Performance Analysis of Dispersion Compensation in WDM Optical Communication Systems

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Abstract: ***The rapid growth in demand for high-capacity telecommunication links, and the speed limitation of single-wavelength links, has resulted in an extraordinary increase in the use of Wavelength-Division Multiplexing (WDM) in advanced lightwave networks. WDM is a technology which multiplexes a number of carrier signals onto a single optical fiber using different wavelengths of light. Hence the capacity of optical transmission systems can be increased using WDM. Dispersion is a major limiting factors in high speed optical WDM network which causes pulse broadening and crosstalk in the system. Therefore it is necessary to compensate dispersion. Dispersion Compensating Fiber (DCF), Fiber Bragg Grating (FBG) and Optical Phase Conjugator (OPC) and its various combinations are used for dispersion compensation in WDM system. Performance analysis of a conventional WDM system with various dispersion compensation schemes and their comparison on the basis of Q Factor is done using optsim software in sample mode.***

Keywords: WDM, DCF, FBG, OPC.

1. Introduction

The rapid growth in demand for high-capacity telecommunication links, and the speed limitation of single-wavelength links, has resulted in an extraordinary increase in the use of Wavelength Division Multiplexing (WDM) in advanced lightwave networks. WDM is a method of transmitting data from different sources over the same fiber optic link at the same time whereby each data channel is carried on its own unique wavelength. WDM technology can maximize the capacity of the existing fiber optic network without adding additional fibers. In WDM each communication channel is allocated to a different frequency and multiplexed onto a single fiber. At the destination wavelengths are spatially separated to different receiver locations. Hence the capacity of optical transmission systems can be increased using WDM.

Dispersion and nonlinearities are the major limiting factors in high speed optical WDM network. Dispersion causes distortion in both analog and digital transmission. It causes broadening of the input optical pulse as it travels through the fiber. This is due to the difference in propagation speed of various frequency components contained in the signal. So they reach the destination at different times causing indistinguishable pulses at the receiver output leading to Inter Symbol Interference (ISI).

2. Various Dispersion Compensation Schemes in WDM

Inorder to increase the efficiency of the network, dispersion and other nonlinear effecs should be supressed. To improve the overall system performance and reduce as much as possible the transmission performance influenced by the dispersion, several dispersion compensation technologies were proposed. Dispersion compensation is often employed between two fiber amplifiers in fiber optical transmission link. Dispersion Compensating Fiber (pre, post and symmetrical), Fiber Bragg Grating (FBG) and Optical Phase Conjugator (OPC) and its various combinations are mainly used for dispersion compensation in WDM networks. DCF has negative dispersion and can compensate positive dispersion of transmission fiber. The main advantage of FBG is that it can reflect a predetermined narrow or broad range of wavelengths of light incident on grating while passing all other. wavelengths of light. The common feature of OPC is to reverse the propagation direction and phase of each plane wave component of an arbitrary incoming beam of light. The various combinations of DCF, FBG and OPC can also be used for dispersion compensation. The performance analysis will be in terms of eye diagram, Q Factor and simulated BER.

3. System Modelling

3.1 Simulation of WDM System to Analyze Dispersion

Block diagram of WDM system to analyze dispersion is shown in Figure 1. It consists of four transmitters, each of which consists of a pseudo random generator, NRZ modulator, continuous wave laser and a Mach-Zehnder modulator. The transmission channel is an optical fiber. The receiver section consists of a Lorentzian filter, PIN detector, LP Bessel filter and a scope.

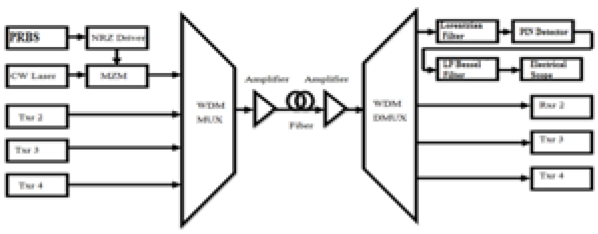

Figure 1: Block diagram of WDM system to analyze dispersion

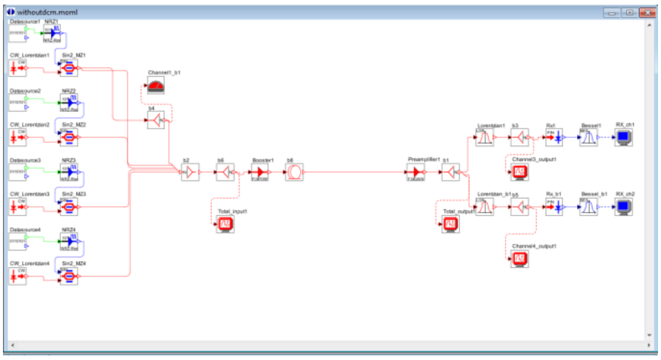

Figure 2: Simulation layout of WDM system to analyze dispersion.

