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Enhancing Performance of 10 Gbps DWDM Optical Link for High Speed Optical Communication

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Abstract: *This paper presents comprehensive analysis of 10 Gbps using Dense Wavelength Division Multiplexing (DWDM) system with 32 channels spaced at 100 GHz. The system design has been optimized for a long haul optical link for Return to zero (RZ) and Non Return to Zero (NRZ) modulation formats using Opti-System simulator. It has been demonstrated that the conventional NRZ modulation format is superior compared to RZ when dealing with large WDM systems as RZ modulation format causes significant eye closure penalty near end channels. It is displayed in simulation that the Non Linear Effect (NLE) in fiber model generates Four-Wave Mixing (FWM) products which lead to deleterious effect on performance of optical link. The simulation results of NRZ modulation format shows that, on increasing channel spacing from 100 GHz to 200 GHz keeping input power fixed, there is mitigation of FWM products which finally enhances performance of optical link.*

Keywords: *Bit Error Ratio (BER), Cross Phase Modulation (XPM), Dense Wavelength Division Multiplexing (DWDM), Four-Wave Mixing (FWM), Light Amplification by Stimulated Emission of Radiation (LASER), Mach-Zender Modulator (MZM), Non Return to Zero (NRZ), Return to Zero (RZ), Stimulated Brillouin Scattering (SBS), Self - Phase Modulation (SPM).*

1. INTRODUCTION

The communication industry worldwide is facing most challenging problem of regular increasing demand of more bandwidth and higher data rates at lower cost. The optical communication experts of photonics, communications, electronics, and signal processing etc., are working side by side to meet out demand for higher capacity while maintaining system design to novel standards [1]. The aim of optical communications is thus to extend reach as well as optimize transmission capacity of optical links by either increasing bit rate, usage of WDM or ultimately both [2]. The Wavelength Division Multiplexed (WDM) optical network is a fascinating solution to fulfill worldwide rising requirement for transmission at high data rates. It utilizes same channel for transmission of data from source to destination of two different windows of optical communication, i.e., if one wavelength transmission was from 2nd window (1270-1350nm) then other will be from 3rd window (1480-1600nm) and vice versa. This was designed in order to prevent any possibility of interference among the transmitted channels.

With the advancement of Light Amplification by Stimulated Emission of Radiation (LASER) technology, a very narrow spectral width allowed simultaneous transmission of two channels belonging to same window with negligible possibility of interference. It allowed optical carriers closely spaced in wavelength domain providing set up with dense packing of carrier signals recognized as DWDM system. The point-to-point DWDM links considered beneficial as increased bandwidth by creating multiple channels at lesser costs [3, 4]. As per ITU standard, ITU G.692 specifies fixed inter carrier spacing of 100GHz and reference frequency of 193.1THz.

While working with DWDM system, it is assumed that different channels propagate along fiber without interfering one another. This assumption fails when power level is increased due to non linear and linear effects (chromatic dispersion) [5]. The nonlinear effects (NLE) are Self - Phase Modulation (SPM), Stimulated Brillouin Scattering (SBS), Cross Phase Modulation (XPM) and Four-Wave Mixing (FWM). Out of these, SBS and SPM are tested in single channel link whereas XPM and FWM in multi - channel link [6, 7]. The non linear distortion is one dominant penalty factors in DWDM system. Its suppression leads to system performance enhancement such as high data rates and large bandwidth.

At high bit rates modulation format, type of dispersion compensation scheme and channel power become important issues for optimum system design.

Applying intensity modulation in spectral direct-detection systems is one technique that has been used to increase network capacity. This technique utilizes DWDM system and optical amplification to achieve very high capacity network [8]. The ideal modulation format for long haul high speed DWDM optical link is one that has narrow spectral width, low susceptibility to fiber non-linearity, large dispersion tolerance, good transmission performance, simple design and cost effective configuration for generation [9].

