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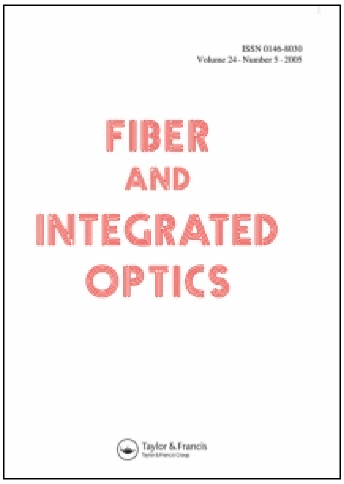

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Investigations on Timing Jitter by Chirp Selection of External Modulator in Return-to-Zero Optical Soliton Pulse Transmission at 10 Gb/s

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Investigations on Timing Jitter by Chirp Selection of External Modulator in Return-to-Zero Optical Soliton Pulse Transmission at 10 Gb/s

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Abstract *We investigate the chirp selection of externally modulated return-to-zero soliton pulse at 10 Gb/s for fiber optical communication system for the reduction in timing jitter. The chirp range (-5 to $+5$), as well as the effect of the post compensation, have been examined up to ten regenerated fiber spans in the link. Here, it is shown that the chirp value of the external modulator should be set to either 0 or -1 to reduce timing jitter. Moreover, for more number of spans, it will be better to adopt other chirp values.*

Keywords chirp, dispersion, timing jitter

Introduction

Pre-distorting the pulse shape in a certain way at the transmitter has been believed to be a technique to get improved optical communication systems. The pre-chirping method is one such scheme used to reduce the timing jitter in optical communication systems. The pre-chirping and pre-shaping method can stabilize the variation of pulse shape due to the perturbation of dispersion compensation fiber (DCF) and timing jitter can be greatly reduced [1, 2]. Chirped return-to-zero (CRZ) modulation format has been observed to have significant advantages comparatively over the non-return-to-zero (NRZ) modulation format in wavelength division multiplexing (WDM) systems. The dynamics of the CRZ systems provides carefully distinguishing noise and single-channel as well as multichannel nonlinear effects.

Chirping of the transmission pulse has been achieved by the chirp factor of modulators or lasers. The main interest in chirp has, so far, been shown for lasers. In comparison, a much smaller interest has been shown for the chirp properties of external optical modulators [3–7]. In modulators, chirp is achieved by current modulation in them, which induces changes in the refractive index and leads to changes of the frequency of the light. This frequency variation is commonly referred to as frequency chirp. Mathematically, assume an adjustable DC bias, which imposes a phase shift $\Delta\varphi_{DC}$ between the two optical branches of the Mach-Zehnder structure. When a high frequency sinusoidal

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voltage, $V(t) = V_0 \cos(\Omega t)$, is applied to the transmission lines, V_0 is the amplitude of the applied voltage and Ω is the modulation frequency. The output optical field whose spectral density is measured with a scanning Fabry Perot can be written as Eq. (1) [5]:

$$E(t) = E_0 \exp(i\omega_0 t) \times [\exp(jA_1 \times \cos(\Omega t)) + \gamma \times \exp(jA_2 \times \cos(\Omega t)) + j\Delta\varphi_{DC}], \tag{1}$$

where ω_0 and E_0 are, respectively, the frequency and amplitude of the optical wave, and the scaling factor, $\gamma(0 \leq \gamma \leq 1)$, accounts for a finite extinction ratio. A_1 and A_2 denote the magnitude of the optical phase induced in each optical path. The chirp parameter of an external modulator is defined by Eq. (2) [6]:

$$\alpha = \frac{\dfrac{d\varphi}{dt}}{\dfrac{1}{2I(t)} \times \dfrac{dI}{dt}}, \tag{2}$$

where $\varphi(t)$ and $I(t)$ are the instantaneous phase and intensity of the output optical wave, respectively. The influence of modulator chirp in assessing the performance implications of the group delay ripple (GDR) [8–14] of DCF Bragg grating has been observed using four modulators—an electroabsorption modulator, a monolithically integrated distributed feedback laser and electroabsorption modulator, a multiple quantum-well Mach-Zehnder modulator, and a $LiNbO_3$ Mach-Zehnder modulator [9].

