Design and Simulation of Long Haul, High Capacity Dense WDM System in the Presence of Nonlinear Effects

Soukhya G Bhat*, Shreehitha M U**, Shwetha M*** and P Venkatrao****
*-***Department of Telecommunication Engineering, BNMIT, Bengaluru-70.
soukhyabht95@gmail.com
****Department of Electronics & Communication Engineering, BNMIT, Bengaluru-70.
saivenkat1996@gmail.com

Abstract: Long Haul optical links are realized by launching higher powers in to the optical fiber. As the launch powers increase, the nonlinear effects become significant and affect the system performance. On the other hand, high capacity optical links are realized by transmitting several wavelengths simultaneously through the fiber. In this paper, simulation analysis of a dense wavelength division multiplexing system with 16 channels for a data rate of 10Gbps and 20Gbps is presented. The performance of DWDM system has been compared for carrier-suppressed, duo binary and modified duo binary return-to-zero modulation techniques. Pre, post, and symmetrical dispersion compensation techniques have been investigated to optimize the system performance. From the simulation results, it is found that MDRZ scheme is optimum choice for a long distance optical link at high power. To mitigate the effects of nonlinearities the designed system is tested under perfect dispersion compensation and also with some residual dispersion in the transmission link.

Keywords: Carrier Suppressed Return to Zero (CSRZ), Dense Wavelength Division Multiplexing (DWDM), Dispersion Compensating Fibers (DCF), Duobinary Return Zero (DRZ), Modified Duobinary Return to Zero (MDRZ).

Introduction

There is a huge demand for bandwidth in this internet age. It is more economical to transmit data at high rates over a single fiber. Hence multiplexing technique is preferred. In order to utilize full bandwidth of the fiber and to achieve high efficiency the signal has to be multiplexed. Using Dense WDM, several independent information carrying wavelengths or channels can be multiplexed and transmitted over a single optical fiber. This technique enables bidirectional communication over one strand of fiber, as well as multiplication of capacity. The achievable data rates are strictly limited by fiber impairments such as nonlinearity and dispersion. To achieve long range transmission these constraints must be managed. Different technologies have been proposed to achieve dispersion. Among many techniques available DCF is found to be efficient and reliable which has been considered. At low powers fiber acts as linear medium, as the power increases fiber becomes nonlinear medium due to the dependency of refractive index on wavelength. In case of DWDM, non-linear effects can become important even at moderate powers and bitrates.

Hayee and Willner [1] have demonstrated that in 10 to 40Gbps dispersion regulated systems (Alternating single-mode fiber with dispersion compensating fiber), NRZ is more adversely affected by nonlinearities, whereas RZ is more affected by dispersion. It was found that for 10 and 20Gbps systems RZ modulation format performs better. Anes Hodzic et al. [2] showed that CSRZ is predominant in both wavelength division multiplexing (WDM) and single-channel 40Gbps systems over standard single-mode fibers (SSMF) because of its high tolerance to Kerr nonlinearities and chromatic dispersion with respect to signal degradation. K. S. Cheng and Jan Conradi [3] proposed that at 40Gbps by altering the phase of adjacent bits interaction between the pulses can be reduced by using either a modified-duo binary return-to-zero (MDRZ) modulation format or RZ with alternating phase. Takeshi Hoshida et al. [4] showed that Nonreturn-to-zero (NRZ) format is capable for transmission of shorter distances because of its spectral compactness and its simple design regardless of fiber type. With fibers having greater chromatic dispersion Carrier-suppressed return-to-zero (CSRZ) format showed better performance as it is more resistant to the self-phase modulation. However, performance of CSRZ system is restricted due to the effect of four-wave mixing. Anu Sheetal et al. [5] carried out a simulation of 40Gbps long haul i.e.500 to 2000 km Dense WDM system with ultra-high capacity upto 1.28Tbps. The simulative results showed that MDRZ system with symmetrical dispersion compensation scheme is the best choice for long distance optical link.

