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Investigations on order and width of RZ super Gaussian pulse in pre-, post- and symmetrical-dispersion compensated 10 Gb/s optical communication system using standard and dispersion compensating fibers

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Abstract

We show the effect of varied order and width of super Gaussian pulse at 10 Gb/s in dispersion compensated optical communication system. The optical communication system consists of standard single-mode fiber of 16 ps/nm/km of a certain length, whose dispersion is compensated using pre-, post- and symmetrical-dispersion compensation schemes with proportionate length dispersion compensating fiber of −80 ps/nm/km. Performance of these three compensation schemes is compared at 14 dBm values of Er-doped fiber amplifiers (EDFA) power at 1st, 2nd and 3rd order RZ super Gaussian optical pulse. The pulse width, full width at half maximum (FWHM) is also varied from 5 to 30 ps to highlight the optimum performance. The graphical results obtained show a relationship among the attributes pulse width, order of RZ super Gaussian optical pulse and dispersion compensation scheme implemented. It shows that to decrease BER and timing jitter in the system, smaller width and 3rd order super Gaussian pulse should be used. It is recommended that to decrease dependency of BER and timing jitter in the communication system on the pulse width i.e. FWHM, the symmetrical compensation scheme should be implemented.

Keyword: Super Gaussian; Dispersion compensation; Timing jitter; Bit error rate

1. Introduction

Optical communication systems have revolutionized the whole telecom world with its deployment. This has happened virtually because of its number of advantages over long distance transmissions. Day-by-day the obstacles posed in the improvement for better performance are being removed. As attenuation, loss of optical signal has been compensated by the use of optical amplifiers like Er-doped fiber amplifiers (EDFA). These amplifiers restore the optical signal strength without regeneration. The frequent regeneration was also one of the problems in the earlier optical communication systems. As EDFA's works on wavelength 1550 nm, chromatic dispersion becomes main cause of concern since the conventional single-mode fiber provide zero dispersion wavelength near 1300 nm. To decrease the chromatic dispersion, one idea is the deployment a of new fiber having low

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chromatic dispersion at 1550 nm but seems cumbersome to implement. Thus, use of EDFA with conventional optical communication systems demand dispersion management as an essential technique for upgrading the bit rate of existing optical links to meet the increasing traffic demand [1]. In fact, for systems operating above 10 Gb/s over standard single-mode fibers, dispersion compensation is mandatory, even for metro distances. Several methods have been proposed to overcome the impairments caused by chromatic dispersion including initial pre-chirp [2,3], microchip compensation [4], mid span spectral inversion [5], optical phase conjugation [6–8], dispersion-supported transmission [9], dispersion compensating devices [10–12] and differential delay method [13–17]. The use of dispersion compensating fiber is an important method for dispersion compensation and to upgrade the already installed links of single-mode fiber [18–19]. Dispersion compensating fibers (DCFs) are specially designed fibers with negative dispersion. The high value of negative dispersion is used to compensate for positive dispersion over large lengths of standard single-mode fibers (SSMFs). Spans made of single-mode fibers and dispersion compensating fibers are good candidates for long distance transmission as their high local dispersion is known to reduce the phase matching giving rise to four wave mixing in wavelength division multiplexed (WDM) systems. Signal degradation in such systems is due to combined effects of group velocity dispersion, Kerr nonlinearity and accumulation of amplified spontaneous emission due to periodic

