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CROSSTALK LIMITATION OF A WDM SYSTEM DUE TO OPTICAL CROSS-CONNECT (OXC)

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ABSTRACT

Performance analysis is carried out to evaluate the bit error rate (BER) performance limitation of a WDM transmission system imposed by crosstalk due to optical cross-connect (OXC). Power penalty evaluated at a BER of 10^{-9} shows that there is a significant impact of crosstalk on the number of wavelengths that can be connected to the OXC. Penalty is higher at higher input power and higher number of wavelengths in a fiber. For a 2 dB penalty, the allowable input power is less than –15 dBm at a BER of 10^{-9}, when the number of fiber is 2 and the number of wavelength is 4.

1. INTRODUCTION

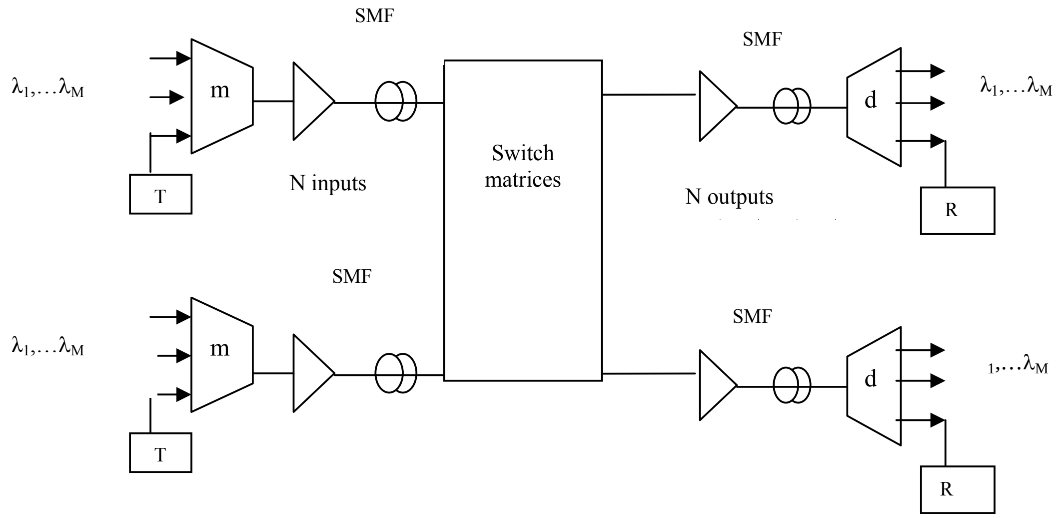
The advent of Wavelength Division Multiplexing (WDM) has led to a virtual revolution in designing optical systems. This is a technique to increase the information capacity of a fiber by transmitting a number of optical signals of different wavelengths simultaneously over the same fiber. This is intended to utilize the vast bandwidth of a fiber, since an optical source only uses a small portion of the bandwidth. WDM networks are very promising not only due to their large bandwidth but also due to the flexibility and possibility of upgrading the existing optical fiber networks to WDM networks.

Optical cross-connect (OXC) is an essential element in a WDM optical network. OXC offers routing flexibility and transport capacity to WDM networks. While cross-connecting wavelengths from input to output fibers, OXC introduces crosstalk. Crosstalk is one of the basic criteria that characterizes the performance of a WDM network. High crosstalk in an optical cross-connect (OXC) has so far prevented commercial use of all optical OXC in WDM networks.

Since crosstalk is a major limiting factor to the implementation of optical cross-connect in WDM systems, in this paper, different crosstalk sources in OXC are identified and quantified by the analytical equation. Afterwards for a particular system, with a specific Bit Error Rate (BER), the amount of power penalty as a function of the component parameters of the OXC is evaluated.

