# A Review on Higher Order Approximation for Stimulated Raman Scattering

Lokesh Chaudhary
M. Tech Scholar, Digital Communication,
Marudhar Engineering College, Bikaner (Raj.)
*prakesh.lokesh@gmail.com*

Gautam Pandit
Assistant Professor, ECE Department
Marudhar Engineering College, Bikaner (Raj.)
*gpandit2009@gmail.com*

***Abstract*****—** The performance of an optical system is reduced by nonlinear effects. It is known that when optical power is very high then non linear effects tend to manifest themselves, so the study became important in DWDM system. The fiber nonlinearities fall into two categories. One is stimulated scattering (Raman and Brillouin), and the second is known as optical Kerr effect. With these effects the results are changed in the refractive index of fiber with optical power. With different input signals kerr-non-linearity manifests itself in three different effects such as Self-Phase Modulation (SPM), Cross-Phase Modulation (CPM) and Four-Wave Mixing (FWM). At high power level, the inelastic scattering phenomenon can induce stimulated effects such as Stimulated Brillouin-Scattering (SBS) and Stimulated Raman-Scattering (SRS). The Brillouin and Raman scattering can be differentiated as the Brillouin generated phonons (acoustic) are coherent and give rise to a macroscopic acoustic wave in fiber, while in Raman scattering the phonons (optical) are incoherent and no macroscopic wave is generated, So SRS is much less problem than SBS. The threshold of SRS is nearly to 1 Watt, more than thousand times higher than SBS. But the real systems are being expanded with EDFAs having output optical powers of 500 mW (+27 dBm), and this will only go higher. A fiber optic link that includes three such optical amplifiers will reach this limit since the limit drops proportionally by the number of optical amplifiers in series.

***Keywords****- optical system, Brillouin-Scattering,Stimulated Raman Scattering.*

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## I. INTRODUCTION

Today in the era of Information Technology and communication systems the high speed data transmission is one of the biggest needs of the industry. Today, in order to do high speed data transfer optical fibers are used in telecommunication links, Internet and small networks to get large channel bandwidth. In today's world, the advent of erbium-doped fiber amplifier (EDFAs) is one of the most notable breakthroughs in the fiber optical communication technology [1].

The optically amplified transmission lines are consider as transparent pipe which are transparent to data rates and format of modulation. However, transmission impairments, which are generally not significant in are regenerative system, accumulate along the transmission link when amplifiers are used, so that they cannot be simply ignored, and this puts a new challenge to first order transmission design.

## II. HISTORICAL PERSPECTIVE OF OPTICAL COMMUNICATION

The usages of light for transmitting information from one place to another place is a very ancient technique. In 800 BC., the fire and smoke signals were used by Greek for sending information of victory in a war, call for help, etc. Mostly a single signal was send. During the second century B.C. optical signals were converted using signalling lamps so that any message could be sent. There was no growth in optical communication till the end of the 18th century. The speed of the optical communication link was limited due to the requirement of line of sight transmission paths, the human eye as the receiver and unreliable nature of transmission paths affected by atmospheric effects such as fog and rain. In 1791, Chappe from France developed the semaphore for telecommunication on land. But that was also with limited information transfer [2].

## III. THE BIRTH OF FIBER OPTIC SYSTEMS

To guide light in a wave-guide, initially metallic and non-metallic wave-guides were fabricated but they have a large amount of loss so they were not suitable for telecommunication. Tyndall discovered the optical fibers and light could be transmitted by the phenomenon of total internal reflection in fiber. During 1950s, the optical fibers with large diameters of about 1 or 2 millimetres were used in endoscopes to see the inner parts of the human body. Optical fibers can provide a much more reliable and versatile optical channel than the atmosphere; Kao and Hockham published a paper about the optical fiber communication system in 1966. But the fibers formed an huge loss of 1000 dB/km. But in the atmosphere, there is a loss of few dB/km. Immediately Kao and his fellow workers felt that these high losses were a result of impurities in the fiber material. Using a pure silica fiber these losses were reduced to 20dB/km in 1970 by Kapron, Keck and Maurer. At this attenuation loss, repeater spacing for optical fiber links become comparable to those of copper cable systems. Thus the optical fiber communication system turns to an engineering reality.

