Chapter 1

Zero Loss Condition Analysis on Optical Cross Add and Drop Multiplexer (OXADM) Operational Scheme in Point-to-Point Network

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Additional information is available at the end of the chapter

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1. Introduction

OXADMs are element which provide the capabilities of add and drop function and cross connecting traffic in the network, similar to OADM and OXC. OXADM consists of three main subsystem; a wavelength selective demultiplexer, a switching subsystem and a wavelength multiplexer. Each OXADM is expected to handle at least two distinct wavelength channels each with a coarse granularity of 2.5 Gbps of higher (signals with finer granularities are handled by logical switch node such as SDH/SONET digital cross connects or ATM switches). There are eight ports for add and drop functions, which are controlled by four lines of MEMs optical switch. The other four lines of MEMs switches are used to control the wavelength routing function between two different paths. The functions of OXADM include node termination, drop and add, routing, multiplexing and also providing mechanism of restoration for point-to-point, ring and mesh metropolitan and also customer access network in FTTH. The asymmetrical architecture of OXADM consists of 3 parts; selective port, add/drop operation, and path routing. Selective port permits only the interest wavelength pass through and acts as a filter. While add and drop function can be implemented in second part of OXADM architecture. The signals can then be re-routed to any port of output or/and perform an accumulation function which multiplex all signals onto one path and then exit to any interest output port. This will be done by the third part. OXADM can also perform 'U' turn to enable the line protection (Ring Protection) in the event of breakdown condition. This will be done by the first and third part. These two features have differed OXADM with the other existing device such as OADM and OXC. The purpose of this study was to obtain the maximum allowed loss for the device OXADM and input power required to maintain the satisfactory performance of the BER (BER $<10^{-9}$) in the specific loss value. Ideal situation is a situation where all the devices that form the optical device were considered to have zero loss. However, this loss is replaced in the BER measurement with the use of optical attenuator is set at 25 dB. The value of 25 dB will represent the total loss in the OXADM device. In zero loss condition, the only contributor to the system loss is the non-linear effect of power penalty. The decrement of data transmission rate with the increment of loss and maximum loss for each operation in the network OXADM point is also studied. The relationship between allowable power loss and the magnitude of input signal is shown in proposed equation. Optical fiber with nonlinear dispersion (attenuation constant, α = 0.25 dB/km) used for connecting two nodes OXADM at a distance of 60 km.

This paper also measured the operational loss value for three main operation of OXADM such as pass through, dropping and adding signal. The relationship between minimum input power and attenuation given by the linear equation, y = x + 25 to intercept the y axis is 25 dB (maximum loss in the input power 0 dBm). Gradient, m = 1 shows no change at 1 dBm of input power will change the power loss of 1 dB. The restoration scheme offers by OXADM is also been investigated. We examine the relationship between the attenuation/loss at optical node on output power and the BER performance of the ring protection mechanism is activated. The simulation study also seeks to obtain the magnitude of the attenuation is allowed during the operation of this ring of protection (if attenuation increases due to inclusion of other optical devices and connectors). Rate of decreasing of output power due to attenuation increased will also be studied and based on the value of the internal amplifier gain can be determined relatively. Finally, the proposed value of the internal amplifier which is suitable for miniaturization compensate signal to a directional orientation to the West and East to have the same attenuation as a ring of protection is turned on.

2. OXADM device

Optical switch based devices is one of the most promising element that is used in optical communication network. Starting with Modulator at the receiver site, then moving to Optical Add and Drop Multiplexing (OADM) and Optical Cross Connect (OXC) at the distribution site and finally ending with Receiver (demodulator) at recovery site have shown the significant useful of the device. However, the rapid change and evolvement in optical network and service today has required the new type of optical switching device to be developed. Optical Cross Node, Tuneable Ring Node, Customer Access Protection Switch (CAPU), Arrayed Waveguide Grating Multiplexing are amongst the new generation of optical switch device [Mutafungwa 2000][Eldada & Nunen 2000][Aziz et al. 2009]. In this paper we introducing of new architecture of switch device that is designed to overcome drawbacks that occur in wavelength management in expected. The device is called optical cross add and drop multiplexing (OXADM) which use combination concept of OXC and OADM. Its enable the operating wavelength on two different optical trunks to be switched to each other and implementing accumulating function simultaneously. Here, the operating wavelengths can be multiplexed together and exit to any interested output port. The wavelength transfer between two different cores of fiber will increase the flexibility, survivability and also efficiency of the network structure. To make device operational more efficient by reducing the power penalty, zero leakage MEMs switches are used to control the mechanism of operation such as wavelength add/drop and wavelength routing operation. As a result, the switching performed within the optical layer will be able to achieve high speed restoration against failure/degradation of cables, fibers and optical amplifiers which had been proposed in [Rahman et al. 2006a][Rahman et al. 2006b]. We had proposed previously the migration of topology will be easier and reduce the restructuring process by eliminating the installation of new nodes because OXADMs are applicable for both types of topologies beside provide efficiency, reliability and survivability to the network [Rahman et al. 2006c][Rahman & Shaari 2007].