The investigation has also revealed that the interplay between the residual and applied chirp of optical duo-binary modulated signals improves transmission performance. The residual chirp accompanying the finite extinction ratio and the applied chirp adjusted by the applied voltage ratio (the chirp parameter) between two electrodes of $LiNbO_3$ modulators is used in 10-Gb/s optical duo-binary transmitters to find the best performance [15]. It has been observed that wide range of chirp was not explored except for Cartledge and Chen [9], who studied the chirp selection of the modulator without the extent of dispersion compensation. Particularly, the post dispersion compensation scheme in which a fiber is placed at the end of last amplifier to reduce net accumulated dispersion has been theoretically found for CRZ systems. The timing jitter (σ_t^2) for such systems is given by Eq. (3) [16]:

$$\sigma_t^2 = (S_{sp}/E_0)T_m^2 \lfloor N_A + N_A(N_A d + C_0 + d_f)^2 \rfloor \tag{3}$$

where C_0 is the input chirp, S_{sp} is spectral density, E_0 is energy of input pulse, $d = \overline{\beta}_2 L_A/T_m^2$, $d_f = \beta_{2f} L_f/T_m^2$ for a post DCF of length L_f, N_A is the number of amplifiers in the link, and minimum pulse width T_m occurs when unchirped and dispersion β_{2f}. As interpreted earlier [16], without post compensation ($d_f = 0$), the dominant term is $N_A^3 d^2$, i.e., cubic relationship with number of amplifiers (N_A). In case average dispersion becomes zero, cubic dependence vanishes. The smallest value of chirp exists when $N_A d + C_0 + d_f = 0$. It gives zero net dispersion over the entire link including initially introduced chirp.

In this article, the work reported in Refs. [9, 16–19] has been further explored on chirp selection of externally modulated return-to-zero soliton at 10 Gb/s for fiber dispersion compensated optical communication system. The modulator chirp parameter, α, considered is in the range of -5 to $+5$ and a varied post DCF is deployed to locate its optimal performing length. At the receiver, sensitivity has been investigated for the chirp range and DCF length to reduce the timing jitter.

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System Description

The block diagram of the optical communication system being considered is given in Figure 1. The data source is pseudo random having a bit rate of 10 Gbit/s with 31 samples per bit using a polynomial of 7°. The return-to-zero (RZ) soliton driver converts logical inputs to electrical outputs −2.5 V low level and 2.5 V high level with 30 ps full wave at half maximum pulse width. The number of poles in low pass filter has been kept to five and uses the −3 dB cutoff frequency of 8 GHz.

The modulator is a single arm Mach-Zehnder amplitude modulator with $\sin^2$ electrical-shaped input-output (P-V) characteristic. The typical transfer function is taken for a Mach-Zehnder external modulator based on the electro-optic effects in the $LiNbO_3$ devices. The level of extinction ratio (corresponding to the ratio between the maximum and minimum values of the input-output transmission characteristics) is kept ideal and the chirp factor, α, is varied in discrete values −5, −3, −1, 0, 1, 3, and 5. The input voltage is equal to maximum transmissivity offset voltage and the power of the optical signal is attenuated by the excess loss only, so the modulator attains the state of maximum transmission. The standard single-mode fiber (SSMF) of length 60 km is taken in the presence of fiber's nonlinearity, polarization mode dispersion (PMD) and birefringence but without Raman crosstalk. The reference wavelength is 1,550 nm at which loss is 0.25 dB/km having −2 ps/nm/km dispersion and 20 km dispersion correlation length. The fiber nonlinearity coefficient is 1.8, the core effective area is 67.56×10^{-12} m^2, and fiber PMD is 0.1 ps/km$^{0.5}$.

