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Modify SRS-induced crosstalk with variety of fiber in SCM–WDM transmission links

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ABSTRACT

In this paper, the SRS-induced crosstalk has been evaluated in a SCM–WDM communication links at different modulation frequencies and transmission lengths for variety of fiber. Results show that SRS-induced crosstalk dominates at low frequency. As the dispersion and effective area of fiber (A_{eff}) decreases, initially the crosstalk remains high and then it decreases with increase in modulation frequency. The present work shows that out of five different types of fiber, standard single mode fiber (SMF) has minimum crosstalk (−78 to −38) dB, (−55 to −33) dB and (−46 to −34) dB at modulation frequencies, transmission lengths and optical powers. Dispersion compensation fiber (DCF) has maximum crosstalk (−60 to −12) dB, (−37 to −12) dB and (−27 to −12) dB at modulation frequencies and transmission lengths.

1. Introduction

Due to the explosive growth of wireless communication in recent years, network operators are having tremendous difficulty accommodating the increasing traffic. As demand on multimedia services including voice, data and video continue to grow, it is necessary to achieve a mature service with a high percentage of consumer use, lower and constant access charge, full time connectivity to service providers and higher bandwidth. In order to cope up with the various demands, future wireless communication systems require a large capacity. The converging requirements for subscriber mobility and high bandwidths have led to the proposal of micro cellular systems in which system capacity can be increased by augmenting the reuse efficiency of limited radio resources [1]. The micro cellular system poses problems, since installation of new radio base stations require time and a large investment. The combination of SCM and WDM is seen as a viable solution to the problems posed by a micro cellular system as it provides the so-called radio over fiber link using microwave photonics techniques. SCM–WDM systems however, suffer from nonlinear effects in fiber. When multiple wavelengths carrying SCM signals propagates in a single mode fiber, fiber nonlinearities can lead to crosstalk between subcarriers on different wavelengths. In a dispersive fiber, one of the dominant fiber nonlinearities that cause crosstalk are stimulated Raman scattering (SRS). Fiber nonlinearities such as SRS may generate significant amounts of nonlinear crosstalk between adjacent SCM channels because they are very closely spaced [2–6]. In paper [7] investigated the SRS induced crosstalk for different types of fiber. In [8] SRS-induced crosstalk evaluated in a SCM–WDM communication link at different modulation frequencies for various types of fibers. This paper extends further work of [8] paper. The paper is organized as follows: Section 2 contains the theoretical analysis and the analysis of nonlinear crosstalk caused by SRS system and the parameter of different type fibers. Section 3 discusses the results of SRS for different types of fiber. Finally, Section 4 summarizes and concludes this paper.

2. SRS – induced crosstalk

Therefore optical power at the input of fiber can be expressed as [9]

$$P_i = P_c[1 + m\cos\omega_1 t] \tag{1}$$

Two WDM channels have been assumed in this work where optical carrier in each is modulated by different sub-carriers, modulation index and phase. Therefore the optical power at the fiber input can be given by

$$P_i = P_0[1 + m_1 a_1 \cos(\omega_1 t + \phi_1) + m_2 a_2 \cos(\omega_2 t + \phi_2)] \tag{2}$$

where $i = 1(\lambda_1)$ or $2(\lambda_2)$ and $\lambda_1 > \lambda_2$, P_0 is the average optical power, m_1 and m_2 are the modulation indices $\cos\omega t$ is the modulation

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signal, ω is the angular frequency and ϕ_1 and ϕ_2 are the phase angles.

In this analysis two optical waves with different modulation index amplitudes and phases have been considered [6]. The optical power at the input of the fiber is given by Eq. (2). A formal approach used to determine crosstalk level is to solve following coupled equation governing phase modulation under the slowly varying envelop are given by [7,10]

$$\frac{\partial P_1}{\partial Z} + \frac{1}{V_{g_1}}\frac{\partial P_1}{\partial t} = (gP_2 - \alpha)P_1 \quad (3)$$

$$\frac{\partial P_2}{\partial Z} + \frac{1}{V_{g_2}}\frac{\partial P_2}{\partial t} = (gP_1 - \alpha)P_2 \quad (4)$$

where V_{g_2} is the group velocity for the transmitted signal at λ_2, V_{g_1} is the group velocity for the transmitted signal at λ_1, α is the fiber loss coefficient g is the standard Raman coefficient divided by the fiber effective area.Hence

$$P_1(z,t) = P(0,\tau_1)e^{-\alpha z} \quad (5)$$

Putting in Eq. (5) in Eq. (4)

$$\frac{\partial P_2}{\partial Z} + \frac{1}{V_{g_2}}\frac{\partial P_2}{\partial t} = (-gP_1(0,\tau_1)e^{-\alpha z} - \alpha)P_2 \quad (6)$$

