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Optical Cross Connect Based on Fiber Bragg Grating

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Abstract *: Wavelength division multiplexing (WDM) is attracting more and more attention because of their ability to provide increased capacity and flexibility. Optical cross-connect node (OXC) is an essential network element in WDM optical networks. In WDM optical networks, intraband and/or interband crosstalk plays a major role in limiting practical implementation of an OXC subsystem. Again Fiber Bragg Gratings (FBGs), due to their properties, are emerging as very important elements for both the optical fiber communication and sensing fields. The crosstalk sources are related to the different individual components of the OXC's. This paper presents the results of a crosstalk analysis of transmission Fiber Bragg Grating for 0.1nm to 1nm different wavelength separation. The results are evaluated interms of BER and power penalty with optical wavelength division multiplexed cross-connect topologies at bit rate of 10 Gbit/s considering 5 and 7 WDM channel.*

Keywords *: Wavelength Division Multiplexing (WDM), Optical Cross Connect (OXC), Fiber Bragg Grating (FBG), Optical Circulator (OC).*

Introduction

Wavelength-division multiplexing (WDM) is based on this fundamental physical principle: several light beams at different wavelengths can simultaneously propagate over the same optical path without interference[1-4]. WDM has already been introduced in commercial systems [5]. Suppose we want to amplify several channels (wavelength) simultaneously, as we do in WDM networks. The first thing we have to worry about in such a case is crosstalk, which is any distortion of a channel caused by the presence of another channel. All-optical cross connects (OXC), however, have not yet been used for the routing of the signals in any of these commercial systems [6]. The crosstalk levels in OXC configurations presented so far are generally so high that they give rise to significant signal degradation and to an increased bit error probability. Because of the complexity of an OXC, different sources of crosstalk exist, which makes it difficult to optimize the component parameters for minimum total crosstalk. The crosstalk sources are related to the different individual components of the OXC's [7]. An analytical model is established to evaluate intra-band crosstalk performance and a novel scheme with improved intra-band crosstalk performance is proposed and intra-band optical crosstalk in an Nx N fiber Bragg grating (FBG), Optical circulator (OC) based optical cross connect (OXC) is presented. A novel scheme of OXC with improved intra-band crosstalk performance is proposed [8].

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This crosstalk occurs in a WDM network if channels with the same nominal carrier frequency are combined. The impact of incoherent crosstalk on signal transmission performance has been studied in [9-10], but the details of incoherent crosstalk have not been analyzed. This paper studied the statistical impact of coherent and incoherent crosstalk in an OXC and in optical networks and then proposed the concept of quintile to relax the crosstalk specification requirement for components such as wavelength de multiplexer, multiplexer, and optical switch. In addition, the analysis is extending of crosstalk in a FBG.

System Block Diagram

A general structure for such WDM Transmission system with optical cross connects are shown in Fig.1. Here, N nodes of a cross connect are shown in a two sided model with the transmit side on the left and the receive side on the right. As shown in the figure, Data comes from any source. Each transmitted signal carries a number of unique wavelengths which correspond to the destination data, here several channel multiplexed and go optical cross connect.

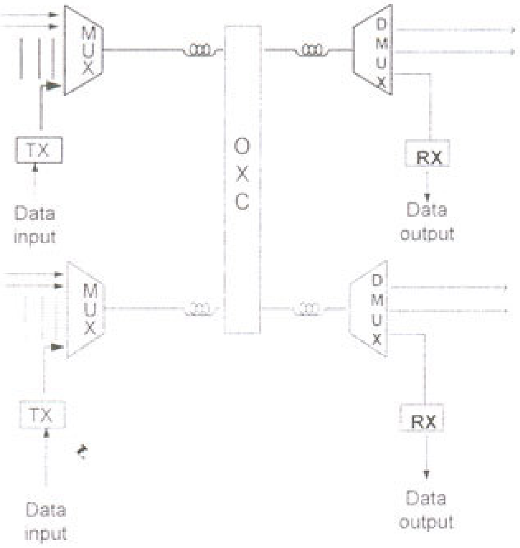

Fig.1 : Block diagram of an Optical WDM Transmission system with an Optical Cross connect (OXC)

All the optical signals are wavelength-multiplexed and are transmitted over a single mode fiber to the network hub. At the hub wavelength de multiplexers separate the signals from each incoming fiber. All channels intended for a given destination are passively re arranged, and since they were allocated different wavelength, they can be wavelength multiplexed and sent towards the destination on a single fiber. At the receiver of each node, the different channels are wavelength de multiplexed.