Simulation layout of WDM system to analyze dispersion is shown in Figure 2. The PRBS represents the information or data that is to be transmitted. NRZ driver encode the data from the pseudo-random bit sequence generator using the non-return zero encoding technique. The transmission rate used is 2.5 Gbps. The frequency of the first transmitter is 193.41 THz and wavelength is 1550 nm. The frequency spacing between the channel is 10 GHz. The last section of each transmitter is a Mach-Zehnder modulator. The output of each Mach-Zehnder modulator will be fed to a WDM multiplexer (4x1).

Different wavelengths of light from different transmitters are combined together by the WDM multiplexer. The output of the MUX is fed to a single mode fiber via a booster. The length of the single mode fiber used for the analysis is 120 km. The Single Mode Fiber (SMF) used has a dispersion of 16 ps/nm/km and the loss is 0.2 dB/km. The output of the SMF is then preamplified. The amplified signal is fed into a WDM demultiplexer which separates it into corresponding channel and is detected at the receiver. Each receiver consists of a Lorentzian filter, PIN detector, low pass Bessel filter and an electrical scope. In each receiver the optical filter i.e; the Lorentzian filter separate each WDM channel from common optical signal. The frequency of the Lorentzian filter is set accordingly to the corresponding channel to be detected. The output of the filter is fed to a PIN detector which converts the optical signal into corresponding electrical signal. The frequency of the PIN detector is also to be adjusted accordingly to the corresponding channel. The output of the detector is filtered by a low pass Bessel filter. Bessel LPF is used with cut-off frequency of 0.75 x bit rate of the signal. An electrical scope is used to view the eye diagram.

3.2 Dispersion Compensation in WDM using DCF.

To improve the overall system performance and reduce as much as possible the transmission performance influenced by the dispersion, several dispersion compensation technologies were proposed. In fiber optical transmission system, Dispersion Compensation Modules (DCM) (also called Dispersion Compensation Units - DCU) can be used for dispersion compensation. These modules can provide a fixed or tunable amount of compensating dispersion value. A dispersion compensating module is often placed between two fiber amplifiers in fiber optical transmission link, for example, Erbium-Doped Fiber Amplifiers (EDFA). Dispersion Compensating Fiber (DCF), Fiber Bragg Grating (FBG) and Optical Phase Conjugator (OPC) can be used as dispersion compensation modules.

Based on the position of DCF, the compensation schemes can be pre-compensation, post compensation and symmetrical compensation. The simulation diagram for pre, post and symmetrical compensation is shown in the Figure 3, Figure 4, Figure 5 respectively. The NRZ driver encodes the data from the pseudo-random bit sequence generator using the non-return zero encoding technique. The transmission rates used are 2.5 Gbps, 5 Gbps and 7.5 Gbps. The frequency of the first transmitter is 193.41 THz and wavelength is 1550 nm. The frequency spacing between the channels is 10 GHz. The last section of each transmitter is a Mach-Zehnder modulator. The output of each Mach-Zehnder modulator will be fed to a WDM multiplexer (4x1). The DCF has a length of 24 km and a large negative dispersion of -80 ps/nm/km. The SMF has a length of 120 and a dispersion of 16 ps/nm/km. The positive dispersion of the transmitting fiber is cancelled by the negative dispersion of DCF.

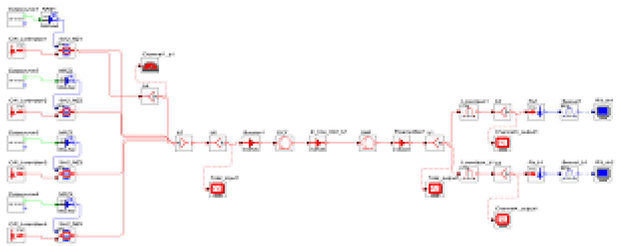

Figure 3: Simulation layout for pre compensation.