By Lagrangian linear partial differential equation in Eq. (6)

$$\frac{\partial z}{1} = \frac{\partial t}{1/v_{g_2}} = \frac{\partial P_2}{-(gP_1(0,\tau_1)e^{-\alpha z} + \alpha} \quad (7)$$

Now, at $z=0$, $t=\tau_2$

$$k_1 = -v_{g_2} t$$

Put the value of k_1

$$z = v_{g_2}(t-\tau_2)$$

Again from Eq. (7), taking first & last two terms,

$$\frac{\partial z}{1} = \frac{\partial P_2}{-(gP_1(0,\tau_1)e^{-\alpha z} + \alpha)P_2}$$

$$\int \frac{\partial P_2}{P_2} = -\int (gP_1(0,\tau_1)e^{-\alpha z} + \alpha)dz$$

$$\frac{\log P_2}{k} = e^{-\alpha z}(1 - gP_1(0,\tau_1))$$

$$P_2 = k_1 \exp\left(\frac{-gP_1(0,\tau_1)}{\alpha}\right)$$

$$k_1 = P_2(0,\tau_2)\exp\left(\frac{-gP_1(0,\tau_1)}{\alpha}\right)$$

$$P_2(z,\tau_2) = k_1 \exp\left\{\int -(gP_1 e^{-\alpha z} + \alpha)dz\right\} \quad (8)$$

$$P_2(z,\tau_2) = P_0 e^{-\alpha z}\exp\left[-\int gP_1(0,\tau_2 + zd_{21})e^{-\alpha z}\right]dz$$

$$P_2(z,\tau_2) = P_0 e^{-\alpha z}\left[1 - g\int_0^z P_0 e^{-\alpha z}dz - \int_0^z mP_0\cos(\omega\tau_2 + \omega z d_{12})e^{-\alpha z}\right]dz$$

$$P_2(z,\tau_2) = P_0 e^{-\alpha z}\left[1 - gP_0\left[\frac{1-e^{-\alpha z}}{\alpha}\right] - g\int_0^z mP_0\cos(\omega\tau_2 + \omega z d_{12})e^{-\alpha z}\right]dz$$

$$P_2(z,\tau_2) = P_0 e^{-\alpha z}\left[1 - gP_0\left[\frac{1-e^{-\alpha z}}{\alpha}\right] - gmP_0\frac{\sqrt{1+e^{-2\alpha z} - 2e^{-\alpha z}\cos(\omega\tau_2 + \Theta_{SRS})}}{\sqrt{\alpha^2 + (\omega d_{12})^2}}\right]dz$$

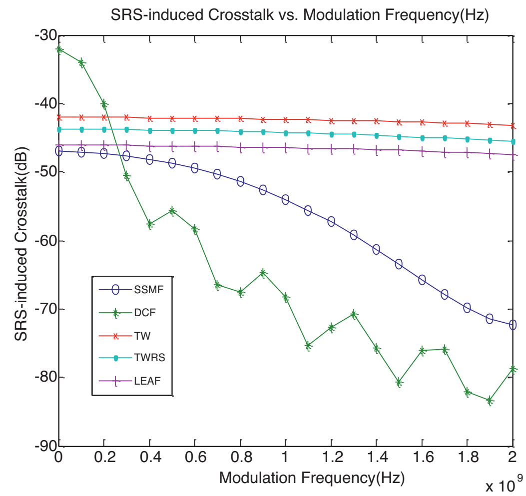

Fig. 1. Variation of SRS induced crosstalk versus modulation frequency with different types of fiber.

where

$$\Theta_{SRS} = \tan^{-1}\left(\frac{-\omega d_{12}}{-\alpha}\right) + \tan^{-1}\frac{e^{-\alpha z}\sin(\omega z d_{12})}{e^{-\alpha z}\cos(\omega z d_{12}) - 1}$$

Hence,

$$g = \frac{g_R}{A_{eff}}$$

In Eq. (8), the first term corresponds to the carrier power after fiber loss. The second term corresponds to the interaction between the optical carriers, this result in optical dc power gain or loss. The third term is the crosstalk as the result of modulation depletion through SRS interaction between pump channel optical carrier and signal channel subcarrier. The crosstalk suffered by the subcarrier in the probe channel due to SRS is [11].

Table 1
Parameter of different fibers.

Fiber	Dispersion D [ps/nm/km]	Dispersion slope D1 [ps/nm^2/km]	Nonlinear refractive index n_2 [10^{-20} m^2/W]	Effective core area A_{eff} [μm^2]	Fiber attenuation α [dB/km]
SSMF	17	0.058	2.8	80	0.25
DCF for SSMF	−90	$0.058 * \frac{-90}{17}$	4.3	14.3	0
TW	3.5	0.08	3.45	45	0.25
TW-RS	4.4	0.045	3.2	55	0.25
LEAF	3.77	0.11	3.0	72	0.25

