Available online at www.sciencedirect.com
ScienceDirect
Optik 120 (2009) 773–781
Optik Optics
www.elsevier.de/ijleo

Improved analysis for SRS- and XPM-induced crosstalk in SCM-WDM transmission link in the presence of HOD

Ajay K. Sharma[a,*], Sandeep K. Arya[b]

[a]National Institute of Technology, Jalandhar 144011, Punjab, India
[b]Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India

Received 9 October 2007; accepted 12 March 2008

Abstract

In this paper, the improved analysis for SRS- and XPM-induced crosstalk has been reported. The modified expression for XPM-induced crosstalk has been obtained and SRS- and XPM-induced crosstalks have been reported at varied walkoff parameter, modulation frequency, input optical power and transmission distance. It has been observed that there is exponent decrease in SRS-induced crosstalk with the increase in modulation frequency from 0 to 2.0 GHz. It varies with the increase in length and lie in the range of (−114 to −122.4) dB and (−115.5 to −124.4) dB at 20 and 100 km, respectively. Moreover, it increases exponentially with the increase in input optical power and lies in the range of (−121.6 to −130.6) dB at 10 mW and grows exponentially up to the range of (−114 to −122.8) dB at 60 mW optical powers at walkoff parameter of (13.6, 27.2, 54.4 and 81.6) ps/km. It has been observed that the XPM-induced crosstalk increases exponentially with the increase in transmission distance and modulation frequency for 2OD and 3OD. Furthermore, it has been found that the total SRS- and XPM-induced crosstalk rises exponentially with fluctuations with the increase in modulation frequency and transmission length in the presence of combined effect of 2OD and 3OD at varied walkoff parameters.

1. Introduction

Optical transmission systems using SCM-WDM techniques are currently being used for CATV transmission systems, as backbones for wireless networks and antenna remoting systems. The fiber nonlinearities lead to crosstalk between sub-carriers of different wavelengths traversing simultaneously through the fiber. Signal distortions in intensity-modulated direct detection WDM systems induced by interaction of XPM and dispersion were investigated [1]. The spectral characteristics of stimulated Raman scattering (SRS) and cross-phase modulation (XPM) in multispan intensity-modulation direct detection optical systems were found to be strongly dependent on fiber dispersion, optical signal channel spacing and data rates [2–4]. Crosstalk between wavelengths in SCM-WDM optical communication systems has been studied [5]. It has been reported that in a dispersive fiber, crosstalk can be attributed to SRS and XPM combined with group velocity dispersion (GVD).

The effect of SRS on the hybrid WDM system was measured in a two-channel hybrid WDM system [6]. Variance due to XPM and four-wave mixing-induced intensity distortion were derived based on the Volterra series transfer function method [7]. Study of XPM- and SRS-induced crosstalk noise evolution as well as their

*Corresponding author. Tel.: +91 181 2690320.
E-mail address: sharmaajayk@rediffmail.com (A.K. Sharma).

0030-4026/$ - see front matter © 2008 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2008.03.010

interaction along lossy, nonlinear dispersive fiber in a cascaded IM-DD system was performed and it was found that it comes mainly from adjacent channels [8]. Power impairments and power penalty due to SRS in dispersion-managed fiber links were evaluated [9]. Transmission limitations due to XPM-induced crosstalk in SCM-dense-wavelength division multiplexing (DWDM) systems were studied at wavelength spacing of 50 and 100 GHz [10]. XPM was reported as the major performance-limiting effect in high bit-rate WDM networks with narrow channel spacing [11]. A four-wavelength bi-directional DWDM CATV system used chirped fiber gratings as the dispersion compensation devices to reduce the fiber dispersion and XPM-induced crosstalk simultaneously [12]. In highly dispersive return-to-zero differential phase-shift keying two adjacent channel transmission systems, without spectral overlap, the standard deviation of XPM-induced phase shift was reported to be inversely proportional to the channel separation [13].

If the peak power of the incident waves is more than a threshold level, both SRS and SBS transfer energy from pump pulse to generate stoke pulses which co-propagate along with the pump signal in the same or opposite directions. The two pulses interact with each other through the Raman gain, Brillouin gain and XPM. A similar situation happens when two or more pulses separated by a small frequency, i.e.100–200 GHz, interact with each other [14]. The intensity-dependent refractive index may in further lead to XPM between the transmitted channels. Cross-phase modulation is severe for adjacent sub-carrier multiplexed WDM channels with the same dispersion value because this allows long interaction lengths between channels during transmission. SRS further may cause the transfer of energy from one signal to another WDM channel operating at the adjacent frequency leading to crosstalk and power depletion effects. The SRS effect is more dominant for the frequencies which are adjoining to the transmitted ones. Crosstalk mainly due to SRS, SBS and XPM occurs due to nonlinearities of the fiber. The crosstalk levels obtained to date [15,16] indicated that crosstalk in SCM-WDM systems can easily reach intolerable levels even with two wavelengths.

Therefore, keeping in view the pressing demand of high bit rate and modulation frequencies for optical transmission links, it is necessary to analyze the performance of optical transmission links by considering the impact of higher-order dispersion. We have extended the work reported in [5] by incorporating the effect of 2OD and 3OD on SRS- and XPM-induced crosstalk. The modified expression for XPM- and SRS-induced crosstalk is reported in Section 2 after describing the brief introduction in Section 1. Results and discussion are mentioned in Section 3 and finally Section 4 concludes the paper.

2. SRS- and XPM-induced crosstalk

Here the modified analysis for XPM- and SRS-induced crosstalk has been reported by considering the higher-order dispersion terms. The investigation is important for pulses of duration $\leqslant 0.1$ ps propagating over the fiber.