The in-line erbium doped fiber amplitude (EDFA) optical amplifier has fixed output power of 3 dBm after every 60 km of fiber span depending upon the case under investigation. After amplification, the optical signal is passed through a DCF of variable length in

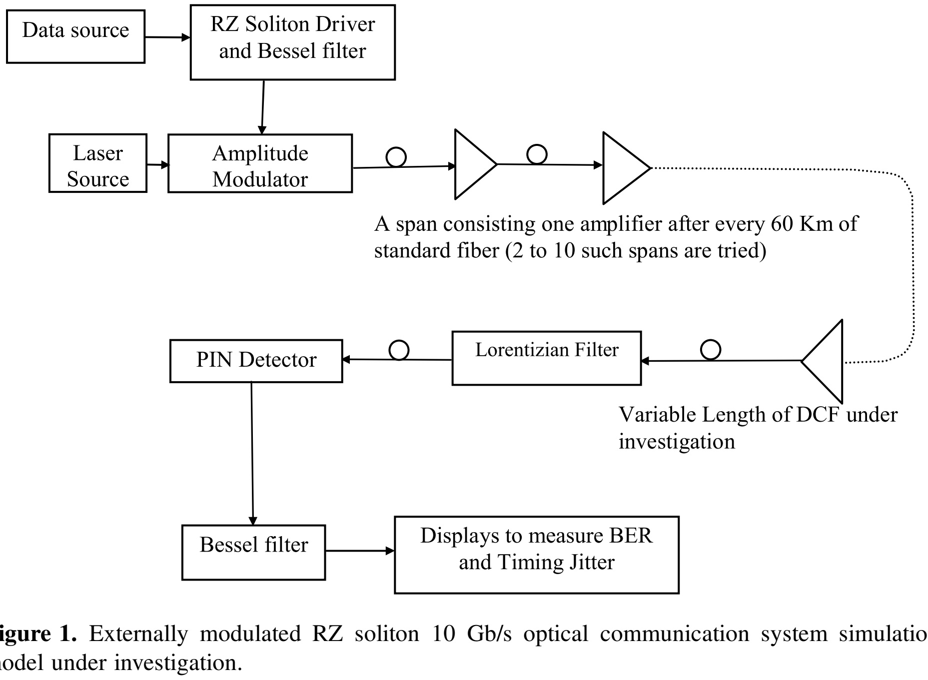

Figure 1. Externally modulated RZ soliton 10 Gb/s optical communication system simulation model under investigation.

the range of 10–100 km in step change of 5 km with a reference wavelength of 1,550 nm, loss of 0.25 dB, dispersion of 16 ps/nm/km, effective core area of 67.56×10^{-12} m^2, and 0.1 $ps/km^{0.5}$ fiber PMD. At receiver, optical signal is pre-amplified with 3 dBm fixed output power amplifier and is then passed through a 3-stage Lorentzian filter of center wavelength of 1,550 nm. The detection is done with the use of PIN photodiode at 1,550 nm wavelength of 0.7 quantum efficiency, 0.875 A/W responsivity, and 0.1 nA dark current. Electrical filter of low pass Bessel type with 5 poles and −3 dB bandwidth gives the electrical signal, which is subsequently measured for bit rate error (BER) and timing jitter.

Results, Analysis, and Discussions

Initially, the simulation setup/model shown in Figure 1 is considered for two spans (consisting of two amplifiers) with modulator chirp of −5, −3, −1, 0, 1, 3, and 5. The corresponding results in the form of graphs are shown in Figures 2–5. Figures 2a and 2b plots show timing jitter and BER variations for different DCF lengths. The BER and timing jitter has been found to be closely related and defines performance of an optical communication system [20]. These graphs indicate that the BER is under 10^{-10} (permissible limit) if length is taken in the range of 10–20 km irrespective of the chirp value. Also, it is observed that the chirp value of −1 and 0 gives the widest range of DCF length, i.e., 10–50 km where BER $< 10^{-9}$ and timing jitter remains below 5 ps.

The simulation model is now set for four spans and its results have been plotted in Figure 3 displaying timing jitter and BER against DCF length. In the figure, the performance for each chirp −5, −3, −1, 0, 1, 3, and 5 have been superimposed. It makes evident that DCF length required for each chirp value is shifted to a higher side. It suggests that DCF length required to obtain a minimum BER $< 10^{-9}$ is in the range of 20–40 km for all chirp cases instead of the range of 10–20 km required earlier in the case of two spans.

