Optimization of Transport Performance of Externally Modulated and Directly Modulated Signals over SMF-28 and MetroCor Fiber in 2.5Gbps WDM Ring Network

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ABSTRACT

In this paper, the transport performance of metropolitan area wavelength division multiplexing (WDM) transparent ring network consisting of three access nodes separated by 40km fiber spans has been studied. The network node feeds all the access nodes with two channels at 193.1THz and 193.2THz that are accessed by number of end stations for different applications. Here, WDM ring is evaluated by varying the gain of in-line erbium-doped fiber amplifier (EDFA) for directly modulated laser (DML) transmitter using SMF-28 and MetroCor fiber. Further, the network has been considered using externally modulated (EM) transmitter and SMF-28 along with various dispersion compensation schemes. It has been found that DML using MetroCor gives the best performance followed by SMF-28 giving the cost effective solution. The optimum performance of the network has been achieved for EDFA gain of 5dB. Also, the network power is optimized for both externally modulated and directly modulated transmitter sources.

Keywords
Metro network, externally modulated (EM), directly modulated (DM), SMF-28 and MetroCor.

1. INTRODUCTION

Over the last few years, data traffic has grown spectacularly due to Internet and data-intensive applications such as e-commerce, enterprise resource planner, backup and recovery, data warehousing and mining. This rapid growth of data rate and bandwidth demands of end users look for a flexible data-optimized metropolitan network infrastructure. The optical transparency has the potential to enable metro networks with increased flexibility at lower costs as compared to opaque networks. The demands on a metro network are stringent because the traffic is more diverse, yet the system costs must be smaller [1], [2]. Earlier several research projects such as the Optical Networks Technology Consortium (ONTC), Multi-wavelength Optical Networking (MONET), and All-Optical Network (AON) had focused on applying dense WDM in long-haul and metro environment [3]. In metro networks, cost effectiveness is a very important factor. The transparent WDM networks have a potential to eliminate expensive transponders. In metro networks, the overall cost is dominated by the cost of the terminal equipment. The transmitter is the significant part of a transponder; hence the cost-effective transmitter is required for WDM metro networks [4].

In today's scenario, the directly modulated lasers (DML) are used with great interest in cost-sensitive metro and access optical links. DMLs have specific characteristics such as low cost, compact size, low power consumption, and high output power. DMLs are carrier density modulation via drive current, giving rise to inherent and highly component specific frequency-chirp, i.e., a residual phase modulation (PM) accompanying the desired intensity modulation (IM). The chirp results in a broad spectrum that severely limits the maximum transmission distance over SMF-28 without dispersion compensation [5]. In order to overcome this issue, a negative dispersion fiber (NDF) was proposed for transmission of directly modulated signals [6].

In this paper, we experimentally demonstrated that in metro WDM ring network, the transmission performance of externally modulated signals is enhanced by employing the dispersion compensation schemes. The dispersion compensating fiber (DCF) having large negative dispersion (Dispersion: -80ps/nm-km) is installed on the link. Further improvement in network efficiency is achieved by the cost-effective directly modulated laser (DML) as transmitter source. DMLs are of particular importance for 2.5Gbps applications. MetroCor fiber is used to take the advantage of positive chirp characteristics of DML to enhance transmission distance. The negative dispersion fiber (NDF) called MetroCor fiber with a small dispersion value of -5.6ps/nm/km at 1550nm is used for the regional metro network.

The paper is organized as follows. In Section 2, the architecture of the metro network is described along with the characteristics of metro networks. The characteristics and parameters of transmitter source and fiber are discussed. The transmission performance results are presented from the network testbed in Section 3. The results are summarized and conclusions are presented from the study in Section 4.

2. METRO NETWORK CHARACTERISTICS

Figure 1 shows the simplified picture of a metro WDM ring network. The metro networks aggregate the various traffic types originating in the access networks and transmit the information either within the same geographical area or to remote locations by interfacing to the long-haul networks.

The metro networks differ from long-haul DWDM systems because these are far more sensitive to equipment cost, requiring the use of low-cost optical components [3]. The network consists of metro core ring and three access rings. The first access ring has two end stations and other two rings are composed of single end stations. The transmission length of first access ring is 30km and other two access rings are of 20km each throughout the analysis [2]. The signals generated in the network node are transmitted over the metro core ring. The access node (AN) is simply an add-drop multiplexer, which is used to add or drop the traffic in metro access rings that are connected to end stations.

