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Simulation of high capacity 40 Gb/s long haul DWDM system using different modulation formats and dispersion compensation schemes in the presence of Kerr's effect

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Abstract

In this paper, simulative analysis of 40 Gb/s long haul (500–2000 km) DWDM system with ultra high capacity upto 1.28 Tb/s has been carried out for carrier-suppressed return-to-zero (CSRZ), duobinary return-to-zero (DRZ) and modified duobinary return-to-zero (MDRZ) modulation formats. The DWDM system has been analyzed for the pre, post and symmetrical dispersion compensation schemes for 16 Channels with 25 GHz channel spacing in order to find the optimum modulation format for a high bit rate optical transmission system. The effect of variation in input power and transmission distances is observed in terms of *Q* value and eye opening for various formats. It is found that symmetrical compensation is superior to pre and post dispersion compensation schemes. It has also been observed that the performance of DWDM system is severely limited by the four-wave mixing (FWM) effect and is determined that MDRZ format seems to be the best choice for the transmission distance beyond 1550 km despite slightly more complex transmitter and receiver configuration. Further, symmetrical compensation scheme has been investigated for 32×40 Gb/s MDRZ format for faithful transmission over 1450 km.

Keywords: DWDM; CSRZ; DRZ; MDRZ; FWM

1. Introduction

In order to achieve dense wavelength division multiplexing (DWDM) systems with high spectral efficiency, it is attractive to operate at bit rates of 40 Gb/s per channel [1–3]. For DWDM systems in which the data rate is >10 Gb/s/channel, the deleterious effects of dispersion and nonlinearity must be managed to achieve transmission over any appreciable distance. Dispersion management, utilizing alternating fiber segments of opposite dispersion values, is a key technique that keeps the total accumulated dispersion low while suppressing most nonlinear effects. In dispersion-managed systems utilizing single-mode fiber (SMF) and dispersion compensating fiber (DCF), the positive dispersion of SMF can be compensated by the large negative dispersion of DCF [6,7]. In this scenario: (1) overall dispersion

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accumulation is minimized over a fairly wide wavelength range and (2) four-wave mixing (FWM) is significantly reduced [4,5].

In conventional standard-fiber transmission lines, the return-to-zero (RZ) and non-return-to-zero (NRZ) modulation formats are most often used. Analysis and investigations have shown that RZ turns out to be superior as compared to conventional NRZ systems [2,9], as long standard single-mode fibers are used as transmission media. On the other hand, because of the narrower optical spectrum of the NRZ format, NRZ enables higher spectral efficiency in WDM systems compared to RZ in the linear regime. But NRZ and RZ formats are not suitable for transmission in DWDM systems, as they are highly susceptible to nonlinear effects As alternatives to RZ and NRZ, several other modulation formats like carrier-suppressed return-to-zero (CSRZ) [1,3,9,12], single-side-band RZ (SSB-RZ) [3,12] and duobinary modulations [4,5] have been proposed.

Takeshi Hoshida et al. [1], compared NRZ, CSRZ, bit-synchronous intensity modulated differential phase shift keying (IM-DPSK) format by numerical simulation of highly dense (75-GHz-spaced for 40 Gb/s channel), long-haul (600–1800 km) wavelength division multiplexed systems with three fiber types i.e., SMF, NZ-DCF A and NZ-DCF B. They showed that NRZ format, is capable of shorter transmission distances < than 1000 km regardless of fiber type. CSRZ format, showed better performance with fibers having larger chromatic dispersion and IM-DPSK format seems to be the best choice for a transmission distance beyond 1000 km because of its superior tolerance to optical noise and fiber nonlinear effects regardless of fiber types.

Hodzik et al. [3] performed comparison of CSRZ and single SSB-RZ formats and the results showed that CSRZ is superior to RZ and SSB-RZ with respect to signal degradation due to Kerr nonlinearities and chromatic dispersion in wavelength division multiplexing (WDM) as well as in single-channel 40-Gb/s systems over standard single-mode fibers (SSMF). It is shown that CSRZ enables a maximum spectral efficiency of approximately 0.7 (b/s)/Hz in $N \times 40$ Gb/s WDM system with equally polarized channels.

Cheng et al. [5] demonstrated that pulse-to-pulse interaction and ghost pulses at 40 Gb/s can be suppressed by alternating the optical phase of adjacent bits by using either duobinary return-to-zero (DRZ) or a modified-duobinary return-to-zero (MDRZ) modulation format. Both DRZ and MDRZ signals suppress all discrete frequency tones that appear in the conventional RZ signal spectrum. MDRZ has the least timing jitter and amplitude distortion and both of these formats can operate at average channel powers higher than the conventional RZ format.

Sano and Miyamoto [8] analyzed the transmission performance of prechirped RZ and prechirped CSRZ signals over a periodically dispersion-compensated transmission line. Prechirping was shown to be effective in suppressing intrachannel pulse-to-pulse nonlinear interaction, such as intrachannel cross phase modulation (XPM) and intrachannel FWM with both RZ and CS-RZ formats. In 40-Gb/s-per-channel DWDM systems with 100-GHz channel spacing, they showed that the transmission performance of the CS-RZ format improves with moderate phase modulation; it is stronger against linear crosstalk and XPM-induced timing jitter because of its compact spectral width and wide pulse width.

Bosco et al. [9] demonstrated the use of NRZ, RZ, and CSRZ modulation formats in an ultra dense wavelength-division multiplexing (UDWDM) scenario at 40 Gb/s with 50 GHz channel spacing. They showed that, due to the narrow transmission filtering, the RZ pulse becomes NRZ-like, and the CSRZ modulation is duobinary coded. Furthermore, they established that NRZ modulation does not benefit from the introduction of a transmission optical filter, while it takes advantage of the orthogonal polarization launch of adjacent channels, but its performance is still worse than the RZ and CSRZ performance in a UDWDM scenario.

Dahan and Eisenstein [10] compared the performance of three different modulation formats nonreturn-to-zero (NRZ), return-to-zero (RZ) and carrier-suppressed RZ (CS-RZ) for forty 40-Gb/s channels spaced at 100 GHz using backward-pumped distributed Raman amplification over transmission distance of 375 km. They proved that the CS-RZ format achieves good performances in forward-pumped Raman amplification and backward-pumped configuration because of the high nonlinear regime.

