Performance Evaluation due to Crosstalk in a WDM System using Multi-stage Optical Cross-connect based on FBG-OC

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***Abstract*— Performance analysis of a optical cross-connect (OXC) is carried out to find the effect of crosstalk due to multistage OXC in WDM system. The OXC is based on FBG and Optical Circulator (OC). The Crosstalk Power at the output of multistage FBC-OC based OXC is evaluated analytically. The bit error rate (BER) of WDM system with OXC in cascade is also evaluated. Results shows that for a given OXC parameter, the amount of crosstalk increases with the increase in the number of stages which is directly related to the number of input fiber. The system thus suffers penalty due to multistage OXC as the number of input fiber is increased.**

Keywords*— *Crosstalk, BER, WDM, Optical cross connect (OXC), Fiber Bragg Grating (FBG), Optical Circulator.

I. INTRODUCTION

A wavelength division multiplexing (WDM) system is a high speed optical transmission system that simultaneously transports optical signals of different wavelengths over a single optical fiber. WDM optical networks are very promising due to their large bandwidth, their large flexibility and the possibility to upgrade the exiting fiber networks to WDM networks for providing greater potential capacities as a next generation optical signal transport technology after a tradition time divisional multiplexed system. Fiber bragg gratings (FBGs) are used extensively in telecommunication industry for WDM, dispersion compensation, laser stabilization, wavelength tuning and sensing in optical communication and optoelectronics [1]. Optical circulator and FBG based Optical Cross-connects (OXCs) are network element that will play a key role in WDM networks to provide more reconfiguration flexibility and network survivability [2]. A FBG-OC based optical cross connect (OXC) is an optical switch that interconnect optical signals between multiple input and output ports. A fundamental difficulty of wavelength routing is the crosstalk from neighboring inputs that causes huge degradation in system performance [3]. Both interband and intraband crosstalk are introduced when FBG-OC cross connects the optical signals from input to output ports. Interferences of small power levels that appear outside the channel bandwidth causes interband crosstalk and intraband crosstalk arises from interferences of leakage signals, inside the channel's bandwidth and is far more acute than interband crosstalk [4].

As high crosstalk is dominant limitation for implementing optical cross connect in WDM network and has prohibited the commercial use so a multi-stage architecture for OXC based on Fiber Bragg Grating (FBG) and optical circulators have been proposed in this paper and performance limitation due to intraband crosstalk in terms of BER has been evaluated that will help the future research to implement the OXC in WDM system.

II. SYSTEM DESCRIPTION

The configuration of a N×N FBG-OC optical cross connect is shown in Figure 1.

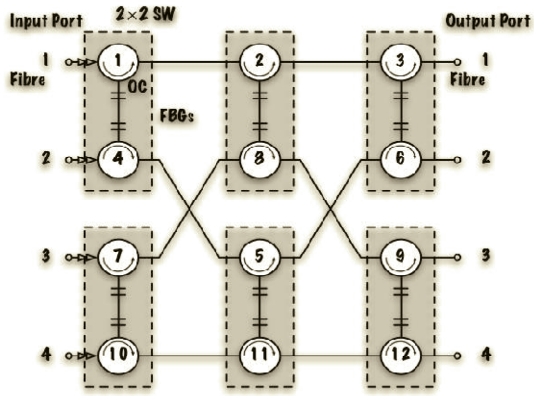

Fig 1. Basic architecture of a FBG-OC based optical cross-connect

At the input port of the cross connect each fiber carries wavelength channels $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_M$. There are N numbers of input fibers in this structure and each fiber carries M number of wavelengths. So there are N x M number of wavelength channels in this structure. This OXC has $k=(2n-1)$ number of stages where $N=2^n$. To evaluate the worst case performance here it is considered that the OXC is in the cross state so that an arbitrary channel signal λ_1 entering into the k^{th} input fiber will pass out from the j^{th} output fiber where $k \neq j$. In Figure 2 cross-state FBG-OC cross-connect with main channel signal and crosstalk is shown.

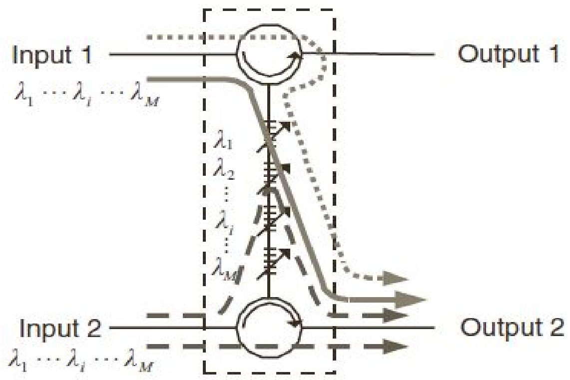

Fig 2. FBG-OC based cross-connect in cross state.