## IV. ADVANTAGES OF OPTICAL FIBER COMMUNICATION

### 1. Wider bandwidth

The information carrying capacity of a transmission system increases as carrier frequency increases and it is directly proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the range 1013 to 1015 Hz while the radio wave frequency is about 106 Hz and the microwave frequency is about 1010 Hz..

### 2. Low transmission loss

Due to the usage of the ultra-low loss fibers and the erbium doped silica fibers as optical amplifiers, one can achieve almost lossless transmission. In the latest optical fiber telecommunication systems, the fibers having a transmission loss of 0.002 dB/km. Further, using erbium doped silica fibers over a short length in the transmission path at selective points, appropriate optical amplification can be achieved.

### 3. Biological Data Analysis

Optical fibers are made from silica which is an electrical insulator. Therefore they do not pick up any electromagnetic wave or any high current lightning. It is also suitable in explosive environments. Further the optical fibers are not affected by any interference originating from power cables, railway power lines and radio waves.

### 4. Signal security

The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a fiber in an easy manner. Therefore optical fiber communication provides hundred per cent signal security.

### 5. Small size and weight.

Fiber optic cables are refined with small radii, and they are flexible, compact and lightweight. The fiber cables can be limp or twisted without damage. Further, the optical fiber cables are admirable to the copper cables in terms of storage, handling, installation and transportation, maintaining comparable strength and durability [1].

## V. DISPERSION AND LOSSES IN FIBERS

Dispersion in the fiber means the broadening of the signal pulse width due to trust of the refractive index of the material of the fiber on the wavelength of the carrier. If we send digitized signal pulses in the form of square pulses, they are reformed into broadened Gaussian pulses due to dispersion. The dispersion leads to the distortion (or) degradation of the signal quality at the output end due to overlapping of the pulses. There are two kinds of dispersion mechanisms in the fiber: (i) Intramodal dispersion and (ii) Intermodal dispersion [7].

### 1. Intramodal dispersion

(a) **Material dispersion:** This dispersion arises due to the variation of the refractive index of the core material with the wavelength or frequency of light. It is directly proportional to the frequency bandwidth of the transmitted pulse. The material dispersion tends to zero at the wavelength of 1300nm. Further by using an optical source with a narrow spectral width, the material dispersion can be reduced. For shorter wavelengths around 600nm to 800 nm, the material dispersion exponentially rises to a higher value.

(b)**Waveguide dispersion:** This dispersion arises due to the finite frequency bandwidth and the dependence of the mode group velocity on the frequency of light. Higher the frequency bandwidth of the transmitted pulse, higher will be the waveguide dispersion. The amount of waveguide dispersion depends on the fiber design like core radius, since the propagation constant ‘‘□ □’’ is a function of $\frac{\alpha}{\lambda}$. In the case of single mode fibers, waveguide dispersion arises when $\frac{d\beta^2}{d\lambda^2} \neq 0$ In the case of multimode fibers, most of the modes propagate far from the cut-off value. Therefore then all are almost free from waveguide dispersion [1].

### 2. Intermodal dispersion

Intermodal dispersion or multimode dispersion arises due to the variation of group velocity for each mode at a single frequency. Different modes arrive at the exit end of the fiber at different times. So there is multimode dispersion and hence there is broadening of the signal pulses [7].

Based on the dispersion effects, one can get the following results:

(i) The multimode step index fibers show a huge value of dispersion due to the enormous amount of multimode dispersion which gives the maximum pulse broadening. At the same time the multimode graded index fiber exhibits an overall dispersion which is 100 times lesser than the multimode step index fiber’s dispersion. This is due to the shaping of the refractive index profile in a parabolic manner [7].