Consider two optical waves with identical polarization, co-propagating in single-mode fiber, and take two coupled equations describing XPM under a slowly varying envelope are given by [5,16]

$$\frac{\partial\partial\xi_1}{\partial z}+\frac{1}{vg_1}\frac{\partial\xi_1}{\partial t}=\left(-\mathrm{j}\gamma\,U_2-\frac{\alpha}{2}\right)\xi_1 \tag{1}$$

$$\frac{\partial\xi_2}{\partial z}+\frac{1}{vg_2}\frac{\partial\xi_2}{\partial t}=\left(-\mathrm{j}\gamma\,U_1-\frac{\alpha}{2}\right)\xi_2 \tag{2}$$

where $\xi_i(z,t)$, $i=1, 2$ denote the slowly varying complex field envelope of each wave, γ = nonlinearity coefficient, $|\xi_i|^2=U_i$ = channel power, z = transmission distance, α = fiber loss coefficient, v_{g_i} = group velocity for transmitted signal at wavelength λ_i. Therefore, optical power at the input of the fiber can be expressed as

$$U_i=U_\mathrm{c}[1+m\cos\omega t] \tag{3}$$

where $i=1(\lambda_1)$ or $2(\lambda_2)$ and $\lambda_1>\lambda_2$; U_c is the average optical power; m the modulation index; $\cos\omega t$ the modulating signal; ω the angular frequency.

SRS interaction in the optical fiber can be described by a set of coupled equations:

$$\frac{\partial U_1}{\partial z}+\frac{1}{vg_1}\frac{\partial U_1}{\partial t}=(gU_2-\alpha)U_1 \tag{4}$$

$$\frac{\partial U_2}{\partial z}+\frac{1}{vg_2}\frac{\partial U_2}{\partial t}=(gU_1-\alpha)U_2 \tag{5}$$

where

$$g=\frac{g_\mathrm{R}}{A_\mathrm{eff}}$$

g_R is the standard Raman coefficient, $A_\mathrm{eff}=\pi w^2$ the effective fiber area, w the width parameter (depends upon fiber parameters). Typically $\mathrm{A}_\mathrm{eff}=55\,\mu\mathrm{m}^2$.

Solving Eq. (1) and (2) of electric envelope by neglecting γ for initial conditions $z=0$ and $t=\tau_1$:

$$\xi_1(z,t)=\xi_1(0,\tau_1)\exp(-\alpha z/2) \tag{6}$$

By substituting the results of $\xi_1(z,t)$ in the second coupled equation:

$$\xi_2(z,\tau_2)=\xi_2(0,\tau_2)\exp(-\alpha z/2)\times\exp\left(-2\mathrm{j}\gamma\int_0^z U_1(0,\tau_2+d_{jk}z)\mathrm{e}^{-\alpha z}\,\mathrm{d}z\right) \tag{7}$$

$$\tau_1=\tau_2+d_{jk}\,z$$

Now phase is given by ϕ

$$\phi = -2\gamma \int_0^z U_1(0, \tau_2 + d_{jk}\, z) e^{-\alpha z}\, dz$$

$$\xi_2(z, \tau_2) = \xi_2(0, \tau_2) \exp(-\alpha z/2) \exp(-j\phi) \tag{8}$$

Considering GVD and HOD, the phase modulation can be converted into intensity modulation via relation [17–20]:

$$U_2(z,\tau_2) = U_2(0,\tau_2)\left|\left\{1 + j\left(\frac{\partial^2\phi}{\partial t^2} + j\left(\frac{\partial\phi}{\partial t}\right)^2\right)F_1 + 1 + j\left(\frac{\partial^3\phi}{\partial t^3} - 3\frac{\partial\phi}{\partial t}\frac{\partial^2\phi}{\partial t^2} - j\left(\frac{\partial\phi}{\partial t}\right)^3\right)F_2\right\}\right|^2 \tag{9}$$

where

$$F_1 = -\beta_2 \frac{z}{2}, \quad F_2 = \beta_3 \frac{z}{6}, \quad \beta_2 = \frac{\partial^2\beta}{\partial\omega^2} \text{ and } \beta_3 = \frac{\partial^3\beta}{\partial\omega^3}$$

where β is the phase constant at wavelength λ_2.

Solving Eq (9) we obtain

$$U_2(z,\tau_2) = U_2(0,\tau_2)\left\{\left(1 - 2F_1 - 6F_2\frac{\partial\phi}{\partial t}\right)\frac{\partial^2\phi}{\partial t^2}\right\} \tag{10}$$

Since the values of β_2^2 and β_3^2 are very small, they are neglected:

$$= U_2(0,\tau_2)e^{-\alpha z}\beta_2\frac{\partial^2\phi}{\partial\tau_2^2} - U_2(0,\tau_2)e^{-\alpha z}\beta_3\frac{\partial^3\phi}{\partial\tau_2^3} \tag{11}$$

$$\frac{\partial U_2(z,\tau_2)}{\partial z} = U_2(z,\tau_2)e^{-\alpha z}\left[\beta_2 + \beta_3\frac{\partial\phi}{\partial\tau_2}\right]\frac{\partial^2\phi}{\partial\tau_2^2} \tag{12}$$

From (12) the effect of β_2 in $\partial U_2(z, \tau_2)/\partial z$ is given by ζ and the effect of β_3 in $\partial U_2(z, \tau_2)/\partial z$ is given by χ. The impact of 2OD and 3OD has been studied in the following cases.