2. SYSTEM DESCRIPTION

The configuration of wavelength division multiplexing optical cross-connect under consideration is shown in Fig1. At the cross-connect, each fiber carries wavelength channels $\lambda_1, \lambda_2, \ldots \lambda_M$. Given that N is the number of input fiber and M is the number of wavelengths, there are a total of $N \times M$ wavelength channels. All the different wavelengths from all the incoming fiber links are demultiplexed, passively rearranged, remultiplexed and transmitted to the appropriate destinations via $NM \times NM$ space switch. The channel signal under consideration is taken from the transmitter and multiplexed with other channels and coupled to the transmitting fiber. The output of the fiber is passed to an OXC. The output of the OXC is passed to the outgoing fiber from which the desired channel is demultiplexed and dropped to the receiver.



m- multiplexer, d- demultiplexer

SMF- Single mode fiber

Fig. 1 Optical Network based on space switch

3. SYSTEM ANALYSIS

The analytical equations for the OXC topologies are illustrated in this section. In the equations the signal power is defined by P_i^j, where i designates the wavelength channel and j the number of the fiber. The fiber which contain the channel under study is indicated by j_o, the wavelength under study by i_o. Hence the input power of the channel under study is defined by P_{io}^{jo} and the output power is defined by P_{io1}^{out} with crosstalk contributions added (assume all wavelength channels carry bit 1) and is given by:

$$P_{io1}^{out} = P_{io}^{jo} + P_{io}^{j}[X_{sw}(N-1)] - 2P_{io}^{j}[X_{sw}\sum_{t=1}^{N-2} t] - 2\sqrt{P_{io}^{jo}}\sqrt{P_{io}^{j}}\,[\sqrt{X_{sw}X_{demux}}\,N(M-1) + \sqrt{X_{sw}}\,(N-1) + \sqrt{X_{mux}X_{sw}}\,(M-1)N + \sqrt{X_{mux}X_{demux}}\,(M-1) + \sqrt{X_{mux}X_{sw}X_{dmux}}\,(M-1)(NM-N-1)] - 2P_{io}^{j}[X_{sw}\sqrt{X_{demux}}\,N(N-1)(M-1) + X_{sw}\sqrt{X_{mux}}\,N(N-1)(M-1) + \sqrt{X_{mux}X_{sw}X_{dmux}}\,(M-1)(N-1)] \quad (1)$$

where X_{sw} is the crosstalk of the switch matrix and is defined as the fraction of the input power routed to other outputs. X_{demux} and X_{mux} are the crosstalk of the demultiplexer and the multiplexer and are also defined as transmission factors (<1). P_{io}^{j} is the wavelength channel power at another fiber j that carries a wavelength i_o. Let $P_{io}^{out(ref)}$ is the output of wavelength channel i_o when the OXC is carrying only wavelength channel i_o (such as when there is no crosstalk). Then the crosstalk is defined as-

$$Crosstalk = \frac{P_{io}^{out(ref)} - P_{io1}^{out}}{P_{io}^{out(ref)}} \quad (2)$$

Equation (1) is valid under assumption that all wavelength channels including wavelength channel i_o carries bit 1. Since wavelength channel i_o may carry bit 1 or bit 0 at any instant of time, (1) has to be modified. If wavelength channel i_o carries bit 0, (1) reduces to:

$$P_{io0}^{out} = P_{io}^{j}[X_{sw}(N-1)] - 2P_{io}^{j}[X_{sw}\sum_{t=1}^{N-2} t] - 2P_{io}^{j}[X_{sw}\sqrt{X_{demux}}\,N(N-1)(M-1) + X_{sw}\sqrt{X_{mux}}\,N(N-1)(M-1) + \sqrt{X_{mux}X_{sw}X_{dmux}}\,(M-1)(N-1)] \quad (3)$$

$$P_{io}^{out(ref)} = 0 \quad (4)$$

The crosstalk model for OXC 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 by:

$$BER_{worstcase} = \frac{1}{8}\left[\begin{matrix} erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CT0} - i_D}{\sigma_{1\_0}}\right) + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_0 - i_{CT0}}{\sigma_{0\_0}}\right) + \\ erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CT1} - i_D}{\sigma_{1\_1}}\right) + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_0 - i_{CT1}}{\sigma_{0\_1}}\right) \end{matrix}\right] \quad (5)$$

where, i_D is the threshold current defined by :

$$i_D = \frac{(\sigma_{0\_1} i_1 + \sigma_{1\_1} i_0)}{(\sigma_{0\_1} + \sigma_{1\_1})} \quad (6)$$

