# 640 Gbps dispersion-managed WDM soliton transmission using crosstalk reduction techniques

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An eight channel dispersion-managed soliton transmission is designed and evaluated. Each channel carries 80 Gbps pseudo-random bit signal. To reduce the crosstalk, polarization interleaved and a proposed modified polarization interleaved techniques are used. Key parameters, like; signal power, average dispersion and number of sections of dispersive fiber within one amplifier spacing are optimized. The performance of the system is monitored by Q-factor, OSNR, noise figure and optical eye-diagram. The proposed modified polarization interleaved system yields better results.

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## 1. Introduction

The demand for the ultra large capacity (~ terabits per second) transmission systems is forcing the researchers to develop new techniques. Dispersion-managed soliton (DMS) systems have capability to fulfill such demand. DMS can provide high speed to optical fiber communication systems over long distances [2]. Dispersion-management plays an important role reducing timing jitter caused by amplifier noise (Gordon-Haus effect) with out sacrificing SNR [3-4]. Dispersion-management has been proved to be the best way for upgrading the installed WDM optical systems at 10 and 40 Gbps [5]. In conventional dispersion-managed systems, it is difficult to achieve bit rates higher than 40 Gbps per channel, because of large breathing and power enhancement factors of these systems [6-7]. To overcome this issue, map period of a dispersion-managed system should be much shorter than the amplifier spacing. In such systems pulse propagates with a strongly reduced breathing compared with the conventional dispersion-managed systems. However, high data-rate dense dispersion-managed soliton systems are adversely affected by nonlinear interaction and Gordon-Haus timing jitter [8-9].

In this paper a 8 channel 80 Gbps dispersion managed soliton system is designed. The polarization interleaved and modified polarization interleaved techniques are used to reduce the interchannel crosstalk. The performance of the system is monitored by Q-factor, OSNR, noise figure and optical eye-diagram.

## 2. Theory

A necessary condition for the solitons to survive is that the dispersion length $L_D$ should be more than the amplifier length $L_{A.}$ At high bit-rates is difficult to satisfy this condition because third-order dispersion (TOD) comes into play for such short pulses [9]. It can be resolved successfully with the proper choice of dispersion management design. Dispersion-management lowers the average group-velocity dispersion (GVD) of entire link while keeping the GVD of each section high enough to make TOD negligible [10].

On decreasing the channel spacing in WDM systems, the leakage from adjacent channels is enhanced. In such systems, the amplitude of the incident signal on $n^{th}$ detector (after demultiplexer) is given by,

$$E_n = S_n + \sqrt{\gamma}\left[S_{n+1} + S_{n-1} + S_{n+2} + S_{n-2} + ........\right] \quad (1)$$

where $S_n$ is the amplitude of the signal in the $n^{th}$ channel and $\gamma$ is the fraction of the optical power that leaks from the adjacent channels. The electrical signal of $n^{th}$ detector is given as,

$$i_n(t) \approx E_n.E_n^* = |S_n|^2 + \sqrt{\gamma}\left[S_n.S_{n+1}^* + S_n.S_{n-1}^* + c.c.\right] + \gamma\left[|S_{n+1}|^2 + |S_{n-1}|^2\right] \quad (2)$$

The second term in equation (2) is the interference term that can be eliminated by means of polarization interleaving, i.e., separating the odd and even channels and them orthogonally []. The third term is due to power leakage from adjacent channels. This still remains but can be minimized by using time interleaved signals in RZ format. The signals in the odd channels are delayed by a half-bit period relative to the signals in the even channels so that the peaks of all signal channels coincides with the valley of the their adjacent channels. This leads to significant reduction in interference from the adjacent channels near sampling point. Unfortunately, such interchannel synchronization is not practical. For the completely asynchronous systems, there is always a chance that the peak of the signal channel and its adjacent channels coincide in time. This is the worst-case scenario and should be avoided [11-17].

In case of asynchronous system the ACI can be reduced by the process of dispersion interleaving []. This method utilizes the residual fiber dispersion to mitigate the interference from the adjacent systems.

We have used polarization interleaving method of reduction of crosstalk in dispersion managed soliton transmission. Further we have proposed a modification of PI system, known as modified PI. Results prove that modified PI system yields better results.

## 3. Experimental setup

The schematic diagram of the system using polarization interleaving method of crosstalk reduction is shown in Fig. 1. In transmitter section, eight WDM-channels are multiplexed with channel spacing of 100 GHz and frequencies are 193.10, 193.20, 193.30, 193.40, 193.50, 193.60, 193.70 and 193.80 THz respectively. An in-line optical filter with a Gaussian shaped band-pass characteristic is used to reduce the effect of timing jitter. The data rate for each channel is taken as 20 Gbps. A pseudorandom bit sequence (PRBS) of length $2^7$-1 is assumed for all eight channels. The eight channels are divided in two sets of odd ($n_1$, $n_3$, $n_5$, $n_7$) and even ($n_2$, $n_4$, $n_6$, $n_8$) channels.