Kaler et al. [11] presented simulated results for DWDM systems using NRZ format with ultra-high capacity upto 1.28 Tb/s and spectral efficiency approaching 0.4 b/s/Hz. They investigated the impact of signal to noise ratio (SNR) on channel spacing, dispersion, length of the fiber and number of channels. Thereafter, Amarpal et al. [13] simulated the eight channel 10 Gb/s NRZ dense wavelength division multiplexing (DWDM) optical communication system having a channel spacing of 10 GHz upto 200 km and calculated power penalty introduced due to neighboring channels required to compensate the crosstalk. Further, Singh and Kaler [14] numerically simulated the ten channels at 10 Gb/s DWDM transmission faithfully over 17,227 km using 70 km span of SMF and DCF using optimum span scheme at channel spacing 20 GHz. For this purpose, inline optimized semiconductor optical amplifiers (SOA's) and differential phase shift keying (DPSK) format are used.

For high bit rate UDWDM system, the modulation format, type of dispersion compensation scheme and channel power become important issues for optimal system design. Up till now the research for CSRZ, DRZ and MDRZ formats is available mostly for WDM systems up to the channel spacing of 75 GHz. Here, we extend the work reported in Refs. [1,9] to find the most suitable format for higher transmission distance at 40 Gb/s for 16 channel Ultra DWDM system with 25 GHz Channel spacing. In this paper, CSRZ, DRZ and MDRZ modulation formats are analyzed using pre, post and symmetrical dispersion compensation schemes on the basis of Q value and eye opening penalty for different transmission distances and signal input powers varying from -15 to 10 dBm. Also, 32×40 Gb/s system is analyzed for MDRZ format using symmetrical dispersion compensation over transmission distances of 1450 km. In Section 2, the transmitters of various modulation formats along with their optical spectrum are described. Section 3, explains the simulated project and parameters. In Section 4, comparison results have been reported for various modulation formats using different dispersion compensation methods and, finally in Section 5, conclusions are made.

2. Transmitters of modulation formats

2.1. Carrier suppressed return-to-zero (CS-RZ) format

CS-RZ format has high tolerance to the mixed effect of self phase modulation (SPM) and group velocity

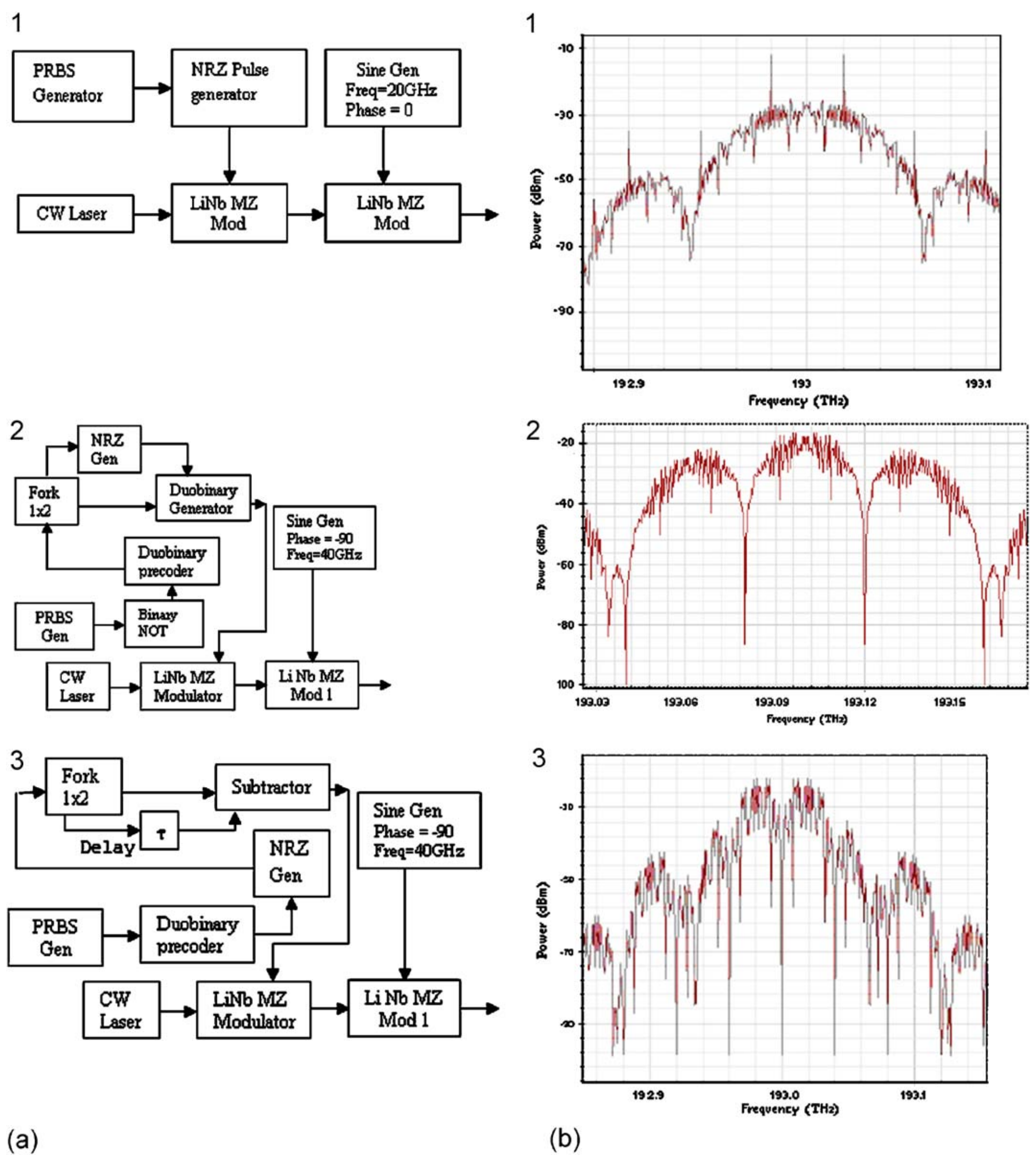

Fig. 1. (1a) Schematic of CS-RZ transmitter, (1b) frequency spectrum of CS-RZ transmitter, (2a) 1,2 schematic of duobinary RZ transmitter, (2b) frequency spectrum of DRZ transmitter, (3a) 1,3 schematic of MDRZ transmitter and (3b) frequency spectrum of MDRZ transmitter.

dispersion (GVD) and has narrower pedestal shape of the optical spectrum than the conventional RZ format [3]. Fig. 1(1a) shows the schematic of the 40 Gb/s CS-RZ transmitter. In case of CSRZ transmitter, the NRZ optical signal after MZ modulator goes through phase modulator driven by analog sine wave generator at the frequency equal to half the bit rate. That will introduce a π phase shift between any two adjacent bits and the spectrum will be modified such that the central peak at the carrier frequency is suppressed as shown in Fig. 1(1b).