The behavior of the system in Figures 3a and 3b also indicates that chirp selection should be either 0 or −1 to make DCF length insensitive. The better performing chirp values expected here are consistent with the theoretical results found, which endorses the use of chirp value −1 or 0 to increase the transmission length of the optical system [20]. For six spans (also six amplifiers), performance was also observed (not shown in diagrams), which again emphasizes selection of chirp −1 or 0 with DCF in the range of 10–70 km for the best performance according to its combination with chirp value. But, in general, for optimum setup, DCF length required is 40 to 50 km for any chirp value.

Lastly, the ten amplifier spans are considered and the corresponding results are plotted in Figure 4 indicating a similar trend. However, it shows that chirp −1 and 0 produce timing jitter greater than 5 ps; therefore, higher values of chirp, such as 5 and 3, should be considered. Also from the figures, it suggested that the DCF length required is in the range of 70–80 km. The successive deterioration can be justified on the basis of nonlinearities and dispersion increase in the system, which is causing eye closure penalty. In order to see the effect of drift, the same simulation set up considering chirp −1 for all the cases observed have been plotted simultaneously in Figure 5. The comparative variations for 2, 4, 6, and 10 spans have shown that the region of minimum BER is drifting toward the higher values of DCF length. The smallest timing jitter was at 40 km DCF average length in the case of 2 and 4 amplifier spans which shifted to a length of 80–90 km for 10 spans. The chirp can be a controlling parameter for timing jitter in a system already set.

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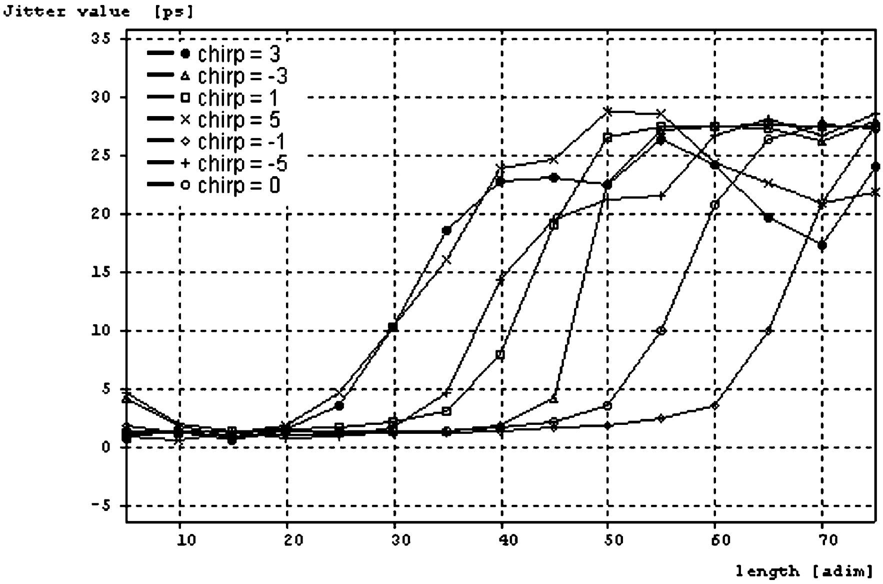
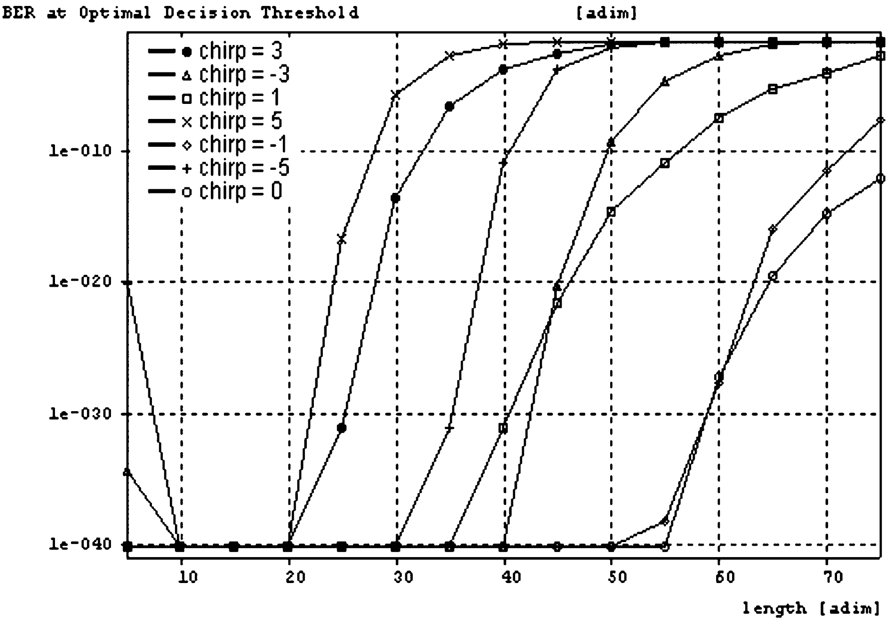