OXADMs are element which provide the capabilities of add and drop function and cross connecting traffic in the network, similar to OADM and OXC. OXADM consists of three main subsystem; a wavelength selective demultiplexer, a switching subsystem and a wavelength multiplexer. Each OXADM is expected to handle at least two distinct wavelength channels each with a coarse granularity of 2.5 Gbps of higher (signals with finer granularities are handled by logical switch node such as SDH/SONET digital cross connects or ATM switches. There are eight ports for add and drop functions, which are controlled by four lines of MEMs optical switch. The other four lines of MEMs switches are used to control the wavelength routing function between two different paths. The functions of OXADM include node termination, drop and add, routing, multiplexing and also providing mechanism of restoration for point-to-point, ring and mesh metropolitan and also customer access network in FTTH. With the setting of the MEMs optical switch configuration, the device can be programmed to function as another optical devices such as multiplexer, demultiplexer, coupler, wavelength converter (with fiber grating filter configuration), OADM, wavelength round about an etc for the single application. The designed 4-channel OXADM device is expected to have maximum operational loss of 0.06 dB for each channel when device components are in ideal/zero loss condition. The maximum insertion loss when considering the component loss at every channel is less than 6 dB [Rahman et al. 2006a]-[Rahman 2008].

In this paper we analyze the performance of OXADM in zero loss condition to obtain the achievable loss of point-to-point network at a specific receiver sensitivity value. Finally to address the operational loss and can be called as power penalty to each function or operation performed by this device.

2.1. Insertion loss calculation

Table 1 shows the modulated launched power to characterize the insertion loss of OXADM operation. Since the launch of the four modulated wavelength operation is almost similar, therefore the process of leveling (equating the amplitude of) the wavelength is not necessary. Specification for the characterization of the insertion loss calculation is as follows:

Attenuation = 25 dB (representing insertion loss)
Photodetector sensitivity = -28.4 dBm at1550 nm
Data transmission rate = 2.5 Gps (OC-48)
WDM analyzer resolution bandwidth = 0.1 nm
Photodetector thermal noise = $1x10^{-23}$ W/Hz
Launched power (before modulation) = 0 dBm

The word 'sensitivity' is used in this paper are based on the simulation using optisystem tool. 'Sensitivity' is actually referring to the power allocation or budget power in actual application. The actual sensitivity in photodetector is defined as

$$\text{Photodetector Sensitivity}(\text{dBm}) = -(\text{Power Budget} + \text{Safety Margin}) \quad (1)$$

Wavelength	Launched Power (Watt)	Launched Power (dBm)
1510 nm	4.680×10^{-4}	-3.297
1530 nm	4.808×10^{-4}	-3.180
1550 nm	4.872×10^{-4}	-3.123
1570 nm	4.808×10^{-4}	-3.180

Table 1. Modulated launched power which injected to OXADM device.

2.2. Attenuation representing network total loss

The purpose of this simulation study was to determine allowable loss of OXADM to maintain the network performance in point to point network and be tested under ideal condition. The decrement of data transmission rate with the increment of loss and maximum loss for each operation in the network OXADM point is also studied. The relationship between allowable power loss and the magnitude of input signal is shown in equation (1). Optical fiber with nonlinear dispersion (attenuation constant, α = 0.25 dB/km) used for connecting two nodes OXADM at a distance of 60 km (Figure 1).

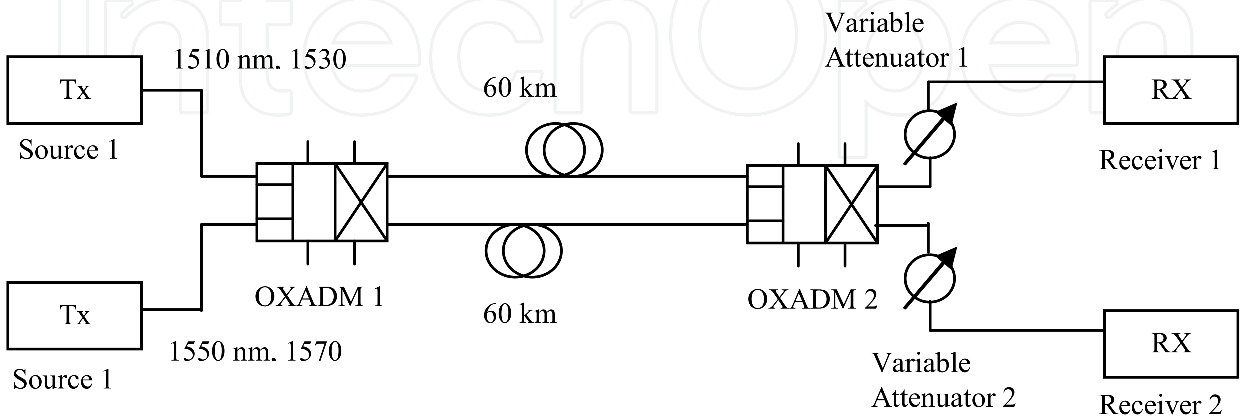

Figure 1. Experimental set up of point-to-point network which uses OXADM as an optical node. The value of OXADM insertion loss is determined by adjusting the attenuator.

2.3. The effect of attenuation to the BER

a) Addition Signal to the Output Signal

Figure 2 shows the effects of attenuation on the BER for the operation of additional signals into the device OXADM. Attenuation value is set starting at 20 dB to 29 dB. The purpose of this characterization was to obtain the actual value of the total insertion loss is acceptable to maintain the BER measurement of $1x10^{-9}$.