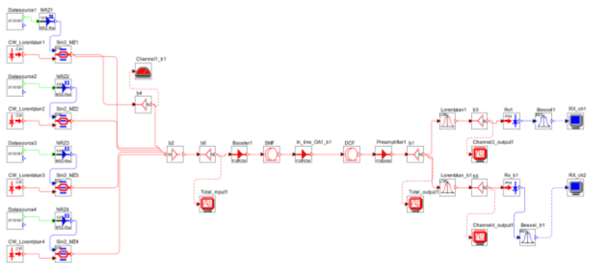

Figure 4: Simulation layout for post compensation.

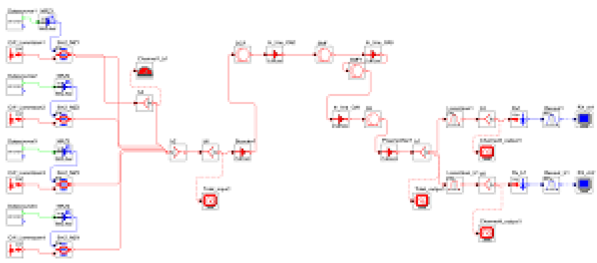

Figure 5: Simulation layout for symmetrical compensation.

3.3 Dispersion Compensation in WDM using FBG and OPC.

Simulation layout of dispersion compensation using FBG and OPC is shown in the Figure 6 and Figure 7 respectively.

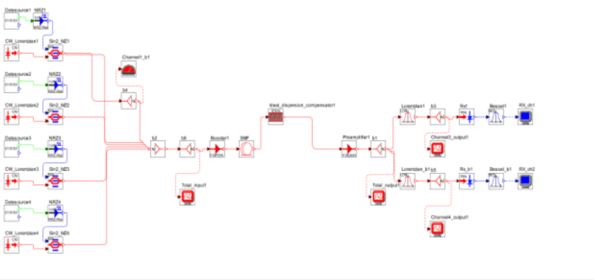

Figure 6: Simulation layout for dispersion compensation using FBG.

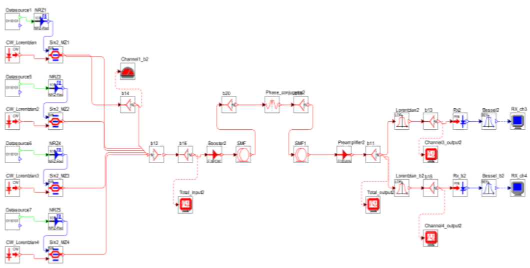

Figure 7: Simulation layout for dispersion compensation using OPC.

The NRZ driver encodes the data from the pseudo random bit sequence generator using the non-return zero encoding technique. The transmission rates used are 2.5 Gbps, 5 Gbps and 7.5 Gbps. The frequency of the first transmitter is 193.41 THz and wavelength is 1550 nm. The frequency spacing between the channels is 10 GHz. The last section of each transmitter is a Mach-Zehnder modulator. The output of each Mach-Zehnder modulator will be fed to a WDM multiplexer (4x1). The transmission link consists of FBG and OPC respectively for Figure 6 and Figure 7. The compensated signal can be obtained at the output.

3.4 Dispersion Compensation in WDM using Combined FBG-DCF, FBG-OPC, OPC-DCF.

Simulation layout of dispersion compensation using combined FBG-DCF, FBG-OPC and OPC-DCF is shown in the Figure 8, Figure 9 and Figure 10 respectively.

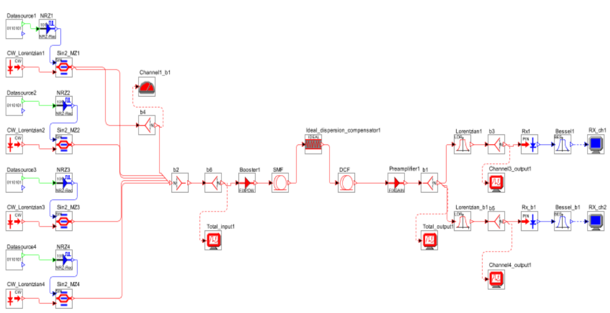

Figure 8: Simulation layout for dispersion compensation using combined FBG-DCF.