(a)



(b)

Figure 2. Performance of 2 spans in the link with varied DCF length at chirp values = −5, −3, −1, 0, 1, 3, and 5: (a) timing jitter and (b) BER.

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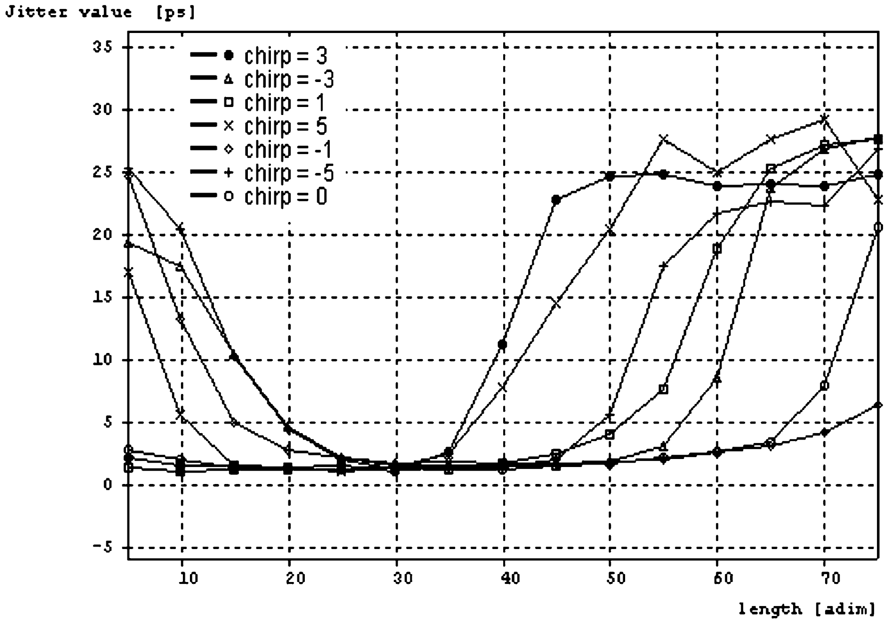

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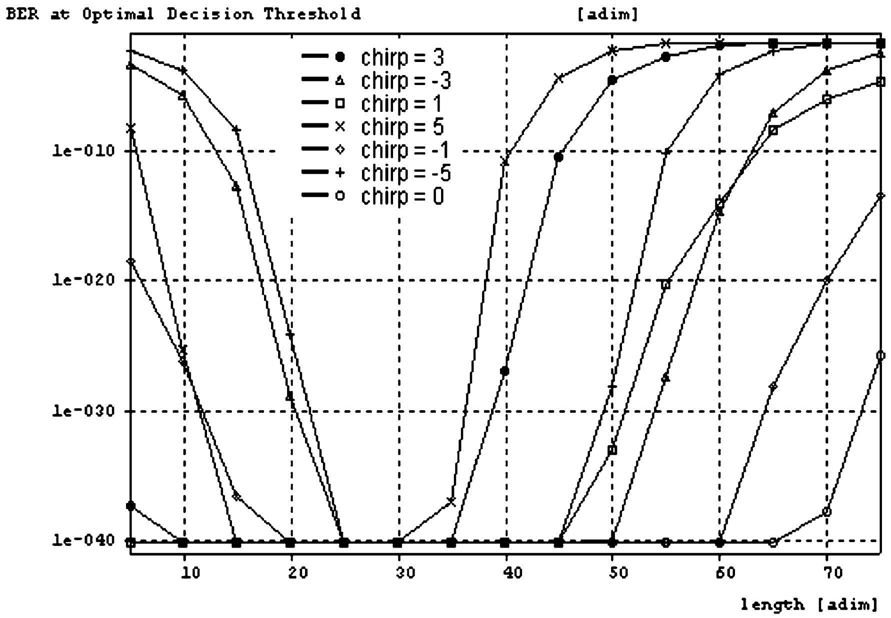

(b)

Figure 3. Performance of 4 spans in the link with varied DCF length at chirp values = −5, −3, −1, 0, 1, 3, and 5: (a) timing jitter and (b) BER.