In this paper, effects of different modulation formats in transmitter design of 10 Gbps DWDM optical links has been discussed along with method to mitigate non linearity effects for achieving optimum performance. The NRZ and RZ, are most efficient intensity modulation format due to its signal bandwidth and easy design architecture. The above said modulation format have been used to accomplish the objective [10, 11].

2. TRANSMITTER DESIGN

In the transmitter design, both NRZ and RZ formats have been used extensively due to their simple set up, Fig.1 and 2. A continuous wave LASER used in the design is on-off keyed by Mach-Zender modulator (MZM) driven by 10 GBPS NRZ and RZ data stream connected to Pseudo-Random Bit Sequence generator (PRBS) [11, 12, 13].

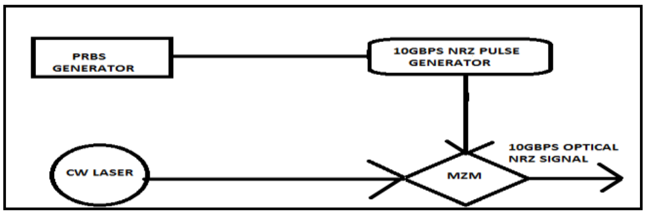


Fig 1: *Block diagram of NRZ transmitter*

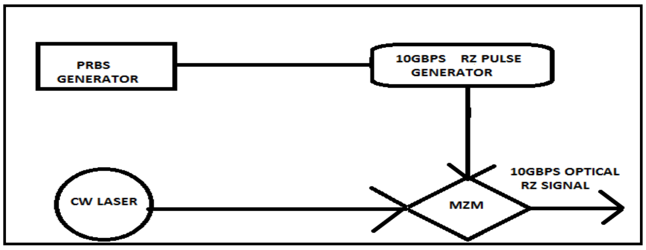
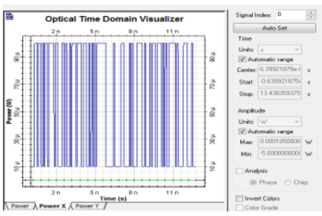


Fig 2: *Block diagram of RZ transmitter*



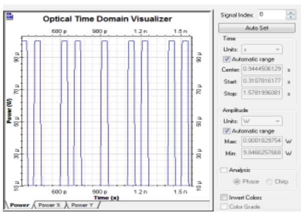


Fig 3: *Optical NRZ signal* *Fig -4: Optical RZ signal*

3. METHODOLOGY

3.1 Design Architecture of 10 Gbps DWDM Optical Link

It presents design architecture of 10Gbps DWDM optical network having post dispersion compensation scheme and mitigation of non-linear effect (XPM and FWM) have been discussed (Fig.5 and Fig.7) [11, 14, 15].

The DWDM network of 32 channels, each one having 10 Gbps bit rate, is designed to make net system of 32X10=320Gbps. In transmitter module, one single channel consists of PRBS of 10 Gbps bit rate followed by NRZ pulse generator. The CW LASER having power of -10dBm has been used in each channel at frequencies ranging from 193.1 to 196.2 THz with channel space of 100 GHz (ITU G.692) followed by MZM. After transmitter, a 32X1 multiplexer has been used to multiplex different wavelengths.

In the Optical link module, number of loops have been set up to five, which indicates that signal will propagate over 5 spans consisting of single mode fiber (SMF), gain compensating Erbium Doped Fiber Amplifiers (EDFAs) and dispersion compensating fiber (DCF). The SMF length extends 50 km with attenuation of 0.2dB/km and dispersion parameters set as per standard specification of SMF. The DCF length is set to 10 km with attenuation of 0.5dB/km and DCF parameters adjusted to compensate for the dispersion incurred by 50 km of SMF at standard wavelength of 1550 nm. The positive and negative dispersions compensated with each other, i.e., (+) 16.75ps/nm/km (SMF) with (-) 85ps / nm / km (DCF).

The DWDM receiver consists of 32 channels, a WDM de-multiplexer, optical receiver and BER tester where the de-multiplexer used frequency spacing of 100 GHz. The receiver comprises PIN photo-detector and Bessel low pass filter. At this point of time observe Eye diagram of three channels out of 32 channels, i.e., channels, 1, 8, 16, using Bit Error Rate (BER) analyzer to record performance parameters, such as Quality-factor (Q-factor), eye height, BER [4, 16].

