER is higher. Our result shows that for the same crosstalk, the BER reported is less for Type-I and Type-II OXC techniques.

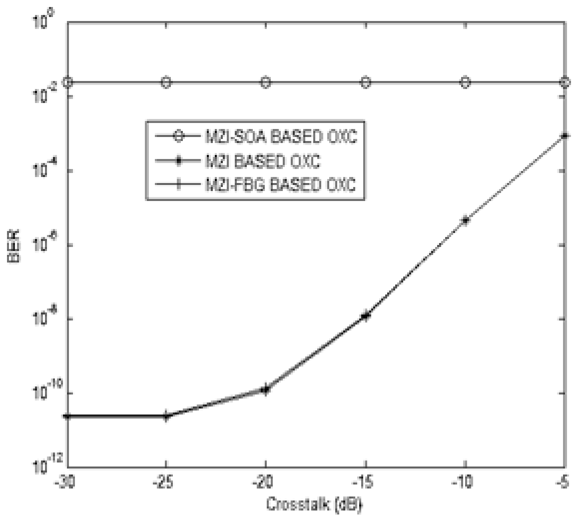


*Fig. 6. BER v/s Crosstalk plot at frequency 192.95 THz (ch-1) of output port C for 80Km*

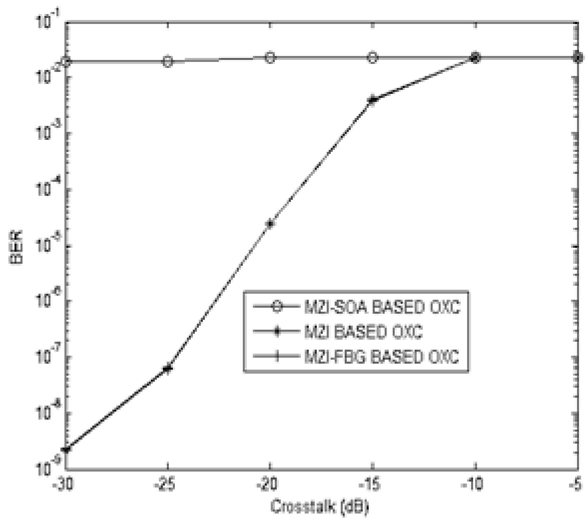


*Fig. 7. BER v/s Crosstalk plot at frequency 192.95 THz (ch-1) of output port D for 80Km*

Fig. 8 shows BER versus Transmission distance plot at output port Cat channel frequency of 192.95THz (ch-1). It is observed that Type-I and Type-II OXC provides acceptable BER i.e. from $9.18888\times10^{-17}$ to $2.16883\times10^{-11}$ and $9.36404\times10^{-17}$ to $2.3777\times10^{-11}$ at -30dB crosstalk as distance increases from 40 to 80 Km as compared to Type-III. After this distance the performance is below acceptable limit.

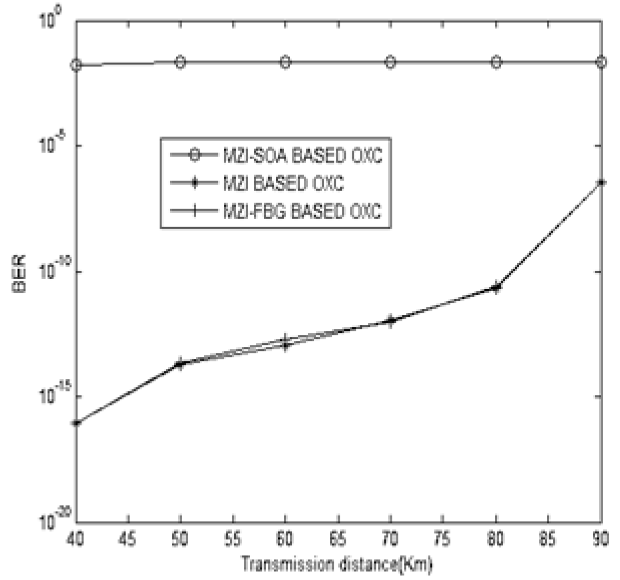


*Fig. 8. BER v/s Transmission Distance plot at frequency 192.95 THz (ch-1) of output port C for -30dB crosstalk*

