Enhanced Analysis for Fiber Nonlinearities

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Abstract

For optical communication links using wavelength-division multiplexing over a long-haul fiber optic backbone, stimulated raman scattering may lead to significant transmission impairment. This paper discusses the enhanced analysis for the SRS induced crosstalk in the optical networks. The expression for Stimulated Raman Scattering induced crosstalk have been observed at different fiber types (as Single Mode Fiber, Dispersion Compensation Fiber, Non Zero Dispersion Fiber and Non Zero Dispersion Shifted Fiber), variation in modulation frequency, transmission length and optical power. It is seen through the below observations that the as the modulation frequency increases the SRS induced crosstalk decreases and lie in the range of (-58 to -70) for single mode fiber at transmission length of 60 km. SRS induced crosstalk increases if the optical is increased and this increase is exponential for above fiber types.

Keywords-- SMF, DCF, NZDF, NZDSF, modulation frequency, transmission length, optical power.

I. INTRODUCTION

A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. Information is often carried by an electromagnetic carrier wave whose frequency can vary from a few megahertz to several hundred terahertz [1]. Virtually there are only two windows used for broadband communications. First window is between 100 KHz to 300 GHz and second window from 30 THz to 300 THz. As per now the demand for bandwidth is increasing enormously so the second window is used which is optical and has a capacity of 100 Tbps and beyond. The initial development of optical fiber was for long haul or submarine transmission but now every where optical fibers are used [2]. Very high-capacity, long-haul optical communication systems are made possible by the extremely wide bandwidth of optical fibers, which is best exploited by wavelength division multiplexing (WDM) [1]. The performance of long distance optical communication systems is limited, however, by chromatic dispersion and nonlinear effects of fiber, which interact and accumulate along the length of the optical link. Chromatic dispersion, which broadens the pulses, can be reduced by using dispersion-shifted fibers at the 1550-nm wavelength range, but low chromatic dispersion enhances some nonlinear effects of fiber, especially Stimulated Raman Scattering [2-3]. SCM is a potential solution for transmission in OPNs [4]. The combination of SCM and WDM is a viable method to further increase the transmission capacity in OPNs [5]. SCM-WDM systems, however suffer from non-linear effects in fiber. These non-linearities cause crosstalk between subscribers on different wavelengths. Fiber nonlinearities such as stimulated raman scattering (SRS) and cross phase modulation (XPM) may generate significant amounts of nonlinear crosstalk between adjacent SCM channels because they are very closely spaced [6,7]. SRS and SBS transfer energy from pump pulse to generate stoke pulses which co-propagates along with the pump signal in the same or opposite direction if the peak power of the incident waves is more than the threshold level, and these two pulses interact with each other through the raman gain and XPM[10]. The SRS effect is more dominant for the frequencies which are adjoining to the transmitted ones[11,12]. SRS in WDM systems is due to nonlinear coupling effect through Raman gain and thus the modulated optical signal causes modulation of all other co-propagating signals. Crosstalk mainly due to SRS. SBS and XPM occurs due to nonlinearities of the fiber. The crosstalk levels obtained to date [13,14] indicated that crosstalk in SCM-WDM systems can easily reach intolerable levels even with two wavelengths.

Table 1 Generations of OFC[3]

<table>
<thead>
<tr>
<th>Generation</th>
<th>Wavelength of Optical Source (nm)</th>
<th>Bitrate (Mbit/s)</th>
<th>Repeater Spacing (Km)</th>
<th>Loss (dB/Km)</th>
<th>Existed up to</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.8</td>
<td>4.3</td>
<td>10</td>
<td>1</td>
<td>1980</td>
</tr>
<tr>
<td>II</td>
<td>1.3</td>
<td>1.7*10⁴</td>
<td>70</td>
<td>&lt;1</td>
<td>1987</td>
</tr>
<tr>
<td>III</td>
<td>1.55</td>
<td>1.0*10⁴</td>
<td>100</td>
<td>&lt;0.2</td>
<td>1990</td>
</tr>
<tr>
<td>IV</td>
<td>1.55</td>
<td>1.0*10⁴</td>
<td>100</td>
<td>&lt;0.002</td>
<td>2000</td>
</tr>
<tr>
<td>V</td>
<td>1.55</td>
<td>&gt;1.0*10⁴</td>
<td>&lt;100</td>
<td>&lt;0.002</td>
<td></td>
</tr>
</tbody>
</table>
II. SRS INDUCED CROSSTALK

In this analysis two optical waves with different modulation index, amplitude and phase have been considered. The optical power at the input of the fiber is assumed to be fixed [13].