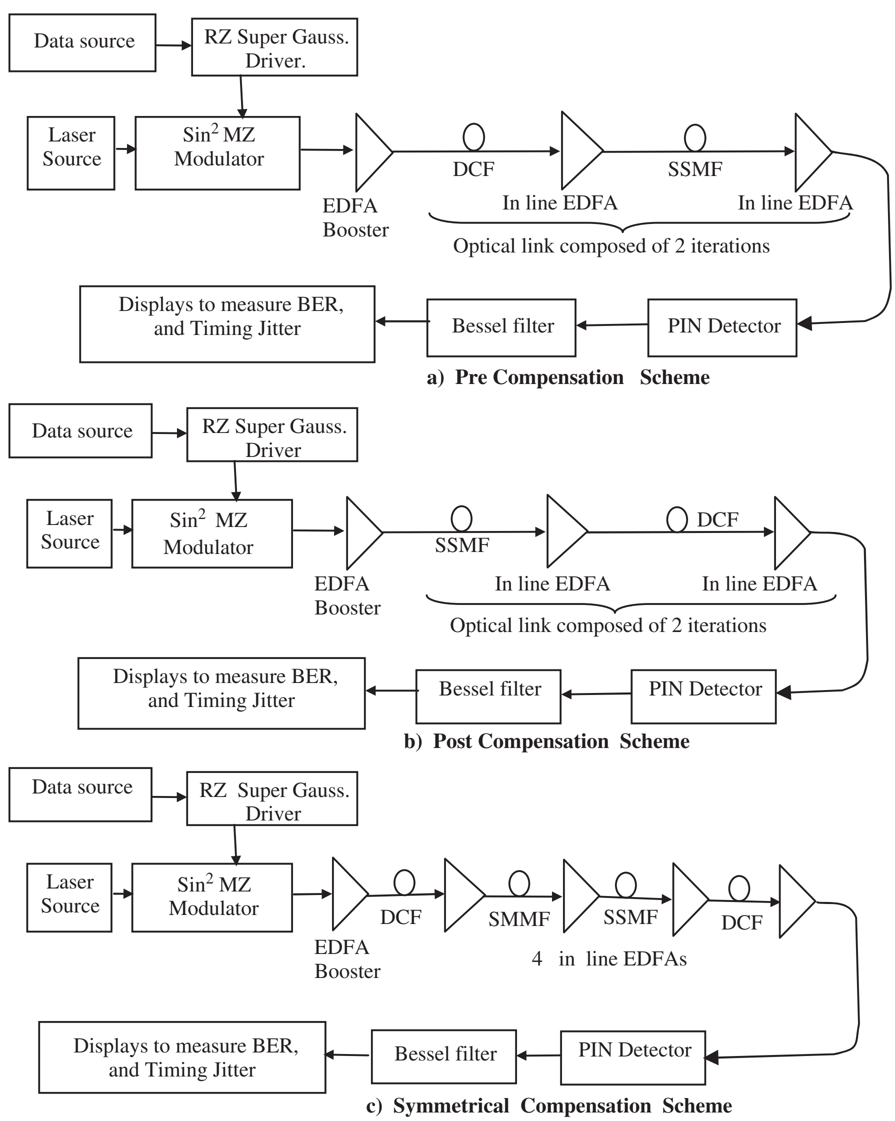


Fig. 1. 10 Gb/s Optical communication system models using dispersion compensating (DCF) fiber of 24 km ($D = -80$ps/nm/km) & Standard single mode fiber (SSMF) 120 km ($D = 16$ ps/nm/km) for comparing duty cycle with three dispersion compensation schemes (a) pre (b) post and (c) symmetrical.

amplification. The dispersion compensation with DCFs is done by three schemes, pre-, post- and symmetrical compensation. In the first method, the optical communication system is pre compensated by the dispersion compensating fiber of negative dispersion against the standard fiber. In the second method, the optical communication system is post compensated by the dispersion compensating fiber of negative dispersion against the standard fiber. In the third method, the optical communication system is symmetrically compensated by two dispersion compensating fibers of negative dispersion against the standard fiber in between. Due to the nonlinear nature of propagation, system performance depends upon power levels [20] and the position of dispersion compensating fibers [21].