Performance Analysis of Crosstalk with OXC Based FBG

The analytical equations for the FBG-OC crossconnect are depicted in this section. Here in this analysis the signal power is defined by P_i^j, where i denotes the wavelength channel and j denotes the number of fibers. J_0 designates the fiber which contain the channel under study and i_0 designates the wavelength under study. The input power of the channel under study is defined by P_{i0}^{j0} and the optical power at the output of the first stage is defined by out io P_{io1}^{out}

$$P_{io1}^{out} = P_{io}^{jo} + \left(P_{io}^{j} X_{FG} + P_{io}^{jo} X_{OC} \right) - 2 \sqrt{P_{io}^{j} P_{io}^{jo}} \sqrt{X_{FG}} - 2 \sqrt{P_{io}^{jo} P_{io}^{j}} \sqrt{X_{OC}} - 2 \sqrt{P_{io}^{jo} P_{io}^{j}} \sqrt{X_{FG} X_{OC}} \tag{1}$$

Among the five contributions of this equation the first term is the input signal, the second and third terms express the crosstalk contributions and the last three are beating terms. Here it is assumed that for the worst case the sign of the beat terms are negative and the amplitude of the beat terms are maximum. Here X_{OC} is the optical circulator crosstalk and X_{FG} is the fiber Bragg grating (FBG) crosstalk which is given by,

$$X_{FG} = 10 \log_{10} \left(1 - R_{FG} \right) \tag{2}$$

where R_{FG} is the FBG reflectivity. $P^j io$ is the wavelength channel power at another fiber j that carries a wavelength i_o. Let $P_{io1}^{out(ref)}$ is the output of wavelength channel i_0 when the FBGOC cross connect carries only wavelength channel i_0 (when there is no crosstalk). Then the crosstalk can be expressed as-

$$crosstalk = \frac{P_{io}^{out(ref)} - P_{io}^{out}}{P_{io}^{out(ref)}} \tag{3}$$

The bit-error-rate (BER) of a WDM transmission system consisting of a bidirectional FBG-OC based OXC can be expressed as:

$$BER_{worstcase} = \frac{1}{8} \left[Q\left(\frac{1}{\sqrt{2}} \frac{i_1 + i_{CTO} - i_D}{\sigma_{1-0}} \right) + Q\left(\frac{1}{\sqrt{2}} \frac{i_D - i_{CTO} - i_0}{\sigma_{0-0}} \right) + Q\left(\frac{1}{\sqrt{2}} \frac{i_1 + i_{CT1} - i_D}{\sigma_{1-1}} \right) + Q\left(\frac{1}{\sqrt{2}} \frac{i_D - i_{CT1} - i_0}{\sigma_{0-1}} \right) \right] \tag{4}$$

Where $Q(\chi) = (1/\sqrt{2\pi}\int_{\chi}^{\infty} e^{-(u^2/2)}du)$ and $i_{1=}\ \Re_D\ P_{i0}^{j0}$ is the photocurrent for transmitted bit "1" where $\Re_D$ is the photo detector responsively and i_0 is the photocurrent for transmitted bit "0". The decision threshold current, i_D can be express as :

$$i_D = \frac{\sigma_{0-1} i_1 + \sigma_{1-1} i_0}{\sigma_{0-1} + \sigma_{1-1}} \qquad (5)$$