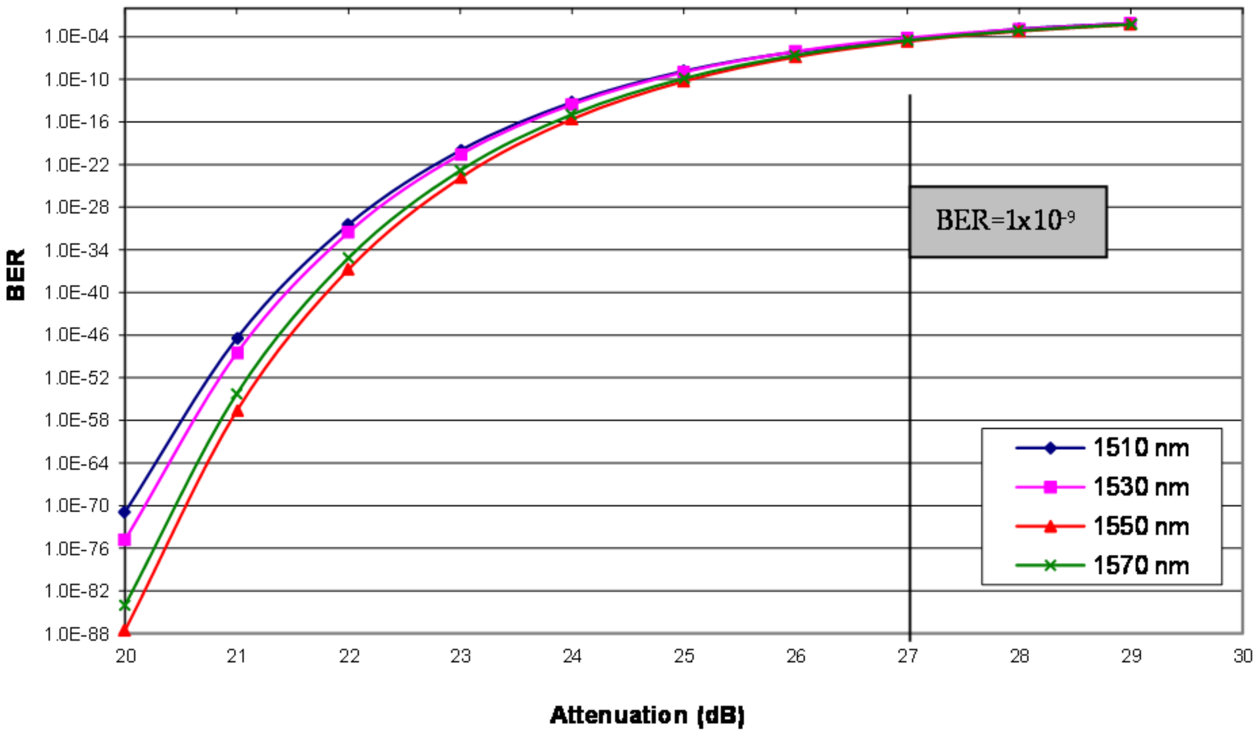

Figure 2. Effect of attenuation to BER performance for four different wavelengths for new additional signal.

From the graph, the value of the attenuation that gave readings equivalent to the BER is $1x10^{-9}$ at 25 dB. This means that the maximum acceptable amount of insertion loss in the OXADM device is 25 dB. However, this value can be increased by increasing the sensitivity of the system depends on the receiver system used.

b) Launched Signal to Output Signal

Figure 3 shows the effect of attenuation on the BER measurements for the operation of pass through to the signal. At 25 dB attenuation values give the same BER measurement readings $1x10^{-9}$. This value is equal to the value obtained for the operation of adding a new signal of OXADM. This shows OXADM single unit provides good performance in the value of the maximum insertion loss of 25 dB to the sensitivity of -28.4 dBm.

Conclusions from the studies on this part of the overall estimated value of OXADM device is 25 dB. Studies in the next section (the theory of product) will have an estimated value of real power for the provision of optical networks based on different values OXADM 25 dB with the insertion loss of OXADM which measured in the product theory.

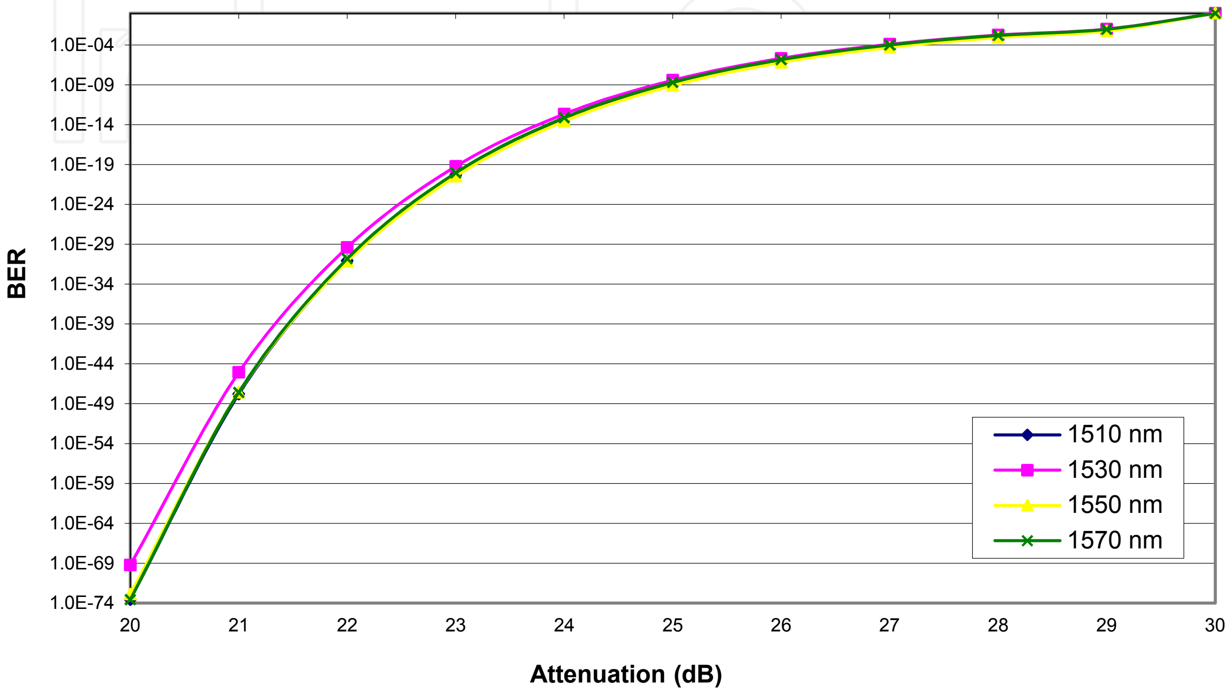

Figure 3. Effect of attenuation to BER performance for four different wavelengths for pass through operation.