2.2. DRZ format

Fig. 1(2a) shows the schematic of the 40 Gb/s duobinary transmitter. The duobinary was generated by first creating an NRZ duobinary signal using a duobinary precoder, NRZ generator and a duobinary pulse generator. The generator drives the first MZM, and then cascades this modulator with a second modulator that is driven by a sinusoidal electrical signal with the frequency of 40 GHz, Phase = −90°. The duobinary precoder used here is composed of an exclusive-or gate with a delayed feedback path. DRZ formats are very attractive, because their optical modulation bandwidth can be compressed to the data bit rate B, that is, the half-bandwidth of the NRZ format 2B [5] as shown in Fig. 1(2b).

2.3. Modified duobinary RZ (MDRZ) format

Fig. 1(3a) shows the schematic of the 40 Gb/s modified duobinary transmitter also called carrier-suppressed duobinary format. The MDRZ was generated by first creating an NRZ duobinary signal using a delay-and-subtract circuit that drives the first MZM and then concatenating this modulator with a second modulator that is driven by a sinusoidal electrical signal with the frequency of 40 GHz and phase −90°. The generation of MDRZ signal is almost identical to the DRZ signal, except the delay-and-add circuit is replaced by a delay-and-subtract circuit. In the duobinary signal used earlier where the phase of bits ‘1’s are modified only after a bit ‘0’ appear whereas in the modified duobinary signal the phase is alternated between 0 and π for the bits ‘1’. The phase of all the “zero” bits are kept constant and a 180° phase variation between all the consecutive “ones” is introduced [5]. Also optical signal spectrum Fig. 1(3b) shows that the carrier of the duobinary signal has been suppressed.

3. Simulation

Fig. 2 shows a schematic of simulation setup of a 16 channel DWDM optical communication system

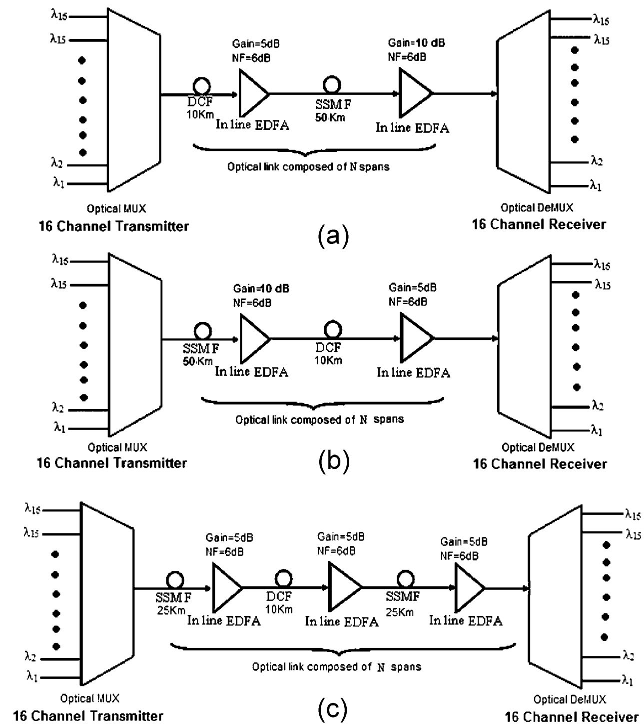

Fig. 2. Schematic of simulation setups: (a) pre-compensation scheme, (b) post-compensation scheme and (c) symmetrical-compensation scheme.

Table 1. Simulation parameters..

Bit rate	40 Gb/s
Sequence length	256
Samples/bit	32
WDM channel spacing	25 GHz
Central Frequency of first channel	192.9THz
Capacity	40 Gb/s × 16 ch, 40 Gb/s × 32 ch
Distance	50 km × N spans; N = 10,20,30,40

at 40 Gb/s with the central frequency of the first channel = 192.9 THz. The simulation parameters and fiber parameters used in the system model are given in Tables 1 and 2 respectively.

The simulation setup is composed of transmitter, fiber and receiver. The WDM transmitter consists of a CW laser array, data modulators and the optical multiplexer. CW laser array has 16 output ports where the emission frequencies are equally spaced; the emission frequency range is 192.9–193.3 THz with the frequency spacing of 25 GHz between the adjacent channels. To each output port of the CW laser array a data modulator (types discussed in Section 2) has been connected. Optical signals from 16 data modulators are fed to the 16 input ports of an optical multiplexer having bandwidth = 32 GHz. The tight channel spacing may induce

Table 2. Fiber parameters..

Fiber	Attenuation α (dB/Km)	Dispersion D (ps/km-nm)	Dispersion slope S (ps/km-nm^2)	Effective core area A_{eff} (μm^2)	Non linear refractive index n_2 (10^{-20} m^2/w)
SMF	0.2	17	0.075	70	2.6
DCF	0.5	−85	−0.3	22	2.6

interchannel interference due to channel spectra overlap. To ensure separation between the channels in the frequency domain (linear cross-talk suppression), before multiplexing, each channel is optically filtered with narrow transmission optical filter. Here, a second order superGuassian filter with a bandwidth equal to 32 GHz has been considered. The channel spacing and operating wavelengths are defined by ITU-T standards.