In design different analyzers have been used to monitor the performance of optical link and at transmitter end Optical Time Domain Visualizer (OTDV) displays NRZ and RZ signals.

After multiplexer, Optical Spectrum Analyzer (OSA), display multiplexed optical signal where as WDM analyzer exhibits characteristics of each channel, such as frequency, signal power and Optical Signal to Noise Ratio (OSNR). In addition, OSA has also been used after 300 km of signal propagation. The BER analyzer at receiver end will display performance parameters [17, 18].

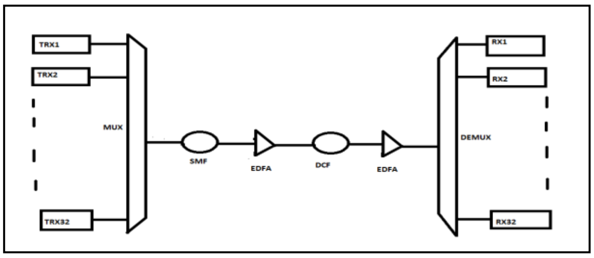


Fig 5: *Design of DWDM optical link*

3.2 Procedure

Above link design is simulated for NRZ modulation format by simply enabling the coding tab in Opti-system. Initially, NLE has not been considered, so disabling the non linearity tab in Opti-system simulator. Once simulation task is completed, results are observed on various analyzers. Now with coding tab switch on again to RZ modulation format and repeat same procedure and results for both NRZ and RZ formats have been compared using performance parameters. In the experiment best modulation format used for further simulation includes activation of non linearity effect in fiber model.

For NRZ modulation format in Opti-system, back to SMF and enabling non linearity tab to select SPM to activate non-linear effect in fiber model so as to enable XPM and FWM. The same procedure is repeated for DCF and rerun simulation to observe results on analyzers. Then compare results for NRZ format excluding and including non linearity effect in fiber model.

For mitigation of non-linear effect in above simulation set up (NRZ modulation format), increase the channel space from 100 GHz to 200 GHz and rerun simulation. After simulation work is finished, observe results on visualizers, compare results for NRZ with channel spacing of 100 GHZ and 200 GHz and also notice effect of increasing channel space.

3.3 FWM Effect

The FWM in fiber is related to self phase and cross phase modulation. It means that all these effects originate from same (Kerr) nonlinearity and differ only in terms of degeneracy of waves involved. It causes cross talk between different wavelength channels in WDM, especially in DWDM networks and limit performance of such systems. It occurs when two or more different frequency component propagate simultaneously in optical fiber. The interference between two co-propagating wavelengths produces two new groups of optical spectral components at different frequencies. The newly produced FWM products can be mixed with channel signals or themselves to produce higher order FWM products which can overlap with channels and produce cross talk. The mixing of two frequencies in pulse creates new frequencies which can be marked as ω112 and ω211.

$\omega112 = 2\omega1 - \omega2$ Equation (1)

$\omega211 = 2\omega2 - \omega1$ Equation (2)

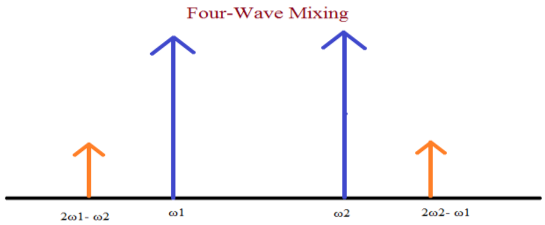


Fig 6: *With four-wave mixing several wavelengths combine to produce new wavelength*

The FWM impact can be suppressed and eliminated by increasing equal or unequal spacing between channels, increasing chromatic dispersion of transmission fiber and core effective area while decreasing average input power per channel. The four-wave mixing effect is minimum at 100 GHz channel spacing between input channels [7, 12, 19, 20]. For further higher multi-channel system with higher order modulation format, a stochastic nature of FWM will also be crucial limiting factor (Fig.6). The number of FWM components increases with increase in number of channels [16, 19].