2.4. Input signal to BER performance

Figure 4 shows the effect of input power diode laser (before the signal is modulated with data) on BER performance in a variety of attenuation. Attenuation value is set between 20 dB to 26 dB. The purpose of this characterization is to obtain the minimum power required by the device OXADM to operate in a satisfactory condition. The relationship between minimum input power and attenuation given by the linear equation, y = x + 25 to intercept the y axis is 25 dB (maximum loss in the input power 0 dBm). Gradient, m = 1 shows no change at 1 dBm of input power will change the power loss of 1 dB. The changes are shown in Figure 5.

The insertion loss under ideal condition is called as operational loss. The magnitude is rely on the operation functioned by OXADM. This term can also be used as power penalty. Power penalty is the other loss need to be compensated instead of insertion loss. Power penalty is the loss due to the non-linear effect such as SRS, FWM and others.

The loss under zero loss condition is also measured for each operation of OXADM. Table 2 listing the operational loss or power penalty for three OXADM operations; pass through, dropping, adding signal. The values is range from 0.05 to 0.18 depend to the number of switch device involve of each operation.

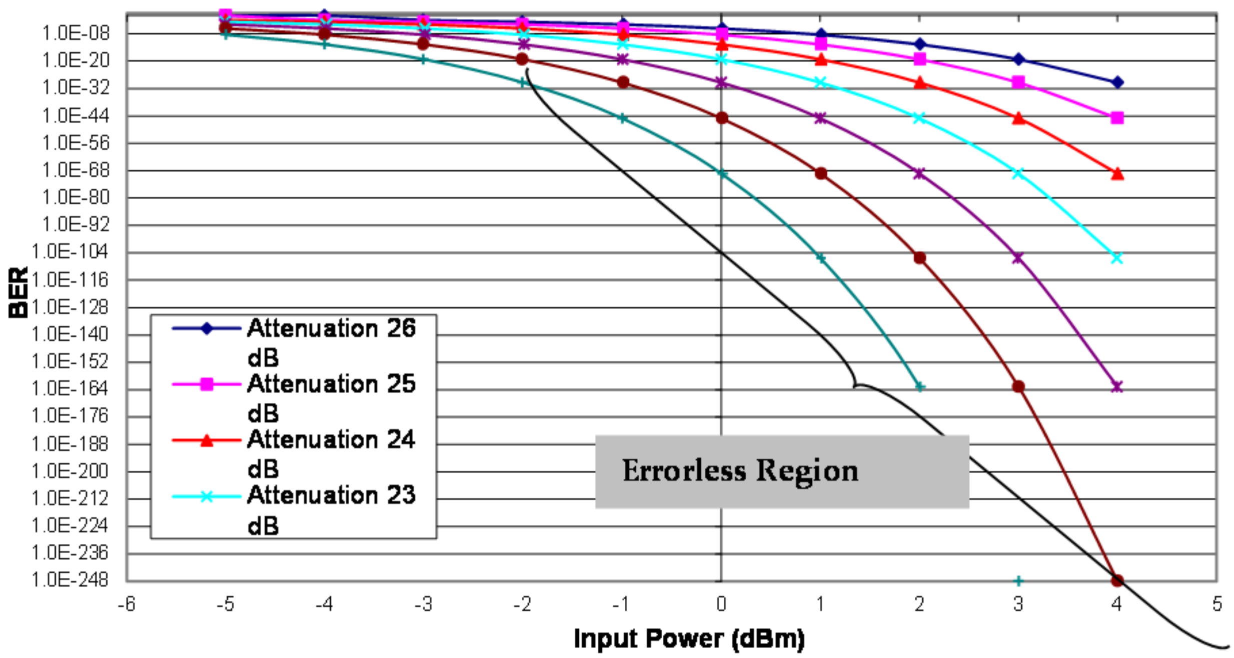

Figure 4. Effect of Input Power to the BER performance at different attenuation values (1530 nm)