Bhumit P. Patel and Rohit B. Patel [6] analyzed performance of WDM system by varying input power from -15dBm to 10dBm for a fixed transmission distance of 300 km (considered only SMF length) for all modulation formats with 100 GHz and 200 GHZ spacing between each channel and also compare performance for 100 GHz and 200 GHz spacing for each modulation formats. P. Venkat Rao and S.B. Bhanu Prashanth [7] demonstrated the influence of SPM on the single channel optical link. Results show that Dispersion present in optical link and SPM compensate each other. Impact of launch power and dispersion on the system performance is investigated. It is found that by optimizing the power and dispersion residue the system performance i.e. transmission distance and data rates can be improved. In section 2, three different modulation formats are explained and section 3 describes the system modelling and simulation setup. Section 4 gives the result and comparison of modulation formats and compensation schemes. Conclusions are given in section 5.

Modulation Formats

Carrier Suppressed Return to Zero

Fig. 1 shows the block diagram of the CSRZ transmitter. CSRZ signal was created by passing the NRZ pulse to the MZ modulator which is driven by Continuous Wave (CW) Laser. This signal is given to the phase modulator that is driven by sine wave generator. Thus a phase shift of π is introduced between the adjacent bits and the carrier frequency's central peak is concealed.

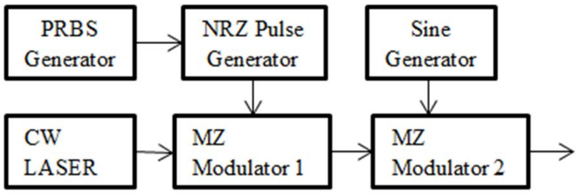


Figure1. Block diagram of CSRZ Modulation Format

Duobinary Return to Zero

Fig. 2 shows the block diagram of the duobinary transmitter. NRZ duo binary signal is created and using this NRZ signal along with precoder and duobinary pulse generator Duobinary Return to Zero signal is generated. Duobinary generator is given to the MZM-1 that is concatenated with the second modulator driven by sinusoidal signal with the frequency equal to bit rate. This modulation format is more resilient to dispersion and is also reasonably simple to implement.

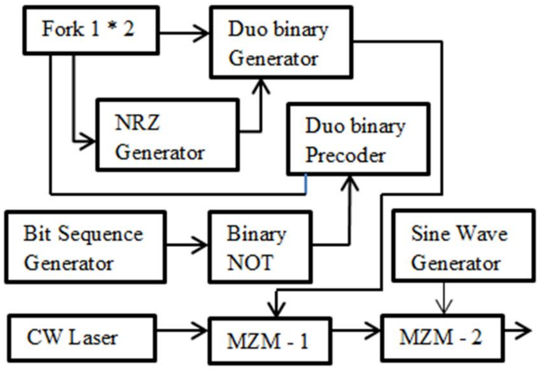


Figure2. Block diagram of DRZ Modulation Format

Modified Duobinary Return to Zero

Fig. 3 shows the block diagram of the MDRZ transmitter. The delay and add circuit in the MDRZ signal generation system is reintegrated by a delay and subtract circuit in the DRZ system. In MDRZ modulation format, MZM-1 is driven by the NRZ duobinary signal which is generated using delay and subtract circuit. The output of MZM-1 is fed to the MZM-2 driven by sinusoidal signal with the frequency same as bit rate and a phase of -90. This modulation scheme is also called CSRZ.