2.1. Case-1 (SRS-induced crosstalk)

The SRS-induced crosstalk is given by [5,17,21]

$$XT_{SRS2} = mgU_c\left[\frac{e^{(-\alpha + j\omega d_{2jk})L} - 1}{(\alpha - j\omega\, d_{jk})}\right] \tag{13}$$

2.2. Case-2 (XPM-induced crosstalk with 2OD)

The XPM-induced crosstalk due to 2OD coefficient is given by

$$\zeta = U_2(0,\tau_2)e^{-\alpha z}\beta_2\frac{\partial^2\phi}{\partial\tau_2^2}$$

XPM-induced crosstalk due to 2OD at wavelength λ_2 is given by [5,17]

$$XT_{XPM2} = -\frac{2\beta_2\gamma U_c\omega^2}{(\alpha - j\omega d_{jk})^2} \times \left\{\begin{array}{l}(\alpha L - 1 + e^{-\alpha L}\cos(d_{jk}\omega L)) \\ +j(e^{-\alpha L}\sin(d_{jk}\omega L) - d_{jk}\omega L)\end{array}\right\} \tag{14}$$

2.3. Case-3 (XPM-induced crosstalk with 3OD)

XPM-induced crosstalk due to 3OD coefficient is given by

$$\chi = -U_2(0,\tau_2)e^{-\alpha z}\beta_3\frac{\partial^3\phi}{\partial\tau_2^3} = -U_2(0,\tau_2)e^{-\alpha z}\beta_3\left[\frac{\partial\phi}{\partial\tau_2}\frac{\partial^2\phi}{\partial\tau_2^2}\right] \tag{15}$$

$$= -U_2(0,\tau_2)e^{-\alpha z}\beta_3\left[\frac{4\gamma^2U_c^2\omega^3m^2e^{2j\omega\tau_2}}{(\alpha - j\omega d_{jk})^2}(1 - e^{-\alpha z}e^{j\omega d_{jk}})^2\right] \tag{16}$$

Because of attenuation, this incremental change is attenuated by a factor $e^{-\alpha(L-z)}$. The modulation is obtained at the end of the fiber by integrating attenuated power over a length of fiber L:

$$\int_o^L \partial U_2(z,\tau_2)e^{-\alpha(L-z)} \tag{17}$$

Effect on modulation due to β_3 is given by integrating the following equation:

$$\int_o^L U_2(z,\tau_2)e^{-\alpha z}\beta_3\frac{\partial^3\phi}{\partial\tau_2^3}e^{-\alpha(L-z)}\,dz$$

$$= U_2(0,\tau_2)\beta_3\left[\frac{4\gamma^2U_c^2\omega^3m^2e^{2j\omega_{jk}}}{(\alpha - j\omega d_{jk})^2}\right] \times \int_O^L (1 - e^{-\alpha z}e^{j\omega d_{jk}})^2 e^{-\alpha L}\,dz \tag{18}$$

The crosstalk in phasor form is obtained by normalizing the expression in Eq. (18) by $mP_ce^{-\alpha L}$. The crosstalk due to 3OD coefficient at λ_2 is given by

$$= -\frac{2m\beta_3\gamma^2U_c^2\omega^3}{(\alpha - j\omega d_{jk})^3}(3 + 2\alpha L + 4e^{-\alpha L}e^{jd_{jk}\omega L} - e^{-2\alpha L}e^{j2d_{jk}\omega L} - 2Lj\omega d_{jk}) \tag{19}$$

$$XT_{\mathrm{XPM2}} = -\frac{2m\beta_3\gamma^2 U_c^2\omega^3}{(\alpha - \mathrm{j}\omega d_{jk})^3} \times \left\{ \begin{array}{c} 3 + 2\alpha L + 4\mathrm{e}^{-\alpha L}\cos(d_{jk}\omega L) - \mathrm{e}^{-2\alpha L} \\ \cos(2d_{jk}\omega L) \\ +\mathrm{j}(4\mathrm{e}^{-\alpha L}\sin(d_{jk}\omega L) - \mathrm{e}^{-2\alpha L} \\ \sin(2d_{jk}\omega L) - 2d_{jk}\omega L) \end{array} \right\} \quad (20)$$

2.4. Case-4 (total SRS- and XPM-induced crosstalk with 2OD and 3OD)

The improved XPM-induced crosstalk due to combined effects of 2OD and 2OD at wavelength λ_2 is given by

$$XT_{\mathrm{XPM2}} = -\frac{2m\beta_3\gamma^2 U_c^2\omega^3}{(\alpha - \mathrm{j}\omega d_{jk})^3} \times \left\{ \begin{array}{l} (3 + 2\alpha L + 4\mathrm{e}^{-\alpha L}\cos(d_{jk}\omega L) - \mathrm{e}^{-2\alpha L} \\ \cos(2d_{jk}\omega L)) \\ +\mathrm{j}(4\mathrm{e}^{-\alpha L}\sin(d_{jk}\omega L) - \mathrm{e}^{-2\alpha L} \\ \sin(2d_{jk}\omega L) - 2d_{jk}\omega L) \end{array} \right\} - \frac{2\beta_2\gamma U_c\omega^2}{(\alpha - \mathrm{j}\omega d_{jk})^2} \left\{ \begin{array}{l} (\alpha L - 1 + \mathrm{e}^{-\alpha L}\cos(d_{jk}\omega L)) \\ +\mathrm{j}(\mathrm{e}^{-\alpha L}\sin(d_{jk}\omega L) - d_{jk}\omega L) \end{array} \right\} \quad (21)$$