$\sigma_{1\_0}^2$ is the noise variance when signal bit 1 is interfered by crosstalk due to bit 0, $\sigma_{0\_0}^2$ is the noise variance when signal bit 0 is interfered by crosstalk due to bit 0, $\sigma_{1\_1}^2$ is the noise variance when signal bit 1 is interfered by crosstalk due to bit 1 and $\sigma_{0\_1}^2$ is the noise variance when signal bit 0 is interfered by crosstalk due to bit 1. The variances of the different noise sources are given by:

$$\sigma_{1\_0}^2 = \sigma_{th}^2 + 2eR_d(P_S + P_{sp} + P_{CT0})B \quad (7)$$

$$\sigma_{1\_1}^2 = \sigma_{th}^2 + 2eR_d(P_S + P_{sp} + P_{CT1})B \quad (8)$$

$$\sigma_{0\_1}^2 = \sigma_{th}^2 + 2eR_d(P_{sp} + P_{CT1})B \quad (9)$$

$$\sigma_{0\_0}^2 = \sigma_{th}^2 + 2eR_d(P_{sp} + P_{CT0})B \quad (10)$$

$$\sigma_{th}^2 = \frac{4KTB}{R_L} \quad (11)$$

$$i_1 = 2R_d P_S \quad (12)$$

$$i_0 = 0 \quad (13)$$

σ_{th}^2 is power of thermal noise, e is electronic charge, R_L is the receiver front-end load, R_d is the receiver responsivity, B is the bandwidth of the filter (at 10GHz for this paper), P_S is the signal power. i_1 is the photocurrent for transmitted bit 1, i_0 is the photocurrent for transmitted bit 0, with Ps assumed to be zero. The spontaneous emission power is given as:

$$P_{sp} = hf\eta_{sp}(G-1)B \quad (14)$$

where, h is the Plank's constant, f is the carrier frequency at wavelength λ=1.55μm, η_{sp} is the spontaneous emission factor, G is the optical amplifier gain.

If P_{CT1} represents the crosstalk power due to bit 1, and P_{CT0} is the crosstalk power due to bit 0, then the corresponding crosstalk currents are given by:

$$P_{Ct0} = -P_{io0}^{out} \quad (15)$$

$$P_{CT1} = P_{io}^{out\,(ref)} - P_{io1}^{out} \quad (16)$$

$$i_{CT1} = R_d P_{CT1} \quad (17)$$

$$i_{CT0} = R_d P_{CT0} \quad (18)$$

4. RESULTS AND DISCUSSION

Following the analytical formulation presented in section 3, we evaluate the bit error rate performance of a WDM transmission system, taking into account the effect of optical WDM MUX/ Demux induced crosstalk in an optical cross-connect. Results are evaluated at a bit rate of 10 Gb/s with several values of the number of input wavelengths. The plots of the bit error rate (BER) versus received power are depicted in Fig 2. The penalty due to crosstalk at a given BER of 10^{-9} are determined from the BER plots. The plots of penalty versus input power, the number of wavelengths and the number of fibers are shown in Fig 3, 4 and 5 respectively. It is found that the system suffers a power penalty due to crosstalk and the penalty increases with increase in input power for a given number of wavelength and input fiber. An input power of –20 dBm with the number of wavelengths 4 and the number of fibers 2 is taken as reference for Fig 3. i.e. penalty at –20 dBm input power is considered to be zero for M=4, N=2. However increase in penalty due to high input power can be compensated if the performance of the switch matrix as well as that of multiplexer and demultiplxer is improved.

It is further noticed from Fig.4 and Fig.5 that there is an increase in crosstalk with increase in the number of wavelengths as well as the number of fibers, at a given input power. In this case an input power of –30 dBm is taken as the reference. Crosstalk thus limits the number of wavelengths, the number of input fibers as well as allowable input power per fiber.