In the following equation σ^2_{1-0} is the noise variance when signal bit "1" is interfered by crosstalk due to bit "0", σ^2_{0-0} is the noise variance when signal bit "0" is interfered by crosstalk due to bit "0", σ^2_{1-1} is the noise variance when signal bit "1" is interfered by crosstalk due to bit "1"and σ^2_{0-1} is the noise variance when signal bit "0" is interfered by crosstalk due to bit "1". These four noise variances can be defined as:

$$\sigma^2_{0-1} = \sigma^2_{th} + 2e\Re_D\left(P_{i0}^{j0} - P_{CT0}\right)B \qquad (6)$$

$$\sigma^2_{0-0} = \sigma^2_{th} + 2e\Re_D P_{CT0} B \qquad (7)$$

$$\sigma^2_{1-1} = \sigma^2_{th} + 2e\Re_D\left(P_{i0}^{j0} - P_{CT1}\right)B \qquad (8)$$

$$\sigma^2_{0-1} = \sigma^2_{th} + 2e\Re_D P_{CT1} B \qquad (9)$$

e denotes the electronic charge and σ^2_{th} is the variance of the thermal noise in the detector with a temperature of 300K. σ^2_{th} can be expressed as :

$$\sigma^2_{th} = \frac{4KTB}{R_L} \qquad (10)$$

K denotes the Boltzman constant, T denotes the receiver temperature. B denotes the electrical bandwidth of the receiver and R_L denote the receiver front end load. P_{CT0} and P_{CT1} represent the crosstalk power due to bit "0" and "1" respectively and can be express as :

$$P_{CTO} = -P_{i0}^{out0} \qquad (11)$$

$$P_{CT1} = P_{i0}^{j0} - P_{i0}^{out1} \qquad (12)$$

Results and Discussion

Following the analytical approach presented in section 3, the performance results of an optical WDM transmission link with optical cross-connect based on Fiber Brag Grating (FBG) are evaluated taking into considerations the effect of crosstalk due to OXC. The results are presented in terms of amount of crosstalk due to OXC and system BER a given number of input wavelength with several values of channel separation. For the convenience of the readers the parameters used for computation in this paper are shown in table 1.

Table1: System Parameters used for computation

Parameter Name	Value
Bit Rate, Br	10 Gbps
Channel Length	160 Km
No. of Channel	5 and 7
First channel operating wavelength	1556 nm
Channel Separation $\Delta\lambda$	0.5nm
Kerr coefficient	2.24·10–20 m2/W
Effective core area	50.0 µm2

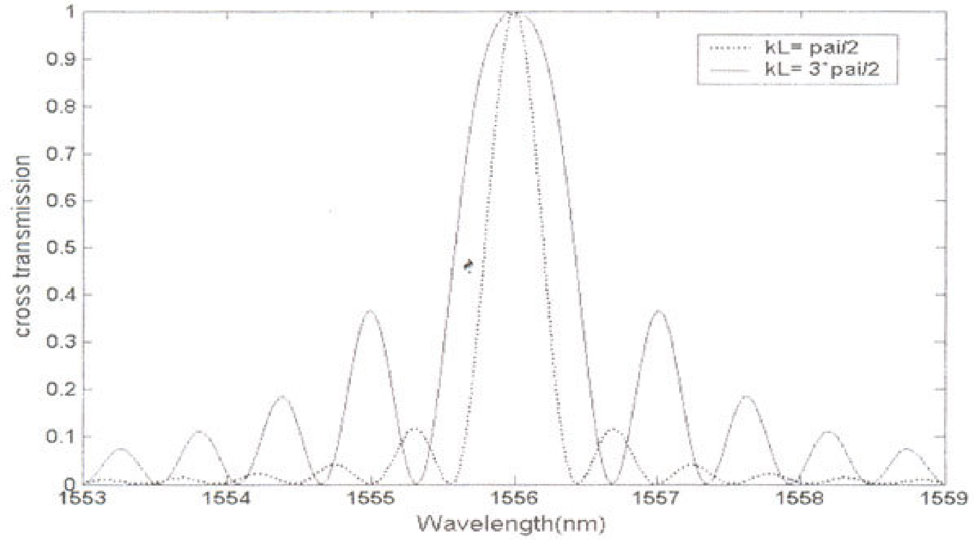

Fig.2: Calculated cross transmission t_ through uniform transmission gratings with $kL = \pi/2$ (dashed line) and $kL = 3\pi/2$ (solid line).