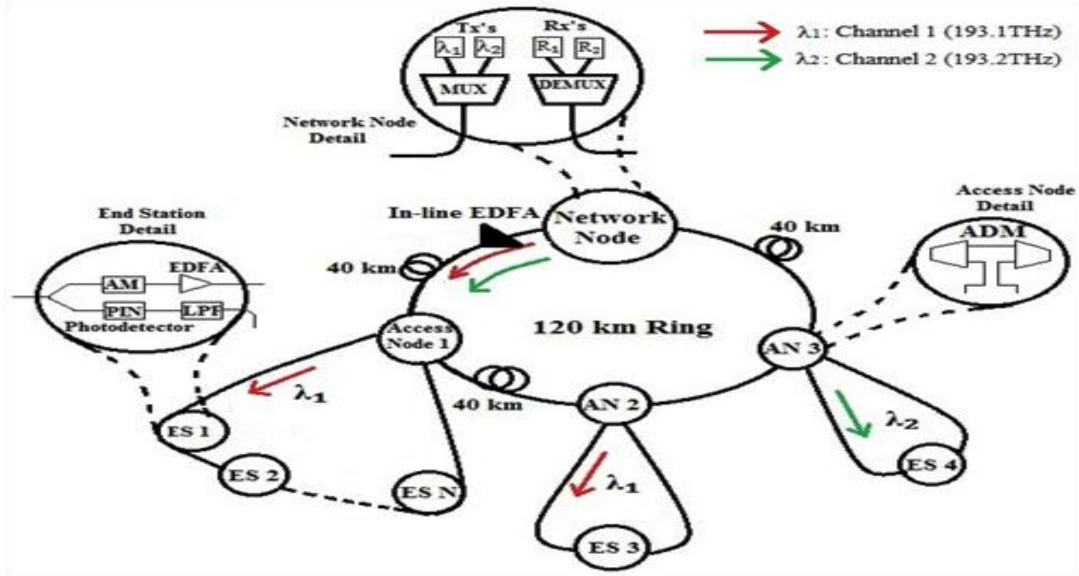

Figure 1: WDM metro ring network architecture

The maximum distance that a signal can be transmitted at a certain bit rate is determined by the choice of the optical transmitter and its associated characteristics. DMLs are of particular importance for 2.5Gbps applications. DMLs have the advantages of low cost, small size, low driving voltage, and high output power. The transient chirp dominated laser diodes exhibit significantly more overshoot and ringing in output power and frequency deviations. The frequency difference between the steady state and zeros is relatively small. Transient chirp dominated laser diodes achieve much better transmission performance over MetroCor [3]. The characteristics of DML are described below in table 1 [7].

Table 1: DML parameters

Name (Units)	**Value**
Active layer volume (cm^3)	195×10^{-10}
Quantum efficiency	0.19
Spontaneous emission factor	2.4×10^{-5}
Gain compression coefficient(cm^3)	5×10^{-18}
Carrier density at transparency(cm^{-3})	2×10^{17}
Differential gain coefficient(cm^2)	5.63×10^{-16}
Group velocity(cm/s)	8.5×10^{8}
Line width enhancement factor	5.6
Mode confinement factor	0.4
Carrier life time	2.5×10^{-10}
Photon lifetime	9.6×10^{-12}

The parameters of different fibers used in the analysis are described in table 2. The standard single-mode fiber (SMF-28) is used in metro networks without dispersion compensation. Due to a large dispersion caused by the fiber characteristics, dispersion compensation is mandatory in order to enhance the network performance. Dispersion compensation is done by inserting Dispersion Compensating Fiber (DCF) in the metro ring network. The position of DCF determines the type of compensation used in the network. The post and symmetrical configurations give the best results [8].

Table 2: Fiber parameters

Fiber	**Attenuation (dB/km)**	**Dispersion (ps/nm/km)**	**Dispersion Slope (ps/km-nm²)**	**Effective Core Area (μm²)**
SMF-28	0.25	16.75	0.075	80
DCF	0.2	-80	0.21	30
MetroCor	0.25	-5.6	0.12	50

MetroCor addresses the need for high-capacity low-cost transmission in metropolitan and medium distance networks. A non-zero dispersion shifted fiber optimized for use in high data rate wavelength division multiplexed (WDM) systems and MetroCor fiber operates in erbium-doped fiber amplifier (EDFA) window. The low negative dispersion substantially decreases operating costs of optical networks [9]. The total dispersion of MetroCor ranges from -10.0 to -1.0 ps/ (nm-km) over the ranges 1530 to 1605nm.

$$D(\lambda) = \left(\frac{D(1605nm) - D(1530nm)}{75} * (\lambda - 1605)\right) + D(1605nm)$$

D (λ) is the dispersion value at operating wavelength.