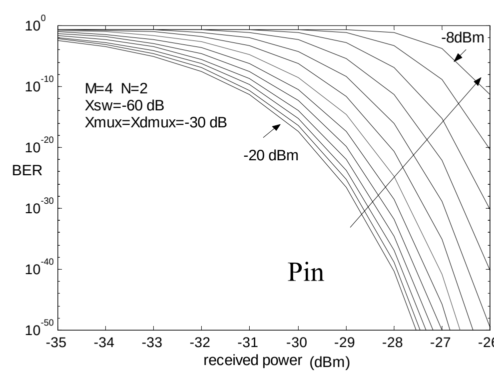


Fig. 2 Plots of BER versus received power for a 10 Gb/s optical transmission system with a WDM optical Cross-connect

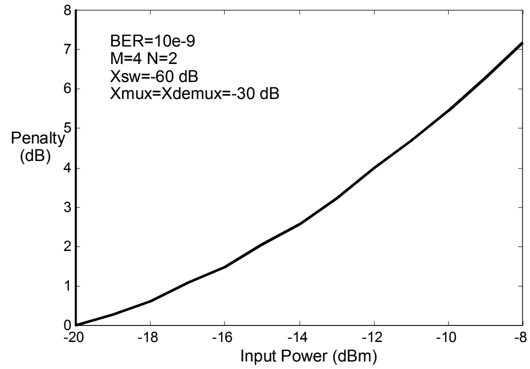


Fig. 3 Plots of Power Penalty versus input power for a 10 Gb/s optical transmission system with a WDM optical Cross-connect

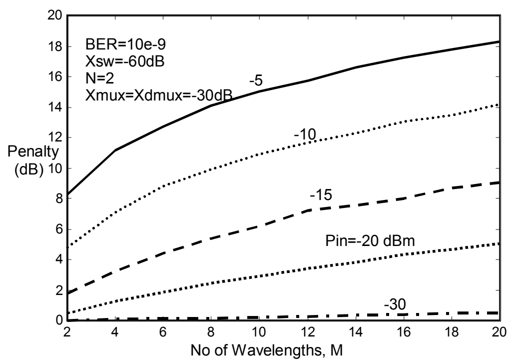


Fig. 4 Plots of Power Penalty vs. Number of wavelengths, M for different values of input power for a 10 Gb/s optical transmission system with a WDM optical Cross-connect

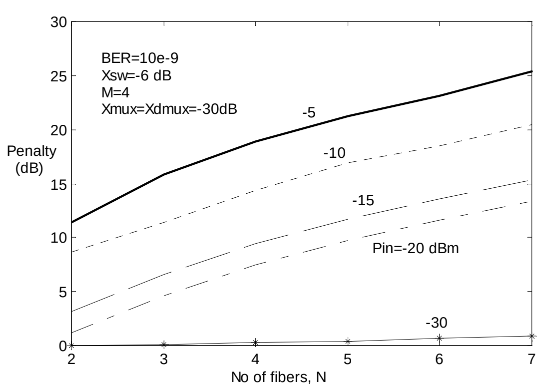


Fig. 5 Plots of Power Penalty vs. Number of input fibers, N for different values of input power for a 10 Gb/s optical transmission system with a WDM optical Cross-connect

5. CONCLUSION

The bit error rate performance of a WDM system is evaluated considering the effect of crosstalk due to WDM optical cross-connect (OXC). The power penalty due to crosstalk is evaluated at a BER of 10^{-9} for transmission rate of 10 Gb/s. It is found that a high input power causes an extra penalty. Penalty also increases as we increase the number of input channels (N X M) i.e. the number of wavelengths as well as the number of input fibers. On the other hand the number of fibers can be increased without significant penalty if the performance of the switch is improved. The number of wavelengths can be increased but requires higher suppression of other channels or regeneration. Realistic systems require a larger number of wavelengths compared to the number of fibers.

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