(ii) In the case of single mode step index fibers, they have only intramodal dispersion. Further amidst the intramodal dispersions, the waveguide dispersion is the dominant one. The material dispersion in them is almost negligible due to axial ray propagation and small core radius. When we compare it with the dispersion in the multimode graded index fiber, the dispersion in the single mode fiber is slight. That is why single mode fibers are highly useful in long distance communication systems [7].

## VI. INTRODUCTION TO NONLINEARTIES & DEVELOPMENT MODEL OF SRS

Nonlinearity effects arose as optical fiber data rates, transmission lengths, number of wavelengths, and optical power levels elevated. The only problem that affects optical fiber in the previous time was fiber attenuation and, sometimes, fiber dispersion; however, these issues are easily handled with using a number of dispersion avoidance and cancellation

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techniques. Fiber nonlinearities give a new realm of obstacle that must be overcome. These nonlinearities prior appeared in specialized applications such as undersea installations. However, the latest nonlinearities that need unique attention when designing state-of-the-art fiber optic systems include stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), four wave mixing (FWM), self-phase modulation (SPM), cross-phase modulation (XPM), and intermodulation. Fiber nonlinearities shows the fundamental limiting mechanisms to the amount of data that can be transmitted on a single optic fiber.

The term linear and nonlinear (Figure 1), in optics, mean intensity independent and intensity dependent phenomena respectively. Nonlinear effects in optical fibers (Figure 2) occur due to (1) change in the refractive index of the medium with optical intensity and, (2) inelastic scattering phenomenon. The power dependence of the reflective index is cause for kerr-effect. Depending upon the type of input signal, kerr- non-linearity manifests itself in three different effects such as Self-Phase Modulation (SPM), Cross-Phase Modulation (CPM) and Four-Wave Mixing (FWM) [8].

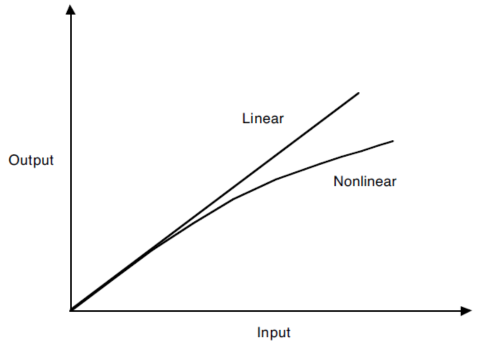


Fig 1. Linear and nonlinear interactions

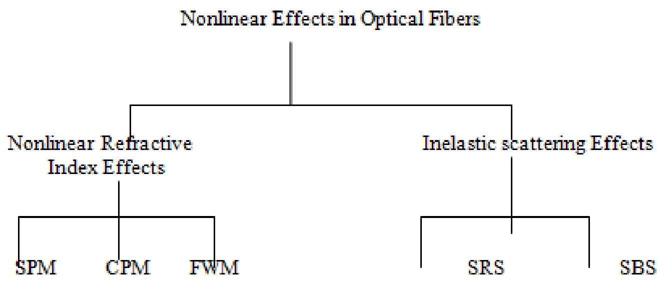


Fig 2. Nonlinear effects in optical fiber

## VII. SCATTERING NONLINEARITIES

When light is incident on material it undergoes various scattering process. Most of the scattering is elastic, and the scattered wave has the same frequency as the incident wave. However, this scattered light is, in general, at some arbitrary angle to the forward direction of propagation. Hence, if one measures the transmitted light in the forward direction, there is a reduction in intensity as a result of the scattering into other directions. This loss is known as Rayleigh scattering loss. In addition to the elastically scattered component, a small fraction (about 1 to 106) of the incident photons undergo inelastic scattering. The scattered photon emerges with a frequency shifted below or above the incident photon frequency. The difference in energy between the incident and scattered photons is deposited in, or extracted from, the scattering medium. The frequency shifts* can be small (approximately 1 cm-1) or large (greater than 100 cm-1). When the frequency shift is small, the process is known as Brillouins cattering. The larger frequency shifts characterize the regime of Raman scattering

## VIII. DEVELOPMENT OF THE MODEL

In DWDM systems due to SRS effect, channels which have lower wavelengths act as pump and the channels which have higher wavelengths that act as stokes. This leads to power transfer among the other wavelength channels. The graphical representation of depletion and amplification of optical power at different wavelength channels due to SRS has been shown in Figure 3 for a four channel DWDM system.