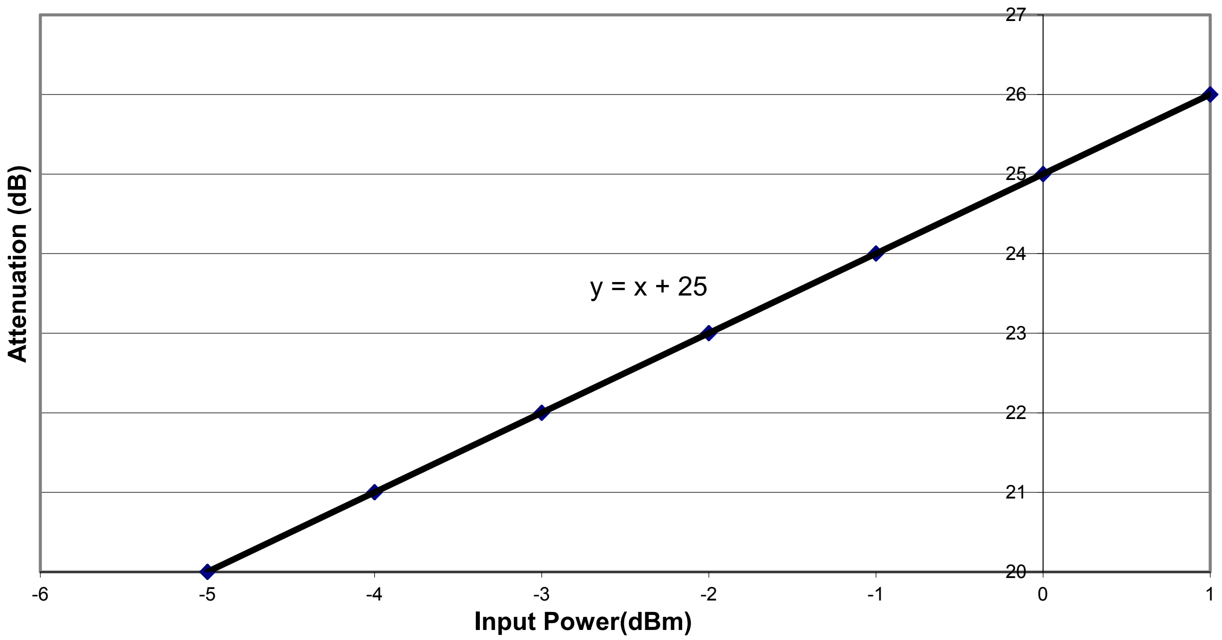

Figure 5. The required input power by OXADM to maintain the performance at different attenuation (λ=1530 nm, BER=3.98x10^{-9}).

2.5. Attenuation over distance

The purpose of this simulation study is to determine the performance of the OXADM in point to point network under the certain loss value. The decrement of achievable distance due to the increment of loss value is also studied. As a result, the relationship between the achievable distances for point to point network to the OXADM insertion loss has been defined in equation (2). Optical fiber with nonlinear dispersion (attenuation constant, α = 0.25 dB / km) is used for connecting two nodes OXADM at a distance of 60 km (Figure 1). Five value if insertion loss (which has a value nearly equal to the loss of each operation OXADM) were selected to estimate the BER performance in this network.

Wavelength (nm)	Insertion Loss (dB)
i. Launched Power (dBm)-Output Power (dBm)	
1510	0.1185
1530	0.1171
1550	0.1128
1570	0.1144
ii. Launched Power (dBm)-Drop Power (dBm)	
1510	0.0938
1530	0.0931
1550	0.0891
1570	0.0903
iii. Add Power (dBm)-Output Power (dBm)	
1510	0.0600
1530	0.0584
1550	0.0599
1570	0.0572

Table 2. Power Penalty for several OXADM operations under ideal condition.

Figure 6 until Figure 10 shows the effect of distance of data transmission to the BER performance of the point to point networks at different attenuation value. The attenuation is set at 0 dB to 20 dB. Observed in these graphs, the boundary lines for the BER = 10^{-9} shifted to the left with the increment of value of attenuation. This shows the increment of device loss, distance of data transmission is also decreased. At zero power loss the boundary lines on the BER is at 95 km but when the loss at 20 dB, BER = 10^{-9} boundary is located at 14 km. This shows the distance is inversely proportional to the devices insertion loss (Saleh & Teich 1991). The decrement rate of distance is 3.92 km/dB, as shown in Figure 11 and equations (2).