At the same time, data formats of optical signal have been explored in dispersion compensated optical communication systems, which play a vital role in its performance. The need of proper data format of optical pulse is the basic requirement still found in literature with equal importance. WDM systems with single-channel data transmission rates of 10 Gb/s have been studied by comparing three different modulation formats: NRZ, RZ without initial chirp, and CRZ [22]. It is suggested that in order to obtain a transmission distance greater than 5000 km with reasonable power margins, CRZ modulation format and symmetrical dispersion compensation is preferred. For the RZ optical signal pulse duty cycle is investigated in 10-Gb/s/ch long-distance transmission. It is seen that the optimum duty factor depends on GVD compensation interval for single-channel transmission. Also, reduced duty factor value suppresses XPM-induced waveform distortion in WDM transmission. Analysis of both single-channel and WDM transmission showed that duty factors 0.5 were suitable for a dispersion managed system with GVD compensation interval of 500 km and a fiber dispersion parameter of 1 ps/nm/km [23]. Numerically, the performance of dispersion managed 40 Gb/s TDM-transmission systems over the already installed standard fiber has been analyzed in simulations assuming conventional NRZ and RZ-modulation format with different duty ratios. It is shown that for 40 Gb/s TDM-systems, RZ-modulation format with a duty cycle of 0.5 is inherently superior to the conventional NRZ-transmission scheme [24–28].

Another data format explored is super Gaussian pulse format. On the basis of calculations carried out, it has

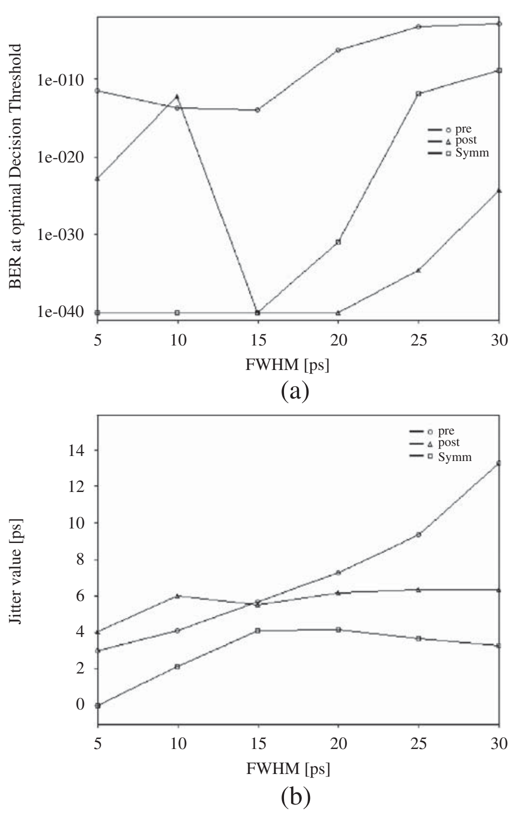


Fig. 2. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 1 of the optical super Gaussian pulse with DCF of 12 km & SSMF of 60 km for three dispersion compensation schemes pre, post and symmetrical.

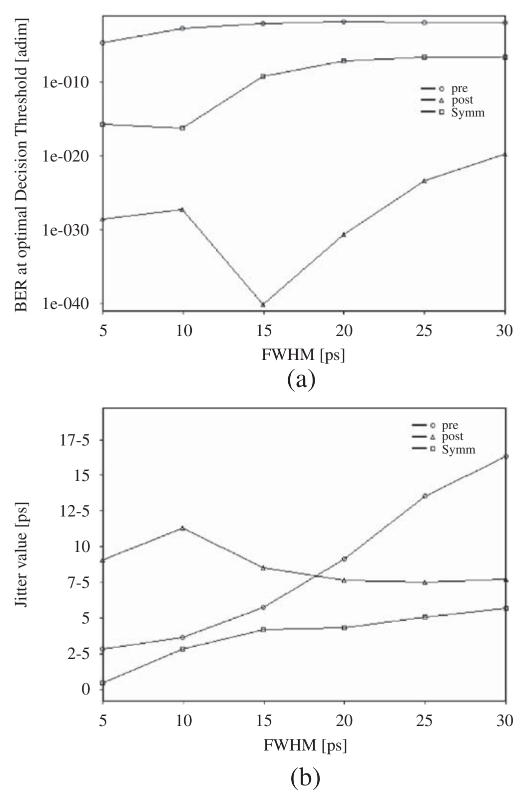


Fig. 3. Bit error rate (a) and timing jitter (b) variation against the optical super Gaussian pulse width (FWHM) at an order 1 with DCF of 18 km & SSMF of 90 km for three dispersion compensation schemes pre, post and symmetrical.