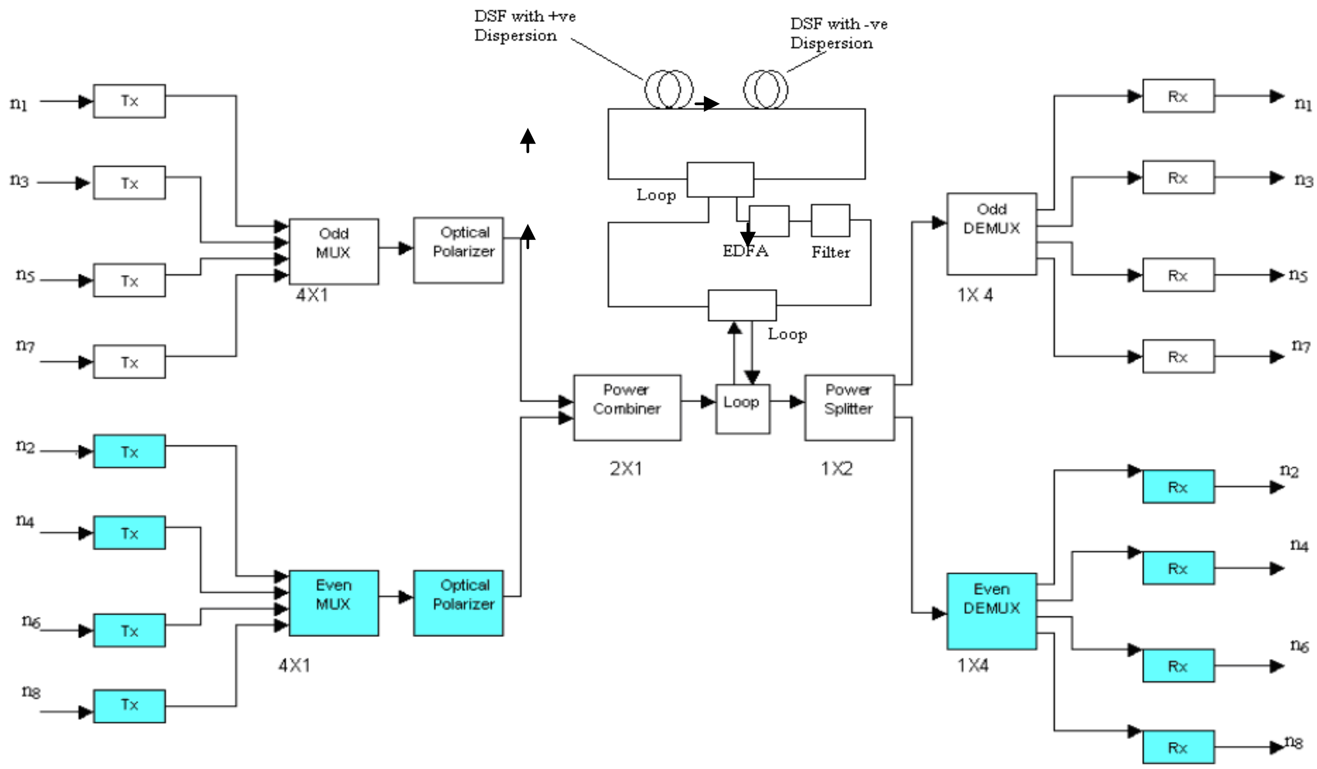



*Fig. 1. Schematic diagram of 80×8 Gbps dispersion-managed soliton system using polarization interleaved system.*

The distance between transmitter and receiver is varied by varying the number of loops. Each loop contains 40.4 km length of fiber. In each loop propagation losses are compensated by an EDFA. Dispersion is compensated using two types of dispersion shifted fibers having positive and negative dispersions. The dispersion map is shown in Fig. 2. Four periods are taken in dispersion map. Each period consists of first 2.5 km DSF with dispersion coefficient D = + 0.50 ps/nm/km, 5.1 km DSF with D = -0.47 ps/nm/km and finally 2.5 km DSF with D = 0.50 ps/nm/km. Thus average dispersion is 0.010 ps/nm/km.