Simulation Setup

OptiSystem-12 is used for the modelling and simulation of optical system. This tool can facilitate simulations of communication systems for higher data rates and longer transmission distances and hence is widely used in both industry and academia. Results obtained by this tool are highly accurate and are close to practical results. Block diagram of the 16 channel Dense WDM simulation setup is shown in Fig. 4. The simulation system comprises of transmitter, optical fiber, and a receiver. The DWDM transmitter module is constructed using an array of lasers, data modulators and a 16:1 multiplexer (MUX). CW laser array consists of 16 output ports with emission frequency ranging from 193.1 THz to 194.5 THz. The

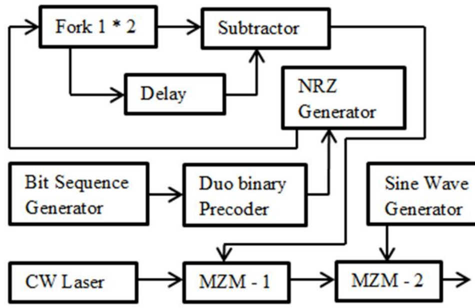


Figure3. Block diagram of MDRZ Modulation Format

channel spacing is 100GHz. The outputs of CW laser array are given to data modulator. Output of each MZM is fed to the 16 channel multiplexer whose bandwidth (BW) is 16GHz.

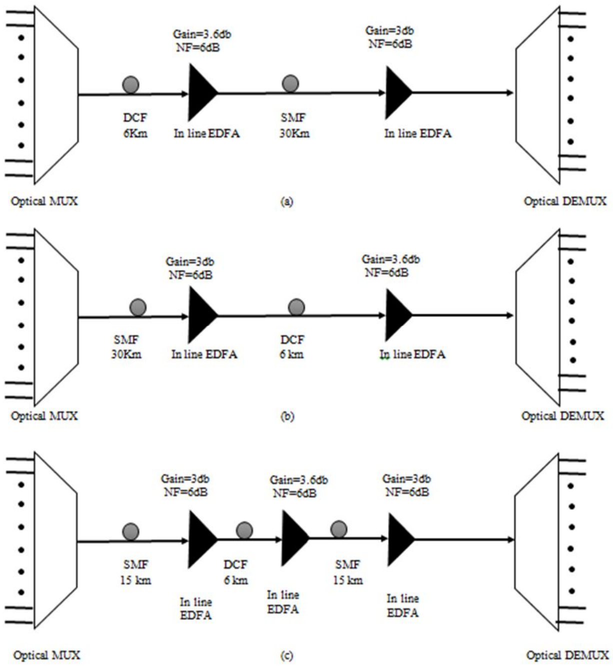


Figure4. Schematic representation of: (a) Pre-compensation method, (b) Post compensation method and (c) Symmetrical method

The design of transmission link consists of single mode fiber (SMF), DCF, and EDFA. Attenuation loss present in the optical link at a given wavelength is compensated using the erbium doped fiber amplifier (EDFA) with noise figure of 6dB. The attenuation and dispersion values of DCF and SMF to achieve complete dispersion compensation are specified in Table 1. Pre, post and symmetrical compensation techniques are simulated for Dense WDM system. To regulate the effect of dispersion, DCF of 6km is used before single mode fiber of 30km in pre compensation technique as shown in Fig. 4(a). Two in-line-EDFA gains of 3.6dB and 3dB are used in the optical link respectively. In post compensation technique as shown in Fig. 4(b), the dispersion is compensated by placing DCF after the SMF. As shown in Fig. 4(c), DCF is placed in middle of the SMF in symmetrical compensation technique. Unlike other two schemes 3 EDFAs has been used in the link.

Table 1. SMF and DCF Specifications

Fiber Type	Attenuation α (dB/km)	Dispersion D (ps/km-nm)
SMF	0.2	16
DCF	0.6	-80

Receiver section of DWDM system consists of demultiplexer (DEMUX), receiver, and BER analyzer. DEMUX of 16 output ports with a BW of 32GHz are fed to the 16 optical receivers. The receiver subsystem has a PIN diode, filter, and a 3R regenerator. The responsivity and dark current of the PIN diode is taken as 1 A/W and 10nA respectively. The signal is filtered and applied to the 3R regenerator. To perform BER analysis, an electrical signal is generated using 3R regenerator and connected to the BER analyzer which is used to analyze bit error rate, Q value, eye diagram, and eye opening.