The transmittance of the Fiber Bragg Grating considered in the OXC is evaluated and is shown in Fig.2 as a function of input optical wavelength for two values of KL, via $\pi/2$ and $3\pi/2$. The figure depicts wavelength of the FBG is 1556 nm with 3dB optical pass band for kL $=\pi/2$ and $3\pi/2$ respectively. The transmittance of an

OXC with five WDM channels with wavelengths 1555.9 nm, 1556nm, 1556.1 nm, 1556.2 nm and 1556.3 nm is shown in Fig.3.

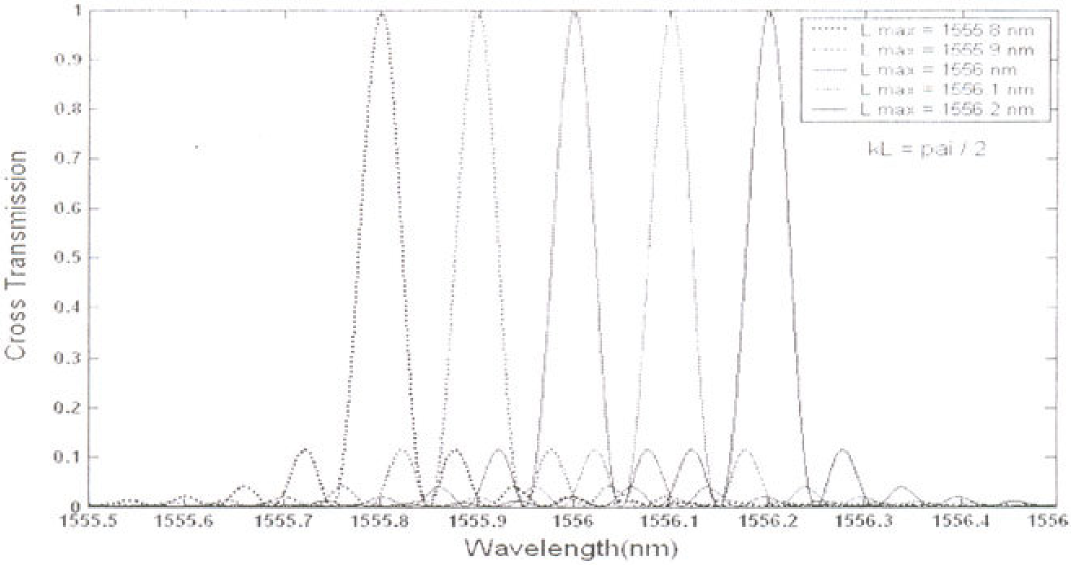

Fig.3 : Plots of five channel crosstalk for kL = $\pi/2$.

The figure depicts the crosstalk introduced by the OXC which transmitting the five wavelength channels due to long frequency of the transmittance function. Similar plot of the cross transmission of the OXC is shown in Fig.4 for number of wavelength N= 7. As the numbers of channels are increased, the amount of crosstalk introduced became higher. It is also notified that maximum amount of crosstalk is introduced in the middle channel.