been found that super Gaussian shape is less sensitive to the destructive influence of the initial linear chirp than Gaussian pulse, and Gaussian shape is less sensitive to initial chirp than hyperbolic secant shape pulse [29]. When the chromatic dispersion is taken into the account, the evolution of an incident super Gaussian pulse during propagation in single-mode fibers numerically show that for an incident super Gaussian pulse, with steep leading and trailing edges, its shape undergoes a variation from near-rectangular to two-peak and, finally, to single-peak. Meanwhile its peak intensity increases at first then, after passing a maximum, finally decreases monotonically [30].

Here, the study is further extended through this paper by taking optical pulse of super Gaussian shape whose order 1st, 2nd and 3rd are taken and observed under different dispersion compensation schemes pre-, post- and symmetrical. In Section 2, the optical simulated project and parameters are defined. In Section 3 comparison results have been reported for these compensation methods and finally in Section 4, conclusions are drawn.

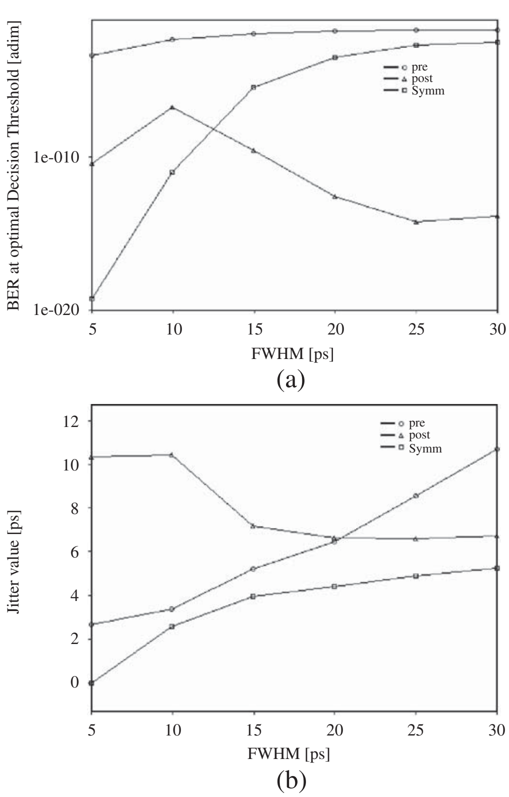


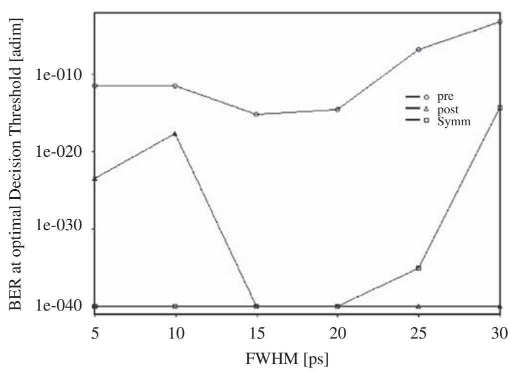
Fig. 4. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 1 of the optical super Gaussian pulse with DCF of 24 km & SSMF of 120 km for three dispersion compensation schemes pre, post and symmetrical.