III. CROSSTALK ANALYSIS

In this section the analytical equations are depicted for the Fiber Bagg Grating-Optical Circulator (FBG-OC) based Cross Connect. In this analysis, P_i^j is the signal power, where i denotes the wavelength channel ($1\leq i \leq M$) and j denotes the number of inlet fiber ($1\leq j \leq N$). So $P_{io}^{jo}(0)$ and $P_{io}^{j}(0)$ are the input power of the signal channel i_o from fiber j_o and j respectively. For the worst case (assuming all wavelength channel carry bit 1) the optical power at output of the first stage is defined by $P_i^{j_{out}}(1)$ and written as [5].

$$\begin{aligned} &P_i^{j_{out}}(1) \\ &= P_{i_0}^{j_0}(0) + \left(P_{i_o}^{j}(0)X_{FG} + P_{i_0}^{j_0}(0)X_{oc}\right) \\ &- 2\sqrt{P_{i_o}^{j}(0)\, P_{i_0}^{j_0}(o)}\ \sqrt{X_{FG}} - 2\sqrt{P_{i_o}^{j}(0)\, P_{i_0}^{j_0}(o)}\ \sqrt{X_{oc}} \\ &- 2\sqrt{P_{i_o}^{j}(0)\, P_{i_0}^{j_0}(o)}\ \sqrt{X_{FG}X_{OC}} \end{aligned} \tag{1}$$

Equation (1) has five terms from which first term is the signal power, second term is the crosstalk, third and fourth terms are the signal crosstalk-beat noise and fifth term is the crosstalk-crosstalk beat noise. For the worst case the sign of the beat terms are negative and magnitude is maximum. In this equation $X_{oc}$is the Optical Circulator crosstalk and $X_{FG}$is the FBG crosstalk which is given by,

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

R_{FG} is the FBG reflexivity. In this paper we have assumed that all the channel have the same initial input power$P(0) = P_{i_0}^{j_0}(0) = P_{i_o}^{j}(0)$. So at the output of the first stage the optical power is simplified as $P_i^{j_{out}}(1) = P(1)$.

$$\begin{aligned} P(1) = P(0)[1 + X_{FG}+X_{OC}] - 2(\sqrt{X_{FG}} + \\ \sqrt{X_{oc}} + \sqrt{X_{FG}X_{OC}})] \end{aligned} \tag{3}$$

This OXC has $k=(2n-1)$ number of stages where $N=2^n$. From Equation (3) the output optical power at k^{th} stage is given by,

$$\begin{aligned} P(k) = P(k-1)[1 + X_{FG}+X_{OC}] - 2(\sqrt{X_{FG}} + \sqrt{X_{oc}} \\ + \sqrt{X_{FG}X_{OC}})] \end{aligned} \tag{4}$$

Let $P_{i0}^{j_{out(ref)}}$ is the output of wavelength channel i_0 when the FBG- OC cross connect carries only wavelength channel i_0 (when there is no crosstalk). Then the crosstalk can be expressed as-

$$Crosstalk = \frac{P_{i0}^{j_{out(ref)}} - P_i^{j_{out}}}{P_{i0}^{j_{out(ref)}}} \tag{5}$$

Equation (1) is valid only in that case when all wavelength channels including wavelength channel i_o carries bit 1. As wavelength channel i_o may carry bit 1 or bit 0 at any instant of time, equation (1) has to be modified. If wavelength channel i_o carries bit 0, then (1) reduces to

$$\begin{aligned} P_{i0}^{j_{out}}(1) = \left(P_{i_o}^{j}(0)X_{FG}\right) - 2\sqrt{P_{i_o}^{j}(0)\ X_{FG}} \\ - 2\sqrt{P_{i_o}^{j}(0)\ X_{FG}X_{OC}} \end{aligned} \tag{6}$$

$$P_{i0}^{j_{out(ref)}} = 0 \tag{7}$$

The crosstalk model for FBG-OC cross connect is used to derive bit error rate (BER) for the transmission link considering the detector shot noise and receiver noise. The BER can be expressed as,

$$\begin{aligned} BER_{worstcase} = \frac{1}{8}\Bigg[& erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CTO} - i_D}{\sigma_{1\_0}}\right) \\ & + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_{CTO} - i_o}{\sigma_{0\_0}}\right) \\ & + erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CT1} - i_D}{\sigma_{1\_1}}\right) \\ & + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_{CT1} - i_0}{\sigma_{0\_1}}\right)\Bigg] \end{aligned} \tag{8}$$

Where i_D is the threshold current and it is expressed as,

$$i_D = \frac{\sigma_{0\_1}i_1 + \sigma_{1\_1}i_0}{\sigma_{0\_1} + \sigma_{1\_1}} \tag{9}$$