$N=M2 (M-1)/2$ Equation (3)

N=Number of Channels

M=Four wave mixing components

In this experiment, effects of FWM products have been mitigated in WDM by increasing channel spacing from 100GHz to 200GHz and effect of variations in channel spacing analyzed by observing performance parameters (Q-factor, eye height, BER).

4. SIMULATION SET UP

In case all parameters are entered properly, accuracy of simulation will be extremely high, (Figure 7).

Table 1: *System parameters for 10 Gbps DWDM link*

System Parameters	*Values*
Number of channels	*32*
Each channel data rate	*10Gbps*
Channel frequency range	*193.1THz to 196.2THz*
Channel spacing	*100GHz and 200 GHz*
Attenuation of SMF	*0.2dB/km*
Input power	*-10dBm*
Attenuation of DCF	*0.5dB/km*
Dispersion of SMF	*16.75ps/nm/km*
Dispersion of DCF	*-85ps/nm/km*
SMF length	*50 km*
DCF length	*10 km*
Number of Loops	*5*
Total length	*300 km*
Modulation format	*RZ and NRZ*
Filter	*Low pass filter cut off frequency0.75x bit rate*
EDFA Gain	*10 db*
EDFA Noise margin	*6 db*
Receiver responsivity	*1A/W*

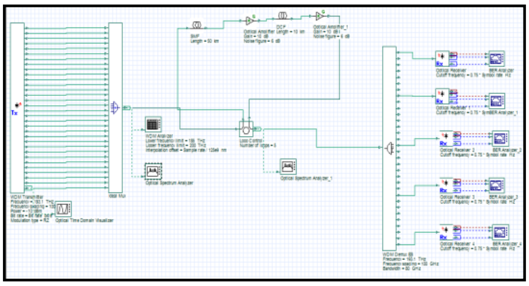


Fig 7: *Simulation Set Up of 10Gbps DWDM Optical Link*

5. RESULTS AND DISCUSSION

The 10 Gbps DWDM optical link with NRZ and RZ modulation format (excluding NLE for channel space of 100 GHz), displays results on BER analyzer. The Eye diagrams for both NRZ and RZ formats for channels, 1, 8 and 16 are displayed in Figures 8 to 10 and 11 to 13 respectively.

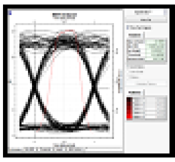
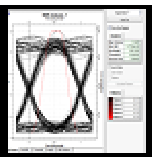
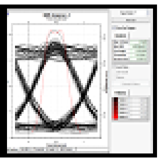




Fig 8: *NRZ (1)* **Fig 9:** *NRZ (8)* **Fig 10:** *NRZ (16)*

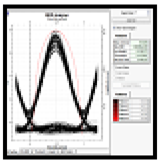
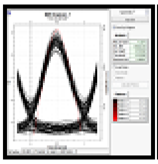
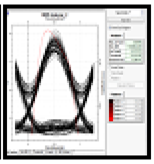




Fig 11: *RZ (1)* **Fig 12:** *RZ (8)* **Fig 13:** *RZ (16)*

Table 2: *Comparative study of performance parameter at 100GHz channel spacing excluding NLE effect*

Performance Parameters	*Channel (1)*	*Channel (8)*	*Channel (16)*
Q-factor (NRZ)	*13.15*	*11.04*	*9.34*
Q-factor (RZ)	*10.94*	*11.03*	*9.25*
Eye height(NRZ)	*0.022*	*0.021*	*0.020*
Eye height (RZ)	*0.016*	*0.016*	*0.012*
Min BER (NRZ)	*7.62e-040*	*1.07e-028*	*4.52e-021*
Min BER (RZ)	*3.40e-028*	*1.29e-028*	*1.05e-019*
SNR dB (NRZ)	*33.14*	*30.11*	*30.25*
SNR dB (RZ)	*26.00*	*21.36*	*21.95*

By comparing the performance parameters for NRZ and RZ modulation format (Table2), It is observed that Q-factor, Eye height, Min BER, SNR are superior for NRZ modulation format. As NRZ shows better performance, proceeded with the activation of non linearity effect in fiber model for NRZ.