$$y = -3.9151x + 94.434 \qquad (2)$$

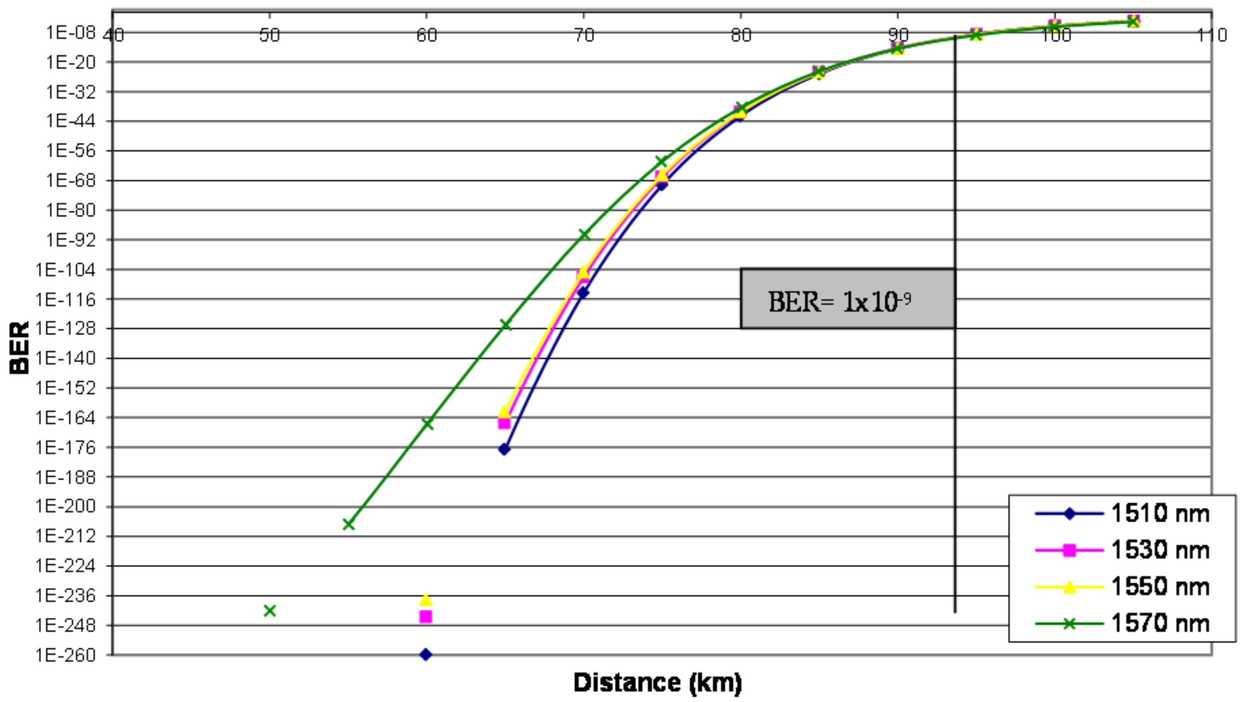

Figure 6. Effect of distance to the BER performance in npoint-to-point network at zero attenuation.

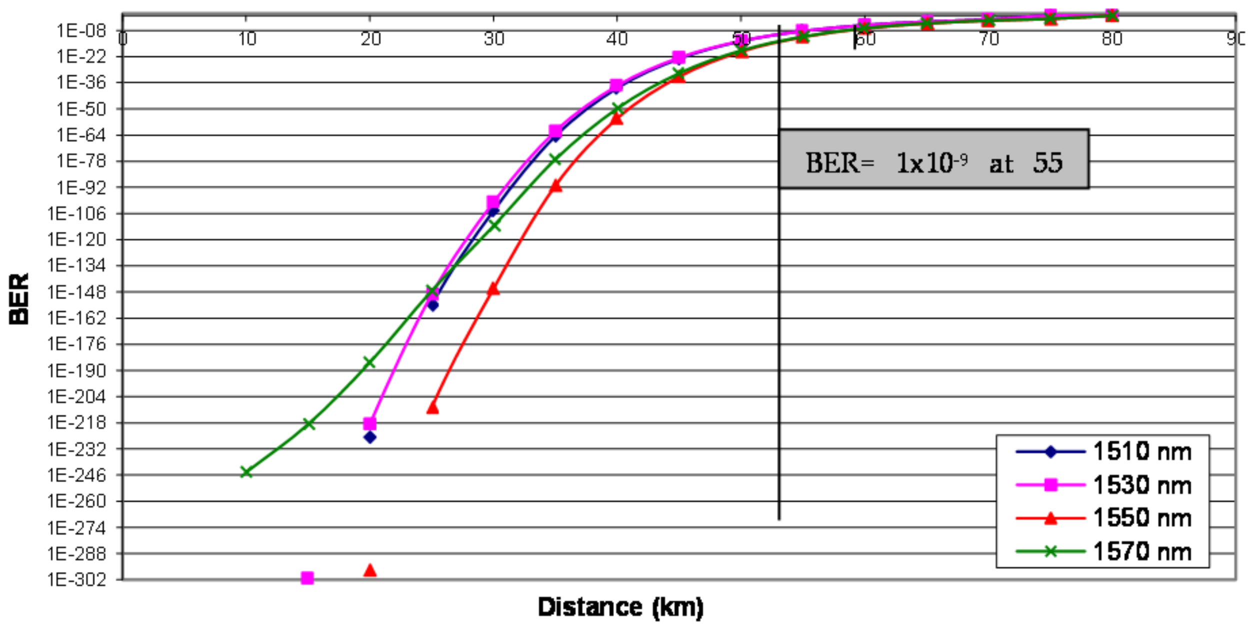

Figure 7. Effect of distance to the BER performance in point-to-point network at attenuation of 10 dB.

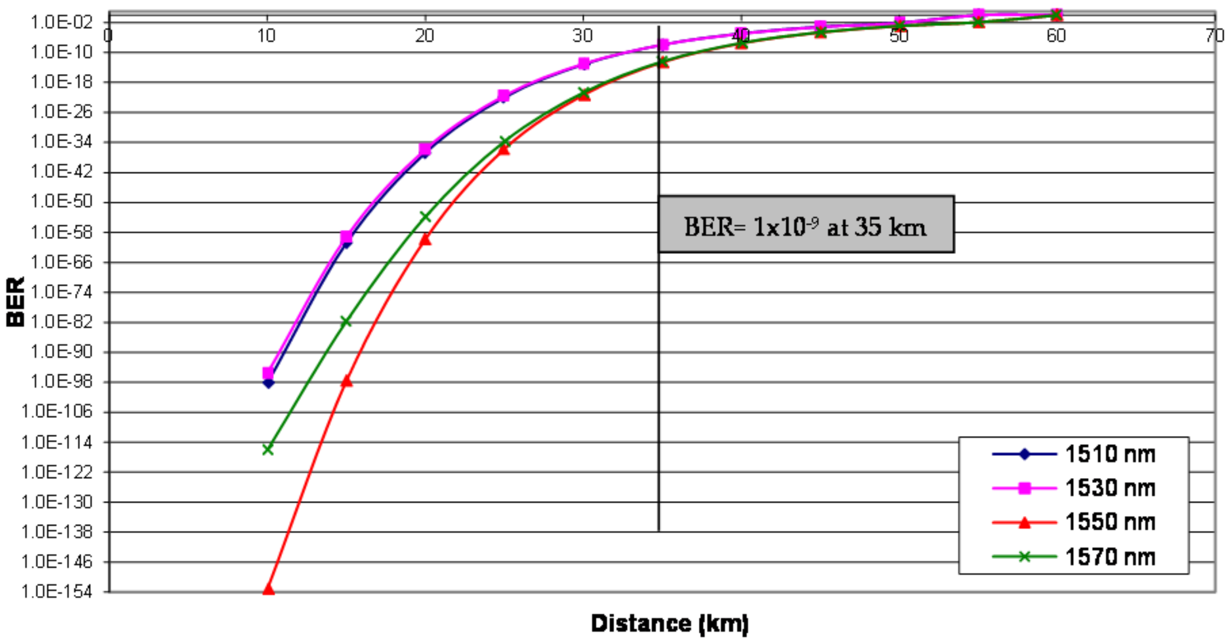

Figure 8. Effect of distance to the BER performance in npoint-to-point network at attenuation of 15 dB.