Therefore, the modified expression for the total cross-talk due to SRS and XPM can be obtained using the same method reported in [5,17,21]:

$$\mathrm{XTALK}_{\mathrm{TOTAL}} = |\mathrm{XT}_{\mathrm{SRS2}} + \mathrm{XT}_{\mathrm{XPM2}}|^2 \quad (22)$$

3. Results and discussions

Here, the results have been mentioned for SRS- and XPM-induced crosstalk at various modulation frequencies in the presence of independent and combined effects of 2OD and 3OD coefficients. An effort has been made for the exhaustive investigation to ascertain the impact of HOD coefficients on non-linear crosstalk in SCM-WDM communication systems. The results have been reported by taking values of various parameters like $\Delta\lambda = 4\,\mathrm{nm}$, $U_c = 17\,\mathrm{dBm}$, $L = 25\,\mathrm{km}$, $m = 0.7$, $\gamma = 0.00095/\mathrm{m\,W}$, $\alpha = 0.22\,\mathrm{dB/km}$, $g = 5.5 \times 10^{-11}\,\mathrm{W^{-1}\,m^{-1}}$, $\lambda_1 = 1546\,\mathrm{nm}$ and $\lambda_2 = 1542\,\mathrm{nm}$.

3.1. Case-1 (SRS-induced crosstalk)

Fig. 1(a) depicts the graph between SRS-induced crosstalk versus modulation frequency at varied walkoff parameter. The modulation frequency is varied from 0 to 2.0 GHz and walkoff is taken as 13.6, 27.2, 54.4 and 81.6 ps/nm. It has been observed that for modulation frequencies below 100 MHz, −111.4 dB SRS-induced crosstalk is observed. However, if we increase the modulation frequency, the SRS-induced crosstalk decreases. Moreover the decrease in SRS-induced crosstalk is dependent on the value of walkoff parameter.

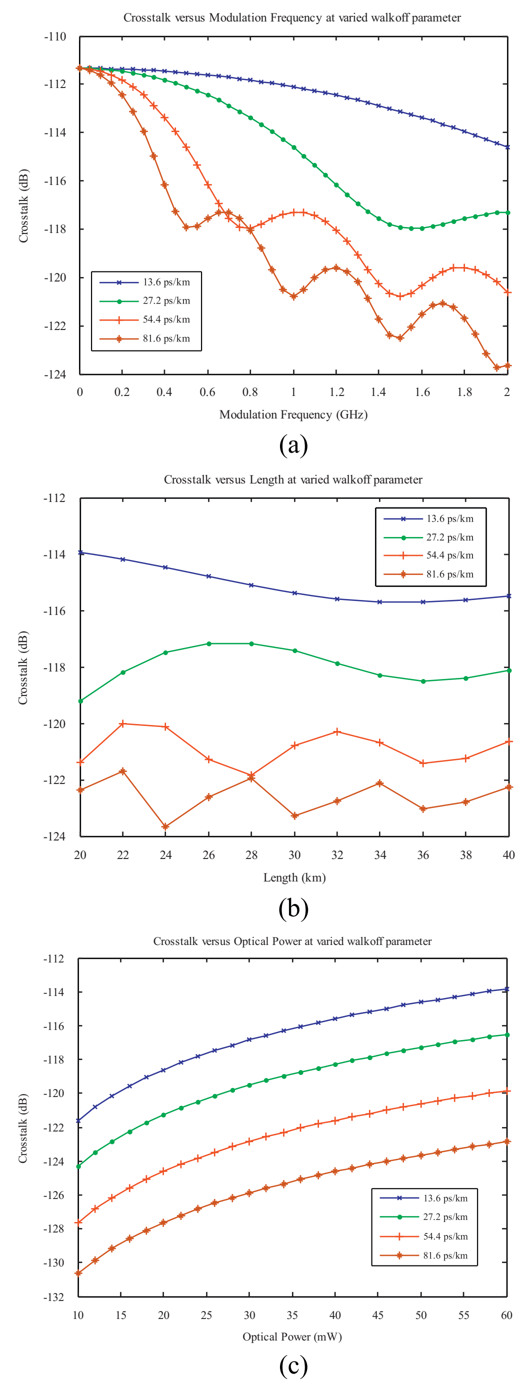


Fig. 1. SRS-induced crosstalk versus (a) modulation frequency, (b) length, (c) optical power at the input at varied walkoff parameter.

The minimum value of SRS-induced crosstalk of 123.8 dB is obtained at walkoff of 81.6 ps/km at an operating modulation frequency of 2.0 GHz.

Fig. 1(b) indicates the SRS-induced crosstalk versus transmission length at varied walkoff parameter. It has been investigated that with the increase in walkoff the SRS-induced crosstalk decreases drastically. With the increase in transmission length, it varies in the range of (−114 to −115.8), (−117 to −119.2), (−120 to −121.9) and (−121.8 to −123.8) for walkoff at 17.6, 27.2, 54.4 and 81.6 ps/km, respectively, which indicate that the tradeoff between walkoff and transmission distance can be optimized. Furthermore, Fig. 1(c) shows that the impact of SRS-induced crosstalk increases exponentially with the increase in input power and lie in the range of (−121.8 to −130.6.3) dB and (−113.9 to −122.9) dB for optical power at 10 and 60 mW, respectively. It has been observed that the walkoff parameter plays an important role for deciding the optimum values of parameters like modulation index, input power and modulation frequency in order to minimize the value of SRS-induced crosstalk.