2. System description

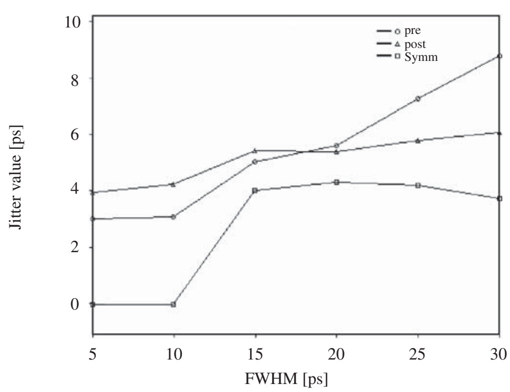
The block diagrams for simulation of pre-, post- and symmetrical-compensation methods using standard and dispersion compensating fibers are shown in Fig. 1. In the figure, each transmitter section consists of data source, electrical driver, laser source, and amplitude modulator. The data source is return to zero (RZ) super Gaussian data format at 10 Gb/s bit rate shown in each pre-, post- and symmetrical dispersion compensation scheme. The electrical driver is important component that generates the desired data transmission format. It converts the logical input signal, a binary sequence of zeros and ones into an electrical signal for pre-, post- and symmetrical configurations, respectively. The laser source in three configurations generates laser beam at 1550 nm. The output of modulator is fed to optical link through EDFA amplifier. The pre- and post-compensations are defined over the span. Two spans are considered so that there are two dispersion compensating fibers each of length L_{DCF} km with −80 ps/nm/km dispersion and two single-mode fibers each of length L_{SSMF} km with 16 ps/nm/km dispersion. The optical signal is amplified after both types of fibers with EDFA amplifiers for pre- and post-compensation over one span so there are total of five EDFA amplifiers in the link. In the first case, the optical communication system is pre compensated by the dispersion compensating fiber of negative dispersion (−80 ps/nm/km of length L_{DCF} km) against the standard fiber (16 ps/nm/km of length L_{SSMF} km) over the span. In the second case, the optical communication system is post-compensated by the dispersion compensating fiber of negative dispersion (−80 ps/nm/km of length L_{DCF} km) against the standard fiber (16 ps/nm/km of length L_{SSMF} km) over the span. In order to compare the three compensation configurations, we define equivalent symmetrical compensation configuration in the third case whereby the system is symmetrically compensated by two dispersion compensating fibers of negative dispersion (−80 ps/nm/km each of length L_{DCF} km) against two standard fibers (16 ps/nm/km of length L_{SSMF} km) with in between amplification by EDFA after each type of fiber. So there are five EDFA amplifiers for this configuration also. Length of optical link comes out, $L_{optical\ link} = 2 \times L_{SSMF}$ (km) in each case. It is kept equal to obtain comparative results for them. The optical communication link length in each case is calculated and listed in Table 1. The output is detected at the receiver by PIN detector and is passed through electrical filter and output is observed on BER meter to read corresponding values which are subsequently plotted. The laser is of type CW Lorentzian with laser center emission frequency 1550 nm (193.4145 THz). The amplitude modulator is of type sine square with excess loss of 3 dB. The simulated bit rate is 10 GHz. The EDFAs are of fixed

Table 1. Optical Communication link length cases considered for the study of an order of optical Gaussian pulse for the system under each dispersion compensation schemes pre, post and symmetrical (*Link length is calculated by omitting DCF length).

S. no.	L_{DCF} (km)	L_{SSMF} (km)	$L_{optical\ link}{}^{*} = 2\times(L_{DCF}+L_{SSMF})$ km
1	12	60	120
2	18	90	180
3	24	120	240



(a)



(b)

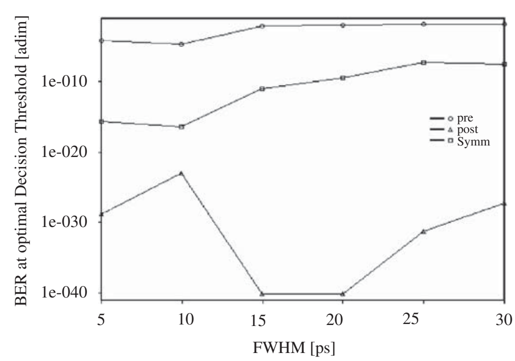
Fig. 5. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 2 of the optical super Gaussian pulse with DCF of 12 km & SSMF of 60 km for three dispersion compensation schemes pre, post and symmetrical.