The design the transmission link span at 40 Gb/s is very crucial and is designed suitably in accordance with Ref. [7] considering the fiber parameters of DCF and SSMF so that the first-order dispersion is compensated exactly ($D = 0$) i.e.,

$$D_{\mathrm{SMF}} L_{\mathrm{SMF}} = D_{\mathrm{DCF}} L_{\mathrm{DCF}}$$

where D means the first-order dispersion parameter [ps/nm/km] of the corresponding fiber and L stands for the total SMF or DCF length per span. The fiber parameters have been specified in the Table 2. The gain of the erbium doped fiber amplifier (EDFA) placed after each fiber is such that is compensates the losses of the preceding fiber. The noise figure of the amplifiers is constant and set to 6 dB. Scalar model of both the fibers have been considered, so that no birefringence effects are there, and consequently polarization mode dispersion (PMD) is not taken into account. The signal is then launched over N spans of standard single mode fiber (SSMF) of 50 km each. WDM system has been simulated for three different dispersion compensation schemes i.e., pre-compensation, post-compensation and symmetrical-compensation. In pre-compensation scheme, as shown in Fig. 2(a)**,** to compensate for the dispersion and the nonlinearities, DCF fiber of 10 km is used prior to the SSMF fiber of 50 km length. Also, two in-line-EDFA's with gain = 5 and 10 dB, respectively, have been used in the link. The post-compensation scheme has been shown in Fig. 2(b) where DCF fiber of 10 km is used after the SSMF fiber of 50 km length to combat the accumulated dispersion. In symmetrical-compensation scheme, as shown in Fig. 2(c), DCF fiber of 10 km is used in the middle of the SSMF fiber of 50 km length. Here three in-line-EDFA's with gain = 5, NF = 6 dB have been used in the link.

In the receiver the signal is demultiplexed, detected by PIN detector, passed through the filter and 3R regenerator. Optical demultiplexer used has 16 output ports having BW = 32 GHz. The electrical signal from each port is then passed through PIN photodiode, reference frequency ranges from 192.9–193.3 THz for the respective PIN photodiodes, responsivity [A/W] = 1 and dark current = 0.1 nA. Raised cosine superGuassian band pass filters with filter parameters: 3 dB cut off frequency = 32 GHz, order of the filter = 4, depth = 100 dB. Thereafter 3R regenerator is used to regenerate an electrical signal connected directly to the BER analyzer which is used as a visualizer to generate graphs and results such as eye diagram, BER, Q value, eye opening etc.

4. Results and discussion

The three modulation formats have been numerically compared for different dispersion compensation schemes i.e., pre-compensation, post-compensation and symmetrical-compensation for 16 × 40 Gb/s DWDM system in terms of received maximum Q value [dB] and eye opening using Split Step Fourier Transform (SSFT) method. To analyze the system, the results of the first channel have been taken, as this is the worst-case scenario (end channels). In case of 40 Gb/s systems, the worst Q-factor comes from 1st and 16th channels as they experience the most dispersion and nonlinear effects [2].

Fig. 3(a)–(c) shows the graphical representation of Q value as a function of signal input power after a transmission distance of 750 km for pre, post and symmetrical-compensation schemes respectively for various modulation formats. It can be seen for all the modulation formats that as the signal input power increases, Q value increases up to certain limit (0–5 dBm) after which it starts falling. This can be understood from the fact that for low powers, the performance of DWDM systems improves with the increase in input power. However, at higher powers, the wavelengths tend to overlap each other causing more dominance of non-linear effects like XPM and FWM caused by optical Kerr's effect and thus reduce the Q value. This shows good agreement with the results of Refs. [1,11]. The dark line defines the lowest bit error rate (BER) of 10^{-15} corresponding to Q value = 11.8 dB when using forward error correction (FEC), virtually error free performance with at least 3 dB of system margin. Further, it can be observed that the worst performance is given by pre-compensation scheme for

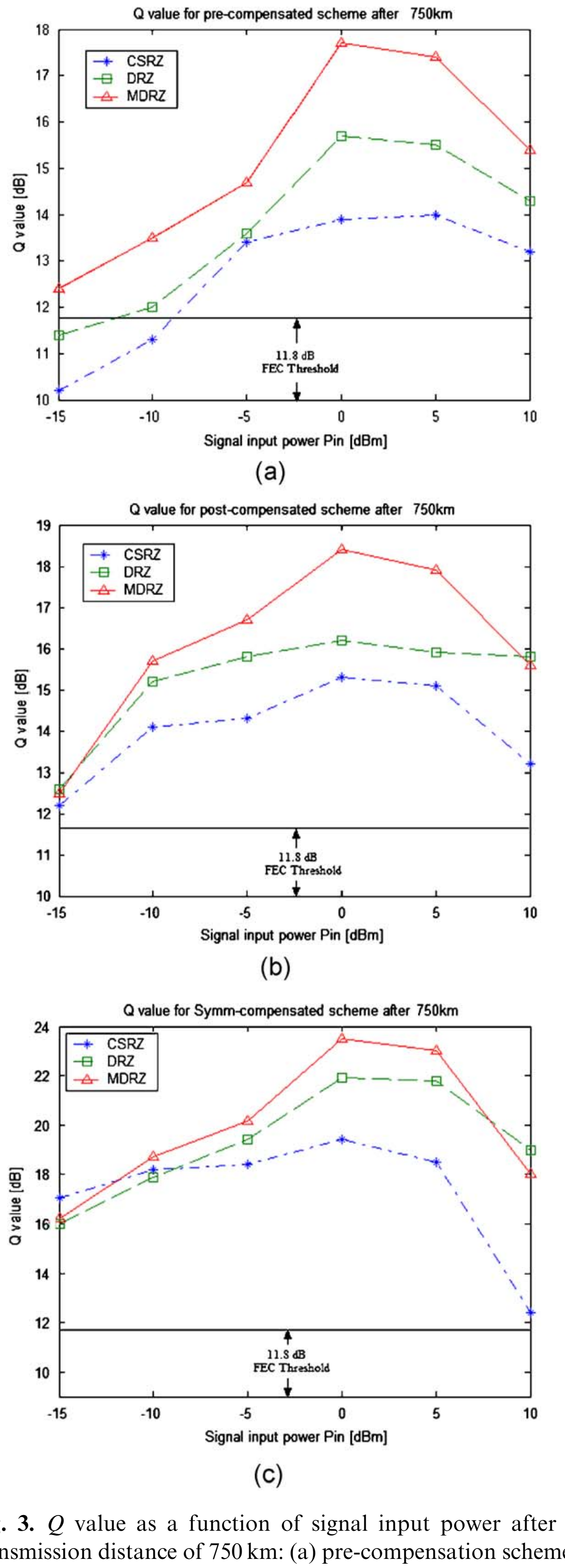

Fig. 3. Q value as a function of signal input power after a transmission distance of 750 km: (a) pre-compensation scheme, (b) post-compensation scheme and (c) symmetrical-compensation scheme.