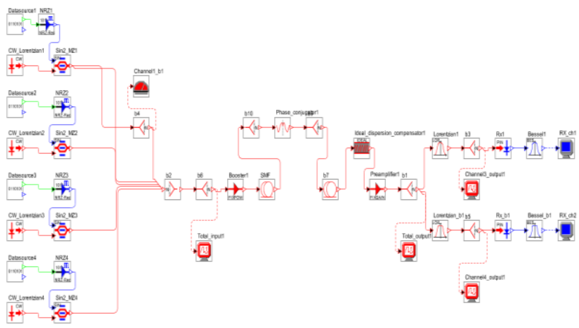

Figure 9: Simulation layout for dispersion compensation using combined FBG-OPC

The NRZ driver encodes the data from the pseudo-random bit sequence generator using the non-return zero encoding technique. The transmission rates used are 2.5 Gbps, 5 Gbps and 7.5 Gbps. The frequency of the first transmitter is 193.41 THz and wavelength is 1550 nm. The frequency spacing between the channels is 10 GHz. The last section of each transmitter is a Mach-Zehnder modulator. The output of each Mach-Zehnder modulator will be fed to a WDM multiplexer (4x1).

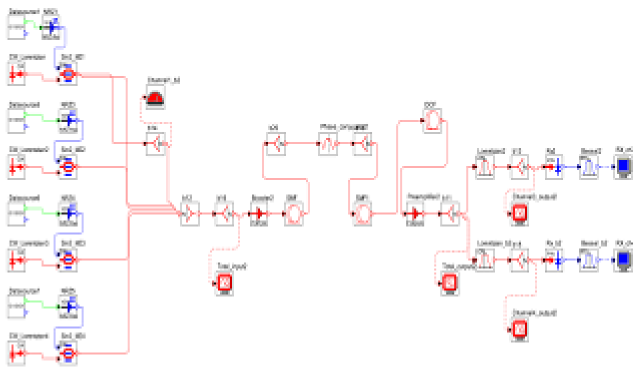

Figure 10: Simulation layout for dispersion compensation using combined OPC-DCF.

4. Results and Discussions

4.1 Eye Diagrams of Various Compensation Schemes.

The eye diagrams for various compensations are given in the Figures below.

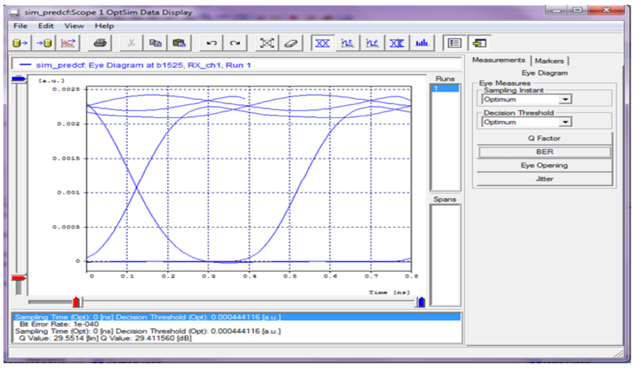

Figure 11: Eye diagram for pre compensation.

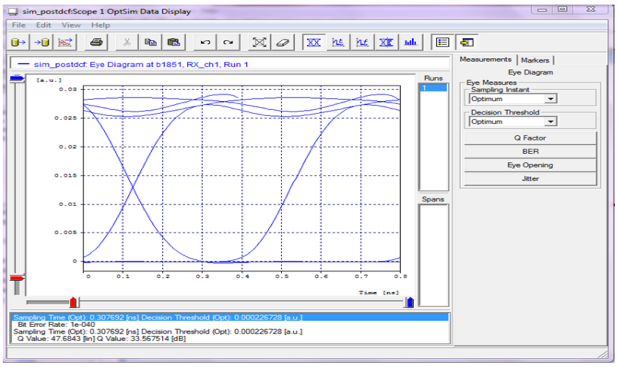

Figure 12: Eye diagram for post compensation.