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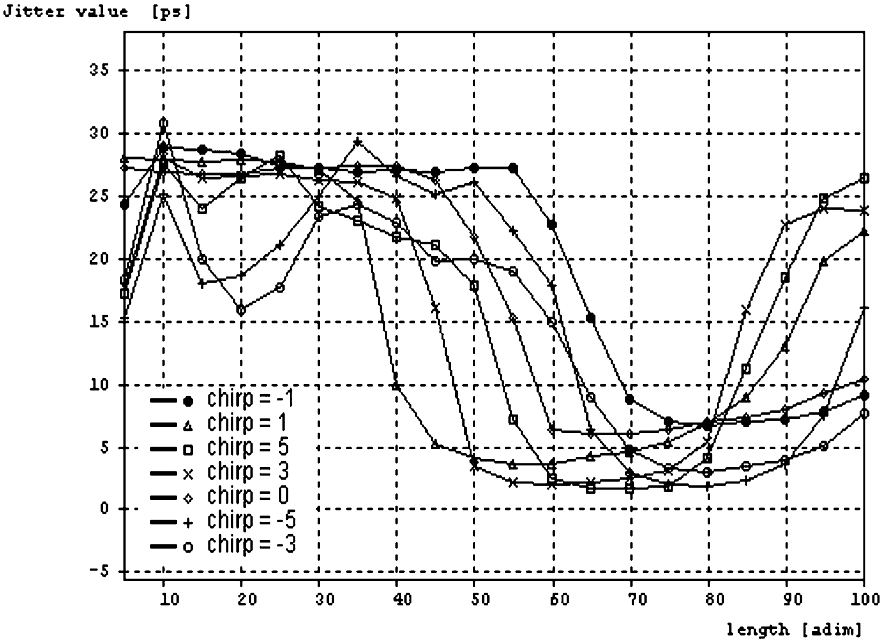
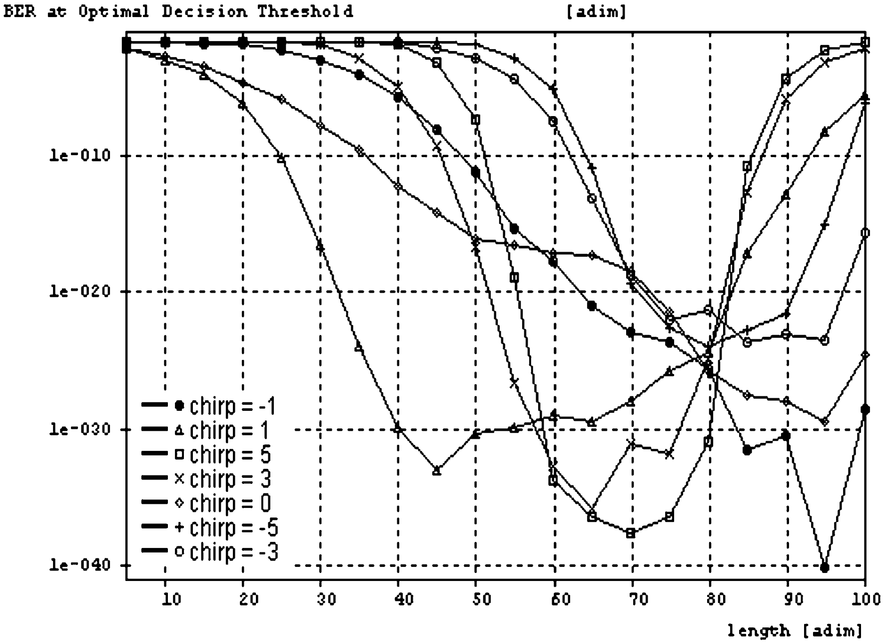


(a)



(b)

Figure 4. Performance of 10 spans in link with varied DCF length at chirp values = −5, −3, −1, 0, 1, 3, and 5: (a) timing jitter and (b) BER.