An approach used to determine crosstalk level is to solve following coupled equation governing phase modulation under the slowly envelop are given by [14,16]

\[
\begin{align*}
\frac{\partial s_1}{\partial z} + \frac{1}{V_{g_1}} \frac{\partial s_1}{\partial t} &= (gS_2 - \alpha) S_1 \quad (1) \\
\frac{\partial s_2}{\partial z} + \frac{1}{V_{g_2}} \frac{\partial s_2}{\partial t} &= (gS_1 - \alpha) S_2 \quad (2)
\end{align*}
\]

Where \(V_{g_1}\) is the group velocity for the transmitted signal at \(\lambda_1\); \(V_{g_2}\) 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 (\(g = g_R/A_{eff}\)).

We first solve for \(S_1\) in equation (1) by neglecting \(g\). We then substitute \(S_1\) into (2) to solve for \(S_2\) to obtain

\[
\begin{align*}
S_2 &= S_2^0 e^{-\alpha z} \left[ 1 - g \int_{0}^{z} e^{\alpha z_2} \frac{1 + e^{-2\alpha z_2} - e^{-2\alpha z}}{\alpha} \cos(\omega_{12} z_2) \, dz_2 \right] \cos(\omega_{12} z + \Theta_{SRS}) \\
&= S_2^0 e^{-\alpha z} \left[ 1 - g \int_{0}^{z} e^{\alpha z_2} \frac{1 + e^{-2\alpha z_2} - e^{-2\alpha z}}{\alpha} \cos(\omega_{12} z_2) \, dz_2 \right] \quad (3)
\end{align*}
\]

where \(\Theta_{SRS} = \tan^{-1} \left( \frac{\omega_{12}}{-\alpha} \right) + \tan^{-1} \left( \frac{e^{-2\alpha z_2}}{\omega_{12}} \right) - \tan^{-1} \left( \frac{1}{\omega_{12}} \right) \).

Hence, \(g = \frac{4\pi}{\lambda_{eff}}\).

In equation (3), 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 (7)

\[
\text{Crosstalk (SRS)} = \left| gS_2^0 \sqrt{1 + e^{-2\alpha z_2} - e^{-2\alpha z}} \cos(\omega_{12} z_2) \right|^2 \quad (4)
\]

II. RESULT ANALYSIS

Here, the results have been mentioned for SRS induced crosstalk using different fiber parameters, 3.1 SRS induced crosstalk

Fig 3.1(a) shows the graph between SRS induced crosstalk with modulation frequency with varied fiber parameters. The modulation frequency is varied from 0 to 4 GHz and different fibers are taken as SMF, variation in modulation frequency in range of 0 – 4 GHz, optical power and transmission length. DCF, NZDF and NZDSF. It has been observed that as the modulation frequency increases the SRS induced crosstalk decreases. Moreover the decrease in crosstalk depends on the fiber type used.
Fig 3.1(a) Crosstalk vs modulation frequencies (i) SMF (ii) DCF, (iii) NZDF, (iv) NZDSF

It shows the graph between SRS induced crosstalk with transmission length with varied fiber parameters. The transmission length have been varied in a range of 0 to 60 Km and it has been observed that the SRS induced crosstalk increases with the increase in length at constant modulation frequency. If lengths remained constant and modulation frequency increases than the crosstalk decreases with increase in modulation frequency.

Fig 3.1 (b) the graph is between SRS induced crosstalk and optical power and it has been observed that as the optical power increases the crosstalk increases gradually as optical power is directly proportional to SRS induced crosstalk.
IV. CONCLUSION

In this paper the impact of SRS induced crosstalk in an optical fiber communication transmission system for different types of optical fibers, modulation frequency, optical power and transmission length. It has been justified in the results that the crosstalk due to SRS increases with increase of transmission length and decreases with the increase in modulation frequency and optical power. By the above results the optical fiber communication transmission system can be optimized to select the minimum value of crosstalk in a given range of modulation frequency, optical power, transmission length and type of fiber used.

REFERENCES