all the formats and the MDRZ format with symmetrical-compensation seems to be most resilient against dispersion and nonlinearities. The MDRZ format shows improvement of 9.1 dB over CSRZ format for symmetrical-compensation scheme as compared to 3.8 dB for pre-compensation scheme at 0 dBm signal input power.

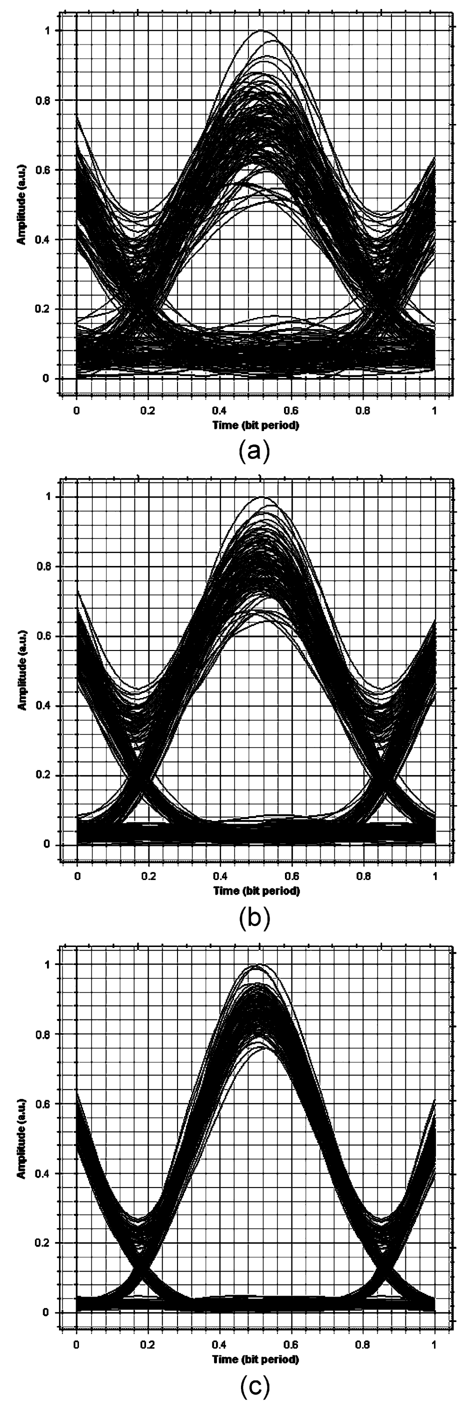

Fig. 4. Showing Eye diagrams of CSRZ modulation format at Pin = 2 dBm after 750 km: (a) pre-compensation scheme, (b) post-compensation scheme and (c) symmetrical-compensation scheme.

The best Q value obtained is 25.5 dB at Pin = 0 dBm for MDRZ format using symmetrical-compensation scheme. The results are also supported by the eye diagrams of dispersion compensation schemes obtained from electrical oscilloscope at Channel 1, Pin = 2 dBm after a transmission distance of 750 km as shown in the Figs. 4–6 for CSRZ format, DRZ format and MDRZ format, respectively. The worst eye opening is shown in Fig. 4(a) by CSRZ format using pre-compensation scheme at Pin = 2 dBm and after a transmission

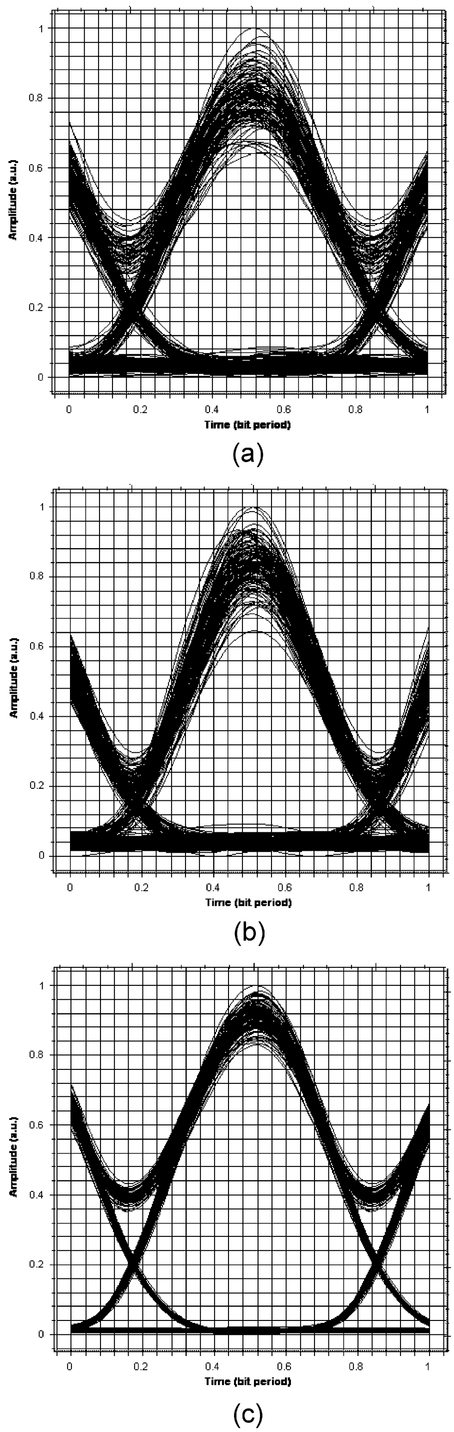

Fig. 5. Showing eye diagrams of DRZ modulation format at Pin = 2 dBm after 750 km: (a) pre-compensation scheme, (b) post-compensation scheme and (c) symmetrical-compensation scheme.