Table 2. Design specification used for system simulation

Data rate	10Gbps, 20Gbps
Distance	30km x N spans; N= 17 and 25
Capacity	10Gbps x 16ch, 20Gbps x 16ch
Channel Spacing	100GHz
Center Frequency	193.1THz
Sequence length	128
Samples/bit	64

Fig.5 shows the simulation setup of 16 channel WDM using MDRZ modulation format. This WDM system is modeled using optisystem-12 and the link performance is evaluated through BER analysis. The system is simulated for 10 and 20Gbps data rates. Performance of the system is analysed by varying input launch power from -6 to 14dBm. Pre, post and symmetric compensation schemes have been studied to analyze system performance.

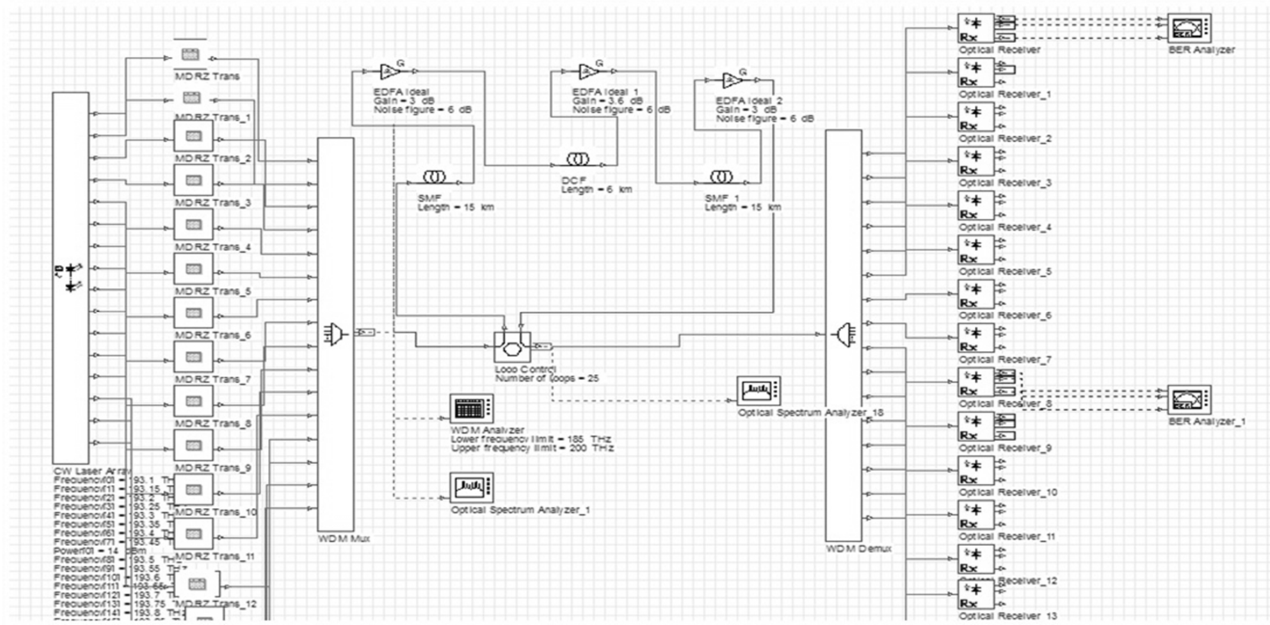


Figure5. Simulation setup of 16 channel WDM using MDRZ - symmetrical compensation scheme

Results and Discussion

16-channel DWDM system

The 16 x 10Gbps DWDM system is simulated using three different modulation formats for 750km with input power values ranging from -6dBm to 14dBm. The result is numerically compared for all modulation formats taking into consideration the Q values and input power. In WDM system Q typically functioning as a quality factor, becomes one of the important quality indicators to measure the optical performance. The results of the first since it gives the worst case plot and middle channel (channel-9) which is the best case plot are considered to analyze the system performance.