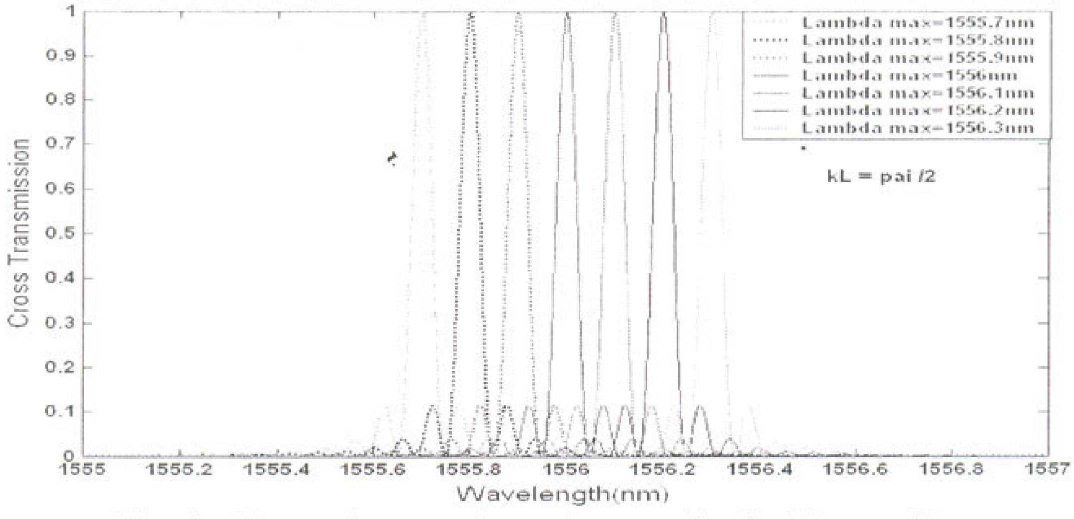

Fig.4 : Plots of seven channel crosstalk for kL = $\pi/2$.

The relative amount of crosstalk introduced in the middle channel is evaluated by integrating the transmition the channel bandwidth. The plots of crosstalk due to OXC verses channel separation among the WDM channels are depicted in Fig.5 for number of channel N=5 ,7 with kL =$\pi/2$.

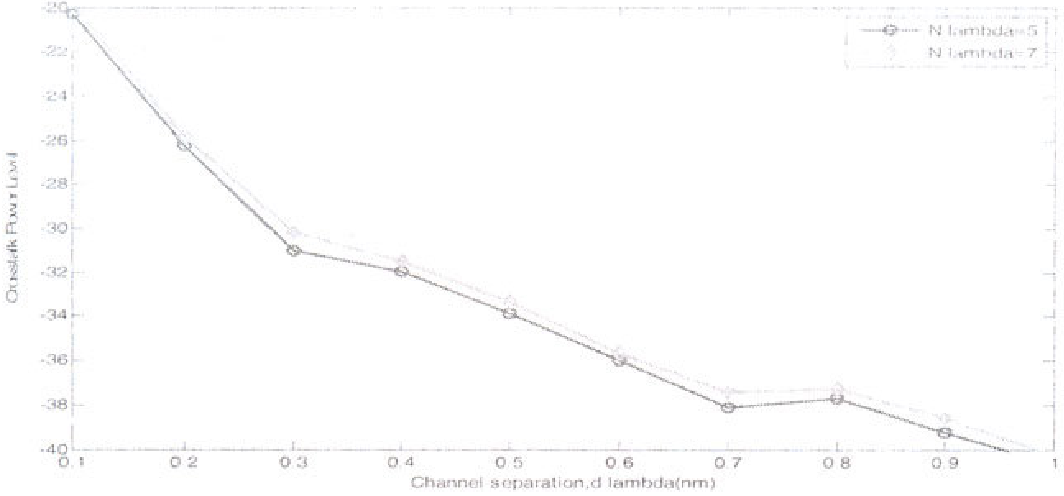

Fig.5 :: Plots of crosstalk power versus channel separation for $kL = \pi/2$

It is noticed that the optical signal power is significantly high at lower value of channel separation and exponentially decreases with increase in channel separation. The bit error rate performance results for a WDM system with number of wavelength N=5 are depicted in Fig.6 with channel wavelength separation $\Delta\lambda$ as a parameter. Similar results are also shown in Fig.7 for N=7 at 10Gbit/s bit rate.