${\sigma_{1\_0}}^2$ is the noise variance when signal bit is interfered by crosstalk bit by 0. So ${\sigma_{a_b}}^2$denotes noise variance where a is signal bit and b is responsible bit for crosstalk that interfered with bit a . The variances of interferences are,

$$ {\sigma_{1\_0}}^2 = {\sigma_{TH}}^2 + 2eR_d(P_s + P_{CT0})B \quad (10) $$
$$ {\sigma_{0\_0}}^2 = {\sigma_{TH}}^2 + 2eR_dP_{CT0}B \quad (11) $$
$$ {\sigma_{1\_1}}^2 = {\sigma_{TH}}^2 + 2eR_d(P_s + P_{CT1})B \quad (12) $$
$$ {\sigma_{0\_1}}^2 = {\sigma_{TH}}^2 + 2eR_dP_{CT1}B \quad (13) $$

e is the electronic charge, R_d is the receiver resposivity and ${\sigma_{TH}}^2$is the thermal noise in the detector at a temperature 300K is expressed as,

$$ {\sigma_{TH}}^2 = \frac{4KTB}{R_L} \quad (14) $$

B is the electrical bandwidth of the receiver and K is the Boltzman constant. In Equation (8) i_1 is the photocurrent for transmitted bit 1 and i_0 is the photocurrent for transmitted bit 0 assuming received signal power P_s to be zero. i_1 can be written as,

$$ i_1 = 2R_dP_s \quad (15) $$

P_{CT0} and P_{CT1}represent the crosstalk power due to bit 0 and 1 respectively then they are expressed as,

$$ P_{CT1} = P_{i0}^{j_{out(ref)}} - P_i^{j_{out}}(1) \quad (16) $$
$$ P_{CT0} = -P_{i0}^{j_{out}}(1) \quad (17) $$

The corresponding crosstalk currents are given by,

$$ i_{CT0} = R_dP_{CT0} \quad (18) $$
$$ i_{CT1} = R_dP_{CT1} \quad (19) $$

IV. RESULT AND DISCUSSION

In this section, the cross talk model presented in the section III has been applied to calculate the bit error rate of a WDM transmission system using multistage cross connect based on FBC-OG, taking into account the effect of component crosstalk X_{FG} and X_{oc} of FBG-OC based optical cross connect. Here the optical cross-connect has 5 stages and bit rate is 10 Gbps. Received power is assumed -60 dBm. Plot of bit error rate versus number of stages with different values of X_{FG} are shown in Figure 3. In this case it is assumed that X_{oc} = - 55 dB. It is noticed from the plot that with the increasing number of stages system suffers BER penalty. BER is also higher for higher value of X_{FG}.

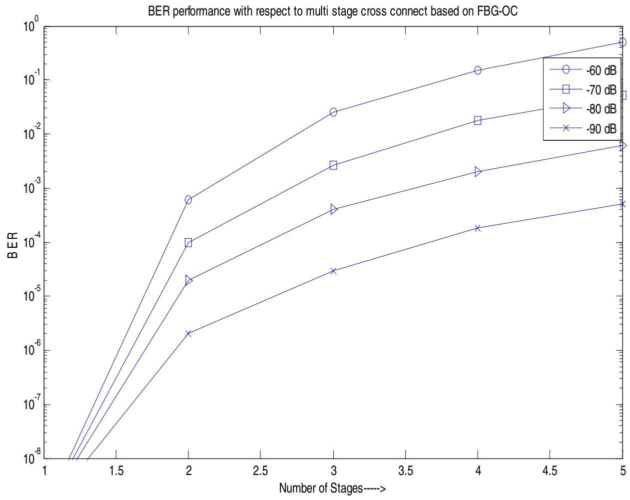

Fig 3. BER performance of a WDM transmission system with respect to number of cross connects stages for different values of X_{FG}(X_{oc}= -55 dB).

Form the plot it is noticed that bit error rate significantly increases with the number of stages. For example for X_{FG}= -60 dB bit error rate increase from the order 10^{-5} to 10^{-3} when stages are increased from 2 to 3. Also The effect of X_{FG} is significant. When the number of stage is 2 BER is in the order of 10^{-5} for lower X_{FG} = -90 dB and BER is in the order of 10^{-4} for X_{FG} = -60 dB.

If X_{FG} is kept constant and X_{oc} is varied in the same way, same degrading performance will be experienced by the system for the increasing number cross-connect stages. Thus cross-connect stages limit the performance of WDM transmission system.

V. CONCLUSION

Bit error rate (BER) due to crosstalk in a WDM network consisted of FBG-OC based multistage optical cross-connect is evaluated here. At 10 Gbps bit rate, bit error rate has been calculated for 5 stages of FBG-OC based optical cross-connect. It is concluded that higher stages of cross-connect cause higher crosstalk that cause higher bit error rate (BER). It is also noticed that for the higher values of X_{FG} and X_{oc} BER increases. The system performance can be improved by compensating the component crosstalk of FBG-OC based cross-connect as well as using minimum number of optical cross-connect stages. However, this research will be helpful and can play a key role in constructing the reconfigurable and upgradable multistage optical cross-connect based on FBG-OC to keep lower crosstalk and BER.

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