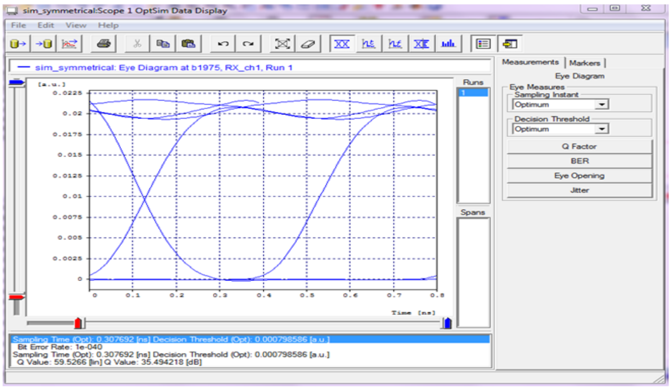

Figure 13: Eye diagram for symmetrical compensation.

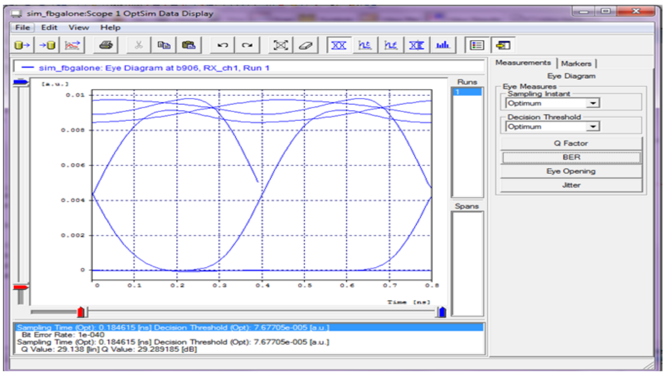

Figure 14: Eye diagram for dispersion compensation using FBG.

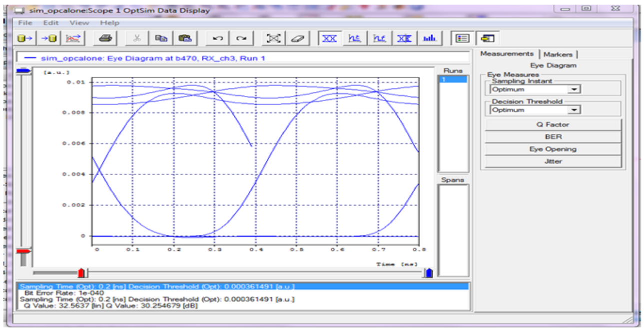

Figure 16: Eye diagram for dispersion compensation using OPC.

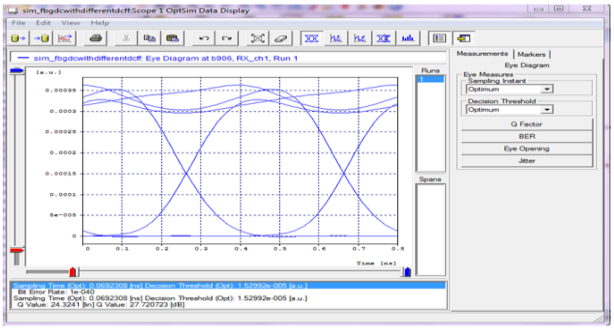

Figure 17: Eye diagram for dispersion compensation using FBG-DCF.

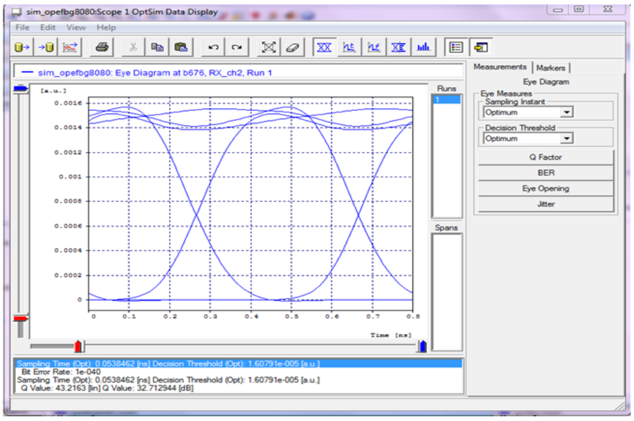

Figure 17: Eye diagram for dispersion compensation using FBG-OPC.