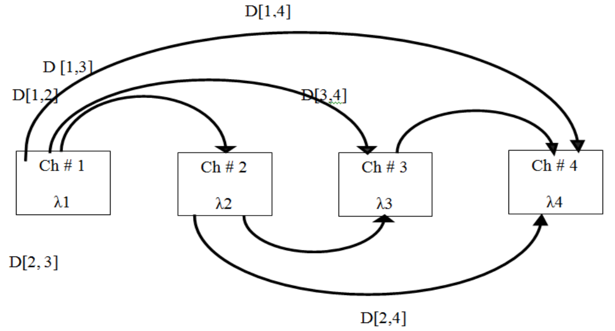


Fig. 3. Optical power transfer among different wavelength channel due to SRS

A simple case of a DWDM fiber optic system having four co-propagating channels is considered first and mathematical expressions for depletion and amplification of power at different wavelength channels due to SRS are obtained as given in equations (1) – (4). A generalized expression for N channel system is then obtained from these equations [9].

$$P_M[1] = P_T[1]\{1 \quad (1)$$

$$P_M[2] = P_T[2]\{1 - \sum_{i=3}^{4} D[2,i]\} + P_T[1] \quad (2)$$

$$P_M[3] = P_T[3]\{1 - D[3,4]\} + \sum_{j=1}^{2}\{P_T[j]I \quad (3)$$

$$P_M[4] = P_T[4] + \sum_{j=1}^{3} (4)$$

where and are the optical power launched in the ith channel and the modified power in the ith channel due to SRS effect after propagation over a given length of optical fiber respectively for i=1,2,3,4. Channel # 1 is the lowest wavelength channel with centre wavelength l1. D[i,j] represents the fraction of power depleted from the ith channel by the jth channel for j>i,

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i.e., $j^{th}$ channel is at a wavelength longer than that of the $i^{th}$ channel. The value of D[i,j] is evaluated using equation (5) that is developed by modifying the expression in [3, 4].

$$\text{for } (f_i - f_j) \le 1.5 \times 10^{13} \text{ Hz and } j > i$$
$$D[i,j] = 0$$
$$\text{for } (f_i - f_j) > 1.5 \times 10^{13} \text{ I} \quad (5)$$

g is peak Raman gain coefficient (cm/W). are the wavelengths (nm) of ith and jth channels and $f_i$ , $f_j$ are the centre frequencies (Hz) of the $i^{th}$ and $j^{th}$ channels. $A_e$ is effective core area of optical fiber in $cm^2$. is optical power in watts launched in the jth channel and value of b varies from 1 to 2 depending upon the polarization state of the signals at different wavelength channels, b=2 is considered for scrambled polarisation [5]. L is actual fiber length in km and is wavelength dependent effective length in km which is calculated using equation (6) given below

$$L_e(\lambda_j) = \left\{1 - \exp\left[\frac{-\alpha(\lambda_j)L}{4.343}\right]\right\}\left[\frac{4.343}{\alpha(\lambda_j)}\right] \times \frac{\text{total lengh}}{\text{inter channel separati}} \quad (6)$$

Where is wavelength dependent linear loss coefficient of optical fiber in dB/km. For calculating, equation (7) is developed by taking into account the variation in linear loss coefficient with wavelength up to 0.7 dB, over 25nm bandwidth (in 1550 mm transmission window) and 100 km fiber length confirmed by the experimental results [6].

$$\alpha(\lambda_j) = \{\alpha_{max} - [(\lambda_j - \lambda_1)/\Delta_{WDM}](\alpha_{max} - \alpha_{min})\}$$
$$\alpha_{max} = \alpha + \alpha_{VM}/2$$
$$\alpha_{min} = \alpha - \alpha_{VM}/2$$
$$\alpha_{Var} = (0.007/25)\Delta_{WDM} \quad (7)$$