λ is the operating wavelength from 1530nm to 1605nm [9].

The attenuation specifications of MetroCor are:

$$\begin{aligned} Attenuation &\leq 0.5dB/km \quad && at\ 1310nm \\ &\leq 0.25dB/km && at1550nm \\ &\leq 0.25dB/km && at\ 1605nm \end{aligned}$$

Here we have used a fiber having dispersion value of -5.6ps/nm/km [10]. The DML directly modulates the 2.5Gbps non-return-to-zero signal (pattern length: 2^{31}-1). The modulated signal is sent to an in-line amplifier whose gain is optimized. The optical amplifier is operated in gain controlled mode having noise figure 4dB. This amplified signal is sent through the fiber along the metro core ring and metro access rings. The metro core link is composed of three 40km fiber spans, having access node consisting of WDM Add Drop multiplexer after every 40km fiber. The length of different fiber spans in each simulation is made constant i.e. only the fiber characteristics are varied [1]. In this configuration, several subscribers share the bandwidth by using packet format. The end station ES1 sends the data to end station ES3 by modulating the signal originating from the network node on channel 1 (193.1THz) over a virtual path [11].

3. RESULTS AND DISCUSSIONS

It is known that Q-factor is a measurement of signal quality. For the better performance of any system higher value of Q-factor is required. Since BER is inversely proportional to Q-factor, the system error decreases with an increase in Q-factor. Moreover, the signals with smaller bit rate travel more than the one with higher bit rate. So to reduce the BER we must try to increase the Q-factor [8].

Figure 2 shows the eye diagrams for externally modulated (EM) signals transmitted over standard single-mode fibers for “Ch1 from ES1 to ES3”. To evaluate the performance of metro WDM networks for different fibers, we transmitted two channels operating at the ITU-standardized wavelength with channel spacing of 100GHz. When externally modulated (EM) signals were transmitted over SMF-28, the Q-factor was measured to be 19.79 at 5dB value of gain.

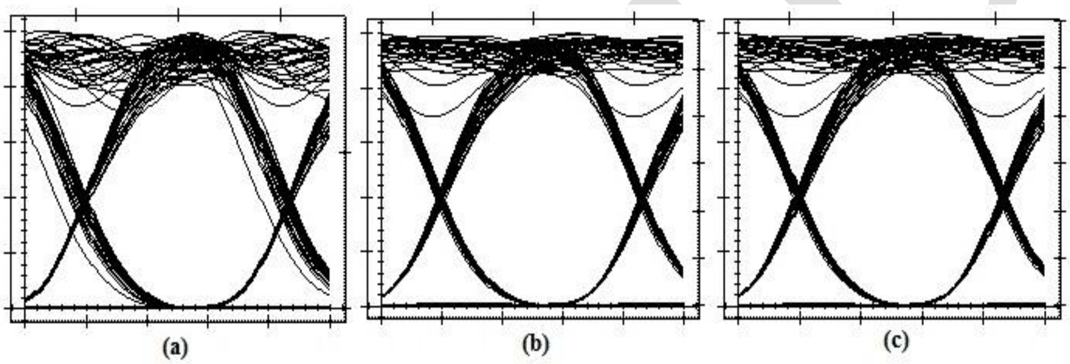

Figure 2: Eye pattern for externally modulated (EM) signals: (a) Uncompensated SMF-28; (b) Symmetrically compensated SMF-28; (c) Post compensated SMF-28.

However, the performance of the network degraded if gain is increased further. The reason for this degradation is the dispersion caused by SMF-28. Therefore, the network should be compensated for dispersion through post compensation and symmetrical compensation schemes by using dispersion compensated fiber (DCF). DCF has large negative dispersion value of -80ps/nm/km which compensates the positive dispersion (16ps/nm/km) of SMF-28 [8]. When the network is symmetrically compensated the Q-factor was measured to be 24.84 and for post compensation the Q-factor was measured to be 25.44. The increase in Q-factor shows that there is a decrease in bit error rate and higher network performance.