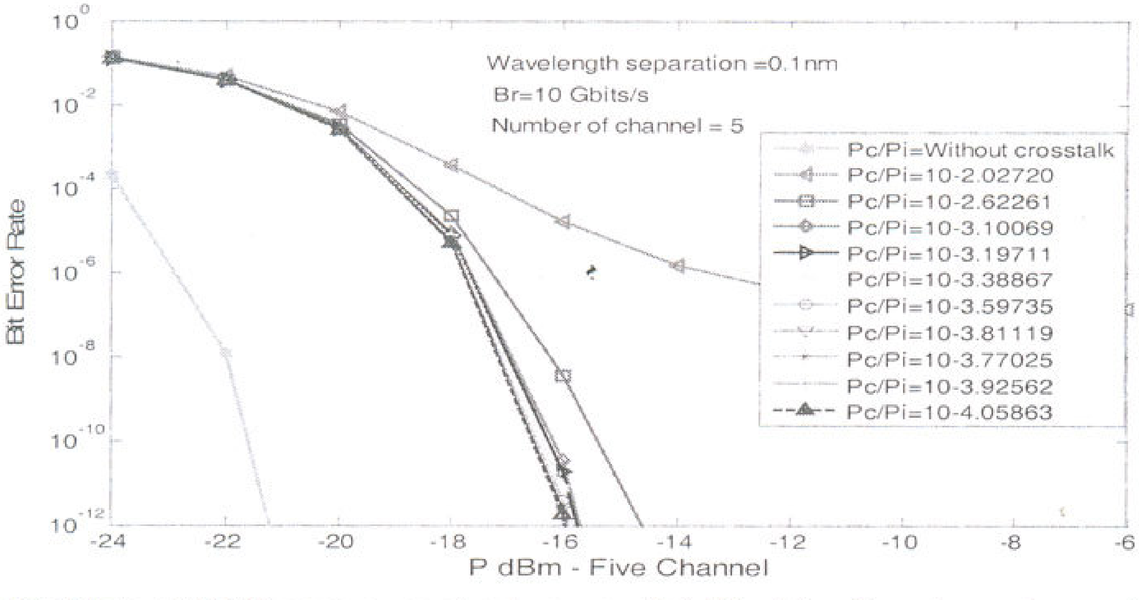

Fig.6 : Plots of BER versus received power, Ps(dBm) for five channel crosstalk, bit rate, Br= 10Gbits/s