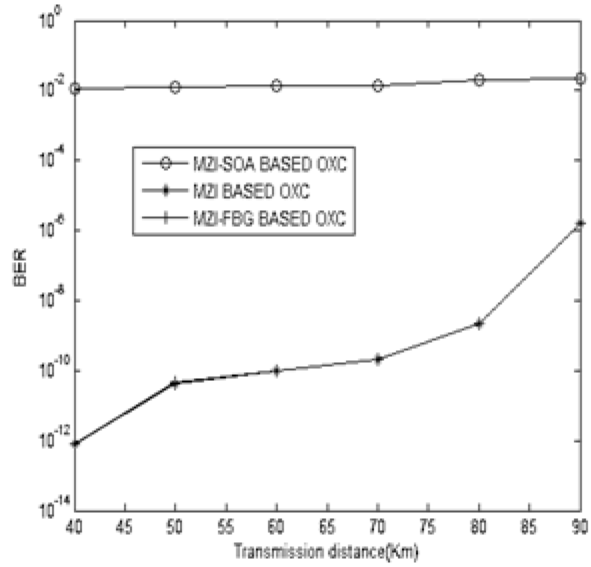


*Fig. 9. BER v/s Transmission Distance plot at frequency 192.95 THz (ch-1) of output port D for -30dB crosstalk*

Fig. 9 shows BER versus Transmission distance plot at output port D for -30dB crosstalk at channel frequency of 192.95THz (ch-1). It is observed that Type-I and Type-II OXC provides acceptable BER i.e. from $8.19333\times10^{-13}$ to $2.13881\times10^{-9}$ and $7.89409\times10^{-13}$ to $2.2553\times10^{-9}$ at -30 dB crosstalk as distance increases from 40 to 80Km as compared to Type-III OXC. After this distance the performance is degraded. The BER and crosstalk values for maximum distance achieved have been shown in Table 2.

*Table 2. BER & Crosstalk at frequency192.95 THz (ch-1) for 80Km distance*

| MZI-based OXC | | | MZI-FBG based OXC | | MZI-SOA based OXC | |
|---|---|---|---|---|---|---|
| Cross talk (dB) | O/P port C (BER) | O/P Port D (BER) | O/P Port C (BER) | O/P Port D (BER) | O/P port C (BER) | O/P Port D (BER) |
| -30 | $2.16883\times10^{-11}$ | $2.13881\times10^{-9}$ | $2.3777\times10^{-11}$ | $2.2553\times10^{-9}$ | 0.0227501 | 0.0196711 |
| -25 | $2.28693\times10^{-11}$ | $6.04651\times10^{-8}$ | $2.38707\times10^{-11}$ | $6.46996\times10^{-8}$ | 0.0227501 | 0.019862 |
| -20 | $1.11926\times10^{-10}$ | $2.42816\times10^{-5}$ | $1.36714\times10^{-10}$ | $2.45264\times10^{-5}$ | 0.0227501 | 0.0227501 |
| -15 | $1.08835\times10^{-8}$ | 0.00394906 | $1.20781\times10^{-8}$ | 0.0039476 | 0.0227501 | 0.0227501 |
| -10 | $4.31394\times10^{-6}$ | 0.0227501 | $4.36927\times10^{-6}$ | 0.0227501 | 0.0227501 | 0.0227501 |
| -5 | 0.000872214 | 0.0227501 | 0.000867963 | 0.0227501 | 0.0227501 | 0.0227501 |

It is found that signal can be transmitted successfully with an acceptable BER with Type-I and Type-II OXC at -30 dB crosstalk as compared to Type-III OXC up to a distance of 80 km.