3.2. Case-2 (XPM-induced crosstalk with 2OD)

Fig. 2 depicts the XPM-induced crosstalk versus modulation frequency at varied walkoff parameter by considering 2OD coefficient. Fig. 2(a) shows that the XPM-induced crosstalk is (−39.7, −42, −45.2 and −47) dB in the presence of 2OD, at 2.0 GHz modulation frequency for a walkoff 17, 34, 68 and 102 ps/km, respectively. Furthermore, Fig. 2(b) illustrates the exponential growth in the XPM-induced crosstalk versus length at varied walkoff in the presence of 2OD.

3.3. Case-3 (XPM-induced crosstalk with 3OD)

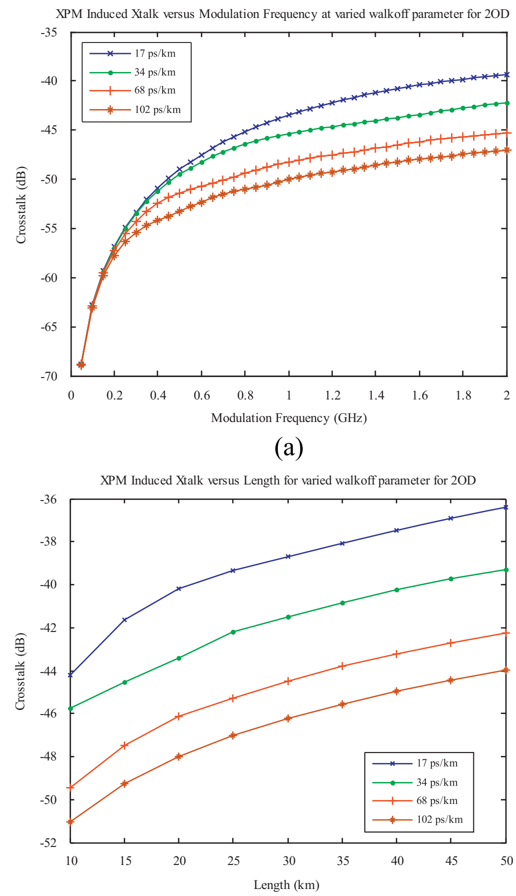
Similar results have been reported for XPM-induced crosstalk versus modulation frequency in the presence of 3OD coefficient at varied walkoff in Fig. 3, but it lies in the range of (−76 to −92) dB at 2.0 GHz modulation frequency at a walkoff 17, 34, 68 and 102 ps/km, respectively. The XPM-induced crosstalk increases exponentially with the increase in modulation frequency, transmission length and optical power.

3.4. Case-4 (total SRS- and XPM-induced crosstalk with 2OD and 3OD)

Fig. 4(a) reveals that the total SRS- and XPM-induced crosstalk increases exponentially with the increase in modulation frequency in the presence of 2OD. However, it decreases with the increase in the walkoff. For walkoff parameter up to 17 ps/km, it increases from −97.5 to −72 dB, as the frequency is increased from 0 to 1.2 GHz and afterwards it starts decreasing. As the walkoff is increased beyond 17 ps/km, it fluctuates in the range of (−97 to −77.5, −84 and −87) dB for a walkoff of 34, 68 and 102 ps/km, respectively.

Fig. 4(b) shows the graph between total SRS- and XPM-induced crosstalk versus transmission length in the presence of 2OD at varied walkoff. At lower values of walkoff, i.e. at 17 ps/km, the total SRS- and XPM-induced crosstalk varies exponentially. However, for transmission distance below 5 km and for larger values of walkoff beyond 17 ps/km, it varies exponentially and afterwards it fluctuates periodically. Moreover, it diminishes with the increase in walkoff parameter but increases with the increase in transmission length. The maximum value of total SRS- and XPM-induced crosstalk in the presence of 2OD is obtained at 50 km transmission length and lie in the range of −69.7 to −85 dB at a walkoff of 17–102 ps/km.

Similar to case-1 and 2, there is exponent variation of the total SRS- and XPM-induced crosstalk in the presence of 3OD (see Fig. 5(a)). However, the crosstalk



(a)

(b)

Fig. 2. XPM-induced crosstalk versus (a) modulation frequency, (b) length at varied walkoff parameter for 2OD coefficient.