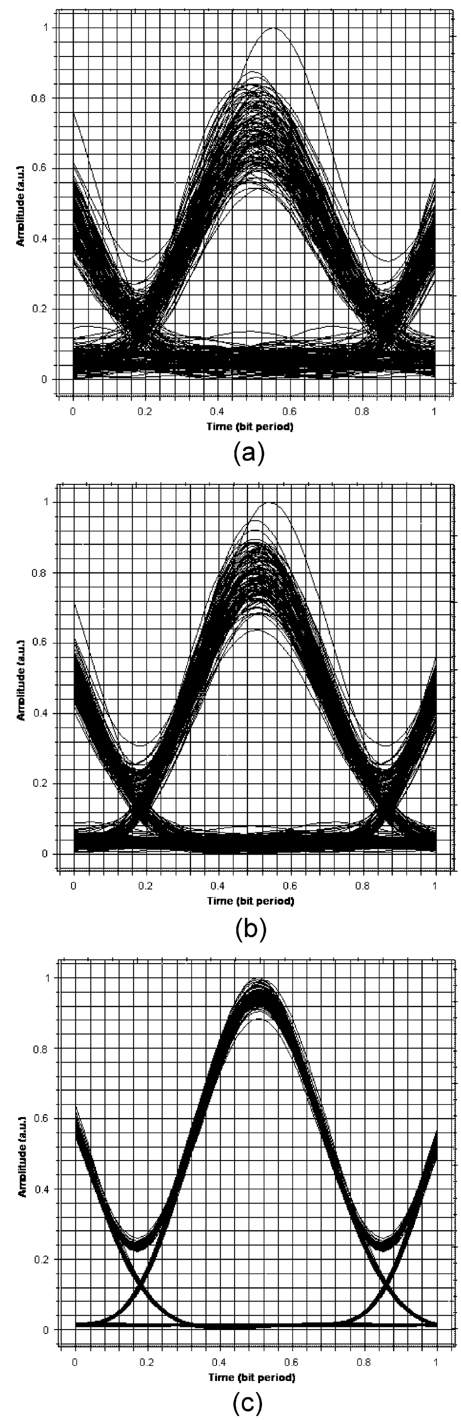

Fig. 6. Showing eye diagrams of MDRZ modulation format at Pin = 2 dBm after 750 km: (a) pre-compensation scheme, (b) post-compensation scheme and (c) symmetrical-compensation scheme.

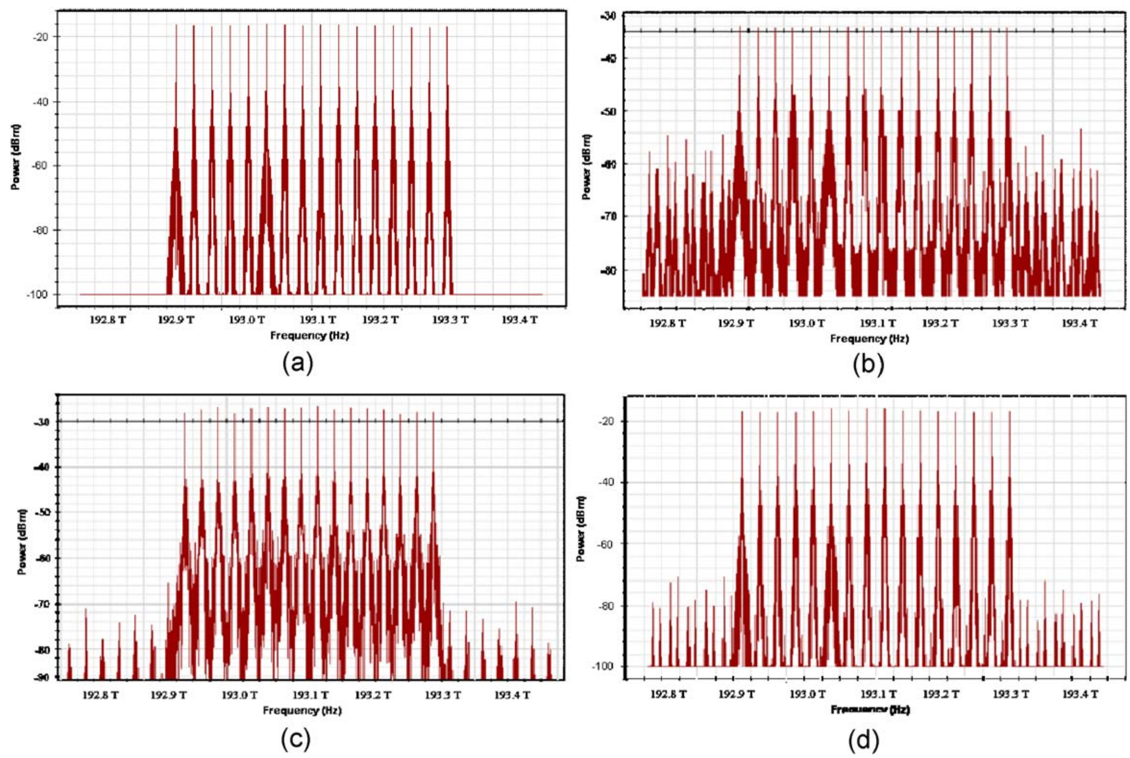

Fig. 7. Showing optical spectrum of 16 channels for symmetrical compensation scheme at Pin = −18 dBm after 1250 km: (a) input signal, (b) output of CSRZ modulation format, (c) output of DRZ modulation format and (d) output of MDRZ modulation format.

Table 3. Comparison of received power/channel and eye opening for various formats and compensation schemes with signal input power − 5 dBm..