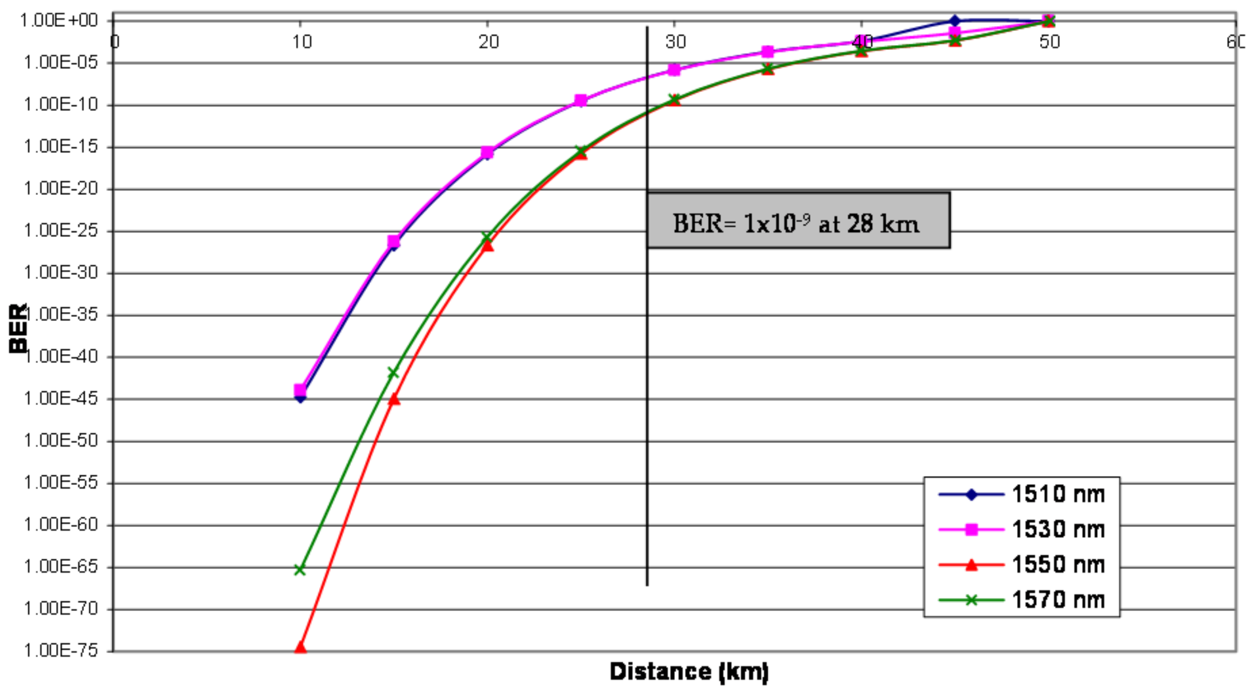

Figure 9. Effect of distance to the BER performance in npoint-to-point network at attenuation of 17dB.

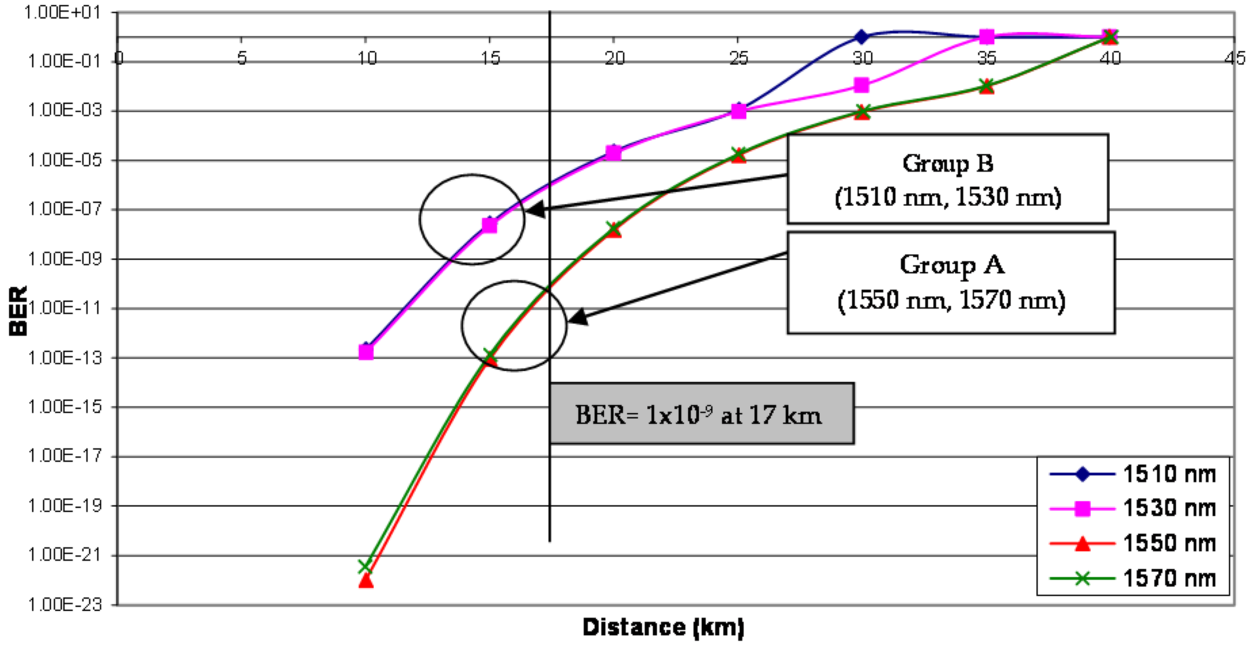

Figure 10. Effect of distance to the BER performance in npoint-to-point network at attenuation of 20 dB.