In simulation by including NLE in fiber model for NRZ modulation format, results are observed on analyzer. The OSA results are shown for both cases excluding and including non linear effect (Figure14 and Figure15).

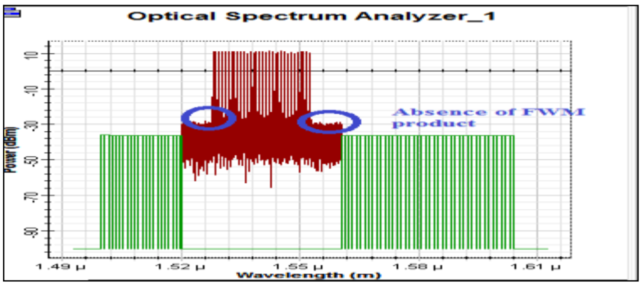


Fig 14: *OSA result after 300 km for NRZ (Excluding non-linear effect for channel space of 100 GHz)*

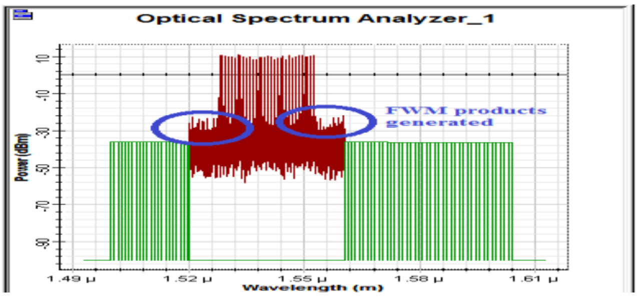


Fig 15: *OSA result after 300 km for NRZ (Including non linear effect with channel space of 100 GHz)*

The comparison of both figures (Figure14 and Figure15) shows that FWM products are generated when considering non-linear effect in fiber model which cause serious effect on performance of optical link. It can also be noticed by comparative study of performance parameters for NRZ modulation format excluding and including NLE (Table 3).

The results on BER analyzer for channel 1, channel 8 and channel 16 shown below for NRZ format (100GHz spacing) including NLE in fiber model shown:

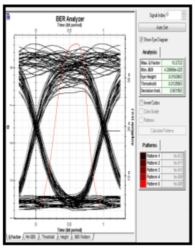
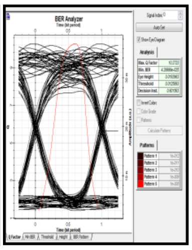
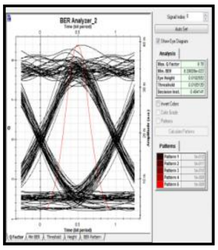




Fig 16: *NRZ (1)* **Fig 17:** *NRZ (8)* **Fig 18:** *NRZ (16)*

Table 3: *Comparative study of performance parameter for NRZ for channel space of 100GHz excluding and including NLE*

Performance parameters	***Channel (1)***	***Channel (8)***	***Channel (16)***
Q-factor (NRZ)	***13.15***	***11.04***	***9.34***
Q-factor(NLE-NRZ)	***10.27***	***10.56***	***9.33***
Eye height(NRZ)	***0.022***	***0.021***	***0.020***
Eye height (NLE-NRZ)	***0.019***	***0.019***	***0.018***
Min BER (NRZ)	***7.62e-040***	***1.07e-028***	***4.52e-021***
Min BER(NLE-NRZ)	***4.29e-025***	***2.06e-026***	***8.29e-020***
SNR dB (NRZ)	***33.14***	***30.11***	***30.25***
SNR dB (NLE-NRZ)	***33.13***	***30.10***	***30.24***

