Investigation of Self-Frequency variation of Higher order Soliton in Optical fiber

Rajeev Sharma, Harish Nagar, G P Singh

Abstract—In this paper, we present Intrapulse Stimulated Raman Scattering in optical fibers. To attain this purpose we used, the Split Step Fourier Method in our simulations. This technique is widely used to simulate soliton like numerical solutions of the Nonlinear Schrödinger Equation (NLSE) and this is a principal method with a very high speed in calculations. During their transmission in optical fiber, soliton pulses are affected by the Raman scattering. Raman scattering is a process that has a substantial role in the higher order nonlinear effects. The Intrapulse Stimulated Raman Scattering (ISRS) is a phenomenon that appears for pulses with a wide spectrum. For these pulses the energy is transported from the high frequency components of the same pulse to the low frequency components. The consequence of this process is that the pulse spectrum shifts in the direction of the red side of the frequencies. The shift toward the red side of the spectra is called self-frequency shift and its physical foundation is related to the delayed nature of the Raman response.

The Intrapulse Stimulated Raman Scattering is useful to generate Raman solitons whose carrier wavelength can be tuned by changing input peak power or fiber length . Also, this phenomenon is accountable for soliton decay. The Raman scattering process can limit the peak power in fiber optical devices and can cause problems in high power fiber lasers and amplifiers. Also, this process can turn optical fibers into Raman amplifiers or lasers.We accomplish our purpose by using MATLAB Software in anomalous dispersion regime. Also, the comparison of Raman scattering with self-steepening is also studied.

Index Terms—ISRS,Soliton,NLSE,SS

INTRODUCTION:

Third order higher nonlinear optical effects are well known to strictly limit the efficiency of multichannel wavelength division multiplexed (WDM) transmission systems deployed on optical fibers. Among these effects, stimulated Raman scattering (SRS) and Self-Steepening(SS) [1] are the main effects which limits the performance of the system . The first effect is foremost considered as a limitation of system performances. Raman scattering make clear the parametric interaction of light with molecular vibrations and provide example of inelastic scattering [2]. Where incident light scattered by molecules experiences a downshift in optical frequency, the transform in optical frequency is just the molecular vibrational frequency (called the Stokes frequency)[3],[4]. It is essential to mention, in the case of optical fibers only the Stokes is prevailing. The cause for this is that the anti Stokes is phase mismatched during collinear propagation. Moreover, because of thermal equilibrium, the majority of molecules is unexcited i.e. the effect of SRS is usually first seen as that the shorter wavelength channels take power, and that power nourish the longer wavelength channels. However, the same effect may also find valuable applications, namely, for efficient amplification of injected signals and for the generation of new frequencies in silica glass, the Stokes shift is a broad distribution but with the strongest peak at 13 THz. This corresponds to 100 nm when the pump is in the region of 1450 nm, resulting in the strongest peak in the Raman amplification when the signal is located at wavelengths around 1550 nm [5]. SRS can couple different channels in a WDM system and give arise to crosstalk and attenuation. Even when $\tau_R = 0$ the second effect (SS) will appears which results from the intensity dependence of the group velocity, that makes the peak of the pulse move slower than wings, however, this phenomenon would still manifest through shift of the pulse center. On the other hand, this effect escort to an asymmetry in