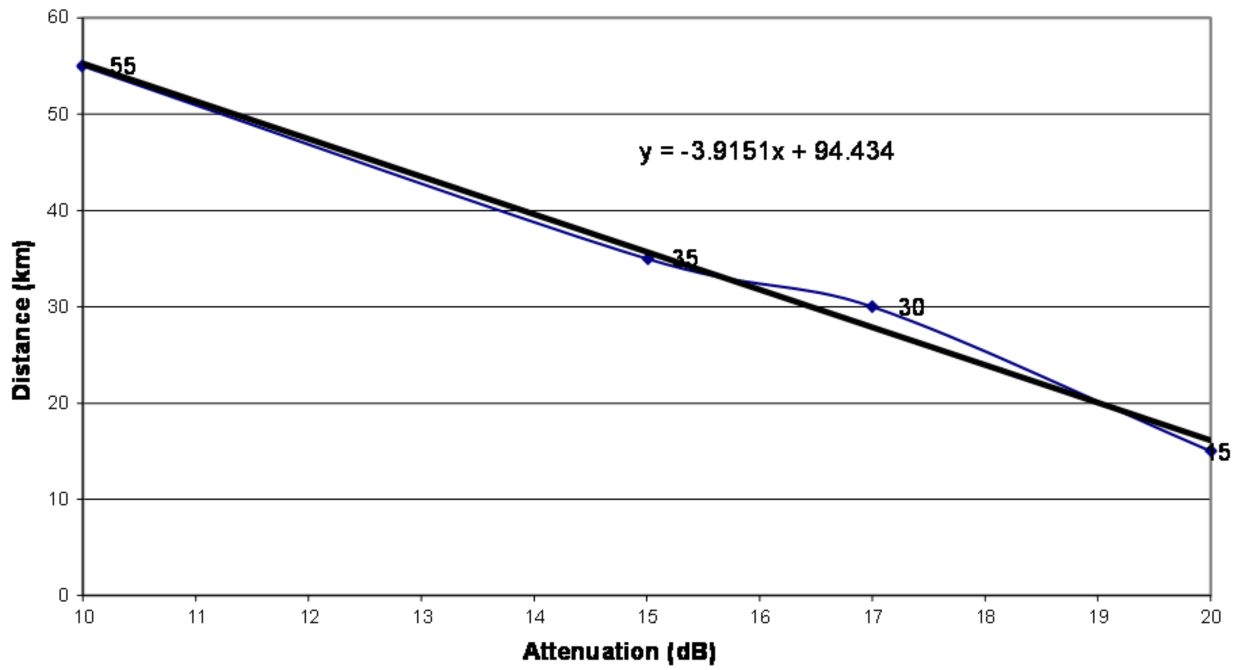

Figure 11. Achievable distance at specific attenuation values in point-to-point network at sensitivity -28.4 dBm (1550 nm at OC-48).

Wavelength of operation of the network is point to point can be divided into two groups: the group A (wavelength 1550 nm and 1570 nm) and group B (wavelength 1510 nm and 1530 nm). Observed in Figure 6, curve B group is under the curve A. But in Figure 7 until Figure 10, the movement to the right occurs at the curvature of the group B that eventually bend the curve B is above the group A. This shows the effect of attenuation to the BER performance is different at different wavelengths. The reduction in the distance occurs suddenly at a wavelength of Group B with the increasing of attenuation compared with the wavelength A.

Achievable distance (maximum span) in point-to-point network is define bu equation (3)

$$L = \frac{P - l_{OXADM}}{\alpha} \tag{3}$$

L = Achievable distance, km

P = Power Budget, dB (ideal condition or zero loss)

l_{OXADM} = Insertion loss of OXADM, dB (product theory condition)

α = fiber constant, dB/km

3. Conclusion

We have introduced a new switching device which utilizes the combined concepts of optical add and drop multiplexing and optical cross connect operation through the development of an optical cross add and drop multiplexer (OXADM). Ideal situation is a situation where all the devices that form the optical device were considered to have zero loss. However, this loss is replaced in the BER measurement with the use of optical attenuator is set at 25 dB. The value of 25 dB will represent the total loss in the OXADM device. The purpose of this study was to obtain the maximum allowed loss for the device OXADM and input power required to maintain the satisfactory performance of the BER (BER $<10^{-9}$) in the specific loss value. In zero loss condition, the only contributor to the loss is the non-linear effect of power penalty.

The experimental results show the value of crosstalk and return loss is bigger than 60 dB and 40 dB respectively.We have obtained the achievable distance associated with insertion loss for the OXADM device at specific fiber used. The result will be the mathematical equation that describe about these parameter relationship as mentioned in equation (3). As a result, analysis using the value of insertion loss was less than 0.06 dB under ideal condition, the maximum length that can be achieved is 94 km. While when considering the loss, with the transmitter power of 0 dBm and sensitivity –22.8 dBm at a point-to-point configuration with safety margin, the required transmission is 71 km with OXADM.

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