Fig.6 shows the graph of variation of Q value versus input power for CSRZ, DRZ, and MDRZ system for a distance of 750km. From the Simulation result it can be observed that for all the modulation schemes, as the input optical power increases the Q value increases up to a certain limit after which it starts to decline. It also depicts that at low power region ranging from -6dBm to 6dBm, CSRZ gives the best performance. CS-RZ scheme has high resistance to the combined effect of Self phase modulation (SPM) and group velocity dispersion (GVD) and has narrow optical spectral width. For power level 9 to 14dBm MDRZ executes superior performance. MDRZ out performs other modulation formats due to its tolerance for the non-linear effects such as XPM and FWM.

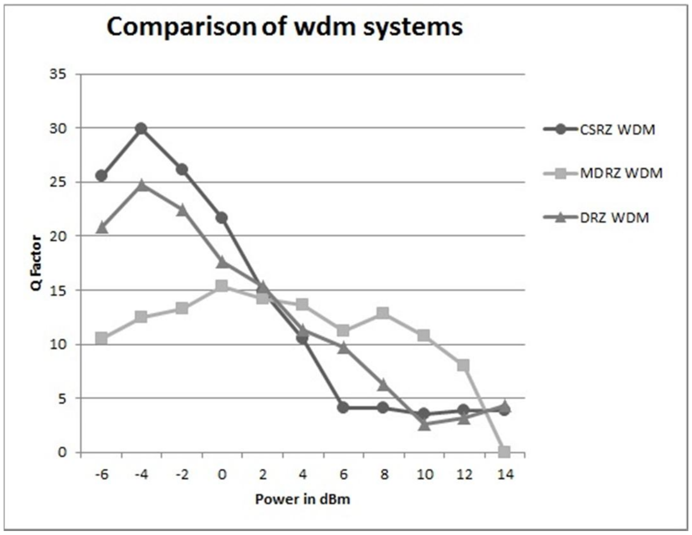


Figure6. Power vs. Q factor for comparison of modulation formats at 10Gbps for an optical link of 750 km

For MDRZ scheme with pre, post and symmetric compensation configuration, the variation of Q value with respect to power is shown in Fig.7.

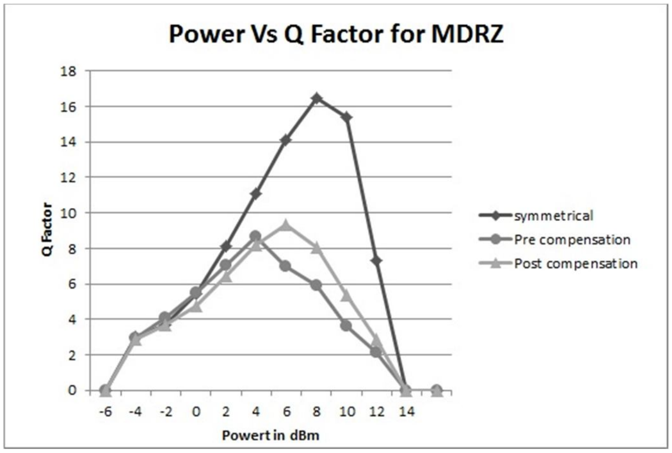


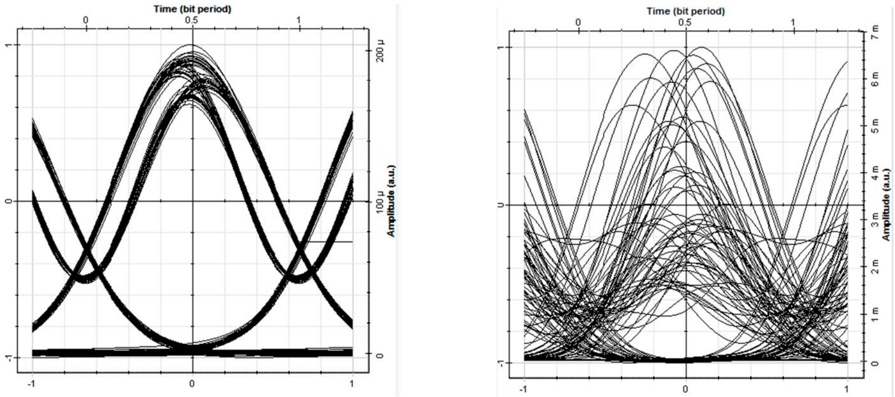
Figure7. Power vs. Q factor for different dispersion compensation schemes