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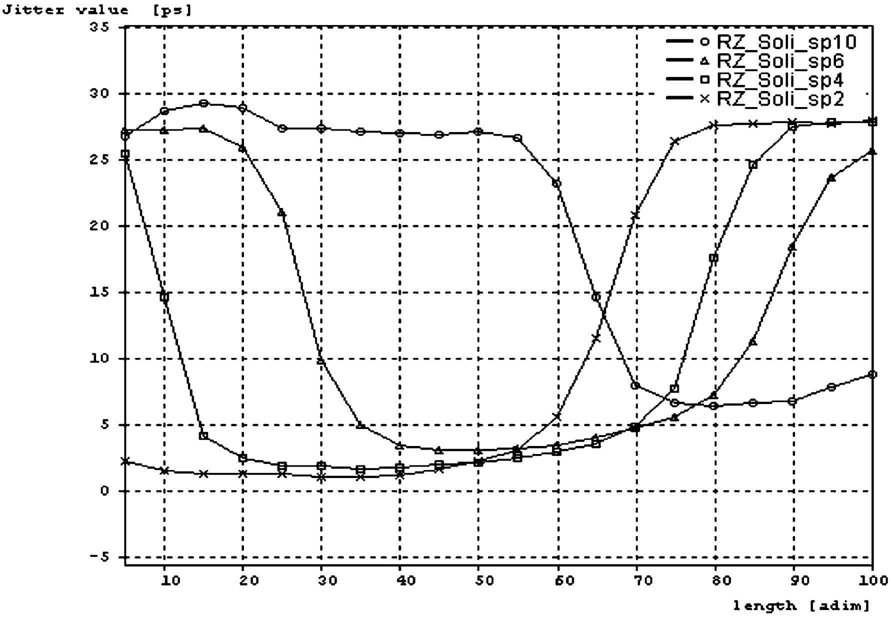
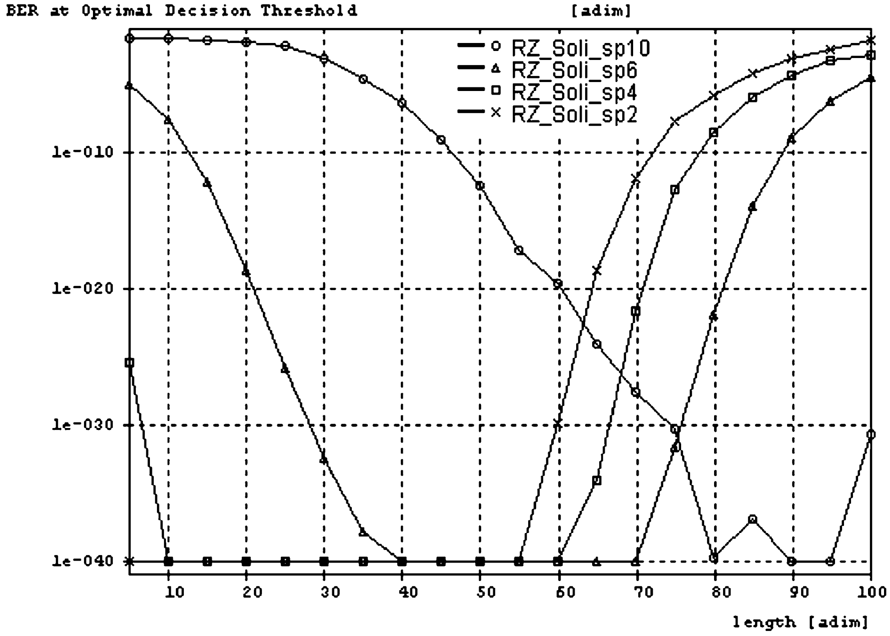


(a)



(b)

Figure 5. Comparative performance 2, 4, 6, and 10 spans in link with varied DCF length at chirp values = −1: (a) timing jitter and (b) BER.