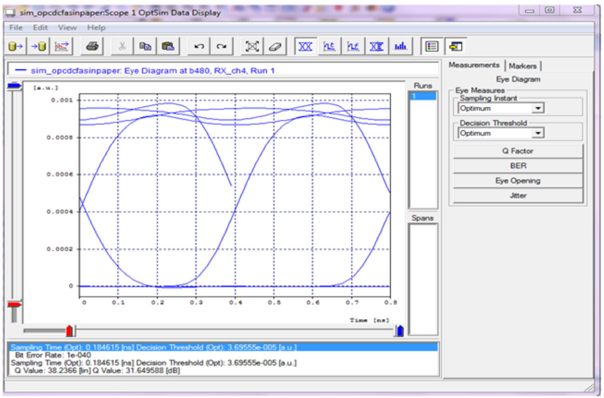

Figure 17: Eye diagram for dispersion compensation using OPC-DCF.

4.2 Graphical Comparison of Various Compensation Schemes.

The comparison of various bit rates on the basis Q Factor and BER for pre, post and symmetrical, FBG and OPC and combined compensation schemes are given in the Figure 17, Figure 18 and Figure. 19 respectively.

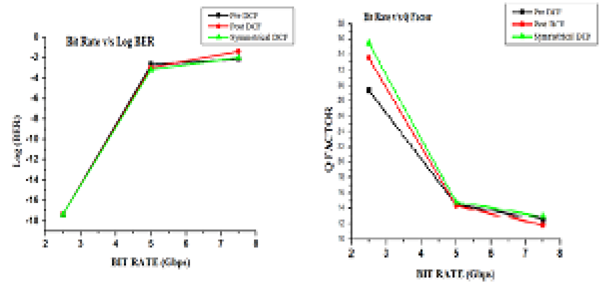

Figure 17: Comparison of pre, post and symmetrical DCF.

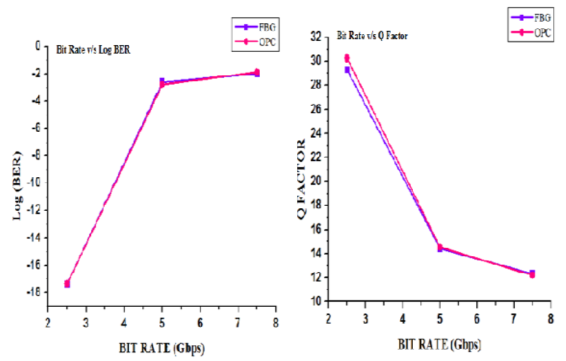

Figure 18: Comparison of FBG and OPC.

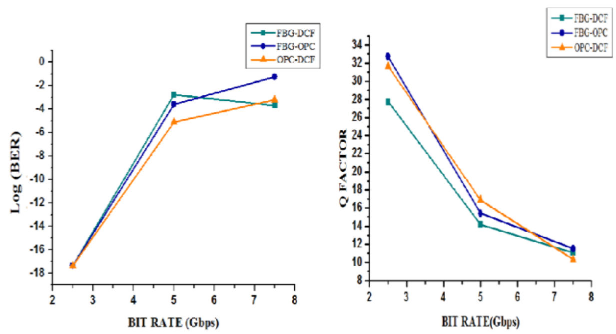

Figure 19: Comparison of combined FBG-DCF, FBG-OPC and OPC-DCF.

From the comparison of dispersion compensation using pre, post and symmetrical DCF, symmetrical DCF has better Q value and hence it provides better com pensation. Comparison of dispersion compensation using FBG and OPC, OPC provides better compensation and from the comparison of combined FBG-DCF, FBG-OPC and OPC-DCF, FBG-OPC provides better Q value and hence provides better compensation.

From the overall comparison from Table.1, on the basis of Q Factor, Symmetrical DCF provides better Q and hence it is the best compensation scheme for disperion.

Table 1: Comparison of Q Factor and log (BER) of various dispersion compensation schemes at 2.5 Gbps

Comparison of various compensation schemes	Q Factor
Pre DCF	29.411560
Post DCF	33.567514
Symmetrical DCF	35.494218
FBG	29.289185
OPC	30.254679
FBG-DCF	27.720723
FBG-OPC	32.712944
OPC-DCF	31.649588

5. Conclusion

Dispersion causes distortion, so it is necessary to avoid dispersion. From the overall comparison of various dispersion compensation schemes on the basis of their Q Factor, Symmetrical DCF provides better Q and hence it is the best compensation scheme for disperion.

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