Pulse Walk Off Effect and Data Format for Stimulated Raman Scattering and Comparison Between Different Data Formats

Kamini Kumari  
PG Student  
Department of Electronics and Communication Engineering  
Thapar university, Patiala

Hardeep Singh  
Assistant Professor  
Department of Electronics and Communication Engineering  
Thapar university, Patiala

Abstract

This article presents almost pulse walk off effect and different data format such as RZ. The performance of optical system is reduced by non-linear effects. It is known that when optical power is very high then non-linear effect tend to manifests themselves so that study became important in DWDM system. Constant modulated power is produce using pulse walk off. Due to SRS effect, channel at shorter wavelength act as pump for the channel act as stokes. To reduce SRS effect or to achieve almost constant modulated power pulse walk off rule is applied. Power tilt Because of SRS effect has been calculated at RZ, NRZ and optical Manchester format. Power has been varied from 1 to 60 mw. Using pulse walk off rule effect on channel was done. Pulse walk off rule limit the effective length and number of channels increases. Using this algorithm, efficiency is also increased.

Keywords: Dense wavelength-division multiplexing, linear power approximation, modulated power, number of channels, nonlinearity, NRZ, optical Manchester, pulse walk off, Stimulated Raman Scattering, transmitted power

I. Introduction

Non-linear effect arises due to change in refractive index with optical intensity & scattering phenomenon. Refractive index is depend on power is responsible for kerr effect. At high power level inelastic phenomenon induce stimulated effect such as stimulated Raman Scattering (SRS) and Stimulated Brillouin Scattering (SBS). If the incident power are exceed certain threshold intensity of light grows exponentially. Difference between Brillouin and Raman scattering is that SRS generated optical phonon are incoherent while SBS generated acoustic phonon are coherent. SRS threshold is close to 1w which is 100 times higher than SBS threshold. Scattered light shifted in frequency is13thz in SRS while in SBS is 10 GHz. SRS is much of less problem than SBS. With erbium-doped fiber amplifier (EDFA) output power is 500 mw and will go higher. Three optical amplifier reach this limit and limit drop proportionally by using number of optical amplifier in series [1-5].

Effect of SRS studies in DWDM taking an assumption like triangular approximation of Raman gain spectrum, when short wavelength transformed into a long wavelength photon no energy loss occur. Model [6-7] evaluate effect of SRS using wavelength independent optical fiber loss and hence wavelength independence, effective length of fiber, While model [8] assume wavelength dependence of the fiber loss coefficient. In this paper the model evaluates the SRS effect by using pulse walk off rule and data format. This gives move accurate results.

II. Mathematical model

As explained in [8] the power transfer among the different wavelength channel i.e. from lower to higher wavelength. The graphical representation of depletion and amplification of optical power at different wavelength channel due to SRS. The modified signal power at various wavelength can be obtained by using equation (1)

\[ P_{M}[k] = P_{T}[k] - \sum_{\lambda=k+1}^{N} D[k, \lambda] + \sum_{\lambda=1}^{k-1} P_{T}[\lambda] D[k, \lambda] \quad \text{for } k = 1, 2, \ldots, N \]  

Where \( D[k, \lambda] = 0 \) for \( i > N \) and \( D[j, k] = 0 \) for \( k = 1 \)

In eq. (1) the term \( P_{T}[k] \sum_{\lambda=k+1}^{N} D[k, \lambda] \) Power depleted from \( k \)th channel by the higher wavelength channel and \( \sum_{\lambda=1}^{k-1} P_{T}[\lambda] D[k, \lambda] \) Indicate power depleted from \( k \)th channel by lower wavelength channel. \( P_{T}[k] \) And \( P_{M}[k] \) are an optical power launched in \( k \)th channel and modified power in the \( k \)th channel propagation over a given length of fiber.

Actual received power \( P_{T}[k] \) in the \( k \)th channel following received equation as:

\[ P_{T}[k] = P_{M}[k] \times \exp (-a(\lambda_{k}) \times L) \]  

\[ D[i,j] \] represent the power depleted from \( i \)th channel by \( j \)th channel

\[ D[i,j] = \left( \frac{\lambda_1}{\lambda_2} \right) P_{T}[i] \left( (f_1 - f_j)/1.5 \times 10^{13} \right) g_{R_{\max}} \times \left( (L_e(\lambda_1) \times 10^5)/(b \times A_c) \right) \quad \text{for } (f_1 - f_j) \leq 1.5 \times 10^{13} \text{ Hz and } j > i \]  