output power type each with noise figure of 4.5 dB. The electrical filter is of the type Bessel with 3 dB bandwidth equal to 8 GHz. The detector is PIN diode with response 0.875. For comparison, 1 mW signal power is fed into the optical communication link. All fiber nonlinear, birefringence and polarization mode dispersion effects are considered in the simulations. The PMD coefficient of both single-mode fiber and dispersion compensating fiber is 0.1 ps/km$^{0.5}$. The attenuation and nonlinear coefficient for dispersion compensating fiber are 0.6 dB/km & 1.8 W^{-1} km^{-1} and that of standard fiber is 0.2 dB/km & 1.2 W^{-1} km^{-1}, respectively.

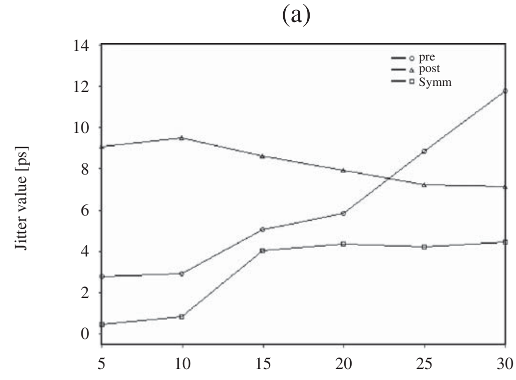
3. Results and discussion

Sequence lengths of 1024 bits are used to obtain realistic output values at the receiver. The calculation of the propagation in the optical fibers is performed by standard split-step algorithm with adaptive step-size. In order to observe the dependence of RZ super Gaussian optical pulse width i.e. full width at half maximum (FWHM) in the range of 5–30 ps and its order 1st, 2nd and 3rd are considered from the source side. Five-fixed gain output EDFAs are used in link whose gains are kept to a level 14 dBm.

Initially, optical Gaussian pulse of 1st order is applied to the system and its results are shown in the Figs. 2–4 for three different link lengths as per the Table 1 when chromatic dispersion is compensated with pre-, post- and symmetrical-compensation schemes. In Fig. 2, optical link length consists of 12 km DCF and 60 km



(a)



(b)

Fig. 6. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 2 of the optical super Gaussian pulse with DCF of 18 km & SSMF of 90 km for three dispersion compensation schemes pre, post and symmetrical.

SSMF to make at total optical link length 120 km. For the setup, it is observed in the Fig. 2(a) that pre compensation scheme gives the poorest performance by indicating BER $< 10^{-10}$ only when FWHM is kept less than 15 ps of width. The post-compensation scheme gives better performance if FWHM is kept greater than 15 ps considered. The least value of BER has been shown by the symmetrical compensation scheme for FWHM value 15 ps though system can be operated below 25 ps. As per the Fig. 2(b), the symmetrical compensation also guarantees timing jitter value less than 30 ps throughout the range of FWHM taken. Comparing the three schemes in the Fig. 2(b), smaller value of FWHM will be always advisable for lower value of timing jitter. Fig. 3(a) and (b) shows the case of 18 DCF and 90 SSMF in the link. It indicates BER and timing jitter is deteriorating at larger distance because of nonlinear effect and ASE noise accumulation of the system. The post-compensation scheme has the least value of BER $< 10^{-20}$ throughout the range of FWHM. The trend of overall BER and timing jitter increase is also evident from the Fig. 4(a) and (b) for the case of DCF 24 km and SSMF 120 km. It can be further observed that the post-compensation scheme give better result for greater FHWM while the symmetrical compensation scheme at lower value of FWHM.