Type of format	Received power/Ch (dBm)			%age eye opening for Ch1		
	Pre	Post	Symm	Pre	Post	Symm
CSRZ	−35.2	−29.5	−18.8	82.2	90.4	92.8
DRZ	−25.7	−21.3	−14.7	85.4	91.6	93.2
MDRZ	−18.5	−12.6	−6.8	89.3	92.7	95.6

distance of 750 km. The CSRZ modulation format although very resistant against group velocity dispersion (GVD) and self phase modulation (SPM) effect due to compact spectral width, but DWDM transmission causes more degradation owing to interchannel XPM and FWM because of spectral broadening caused by the phase variation. However, DRZ and MDRZ are stronger against linear crosstalk and interchannel FWM (IFWM) induced timing jitter as both these formats suppress all discrete frequency tones that appear in conventional RZ signal spectrum; whereas CSRZ only suppresses the optical carrier tone and creates sideband tones spaced at odd multiples of B/2 on both sides of carrier frequency. The finest eye opening is shown in Fig. 6(c) for MDRZ format using symmetrical-compensation.

The optical spectrum of 16 channels for symmetrical compensation scheme at Pin = −18 dBm after 1250 km are shown in Fig. 7. The input optical spectrum is shown in Fig. 7(a) where 16 channels are spread over the frequency range of 192.9–193.3 THz with the frequency spacing of 25 GHz between the adjacent signals. The output optical spectra for CSRZ, DRZ and MDRZ modulation format are shown in Fig. 7(b)–(d), respectively. It is clearly visible that spectrum of CSRZ format shows large number of spurious signals, thus proving that it has the lowest nonlinearity tolerance [1,2]. Due to the IFWM, the initial signal bandwidth has been

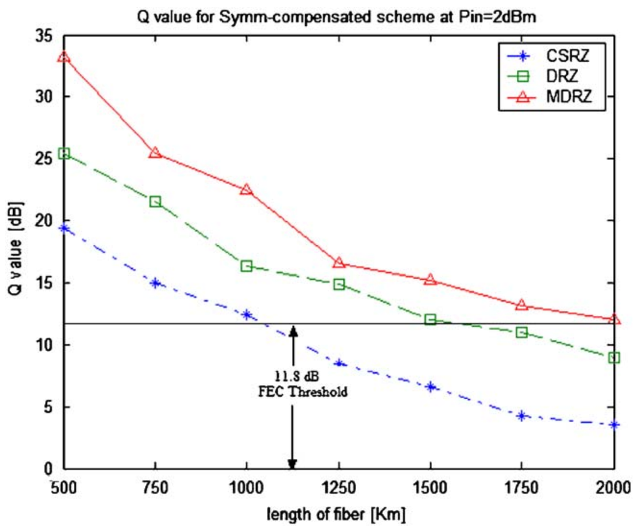

Fig. 8. Q value as a function of transmission distance for symmetrical-compensation scheme at input power Pin = 2 dBm, Ch# 1.

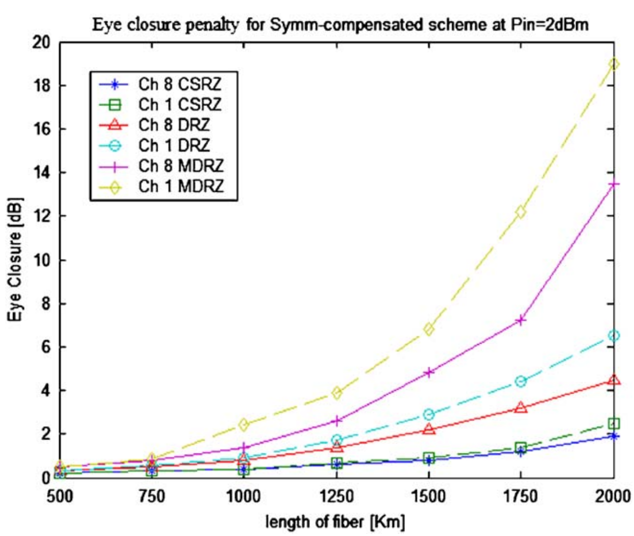

Fig. 9. Eye closure [dB] as a function of transmission distance for symmetrical-compensation scheme at input power Pin = 2 dBm.

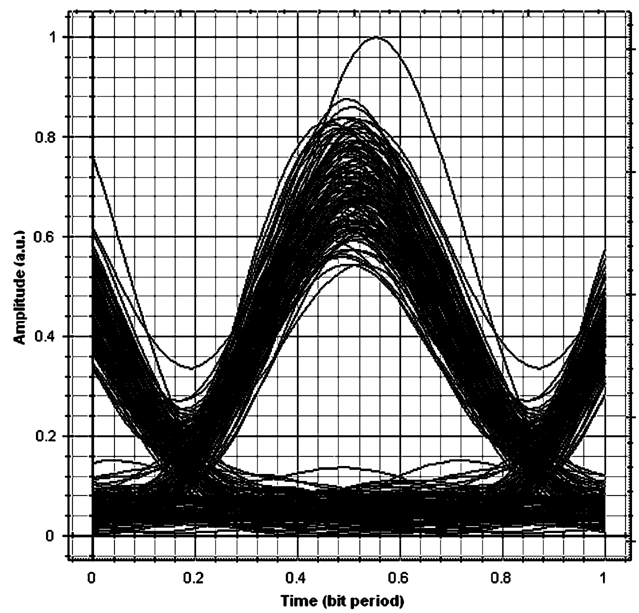

Fig. 10. Showing eye diagram of 32×40 Gb/s MDRZ modulation format at Pin = 2 dBm for ch#1 after 1450 km using symmetrical-compensation scheme.

expanded after the transmission through a nonlinear optical fiber. The wave frequencies interacting through FWM obeys $f_1+f_2=f_3+f_4$ and the interactions between input signal frequencies leads to the generation of new frequencies known also as "spurious waves" [6,7], which interact among each other leading to further bandwidth expansion. To accommodate the expanded bandwidth the simulated bandwidth has been chosen three times, so that second-order and higher order FWM products (i.e., products of the products) are aliased and thus their power is much smaller than that of the first order products. DRZ and MDRZ modulation format spectra as can be seen in Fig. 7(c) and (d) are less expanded and have lesser number of spurious signals as both these formats suppress all discrete frequency tones that appear in signal spectrum. Also, the ghost pulses caused by the IFWM between discrete tones are suppressed by the absence of tones in the signal spectrum. Furthermore, it is observed that the output power has dropped to −35 dBm for CSRZ format, −28 dBm for DRZ whereas it remains almost same as the input power for MDRZ modulation format, thus, largely degrading the performance of CSRZ and DRZ formats. The CSRZ format shows maximum power penalty of −17 dB, thus largely degrading the transmission performance of the system. The results are supported by the work reported in Refs. [1,5].