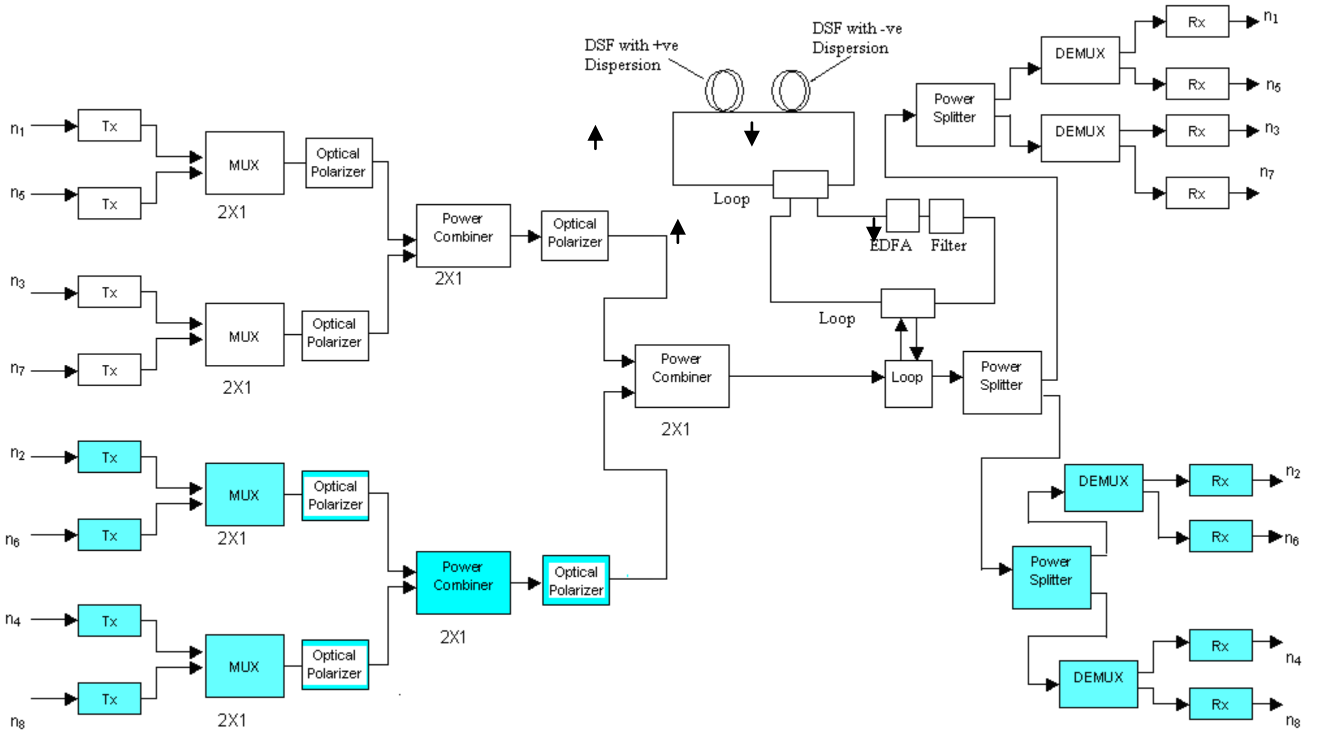



*Fig. 2. Schematic diagram of 80×8 dispersion-managed soliton system using modified polarization interleaved system.*

In modified polarization interleaving system, as shown in Fig. 3, the splitting of channels has been done in two steps instead of one. That is first 8 channels are splitted in odd ($n_1$, $n_3$, $n_5$, $n_7$) & even ($n_2$, $n_4$, $n_6$, $n_8$) channels. The odd & even channels are again splitted into odd & even channels i.e., ($n_1$, $n_5$) ($n_3$, $n_7$) ($n_2$, $n_6$) ($n_4$, $n_8$). These channels are then multiplexed at first stage. At second stage channels ($n_1$, $n_3$, $n_5$, $n_7$) & ($n_2$, $n_4$, $n_6$, $n_8$) are multiplexed.

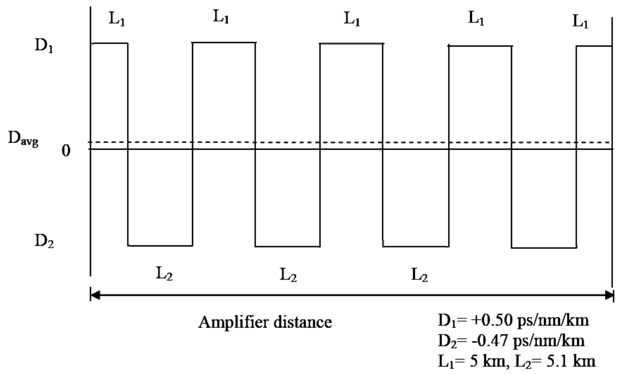



*Fig. 3. Dispersion map for 80×8 Gbps dense dispersion-managed soliton system.*

## 4. Results

The performance of the system is evaluated by measuring the signal power, OSNR, noise figure and Q factor at the output of each channel, the measured values and results are shown in Table 1.