Fig. 10 and Fig. 11 shows the Output power versus input power plot at -30 dB crosstalk for 80 Km distance. It is observed that the output power at port C for Type-I is -32.099 dBm and for Type-II it is-32.103 dBm for the input power level of -45dBm. For port D the output power for Type-I is -35.139 dBm and for Type-II it is -35.148 dBm for the input power level of -45dBm. The Type III is having worst performance in terms of output power. At port C for the input level of -45dBm the output power is only -15.154 dBm and for port D it is -18.193 dBm only. Our results are in coincidence with the results reported by Shien-KueiLiaw et al. [19] where it was reported that 2×2integrated OXC with conventional EDFA provides the output power of -21dBm approximately with the input power of -45 dBm. Our result shows improvement up to -14dBm approximately in output power for Type-I and Type-II OXCs.

The cost of the system depends upon the number of equipments used i.e. higher-layer equipment and the optical layer equipment. The structure of Type-I OXC is simple and cost effective since it requires less number of components. Its total approximate cost is quite less as compared to other two types as shown in Table 3.

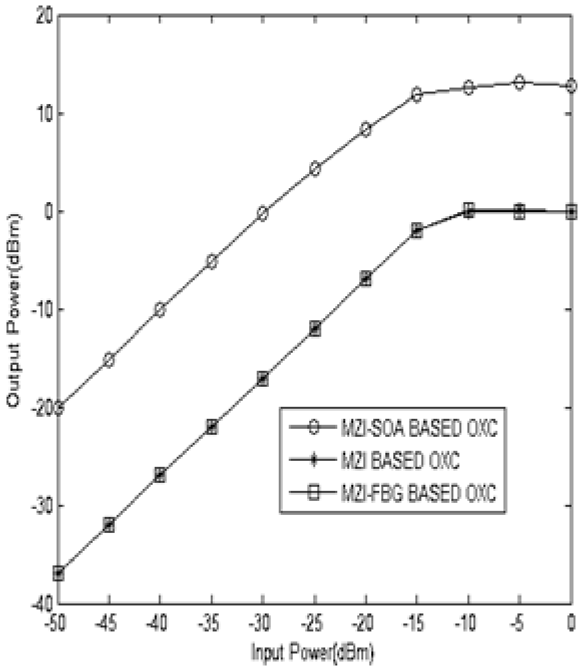


*Fig. 10. Output power v/s Input power plot at -30dB crosstalk for 80 KM distance of output of port C*

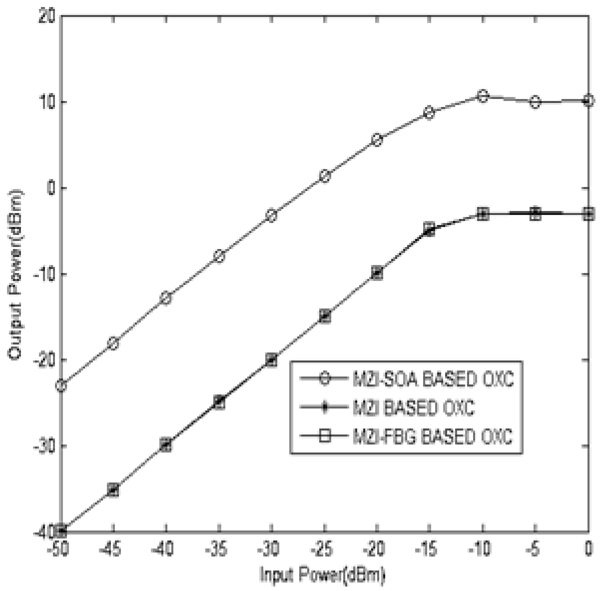


*Fig. 11. Output power v/s Input power plot at -30dB crosstalk for 80 KM distance of output of port D*

Whereas, Type-II and Type-III OXC structures require couple of FBG's and SOA's, which add to the complexity and cost of the design as compared to Type-I structure.