Table 3 illustrates the performance of various modulation formats based on the received power per channel and %age eye opening for pre, post and symmetrical compensation schemes with signal input power −5 dBm and transmission distance 750 km. For faithful transmission of the optical information, the minimum %age eye opening required is 80% corresponding to eye opening penalty (EOP) of 1 dB as per Ref. [3]. It is observed that the received power per channel is lowest for pre-compensation scheme i.e., −35 dBm for CSRZ modulation format and it is −6.8 dBm for MDRZ modulation format using symmetrical-compensation scheme. The similar trend is observed for %age eye opening for Ch1. The best performance is shown by the MDRZ format giving maximum %age eye opening value of 95.6%. However, DRZ format performs better than the CSRZ format as can be clearly visualized in the table.

The transmission performance of 16×40 Gb/s DWDM system using various formats for varying lengths is plotted in Fig. 8. Here Q value as a function of transmission distance for Symmetrical-compensation scheme at input power Pin = 2 dBm has been shown. It is seen that for the transmission distances more than 1050 km the Q value drops below the minimum specified value of 11.8 dB for CSRZ due to dominance of IFWM effect and amplified spontaneous emission (ASE) noise of in-line-EDFA's. DRZ format can be used for faithful transmission upto a distance of 1550 km, whereas MDRZ format seems to be most robust against the fiber nonlinearities and optical Kerr's effect thus can even be used beyond 2000 km. The graph shows that as the distance increases the Q value deteriorates. This shows improvement over the results reported in Refs. [1,9]. A similar trend is shown in Fig. 9**,** where eye closure penalty goes on increasing with the increasing distance. Here, eye closure penalty for various formats has been presented for Channel 1 (end channel) and Channel 8 (middle channel). The graph clearly shows that the end channels are more affected by interchannel FWM and produces more spurious frequencies as compared to the middle channels at 40 Gb/s.

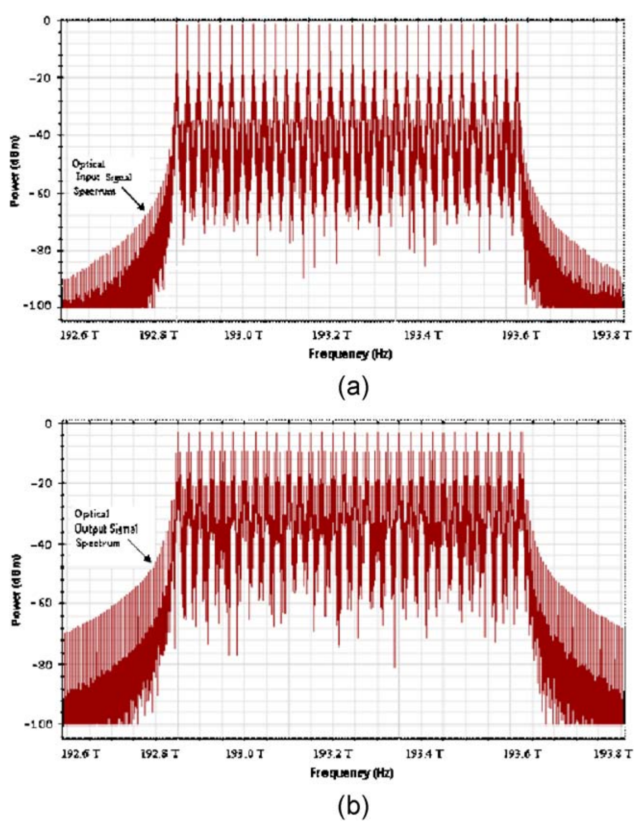

Fig. 11. Showing optical spectrum of 32 channels of MDRZ modulation format for symmetrical compensation scheme at Pin = 2 dBm after 1450 km: (a) input signal spectrum and (b) output signal spectrum.

Also reported in Ref. [14], the ASE noise and thermal noise of EDFA's at extreme bandwidth is more. It is further seen that the eye closure penalty for MDRZ format is less than 2 dB for both the channels whereas it approaches upto 19 dB for CSRZ format at 2000 km.

We also investigated the transmission performance of 32×40 Gb/s MDRZ based DWDM system with frequency range of 192.8–193.6 THz using 25 GHz frequency spacing between the adjacent channels. Fig. 10 shows the eye diagram obtained after1450 km for the system at Channel 1. The optical spectrum of input and output signals are shown in Fig. 11(a) and (b), respectively, for symmetrical-compensation scheme at Pin = 2 dBm. It is observed that we can reliably transmit the signal using MDRZ format over a distance 1450 km. The figure shows expansion of about 20% in the bandwidth of the optical spectrum owing to IFWM. Also, at this transmission distance, we obtained Q value >11.8 dB for all the channels and it is 12.3 at Channel 1.

5. Conclusions

We have simulated 16 channel 40 Gb/s DWDM system with 25 GHz channel spacing over a transmission distance of 2000 km using CSRZ, DRZ and MDRZ modulation formats. For this, we analyze the performance of the system for pre, post and symmetrical dispersion compensation schemes using DCF by varying the signal input power. Superior performance of MDRZ has been observed as it suppresses all the discrete frequency tones that appear in conventional RZ signal spectrum; whereas CSRZ only suppresses the optical carrier tone and creates sideband tones spaced at odd multiples of B/2 on both sides of carrier frequency. CSRZ format, thus results in the expansion of optical spectra and decline in the Q value. It is found that as the signal input power increases Q value increases up to certain limit (0–5 dBm) after which it starts decreasing which is due to the dominance of non-linear optical Kerr's effects like cross phase modulation (XPM) and FWM at higher power. It is established that symmetrical compensation shows better performance in terms of Q value, %age eye opening and received power as compared to pre and post dispersion compensation schemes. Further, maximum transmission distance obtained for 32 channel DWDM system for MDRZ format using symmetrical compensation scheme is 1450 km.

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