The symmetrical dispersion compensation scheme exhibits better performance in terms of Q factor when compared with other dispersion compensation schemes as shown in above figure. Thus it can be concluded that, symmetrical dispersion compensation scheme is superior and hence it is preferred over other schemes.

Non-linear effects

The effect of nonlinearities on WDM system is investigated in terms of eye diagram, BER, and Q factor by varying the compensation ratio. For perfect dispersion compensation case with an objective to achieve complete dispersion compensation, the dimensions of SMF and DCF are selected. Complete compensation of dispersion makes the waves travel with same phase due to which effect of FWM and XPM increases. Therefore, complete compensation of dispersion present in optical link degrades the system performance. To reduce the effect of nonlinearities and to increase the performance, dispersion residue technique is used.

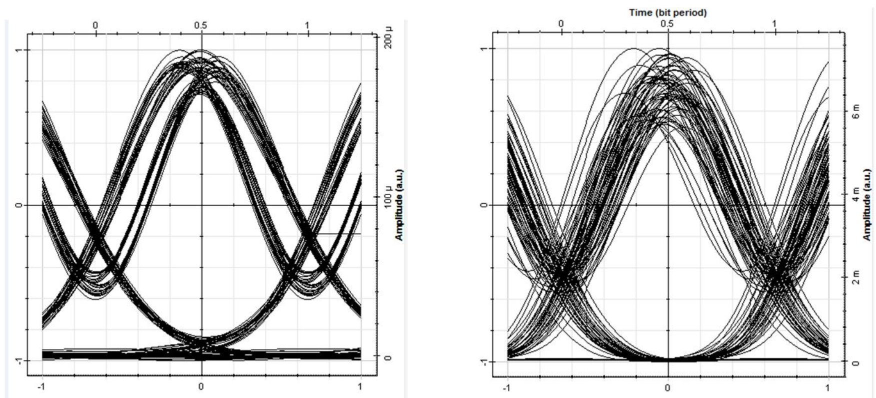
Results show that the effect of SPM can be compensated by effectively managing the dispersion residue in the optical link. In order to achieve better performance from the existing optical link; complete compensation and residual compensation are simulated for two different power levels 0dBm and 16dBm. Fig.8 (a) and 8(b) shows eye diagram for complete compensation at 0dBm and 16dBm respectively.



(a) (b)

Figure8. Eye diagram of MDRZ DWDM system after 510 km when dispersion residue is 0 ps/nm: (a) power = 0dBm, (b) power = 16dBm

Complete compensation results in a Q value of 15.5 at 0dBm and 4.31 at 16dBm and hence in low power region i.e. at 0dBm complete compensation gives better performance. For dispersion residue case, compensation ratio is varied to find the optimum DCF length. Fig.9 outlines the performance of the system when dispersion residue is 544ps/nm. Residual compensation results in a Q value of 15 at 0dBm which is same as complete compensation whereas at 16dBm the Q value is 11.62 and hence in high power region, residual compensation gives better performance.



(a) (b)

Figure9. Eye diagram of MDRZ DWDM system after 510 km when dispersion residue is 544 ps/nm: (a) power=0dBm, (b) power=16dBm

Conclusion

In this paper, DWDM system for CSRZ, DRZ, and MDRZ modulation formats has been demonstrated for a 16 channel 10Gbps data rate over an optical link of 750km. For pre, post and symmetrical dispersion compensation techniques the system performance is analysed using DCF. In order to increase the system performance launch power is increased which gives rise to nonlinear effects. Performance analysis of the DWDM system is carried out in the presence of nonlinear effects and dispersion residual technique is used to enhance the Q value.

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