*Table 3. Number of components required*

| Components | MZI based OXC | MZI-FBG based OXC | MZI-SOA based OXC | Approx. Cost ( $) |
|---|---|---|---|---|
| V.O.A | 6 | 6 | 6 | 510 |
| Optical Demux. | 2 | 2 | 2 | 3200 |
| Optical Mux. | 2 | 2 | 2 | 3134 |
| Splitter | 2 | 2 | 2 | 60 |
| Combiner | 2 | 2 | 2 | 60 |
| 3dB Coupler | 2 | 2 | 2 | 32 |
| SOA | -------- | -------- | 2 | 3600 |
| FBG | -------- | 2 | -------- | 1400 |
| Total Cost ($) | 6996 | 8396 | 10596 | |

Fig. 12 shows the BER and Cost approximation for the described architectures. The BER is plotted for -30 dB crosstalk at output port C with a distance of 80 Km from the transmitter, with a channel frequency of 192.95 THz. BER of Type-I and Type-II are in the acceptable limits whereas BER of Type-III is beyond acceptable limit. Cost of the system is presented in USD with approximated cost of the components used. The cost of Type-I is minimum, whereas the cost of Type-III is more than others. Therefore Type-I is better due to minimum BER and Minimum cost.

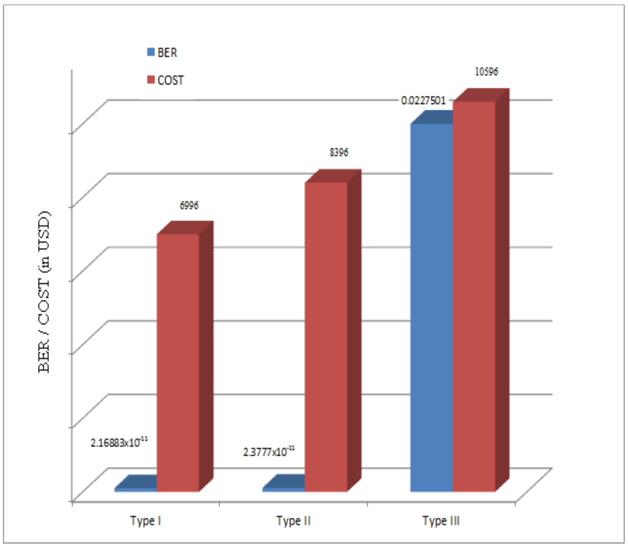


*Fig. 12. BER and Cost approximation*

## 4. Conclusion

In this paper, we have demonstrated the feasibility and the performance of the system based on optical cross connects using different techniques with the influence of increase in length of SSMF operating at 10 Gbps with

0.1 nm channel spacing. The results have been reported for NRZ Rectangular modulated data signal. We have observed that the signal can be transmitted up to 80 Km through Type-I and Type-II OXC successfully with improved performance as compared to Type-III OXC. The signal can be transmitted successfully with an acceptable BER i.e. $2.16883\times10^{-11}$ and $2.3777\times10^{-11}$ at output port C, $2.13881\times10^{-9}$ and $2.2553\times10^{-9}$at output port D, with Type-I and Type-II OXC at -30 dB crosstalk as compared to Type-III OXC up to a distance of 80 km. The worst case is the Type-III OXC as seen from the results as far as BER is concerned. The input-output power relationship shows improvement up to -14dBm approximately in output power for Type-I and Type-II OXCs hence our system becomes more efficient and consumes lesser power. Thus, the complete analysis of the system based on optical cross connects with different MZI techniques with the variations of distances is done here. It is also observed that the Type-I OXC system has low cost as compared to other techniques which proves that Type-I and Type-II OXC are beneficial as the main backbone in our present infrastructure.

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