\[ D[i,j] = 0 \quad \text{for } (f_1 - f_j) > 1.5 \times 10^{13} \text{ Hz and } j \leq i \]
$g_{R, \text{max}}$ is peak gain coefficient (cm/W). $\lambda_i \lambda_j$ are the wavelength of the $i^{\text{th}}$ and $j^{\text{th}}$ channel and $f_i, f_j$ are central frequency in Hz. $A_e$ is an effective area core area of optical fiber in $\text{cm}^2$. $b$ varies from 1 to 2 depending upon different wavelength channel polarization [9]. $L$ Length of fiber in km and $L_e(\lambda_j)$ is effective length in km expressed by equation (4) as:

$$L_e(\lambda_j) = \left\{ 1 - \exp \left[ - \frac{\alpha(\lambda_j) L}{4.343} \right] \right\} \left[ 4.343 / \alpha(\lambda_j) \right]$$  \hspace{1cm} (4)

Where $\alpha(\lambda_j)$ is wavelength dependent linear loss coefficient of optical fiber in $\text{dB/km}$ and it vary when wavelength up to 0.7 dB, over 25 nm bandwidth and 100 km fiber length [9]:

$$\alpha(\lambda_j) = \left\{ \alpha_{\text{max}} - \left[ (\lambda_j - \lambda_1) / \Delta_{\text{wdm}} \right] (\alpha_{\text{max}} - \alpha_{\text{min}}) \right\}$$

$$\alpha_{\text{max}} = \alpha + \alpha_{\text{var}} / 2$$

$$\alpha_{\text{min}} = \alpha - \alpha_{\text{var}} / 2$$

$$\alpha_{\text{var}} = \left( \frac{0.007}{25} \right) \Delta_{\text{wdm}}$$  \hspace{1cm} (5)

$\Delta_{\text{wdm}}$ is spectral width of DWDM is separation between highest and shortest wavelength channel $\lambda_i$ and $\lambda_j$ in nm and $\alpha$ is fiber loss coefficient in $\text{dB/km}$.

### III. Pulse Walk Off and Data Format

Power transfer occurs among the co-propagating wavelength channel only when the pulses on both channels overlap. SRS effect will not result in power transfer when pulse walk off is completed. When the pulse at co-propagating wavelength align or walk in power transfer will restart. Pulse walk off limit the effective length. The change in effective length will be a function of the dispersion coefficient of the fiber, data rate, inter-channel separation and data format. Walk off length calculated using equation (6):

$$L_{\text{walkoff}} = \frac{10^3}{B \times D \times (\lambda_i - \lambda_j) \times 10^9}$$  \hspace{1cm} (6)

Where $B$ is the data rate in Gb/s, $D$ is the dispersion coefficient of the fiber in ps/nm km, $(\lambda_i - \lambda_j)$ is the separation between the $i^{th}$ and $j^{th}$ channel nm. $L_{\text{walkoff}}$ is calculated in km. Walk off distance depend on dispersion coefficient and data rate. Pulse walk off result in decrease in effective fiber length.

**A. Non Return to Zero Format (NRZ)**

For given data signaling rate, i.e. bit rate the NRZ require only half the baseband bandwidth required by Manchester code.

1) **Case**:

1) Effective length $L_{\text{e}}$ is less than or equal to $L_{\text{Walkoff}}$

No change in the $L_{\text{e}}$ because of pulse walk off i.e $L_{\text{e}} = L_{\text{Walkoff}}$

2) $L_{\text{e}} > L_{\text{Walkoff}}$

Sub-case A. if

$$\frac{L_{\text{e}}}{L_{\text{Walkoff}}} = A + R$$

Where $r$ is remainder, $A$ is odd integer other than 1

$$L_{\text{e}} = \left( \frac{A + 1}{2} \right) \times L_{\text{Walkoff}} + R$$

For $A = 1, L_{\text{e,new}} = L_{\text{Walkoff}}$

Sub-case B. if

$$\frac{L_{\text{e}}}{L_{\text{Walkoff}}} = B + R$$

Where $B$ is any even integer

$$L_{\text{e,new}} = \left( \frac{B}{2} \right) \times L_{\text{Walkoff}} + R$$

**B. Optical Manchester Format**

Manchester has transition at middle of each period and have transition at start of period. The direction of mid bit transition indicate data. Transition period boundaries do not carry information. This format is same as NRZ (non return to zero) format except for the time shift of half bit periods. The occurrence of 1’s and 0’s the width of the pulse representing 1’s in Manchester format is half the width of the pulse representing 1’s in NRZ. This factor of 2 is used in the numerator while evaluating $L_{\text{walkoff}}$ as given below:

$$L_{\text{walkoff}} = \frac{10^3}{2 \times B \times D \times (\lambda_i - \lambda_j) \times 10^9}$$  \hspace{1cm} (9)

**C. RZ (Return to Zero) Format**

$L_{\text{walkoff}}$ will be calculated by using equation eq. 9
Because pulse representing ‘1’ in RZ format is half the width of pulse representing ‘1’ in NRZ.