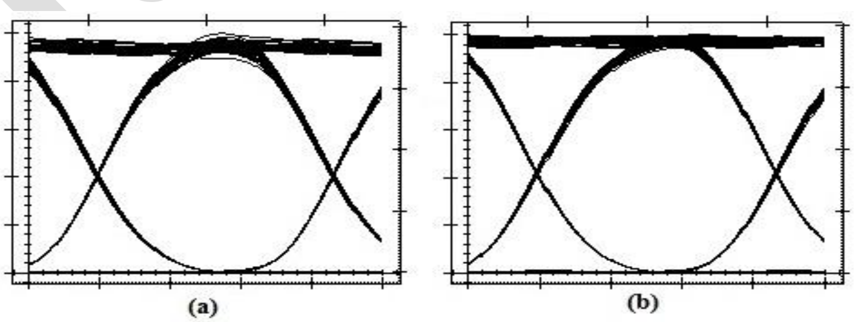

Figure 3: Eye pattern for directly modulated (DM) signals: (a) Uncompensated SMF-28; and (b) MetroCor Fiber.

In order to analyze the performance of SMF-28 and MetroCor using directly modulated lasers (DML), same channels were transmitted. We directly modulated the two channels using DML. Figure 3 shows the eye diagrams of directly modulated signals. The Q-factor was measured to be 52.06 for SMF-28 and 65.29 for MetroCor fiber. The difference between Q-factor values for externally modulated (EM) and directly modulated (DM) signals is to be 32dB.

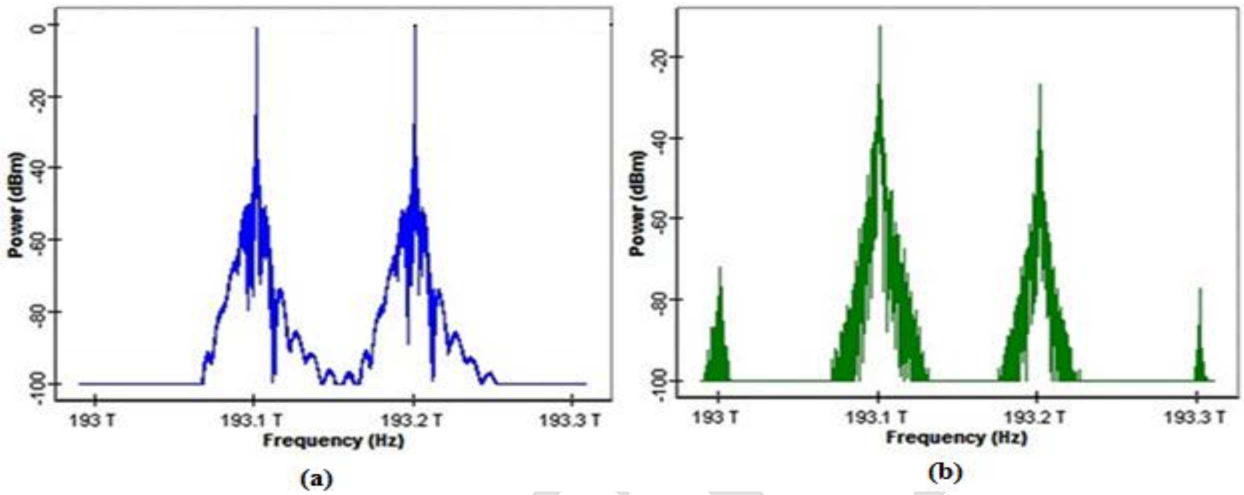

Figure 4: Optical Spectra of DM signals: (a) Input to ring from Network Node; and (b Output of ring to Network Node.

Figure 4 shows the optical spectrums of the signals after traversing the 120km of the MetroCor fiber. The channels are spaced at 100GHz and the signals generated by DML are centered at 193.1THz and 193.2THz. After the propagation through the MetroCor fiber, the signals get distorted due to fiber nonlinearities. The amount of distortion generated after traversing the 120km of MetroCor fiber link is less than that generated by SMF-28 link.