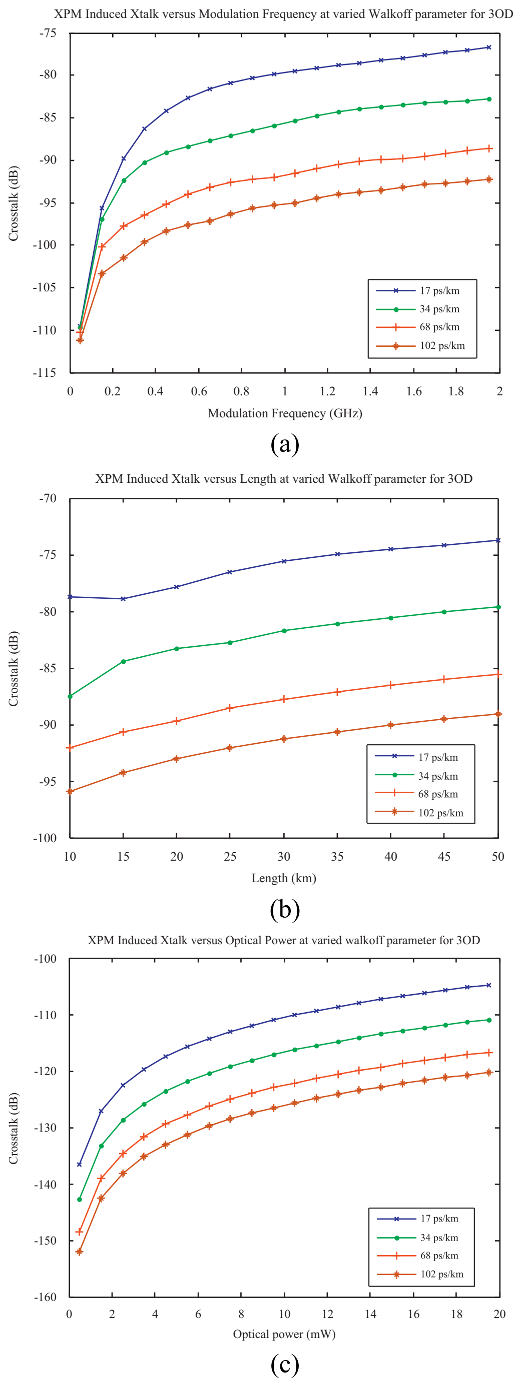


Fig. 3. XPM-induced crosstalk versus (a) modulation frequency, (b) length, (c) optical power at varied walkoff parameter for 3OD dispersion coefficient.

fluctuates for modulation frequencies beyond 200 MHz and it reduces drastically with the increase in walkoff. It varies in the range of −140 to −110, −119, −127 and −132 dB at walkoff parameter of 17, 34, 68 and 102 ps/km, respectively. Furthermore, Fig. 5(b) investigates that the total SRS- and SPM-induced crosstalk increases with the increase in transmission length in a similar

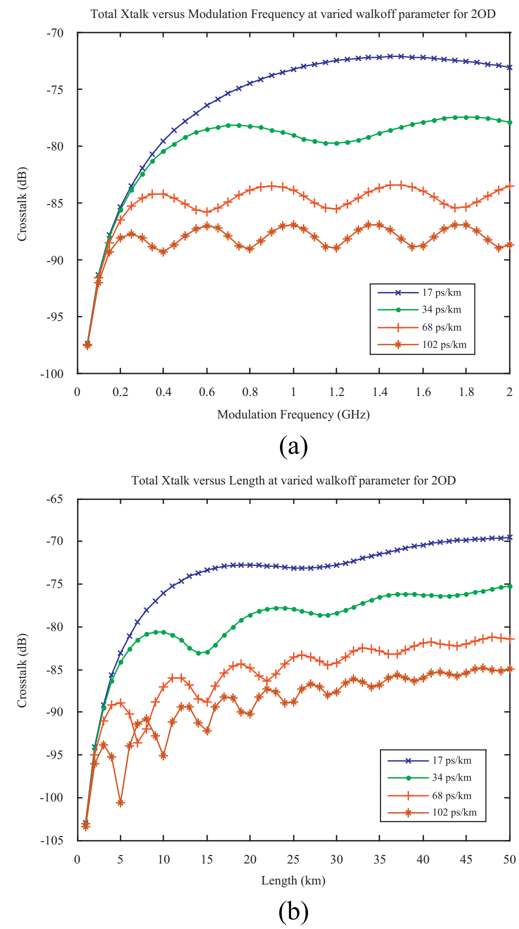


Fig. 4. Total SRS- and XPM-induced crosstalk versus (a) length, (b) modulation frequency at varied walkoff parameter for 2OD coefficient.

manner. The total crosstalk in the presence of 3OD at a transmission length of 50 km is maximum and is shown in the range of −106.4 to −130 dB at walkoff from 17 to 102 ps/km. The results reveal that the 3OD coefficient has lesser significance on the crosstalk in comparison with 2OD coefficient. Further, the effort has been made to see the combined impact of 2OD and 3OD on the total crosstalk due to SRS and XPM.

Here the results as shown in Fig. 6 indicate that the total SRS- and XPM-induced crosstalk in the presence of combined effect of 2OD and 3OD at varied walkoff parameter rises in a similar way to that for 2OD and 3OD independently. The total crosstalk in the range of (−73 to −88.7) dB at 2 GHz modulation frequency is shown in Fig. 6 (a). Further, Fig. 6 (b) shows that the total crosstalk in the presence of combined effect of 2OD and 3OD rises from (−104 to −73) dB at 17-ps/km and (−104 to −85) dB for 102-ps/km walkoff, at a transmission length of 1 and 20 km, respectively. So an optimum value of walkoff and transmission length may

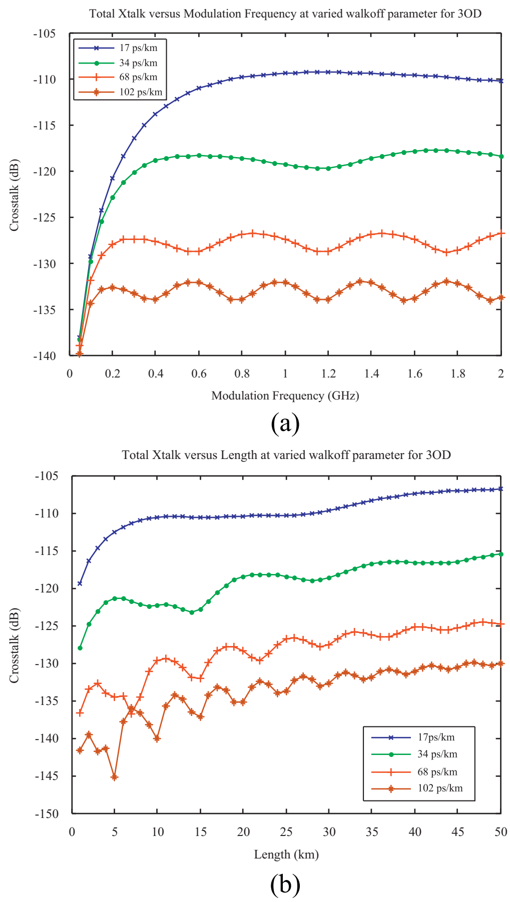


Fig. 5. Total SRS- and XPM-induced crosstalk versus (a) modulation frequency, (b) length at varied walkoff parameter for 3OD coefficient.