In the next trial, 2nd order super Gaussian optical pulse model is used whose result has been indicated by Figs. 5–7 and its parts. The result of Fig. 2(a) shows that symmetrical compensation scheme gives the best performance by BER value quite low of the order 10^{-40} throughout the range of optical pulse width (FWHM) in the 120 km optical communication system but on comparison of Figs. 2(a) and 5 (a) higher-order super Gaussian optical pulse gives better performance. Thus, for the same optical link length and under other similar conditions of the setup, 2nd order optical pulse gives better result than 1st order as BER and timing jitter is less in the former. The pre compensation scheme gives BER close to the maximum permissible value (10^{-10}) up to FWHM < 20 ps that too is increasing if link length is further increased. The symmetrical compensation gives intermediate performance as evident from the results in Figs. 8(a), 9(a), 10(a), as optical link length increases, the post compensation observed to be a leader. The pre compensation is ruled out for desired optimum reliable operation. By going through the timing jitter graphs in figures from Figs. 2–10, one can conclude that the

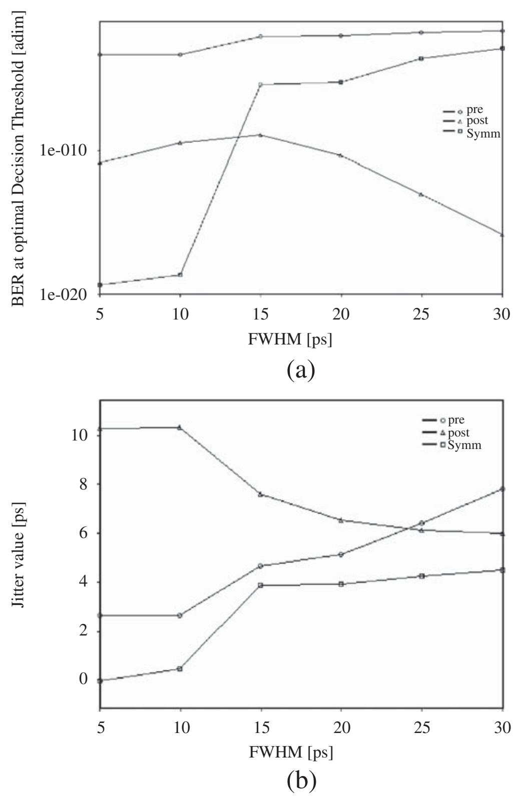


Fig. 7. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 2 of the optical super Gaussian pulse with DCF of 24 km & SSMF of 120 km for three dispersion compensation schemes pre, post and symmetrical.

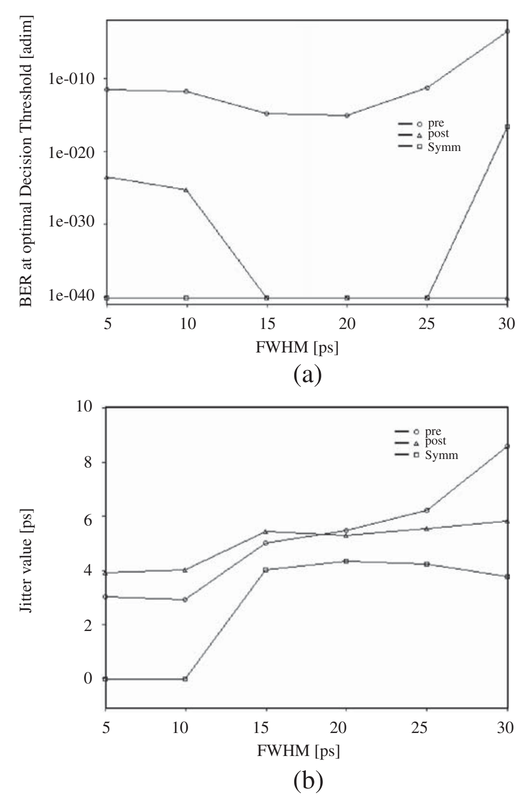


Fig. 8. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 3 of the optical super Gaussian pulse with DCF of 12 km & SSMF of 60 km for three dispersion compensation schemes pre, post and symmetrical.