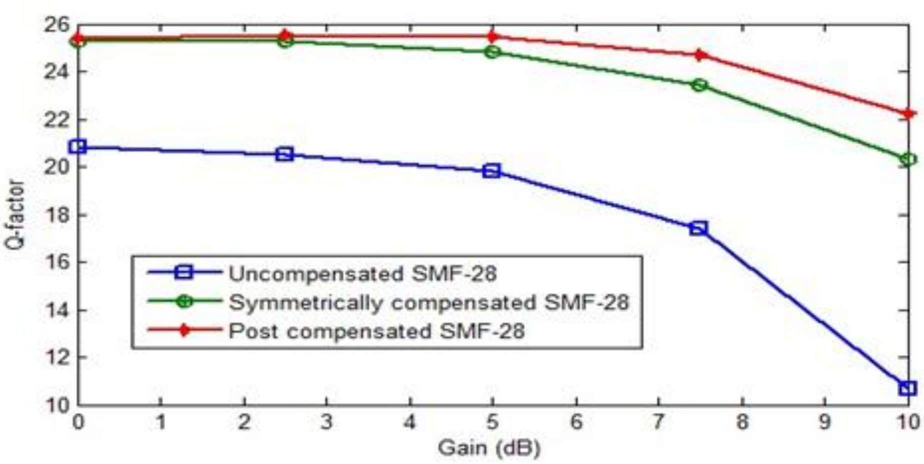

Figure 5: Comparison of externally modulated (EM) signals transmitted over SMF-28.

Figure 5 shows a comparison of externally modulated (EM) signals transmitted over SMF. When externally modulated signals are transmitted over SMF-28, dispersion is the main impairment that limits the unregenerate signals to reach long distances. The use of dispersion compensating fiber (DCF) is also cost prohibitive for metro systems and the placement of DCF becomes an issue in network topologies where different optical channels in a fiber originate from different nodes and hence see different amount of dispersion. In addition, increased loss of DCF would negatively impact system performance. Therefore, for such systems, there is always a preference to use a fiber whose dispersion is optimized for increased transmission distance with DMLs [6].

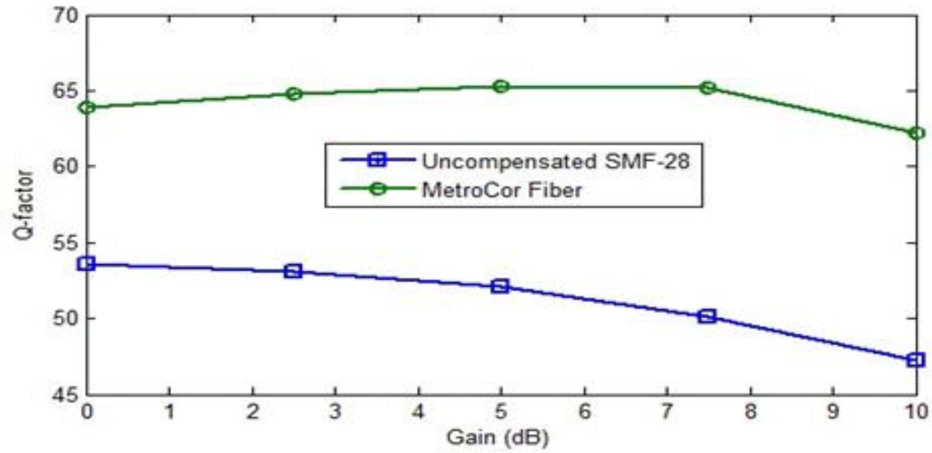

Figure 6: Comparison of directly modulated (DM) signals transmitted over SMF-28 and MetroCor Fiber.

The results in figure 6 confirm that the performance of the transmission system using direct modulation is far better than the system using external modulators. Although external modulation schemes have better chirp characteristics but these are less preferred in metro networks because of their higher costs. This is the reason that directly modulated lasers are used in metro networks as these are highly cost-sensitive.

Furthermore, the optimum power for the metro WDM ring network is evaluated. For externally modulated network, the performance of the network increases with increase in the power level at the network node (NN). The best possible value of Q-factor is achieved for a power levels between 4dBm and 5dBm. After this power level the network performance degrades due to higher of distortions.

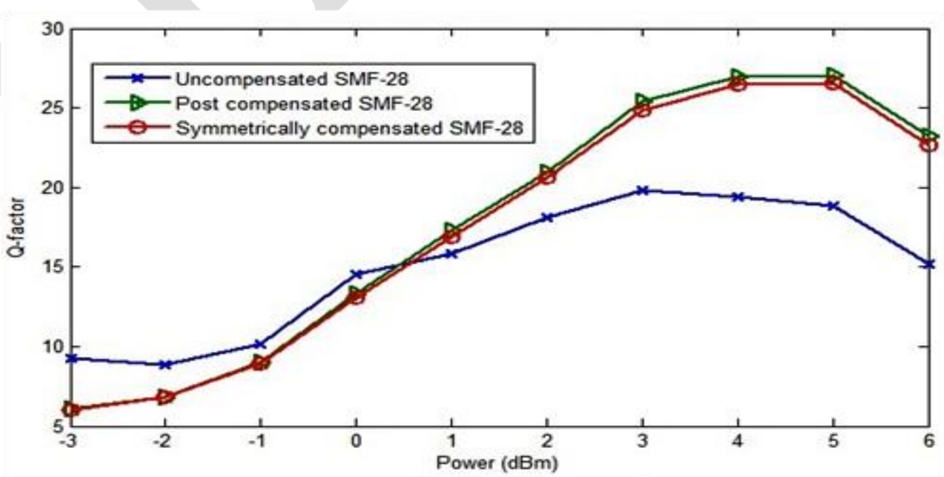

Figure 6: Power versus Q-factor for externally modulated signals transmitted over SMF-28.