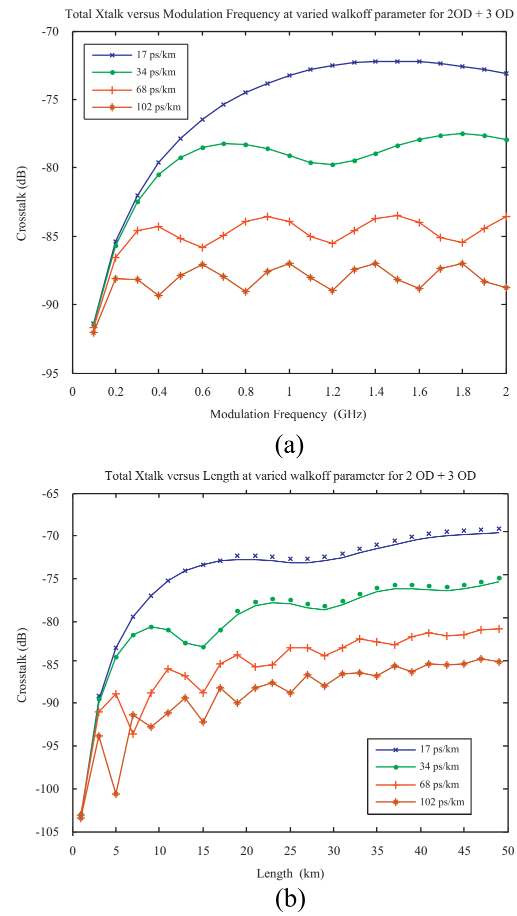


Fig. 6. Total SRS- and XPM-induced crosstalk versus (a) modulation frequency, (b) length at varied walkoff parameter for combined effect of 2OD and 3OD coefficients.

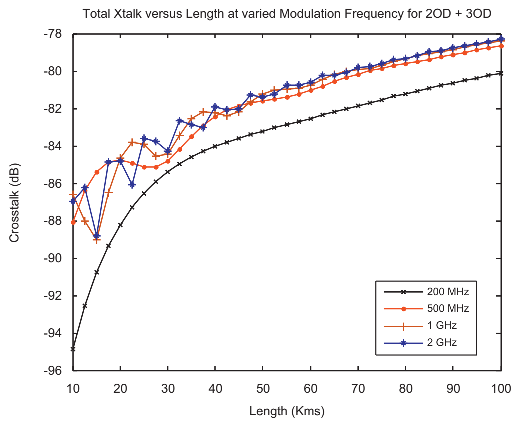
be selected at a tolerable value of total SRS- and XPM-induced crosstalk including the combined impact of 2OD and 3OD.

Fig. 7(a) and (b) show the total SRS- and XPM-induced crosstalk versus transmission length and optical power, respectively, in the presence of combined effect of 2OD and 3OD at varied modulation frequencies varying from 200 MHz to 2.0 GHz. At 200 MHz the SRS- and XPM-induced crosstalk rises with transmission length and lie in the range of (−95 to −80.2) dB at transmission length of 10 and 100 km, respectively. However, it oscillates for frequencies above 200 MHz. The maximum value of it has been observed at a transmission length of 100 km, which lies in the range of (−80.2 to −78.8) dB for modulation frequency varying from 200 MHz to 2.0 GHz. Moreover, Fig. 7(b) shows total SRS- and XPM-induced crosstalk increases with the increase in carrier power. The minimum crosstalk lies in the range of (−140 to −137) dB at a modulation frequency of 200 MHz and 2.0 GHz, respectively, at a carrier power of 1 mW. Furthermore, with the increase in optical power up to 20 mW, it rises exponentially up to the range of (−114.6 to −112) dB.

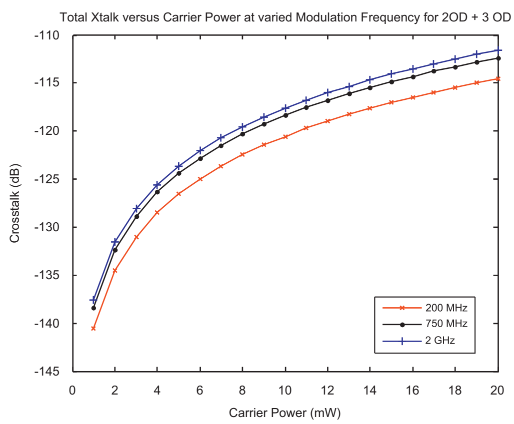
4. Conclusions

This paper targets the impact of independent and combined effects of 2OD and 3OD on SRS- and XPM-induced nonlinear crosstalk in an SCM-WDM optical transmission system for different values of walkoff parameters, modulation frequencies, transmission length and input optical power. The results show that the total crosstalk due to SRS and XPM in the presence of higher-order dispersion increases with the decrease in walkoff parameter, increase in optical power, transmission length and modulation frequency.