For mitigation of FWM effect, channel spacing increased from 100 to 200 GHz and results are observed on OSA and BER analyzer as shown below:

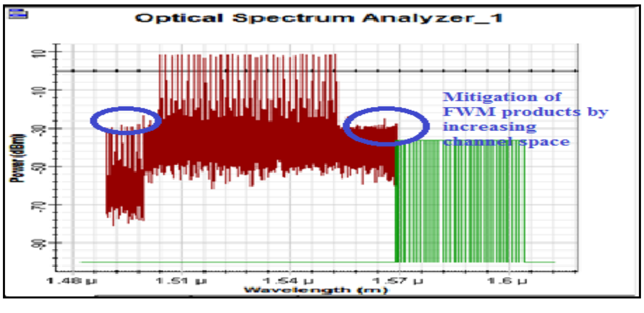


Figure 19: *OSA result after 300 km for NRZ (Including non linear effect with channel space of 200 GHz)*

The above figure shows that on increasing the channel spacing, the FWM products are mitigated which also enhances performance of optical link. This also can be observed by comparative analysis of NRZ modulation format including NLE for channel space of 100 and 200 GHz (Table 4).

Results on BER analyzer for channel 1, channel 8 and channel 16 shown below for NRZ format (channel spacing 200GHz) including NLE in fiber model shown:

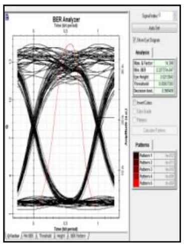
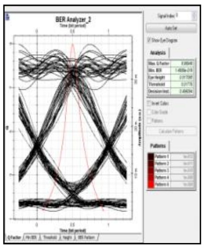
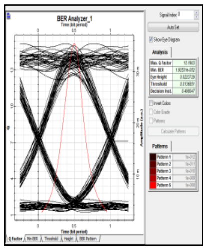




Fig 20: *NRZ (1)* **Fig 21:** *NRZ (8)* **Fig 22:** *NRZ (16)*

Table 4: *Comparative study of performance parameter of NRZ including NLE for channel space of 100 and 200 GHz*

Performance Parameters NLE	***Channel1***	***Channel 8***	***Channel 16***
Q-factor (100-NRZ)	*10.27*	*10.56*	*9.76*
Q-factor(200-NRZ)	*14.39*	*15.19*	*9.96*
Eye height(100NRZ)	*0.019*	*0.019*	*0.019*
Eye height (200NRZ)	*0.021*	*0.022*	*0.019*
Min BER (100NRZ)	*4.29e-025*	*2.06e-026*	*8.29e-023*
Min BER (200NRZ)	*2.22e-047*	*1.92e-052*	*1.48e-024*
SNR dB (100NRZ)	*33.18*	*30.23*	*30.26*
SNR dB (200NRZ)	*34.27*	*31.14*	*34.35*

6. CONCLUSION

The performance parameters for NRZ and RZ modulation formats, excluding NLE for 10Gbps DWDM optical link with channel spacing of 100 GHz keeping input power fixed on -10dBm, displayed that the conventional NRZ modulation format is superior compared to RZ modulation when dealing with large WDM systems, as RZ modulation causes significant eye closure penalty near end channels.

Now considering NLE in fiber model for NRZ modulation format for channel space of 100 GHz, it exhibited that FWM products are generated at far sides of spectrum displayed on OSA. This FWM product cause serious effect on performance of DWDM link which is observed by comparison of performance parameters for NRZ excluding and including non linearity effect in fiber model.

It has also been observed that by increasing channel spacing from 100 to 200 GHz for NRZ modulation formats, mitigation of non linear effects, especially FWM and XPM takes place and also displayed on OSA and by comparing performance parameters for NRZ modulation format including NLE effect for the said channel spacing.

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Rajat Paliwal, started teaching in engineering college in the year 2007 and was felicitated for exemplary performance in 2013. He taught, Network analysis and synthesis, Signal and Systems, Linear integrated circuits, Analog communication systems and also guided students for developing application based minor projects. One such project was selected for Avishkar competition in year 2013.

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