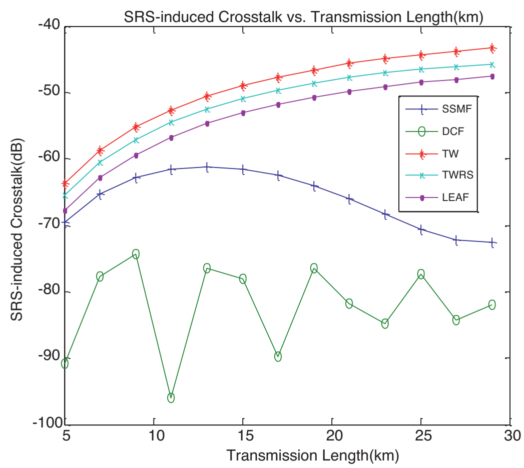

Fig. 2. Variation of SRS induced crosstalk versus transmission lengths with different types of fiber.

$$\text{Crosstalk(SRS)} = \frac{\left| -P_0 e^{-\alpha z} mgP_0 (\sqrt{1+e^{-2\alpha z} - 2e^{-\alpha z}\cos(\omega\tau_2 + \Theta_{SRS})} / A_{eff}\sqrt{\alpha^2 + (\omega d_{12})^2}) \right|}{\left| mP_0 e^{-\alpha z}\{1 + (gP_0/A_{eff}) \left|(1-e^{-\alpha z})/\alpha\right|\} \right|^2} \approx \left| gP_o \frac{\sqrt{1+e^{-2\alpha z} - 2e^{-\alpha z}\cos(\omega\tau_2 + \Theta_{SRS})}}{A_{eff}\sqrt{\alpha^2 + (\omega d_{12})^2}} \right|^2 \quad (9)$$

Five different types fiber used in the simulations. They are standard single mode fiber (SMF), dispersion compensation fiber (DCF) for standard single mode fiber single, true wave fiber (TW), true wave-reduced slope fiber (TW-RS) and large effective area fiber (LEAF) (Table 1).

3. Results and discussion

These result have been evaluated contain SRS-induced crosstalk with variety of fiber in SCM–WDM transmission link. The results have been reported by taking values of the various parameters like phase matching factor $(m) = 0.0434$, fiber loss 'α' = 0.25 dB/km, wavelength = 1552 nm, $P_0 = 10$ dBm, frequency spacing = 4 nm, transmission length 30 km and the fiber non-linear refractive index $n_2 = 2.68 \times 10^{-20}$ m^2/W.

Fig. 1 indicates the SRS – induced crosstalk versus modulation frequencies with variety of fiber and shows that the SRS-induced crosstalk at SSMF varies from (−47 to −70) dB. Further at TWRS it varies from (−44 to −45) dB, at LEAF it varies from (−46 to −45) dB, at TW it varies from (−42 to −43) dB, at dispersion compensation fiber (DCF) it varies from (−32 to −57) dB for SCM–WDM transmission link. It can be observed, standard SMF has the least crosstalk at the modulation frequency of 2 GHz. And dispersion compensation fiber also has less crosstalk as compared to TW, and LEAF. That is why we prefer SSMF for long distance. It has been observed that in SRS as the dispersion and effective area of fiber decrease, initially the crosstalk remains high and then it decreases with increase in modulation frequency.

Further Fig. 2 illustrates the exponential growth in the SRS – induced crosstalk versus transmission lengths with variety of fiber and shows that the XPM-induced crosstalk at SSMF varies from (−69 to −74) dB. Further at TWRS it varies from (−65 to −46) dB, at LEAF it varies from (−67 to −52) dB, at TW it varies from (−63 to −44) dB, at DCF it varies from (−90 to −76) dB for SCM–WDM transmission link.

4. Conclusion

Five different types of fiber are used in the simulations. They are standard single mode fiber (SMF), dispersion compensation fiber (DCF) for standard single mode fiber, true wave fiber (TW), true wave-reduced slope fiber (TW-RS) and large effective area fiber (LEAF). Our results show that as the dispersion and core effective area decreases, SRS-induced crosstalk increases. Also, as modulation frequencies increase, SRS-induced crosstalk decreases and transmission distance increase, SRS-induced crosstalk increases. In out of five different types of fiber standard single mode fiber (SMF) has minimum crosstalk (−53 to −64 dB) and true wave fiber (TW) has maximum crosstalk (−47 to −48 dB). At modulation frequency of 1 GHz, SRS-induced crosstalk for SSMF is −53 dB, for LEAF is −47 dB, for TWRS is −44 dB, for TW it is −42 dB and −67 dB for DCF. At transmission length of 20 km, SRS-induced crosstalk for SSMF is −65 dB, for LEAF is −50 dB, for TWRS is −47 dB, for TW it is −44 dB and −77 dB for DCF. So standard SMF is suitable fiber for SCM–WDM transmission link. So standard single mode fiber (SMF) is appropriate fiber for subcarrier multiplexed–wavelength division multiplexed (SCM–WDM) communication systems as it has minimum crosstalk effect of SRS.

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