When directly modulated lasers are used as transmitter sources, the optimum power level obtained is 0dBm. The optimum value of power is launched from the network node because it is expected from this value that it will not introduce penalties due to fiber nonlinearities, mainly due to wide channel spacing and low bit rate [3].

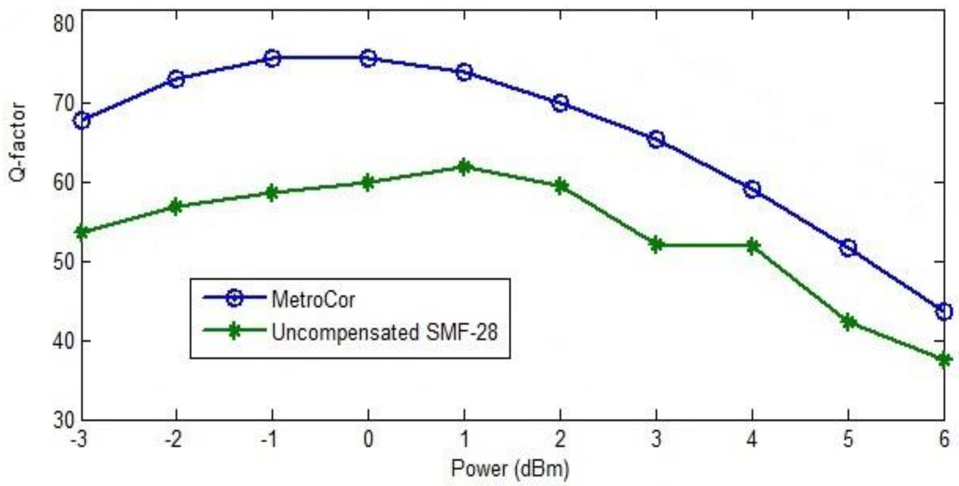

Figure 7: Power versus Q-factor for directly modulated signals transmitted over SMF-28 and MetroCor fibers

Figures 5 and 6 depict the optimum value of gain to be 5dB. After 5dB, if the gain is increased the value of Q-factor decreases. Hence, the optimum value of gain of an in-line amplifier is 5dB. Also, when direct modulation is used for both SMF and MetroCor, the MetroCor is having minimum bit error rate. The negative dispersion of transmission fiber compressed the broadened optical pulse by the positive chirp of DML. When only SMF-28 was used without dispersion compensation the value of bit error rate was quite high. The above results show that the performance of MetroCor is even better than that of dispersion compensated SMF-28 link. This is because high losses of the DCF modules degraded the optical signal-to-noise ratio. Thus, the MetroCor is well-suited for use in cost-sensitive regional metro networks using DMLs without dispersion compensation. However, the use of MetroCor is suitable for a new deployment of the optical system rather than to upgrade or change the installed base of metro fiber links [12].

4. CONCLUSION

We have demonstrated the transport performance of externally modulated (EM) as well as directly modulated (DM) 2.5Gbps signals over 120km of metro WDM ring network. For externally modulated signals dispersion compensation is used to enhance the network performance in terms of Q-factor. The results confirm that externally modulated signals transmitted over post compensated SMF-28 ring gives lower bit error rate. The value of Q-factor obtained was 25.44dB for post compensated fiber network. The improvement in the performance is seen with the use of directly modulated lasers (DML). The Q-factor measured for directly modulated signals transmitted over SMF is 52.06. Further increase in Q-factor (65.29) is observed when directly modulated signals are transmitted over MetroCor fiber. The directly modulated lasers are highly cost-effective solution because there is no requirement for external drivers to operate them as in external modulators. Hence, the DML using MetroCor fiber gives the best results for WDM ring network. Also, the optimum performance of the network is achieved for EDFA gain of 5dB and power level of 4dBm and 0dBm for externally modulated transmitter and directly modulated transmitter respectively.

5. REFERENCES

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