Performance evaluation of SCM–WDM communication in the presence of SRS induced crosstalk for different types of fiber

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**Abstract**

In this paper, the SRS-induced crosstalk has been evaluated in a SCM–WDM communication link at different modulation frequencies for various type of fibers. Results show that SRS-induced crosstalk dominates at low frequency. As the dispersion and effective area of fiber \(A_{\text{eff}}\) 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 fibers, Standard Single Mode Fiber (SMF) has minimum crosstalk (\(-53 \text{ to } -64 \text{ dB}\)) and True Wave fiber (TW) has maximum crosstalk (\(-47 \text{ to } -48 \text{ dB}\)).

**Keywords:**
Sub-carrier multiplexing
Wavelength division multiplexing
Stimulated Raman scattering
Dispersion

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 photonic techniques. SCM–WDM systems however, suffer from nonlinear effects in fiber. When multiple wavelengths carrying SCM signals propagate in a single fiber, fiber nonlinearities can lead to crosstalk between subcarriers on different wavelengths. In a dispersive fiber, 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 [2–5].

The paper is organized as follows: Section 2 contains the theoretical analysis and the analysis of nonlinear crosstalk caused by SRS system. Section 3 discusses the effects of SRS with different types of fiber. Finally, Section 4 summarizes and concludes this paper.

2. Theoretical analysis

The optical power at the fiber input can be given by

\[ P_i = P_0 [1 + m \cos \omega t] \]  \hspace{1cm} (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

\[ P_i = P_0 [1 + m_1 \cos (\omega_1 t + \phi_1) + m_2 \cos (\omega_2 t + \phi_2)] \]  \hspace{1cm} (2)

where \( i = 1(\lambda_1) \text{ or } 2(\lambda_2) \) 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 signal, \( \omega \) is the angular frequency and \( \Phi_1 \) and \( \Phi_2 \) are the phase angles.

2.1. SRS-induced crosstalk

In this analysis two optical waves with different modulation index amplitudes and phases have been considered. 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 [6–8]

\[
\frac{\partial P_1}{\partial z} + \frac{1}{V_p} \frac{\partial P_1}{\partial t} = (gP_2 - \alpha)P_1 \\
\frac{\partial P_2}{\partial z} + \frac{1}{V_p} \frac{\partial P_2}{\partial t} = (gP_1 - \alpha)P_2
\]  

(3)

(4)

where \( V_p \) is the group for the transmitted signal at \( \lambda_1 \), \( V_p \) is the group velocity for the transmitted signal at \( \lambda_2 \), \( \alpha \) is the fiber loss coefficient, \( g \) is the standard coefficient divided by the fiber effective area (\( g = g_{r}/A_{\text{eff}} \)).

\[ P_1(z, t) = P_1(0, t_2) e^{-\alpha z} \]  

(5)

We first solve for \( P_1 \) in Eq. (3) by neglecting \( g \). We then substitute \( P_1 \) with (4) to solve for \( P_2 \) to obtain

\[ P_2(z, t_2) = P_2(0, t_2) e^{-gP(0, t_1) \alpha e^{-\alpha z}} e^{-\int gP(0, \tau_1) e^{-\alpha z} d\tau_1} \]  

(6)

Also

\[ \tau_1 = t_2 + zd_{12} \]

\[ P_2(z, t_2) = P_0 e^{-e^{-\alpha z} \int gP(0, \tau_1 + zd_{12}) e^{-\alpha z} d\tau_1} \]  

(7)

\[ P_2(z, t_2) = P_0 e^{-e^{-\alpha z} \left\{ \int gP(0, \tau_2 + zd_{12}) e^{-\alpha z} d\tau_2 \right\}} \]  

(8)

From Eq. (1)

\[ = P_0 e^{-\alpha z} \left[ 1 - g \int_0^z P_0 e^{-\alpha z} d\tau - \int_0^z mP_0 \cos(\omega \tau_2 + ozd_{12}) e^{-\alpha z} d\tau \right] \]

\[ = P_0 e^{-\alpha z} \left[ 1 - gP_0 \left\{ \frac{e^{-\alpha z}}{\alpha} \right\} - gmP_0 \int_0^z \cos(\omega \tau_2 + ozd_{12}) e^{-\alpha z} d\tau \right] \]

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

(9)

where

\[ \Theta_{\text{SRS}} = \tan^{-1} \left( \frac{-ozd_{12} \alpha}{-\alpha} \right) + \tan^{-1} \frac{e^{-\alpha z} \sin(\omega zd_{12})}{e^{-\alpha z} \cos(\omega zd_{12}) - 1} \]

Hence \( g = g_{r}/A_{\text{eff}} \).

Five different types of fibers 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) (Table 1).

![Graph showing variation of SRS induced crosstalk with modulation frequency for different types of fibers.]

**Fig. 1.** Variation of SRS induced crosstalk with modulation frequency for different types of fibers.

**Table 1**
Parameters of different fibers.

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Dispersion, D [ps/nm/km]</th>
<th>Nonlinear refractive index, ( n_2 ) [10(^{-20}) m(^2)/W]</th>
<th>Effective core area, ( A_{\text{eff}} ) [\mu m(^2)]</th>
<th>Fiber attenuation, ( \alpha ) [dB/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSMF</td>
<td>17</td>
<td>2.8</td>
<td>80</td>
<td>0.25</td>
</tr>
<tr>
<td>DCF for SSMF</td>
<td>–90</td>
<td>4.3</td>
<td>14.3</td>
<td>0</td>
</tr>
<tr>
<td>TW</td>
<td>3.5</td>
<td>3.45</td>
<td>45</td>
<td>0.25</td>
</tr>
<tr>
<td>TW-RS</td>
<td>4.4</td>
<td>3.2</td>
<td>55</td>
<td>0.25</td>
</tr>
<tr>
<td>LEAF</td>
<td>3.77</td>
<td>3.0</td>
<td>72</td>
<td>0.25</td>
</tr>
</tbody>
</table>
3. Results and discussion

Here, the results have been mentioned for SRS crosstalk at various modulation frequencies. An effort has been made for the exhaustive investigation to ascertain the impact of High Order Dispersion coefficients on non-linear crosstalk in SCM–WDM communication systems. The results have been reported by taking values of the various parameters like phase matching factor \( m = 0.0434 \), fiber loss \( \alpha' = 0.25 \text{ dB/km} \), wavelength = 1558 nm, \( P_s = 10 \text{ dBm} \), frequency spacing = 4 nm, transmission length 30 km and the fiber non-linear refractive index \( n_2' = 2.68 \times 10^{-20} \text{ m}^2/\text{W} \).

Fig. 1 indicates the graph between nonlinear crosstalk due to SRS and modulation frequencies with different types of fibers. From the above results in Fig. 1, it has been observed that in SRS as the dispersion and effective area of fiber \( (A_{\text{eff}}) \) decrease, initially the crosstalk remains high and then it decreases with increase in modulation frequency. The value of SRS crosstalk at SSMF varies from −53 to −64 dB. Further at TWRS it varies from −48 to −50 dB, at LEAF it varies from −51 to −53 dB, at TW it varies from −47 to −48 dB, at dispersion compensation fiber (DCF) it varies from −36 to −54 dB for SCM–WDM communication systems.

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 result shows that in stimulated Raman scattering (SRS) as the dispersion and effective area of fiber \( (A_{\text{eff}}) \) decrease, initially the crosstalk remains high and then it decreases with increase in modulation frequency. 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). 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.

References