These results showed improvement on lines as a contrast among CRZ, RZ, and NRZ modulation formats in optical communication systems. It has shown that physical phenomena are responsible for the performance advantages and disadvantages of these formats during transmission and in the receiver. The advantage of CRZ and RZ during the transmission is in rapid stretching and compression of pulses, which reduces the inter-channel nonlinear interactions. In the receiver, the CRZ signal performs best due to the pulse compression at the end of transmission and exhibits the highest tolerance to the nonlinearity due to modulational instability. In addition, concentration of energy in the middle of the bit slot helps avoid receiver intersymbol interference [1, 2].

In present results, the fall of timing jitter in the valley area is because of the balance between the net positive dispersion offered by the SSMF and net negative dispersion offered by the DCF. Moreover, the optimum results are provided by the chirp selection on the same grounds of CRZ characteristics during transmission and at the receiver [16]. Although the trials are carried out independently with simulation but validates the theoretically found expression for such behavior in Eq. (3). The advantage of the wide range of chirp investigations and DCF relationship could be a guide map in the design of optical communication systems.

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Conclusions

The reduction of timing jitter has been achieved by the chirp selection of externally modulated RZ soliton pulse at 10 Gb/s for optical fiber communication system. A single arm Mach-Zehnder amplitude modulator at the transmitter was used to vary the chirp from -5 to $+5$. The optical link has a span of 60 km of SSMF, a fixed output amplifier to compensate the fiber loss. Investigations up to ten such repeated spans have been provided to observe the effect over the long length. Before detection at the receiver, a varied length DCF was installed to compensate accumulated dispersion. The results produced the effect of the length of the post DCF and the chirp selection on timing jitter, which validate expected theoretical results. In two spans, the performance was improved by the DCF length less than 20 km irrespective of the chirp considered by the transmitter. While after 10 spans, the required DCF length lies in the range of 60–90 km, depending upon the value of chirp selected. The control of accumulated timing jitter after the addition of each span has been established by the respective choice of the modulator chirp. It is concluded that the chirp value of external modulator should be set to either 0 or -1 to reduce the timing jitter to a reasonably low value, but for a large number of spans, optimum performance may be achieved at other higher chirp (3 or 5) values leading to smaller length of DCF.

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Biographies

Manjit Singh graduated in Electronics and Communication Engineering from Panjab University, Chandigarh, India in 1994. In 1996, he received the Post Graduate Diploma in Computer Application from Punjab Agriculture University-Ludhiana. He obtained his M.Tech. (ECE) from Punjab Technical University, Jalandhar in 2003. Presently, he is pursuing a Ph.D. in Optical Communication Systems from Punjab Technical University, Jalandhar. He started his professional career as a Technical Assistant at Science & Technology Park, Ludhiana for several months. From 1996 onwards, he adopted teaching as his life-long profession beginning as a Lecturer at Regional Engineering College-Jalandhar. He served in the same capacity at the institutes Guru Nanak Dev Engineering College-Ludhiana and Guru Nanak Dev Polytechnic-Ludhiana for the period January, 1997 to January, 2003. From January, 2003 to July, 2005 he worked as Senior Lecturer and Assistant Professor at the Institute of Engineering & Technology, Bhaddal, Ropar. Since July, 2005 he is continuing as Reader in the ECE department, University College of Engineering, Punjabi University, Patiala. He has teaching experience in electronics engineering subjects of nearly 11 years (which includes UG and PG classes). He has contributed 15 publications, i.e., International Journal (3), International Conference (1), National Conference (9). He has delivered four expert talks on the topics of fiber optic communication and advanced microprocessors at various places. He is a member of the Indian Society of Technical Education (ISTE).

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Institute of Engineering and Technology, Longowal, Punjab, India as Assistant Professor in the Department of Electronics and Communication Engineering and continued till 2003. In 2003, he joined as Professor in Electronics and Communication Engineering Department at Thapar Institute of Engineering and Technology (Deemed University), Patiala. Presently he is working as Professor and Head of the same department. His present interests are fiber dispersion and nonlinearities. He has over 100 research papers out of which 40 are in International/National Journals and the rest are in International and National Conferences. He has two R&D projects and has organized many conferences. He is a life member of the Institution of Engineers (India) and Indian Society of Technical Education.

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