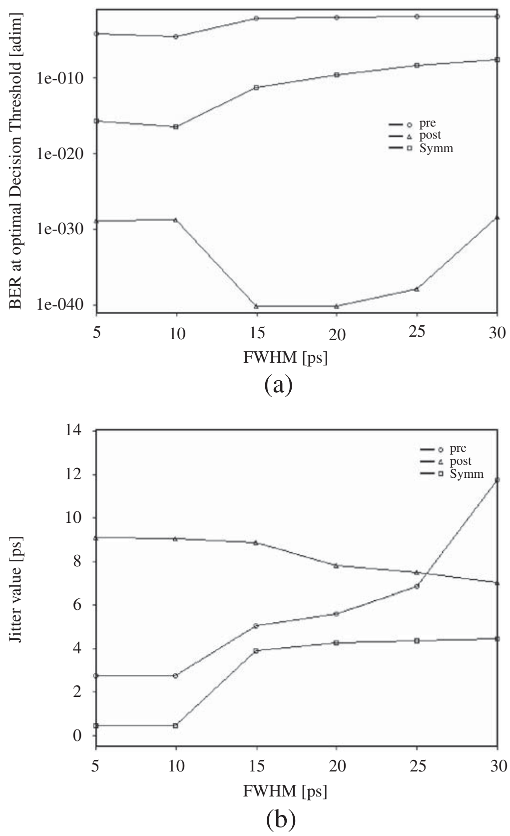


Fig. 9. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 3 of the optical super Gaussian pulse with DCF of 18 km & SSMF of 90 km for three dispersion compensation schemes pre, post and symmetrical.

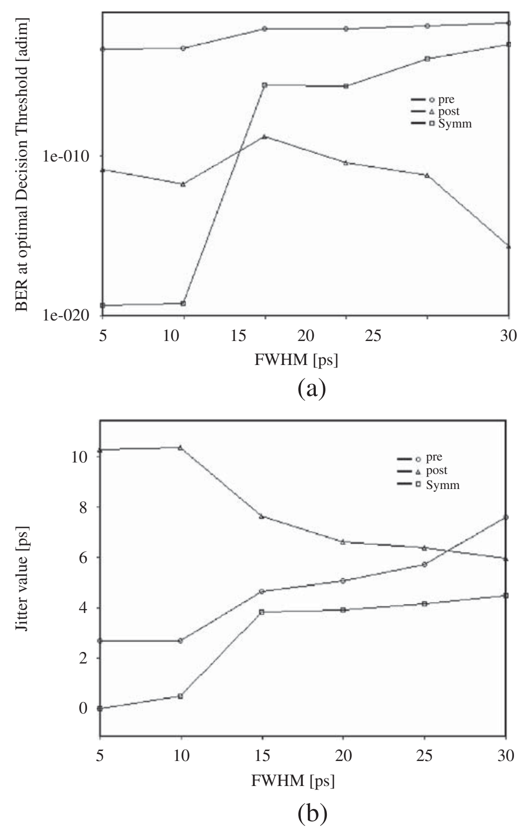


Fig. 10. Bit error rate (a) and timing jitter (b) variation against width (FWHM) at an order 3 of the optical super Gaussian with DCF of 24 km & SSMF of 120 km for three dispersion compensation schemes pre, post and symmetrical.

overall jiter can be decreased with use of the symmetrical dispersion compensation scheme and smaller value of FWHM and higher order of optical super Gaussian pulse out of three cases taken up here.

4. Conclusions

Optical communication system is sensitive to the type of dispersion compensation scheme and to the order of super Gaussian pulse as well as pulse width i.e. FWHM. These three attributes of optical communication system are observed over various optical link lengths. The important conclusions observed are that to improve the system performance, firstly the symmetrical dispersion compensation scheme may be used in some cases although post-dispersion compensation scheme could do better according to the pulse width and the order. Secondly, 3rd order optical super Gaussian pulse among the orders considered 1st, 2nd and 3rd is the preferred candidate to improve the system performance. For long distance, timing jitter and BER are less in 3rd order of super Gaussian pulse giving more flexibility to size of pulse i.e. FWHM. However, timing jitter performance dependency on pulse width can be decreased if the symmetrical compensation is implemented.

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