Where is spectral width of DWDM signal (i.e. separation between the shortest wavelength channel and the longest wavelength channel) in nm, and are wavelengths of channel # j and channel# 1 respectively in nano meters and is in dB/ km and is fiber loss coefficient in dB/km at centre wavelength. It is assumed that varies linearly with wavelength. However, in transmission windows other than 1550 nm window the variation of fiber loss coefficient with wavelength will change and so the factor 0.007/25 in equation (7) will have to be changed accordingly. This makes the model competent of taking into account the consequence of wavelength dependent linear loss coefficient of fiber while calculating SRS convinced spectral distortion in DWDM fiber optic systems. The equations (1) to (4) are combined together to form a single equation, which is further generalized for N channel systems as given below (8).

$$P_M[k] = P_t[k] - P_t[k]\sum_{i=k+1}^{N} D[k,i] + \sum_{j=1}^{k-1} P_t[j]D[j,k] \quad (8)$$

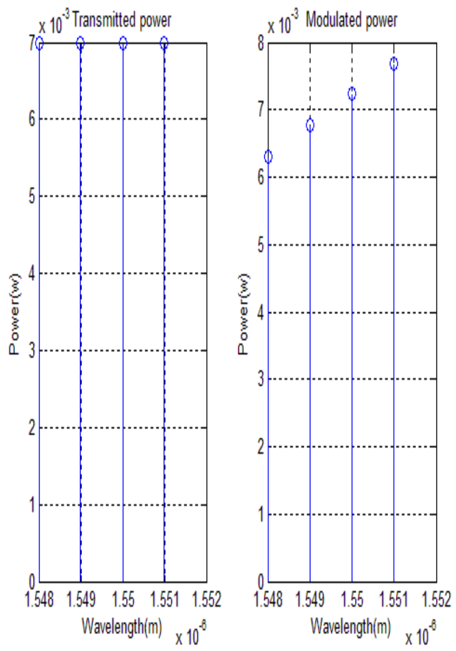


Fig 4. Power transmitted and modulated power due to SRS

Figure 4 shows the typical transmit spectrum or a four channel DWDM system. Note that all the four wavelengths have identical amplitudes (power). These signals are in 1550 nm window and illustrate the SRS effect. It can be seen modulated power that short wavelength channels have much smaller amplitude compared to the longer wavelength channels.

## IX. ALGORITHM

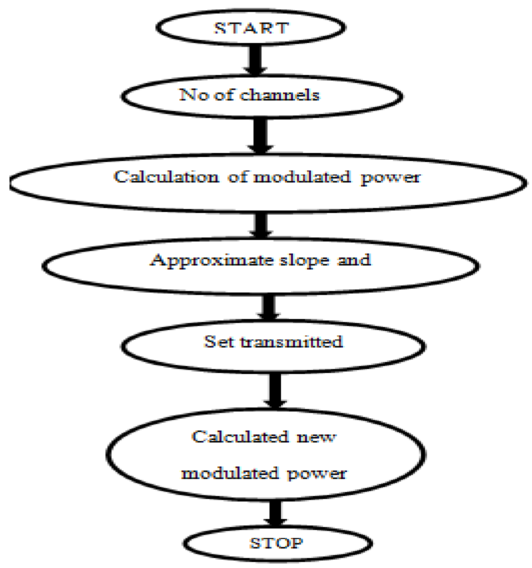


Fig 5 Flow chart of algorithm

The proposed linear power division algorithm is given in Figure write fig no. 5. In this algorithm, the number of channels varied from 4 to 35, and corresponding modulated power has been calculated. In the next step, the slope and intercept of modulated power are approximated and transmitted power is set according to the proposed equation. In the last step, the new modulated power for corrected transmitted power is calculated.

## X. CONCLUSION

We can say that using linear approximation on the transmitted side can negate the effect of SRS in DWDM system. It can be said that efficient power division algorithms can help to achieve almost constant power across all the wavelengths.

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