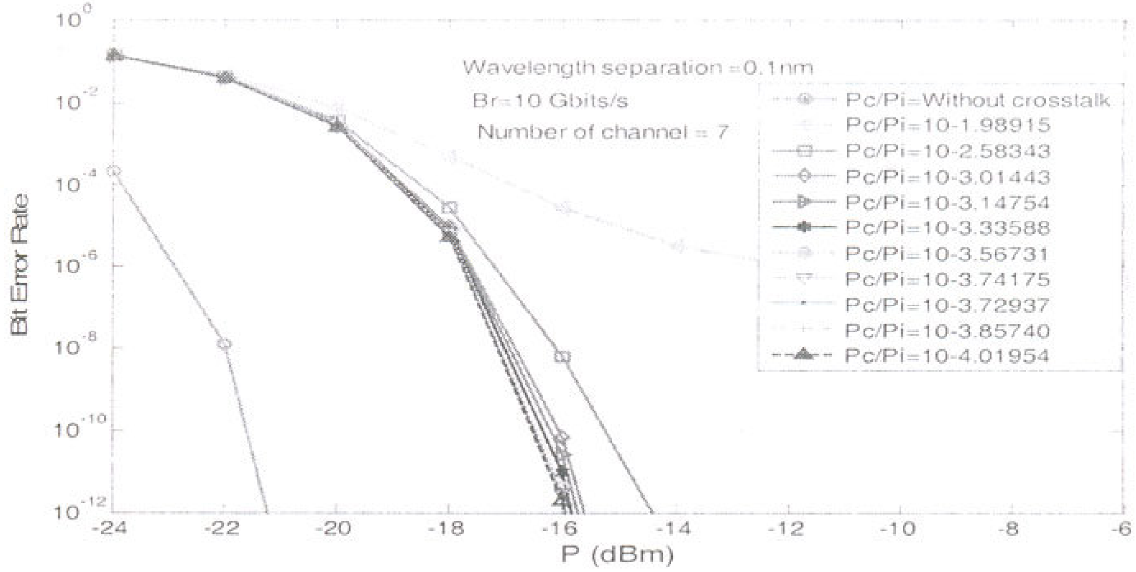

Fig.7 : Plots of BER versus received power, Ps(dBm) for seven channel crosstalk, bit rate, Br= 10Gbits/s

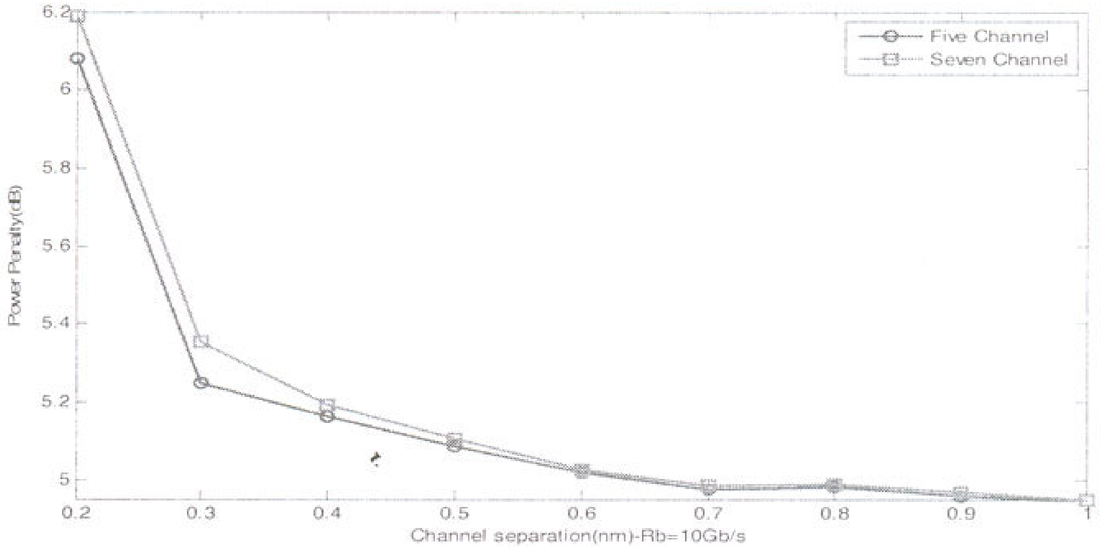

Fig.8 :: Plots of power penalty versus channel separation for kL = π /2

The increase in required received optical power in presence of OXC induced crosstalk at BER=10^{-9} compared to the receiver sensitivity without crosstalk can be tuned as the power penalty due to OXC induced crosstalk. The plots of power penalty versus channel separation for bit rate, Br= 10Gbits/s at BER = 10^{-9} due to OXC induced crosstalk are depicted in Fig. 8. Plots are shown for two different values of WDM channels N=5 and 7. From the overall analysis it is found that a high input power causes an extra penalty.

Conclusions

This paper presents the crosstalk analysis of transmission Fiber Bragg Grating architecture in WDM optical network. The crosstalk sources have been identified and their total crosstalk is calculated based on analytical equations. The results are evaluated interms of BER and power penalty considering the effect of crosstalk due to optical WDM MUX/ DMUX. The power penalty due to crosstalk is evaluated at a BER of 10^{-9} for transmission rate of 10 Gb/s considering 5 and 7 WDM channel. It shows that at high input power causes an extra penalty and penalty also increases as we increase the number of input channels. On the other hand the number of fibers can be increased without significant penalty if the performance of the switch is improved.

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