The total crosstalk increases exponentially with the increase in carrier power in the presence of 2OD and 3OD. At a lower value of walkoff at 17 ps/km, total SRS- and XPM-induced crosstalk rises exponentially in the range of (−92 to −73) dB at modulation frequency of 100 MHz and 2.0 GHz, respectively, in the presence of both 2OD and 3OD. However, for higher walkoff values beyond 17 ps/km, it varies in a fluctuating manner. The total crosstalk due to SRS and XPM fluctuates with the increase in transmission length. However, with the increase in walkoff the total crosstalk decreases rapidly.



(a)



(b)

Fig. 7. Total SRS- and XPM-induced crosstalk versus (a) length, (b) carrier power at varied modulation frequency for combined effect of 2OD and 3OD coefficients.

So, the optical communication system can be optimized, in order to select minimum value of total SRS-and XPM-induced crosstalk at a given value of modulation frequency as well as at an optimum value of walkoff parameter.

Acknowledgment

The authors would like to thank the Ministry of Human Resource Development, Government of India, New Delhi, for financial support for the work done under the project, "Designing and Simulation of High Data Rate Optical Fiber Transmission Systems".

References

[1] Lutz Rapp, Experimental investigation of signal distortions induced by cross-phase modulation combined with dispersion, IEEE Photon. Technol. Lett. 9 (12) (1997) 1592–1594.

[2] R. Hui, Y. Wang, K. Demarest, C. Allen, Frequency response of cross-phase modulation in multispan WDM optical fiber systems, IEEE Photon. Technol. Lett. 10 (9) (1998) 1271–1273.

[3] Rongqing Hui, Kenneth R. Demarest, J. Lightwave Technol. 17 (6) (1999) 1018–1026.

[4] H.S. Seo, K. Oh, U.C. Paek, Gain optimization of germanosilicate fiber Raman amplifier and its applications in the compensation of Raman-induced crosstalk among wavelength division multiplexing channels, IEEE J. Quantum Electron. 37 (9) (2001) 1110–1116.

[5] Frank S. Yang, Michel E. Marhic, Leonid G. Kazovsky, Nonlinear crosstalk and two countermeasures in SCM–WDM Optical communication systems, Journal Of Lightwave Technology 18 (4) (2000) 512–520.

[6] H. Kim, K.H. Han, Y.C. Chung, PERFORMANCE limitation of hybrid WDM systems due to stimulated raman scattering, IEEE Photon. Technol. Lett. 13 (10) (2001) 1118–1120.

[7] Bo Xu, Maïté Brandt-Pearce, Comparison of FWM- and XPM-induced crosstalk using the Volterra series transfer function method, J. Lightwave Technol. 21 (1) (2003) 40–53.

[8] Zhi Jiang, Chongcheng Fan, A comprehensive study on XPM- and SRS-induced noise in cascaded IM-DD optical fiber transmission systems, J. Lightwave Technol. 21 (4) (2003) 953–960.

[9] Toshiaki Yamamoto, Seiji Norimatsu, Statistical analysis on stimulated Raman crosstalk in dispersion-managed fiber links, J. Lightwave Technol. 21 (10) (2003) 2229–2239.

[10] W.H. Chen, Winston I. Way, Multichannel single-sideband SCM/DWDM transmission systems, J. Lightwave Technol. 22 (7) (2004) 1679–1693.

[11] G. Goeger, M. Wrage, W. Fischler, Cross-phase modulation in multispan WDM systems with arbitrary modulation formats, IEEE Photon. Technol. Lett. 16 (8) (2004) 1858–1860.

[12] Hai-Han Lu, W.J. Wang, Wen-Shing Tsai, CSO/CTB performances improvement in a Bi-Directional DWDM CATV system, IEEE Trans. Broadcasting 50 (4) (2004) 377–381.

[13] K. Keang-Po Ho, H. Hsi-Cheng Wang, Cross-phase modulation-induced crosstalk for RZ-DPSK signals in dispersive transmission systems, J. Lightwave Technol. 24 (1) (2006) 396–403.

[14] A. Djupskobacka, G. Jacobson, B. Tromborg, Dynamic stimulated scattering analysis, J. Lightwave Technol. 18 (3) (2000) 416–424.

[15] Sandeep K. Arya, Ajay K. Sharma, R.A. Agarwala, R.S. Kaler, T.S. Kamal, Analytical investigations on nonlinear cross talk for SCM-WDM optical communication systems, In: International Conference on Broadband Optical Communication Technology (BBOFCT–2001) held at North Maharashtra University, Jalgaon (M.S.), December 3–7, 2001, pp. 87–93.

[16] G.P. Agarwal, Application of Nonlinear Fiber Optics, Academic Press, San Deigo, CA, 2001.

[17] Z. Wang, E. Bodker, G. Jacobsen, Effects of cross-phase modulation in wavelength multiplexed SCM video transmission systems, Electron. Lett. 31 (18) (1995) 1591–1592.

[18] K. Peterman, FM–AM noise conversion in dispersive single mode fiber transmission lines, Electron. Lett. 26 (25) (1990) 2097–2098.

[19] Ajay K. Sharma, R.K. Sinha, R.A. Agarwala, Improved analysis of dispersion compensation using differential time delay for high -speed long-span optical link, Fiber Integrated Opt., USA 16 (4) (1997) 415–426.

[20] Ajay K. Sharma, R.K. Sinha, R.A. Agarwala, Higher-order dispersion compensation by differential time delay, Opt. Fiber Technol., USA 4 (1) (1998) 135–143.

[21] Sandeep K. Arya, Ajay K. Sharma, R. A. Agarwala, Impact of 2OD and 3OD on SRS- and XPM-induced crosstalk in SCM-WDM optical transmission link, Optik, 2007, in press, doi:10.1016/j.ijleo.2007.10.004.