1) Case 1. When \( L_e < L_{\text{walkoff}} \)
No change in the effective length because of pulse walk off i.e. \( L_{\text{enew}} = L_e \)

2) Case 2. When \( L_e > L_{\text{walkoff}} \)
Sub-case A. if
\[
\frac{L_e}{L_{\text{walkoff}}} = A + R
\]
Where R is remainder and quotient A is any integer
\[
L_e = \left( \frac{A + 1}{2} - Z \right) L_{\text{walkoff}} + R
\]
Where \( Z = 0 \) for \( A = 1 \)
\( Z = 1 \) for \( B = \) any odd number other than 1
Sub-case B. if
\[
\frac{L_e}{L_{\text{walkoff}}} = B + R
\]
Where B is any even integer
\[
L_{\text{enew}} = \left( \frac{B}{2} - Z \right) L_{\text{walkoff}} + R
\]
\( Z = 0 \) for \( B = 2 \) or 4.
\( Z = 1 \) for \( B = \) any integer other than 2 or 4.
All the above model become capable of evaluating the SRS effect and pulse walk off effect.

IV. SIMULATION RESULTS

To transmit power linearly across channels, the transmitted power can be set according to equation (10), which provide approximate constant power across all channels according to the specified power value:
Corrected modulated power = \( \text{[slope} \times \text{wavelength} + \{\text{power} + (\text{slope} \times \text{wavelength of third channel})\}\] \( \text{(10)} \)

Figure 1 shows transmitted power for all twelve wavelengths have identical amplitude. It can be seen in modulated power that shorter wavelength has much smaller amplitude than longer wavelength is due to SRS effect. The linearly varying modulated channel can be decreased by using power specified by eq.(9).

![Fig. 1: transmitted power and modulated power for 31 channel in RZ format at 1mw power](image-url)
Fig. 2: Corrected and modulated power for 31 channel in RZ format

Fig. 3: Transmitted and Modulated Power for 5 channels in NRZ format at 25mw power

Fig. 4: Corrected and Modulated power for 5 channels in NRZ format
Fig. 5: transmitted and modulated power for 23 channel in optical Manchester format

Fig. 6: Corrected and modulated power for 23 channel in optical Manchester and effect of SRS

Table 1:
Number of channel used for with walk off effect and data format such as RZ and NRZ and optical Manchester.

<table>
<thead>
<tr>
<th>power</th>
<th>Channel length(km)</th>
<th>Amplifier distance</th>
<th>With walk off effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RZ</td>
</tr>
<tr>
<td>1mw</td>
<td>2,000</td>
<td>100</td>
<td>31</td>
</tr>
<tr>
<td>2mw</td>
<td>2,000</td>
<td>100</td>
<td>22</td>
</tr>
<tr>
<td>5mw</td>
<td>2,000</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>10mw</td>
<td>2,000</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>20mw</td>
<td>2,000</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>25mw</td>
<td>2,000</td>
<td>100</td>
<td>7</td>
</tr>
</tbody>
</table>

Figure 2 shows that modulated power for twelve channels nearly constant as if there is no effect of SRS in the channel. Table 1 shows maximum no. of channel that can be corrected for a given power value using the proposed algorithm.

V. CONCLUSION

Above Figure and table 1 show that almost constant modulated power on given no. of channel by using with pulse walk off and data formats such as RZ, optical Manchester and NRZ e.g., for 1 mw of power with pulse off effect, a 31 channel DWDM system can be used. Other format such as optical Manchester and in NRZ 23 channel can be used. This algorithm reduces the effect of SRS by efficient power division. It can thus be said that using pulse walk off rule and data formats SRS effect reduces
and almost constant modulated power is achieved across all wavelengths. Decrease in SRS induced power tilt with increase in data rate prominent upto 10Gb/s.

RZ helps in reducing SRS effect in DWDM and it gives lower SRS induced power tilt in comparison with NRZ and optical Manchester data transmission format. The data rate is increased upto 10 Gb/s with decrease in SRS and power tilt due to pulse walk off.

It can also be said that using pulse walk off rule number of channel is increased and efficiency is also increased.

REFERENCES