The Q factor for different values of distance for both systems is measured and the result is shown in Fig. 4. The performance of the system is acceptable if Q is more than 6 i.e., BER is less than $10^{-9}$. The optical eye-diagrams for different transmission distances are shown in Table 2.

Results show that modified polarization interleaved system is better. A distance of almost 2600 km can be achieved by using it, while in case of simple polarization interleaved system, a distance of only 2150 km can be achieved.

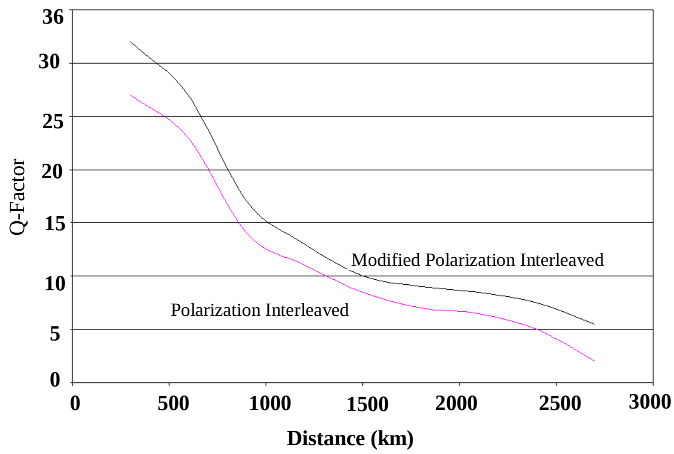



*Fig. 4. Q-factor versus transmission distance for polarization interleaved and modified polarization interleaved system.*

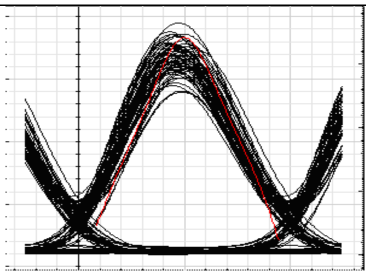
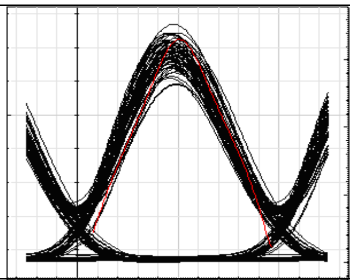
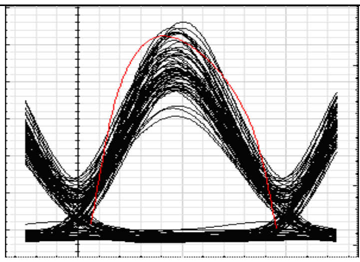
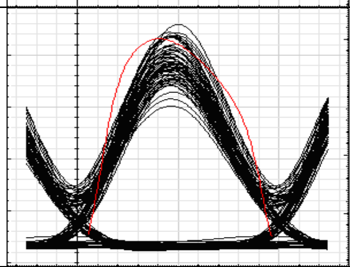
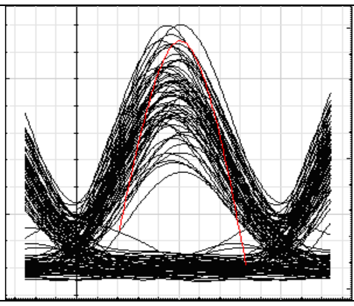
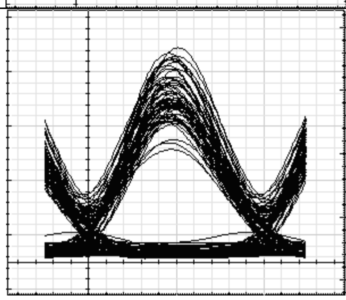
*Table 1. Signal power, OSNR and noise power at 193.40 THz.*

| Parameters | Polarization Interleaved | Modified Polarization Interleaved |
|---|---|---|
| OSNR (dB) at 80Gb/s | 15.89 | 21.95 |
| Noise Figure (dB) at 80Gb/s | -3.17 | -2.04 |

## 5. Conclusions

The performances of 80×8 Gbps densely dispersion-managed soliton systems transmission using polarization interleaved and a proposed modified polarization interleaved systems are evaluated. The modified polarization interleaved systems shows good performance till 2600 km, while the conventional one is acceptable till 2150 km. The OSNR, noise figure, Q-factor and optical eye-diagrams are obtained for 100 GHz channel spacing at 80 Gbps bit rate. Significant improvement in performance of the proposed modified polarization interleaved system and reduction in crosstalk, as compared to conventional polarization interleaved system, is observed.

*Table 2. Optical eye-diagrams 193.40 THz for different transmission lengths.*

| Distance (km) ↓ | Polarization Interleaved | Modified Polarization Interleaved |
|---|---|---|
| 1000 |  |  |
| 2150 |  |  |
| 2700 |  |  |

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