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the SPM broadened spectra of ultrashort pulses and the another most important characteristic of this phenomenon is that it can fabricate spectral and temporal shifts of the soliton. Specially, when the solitons are of higher order, it leads to division of such solitons into their constituents known as soliton decay[6],[7]. Also, silica glass is the dispersive medium, this characteristic becomes more imperative when the length of the fiber much shorter than the dispersion length. So the higher order of dispersion becomes more significant when the ultrashort pulses are transmitted through the fiber , the reliance of phase velocity on frequency is known as chromatic dispersion. As a consequence of the chromatic dispersion, distinct frequency components of the pulse propagate with unequal speeds. This can lead to alter the shape or even a broadening of the pulse. In addition, the velocity of energy flow of an optical pulse in a dispersive medium may be different from the phase velocity . The amalgamation of nonlinear interaction such as Raman scattering and the anomalous group velocity dispersion that is lead to an important factor which causes very different behaviors of nonlinear propagation of short pulses, as very dissimilar spatial and temporal behaviors, i.e. optical solitons are formed by balancing the dispersion and nonlinear effects [8],[9]. This paper is mainly concerned to investigate the influence of SRS attenuation and SS on the pulse transmission in single mode fiber alone in presence of higher order dispersion effects concurrently. These effects are studied by demonstrating the generalized propagation equation that is affected by the characteristic of SRS and the related topics.

Theory and Simulation:

The generalized NLSE used in our simulations is

$$i\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = \delta_3 \frac{\partial^3 u}{\partial \tau^3} - is\frac{\partial}{\partial \tau}(|u|^2 u) + \tau_R u\frac{\partial |u|^2}{\partial \tau} \quad (1)$$

To separate the effects of intrapulse Raman scattering, it is useful to set $\delta_3 = 0$ and $s = 0$ in Eq. (1). Pulse advancement inside fibers is then governed by

$$i\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = \tau_R u\frac{\partial |u|^2}{\partial \tau} \quad (2)$$

with $\epsilon(u) = -i\tau_R u\frac{\partial |u|^2}{\partial \tau}$ (3)

It is easy to see that the amplitude of the soliton is not altered by the Raman effect but its frequency δ alters as

$$\frac{d\delta}{d\xi} = \frac{-8}{15}\tau_R \eta^4 \quad (4)$$

Because η is a constant, this equation is readily integrated with the result

$$\delta(\xi) = \frac{8}{15}\tau_R \eta^4 \xi \quad (5)$$

Using $\eta=1$ and $\xi = z/L_D = |\beta_2| z/T_0^2$ the Raman induced frequency shift can be written in real units

$$\Delta\omega_R(z) = -8|\beta_2|T_R z/(15T_0^4) \quad (6)$$

The negative sign illustrate that the carrier frequency is reduced, i.e., the soliton spectrum shifts in the direction of longer wavelengths or the "red" side.Physically, the red shift can be implicit the terms of stimulated Raman scattering . For pulse widths ~1 ps or shorter, the spectralwidth of the pulse is huge enough that the Raman gain can amplify the low frequency(red) spectral components of the pulse, with high frequency (blue) components of the same pulse acting as a pump. This mechanism continues along the fiber, and the energy from blue components is constantly transmitted to red components. Such an energy transfer come into view as a red shift of the soliton spectrum, with shift increasing with distance.The consequence of intrapulse Raman scattering on higher order solitons is analogous to the case of self-steepening. Especially, even moderately small values of τ_R lead to the decay of higher order solitons into its constituents . Figure.2 shows such a decay for a second order soliton (*N*=2) by solving Eq. (2) numerically with τ_R= 0.02.

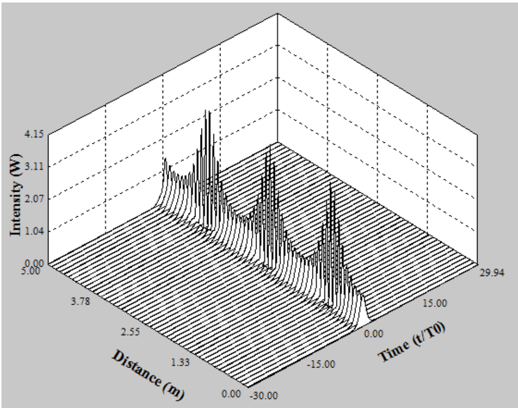

Figure.1 Soliton decay in presence of self steepening for N=2 (s=0.02, τ_R=0,β_2= -1)

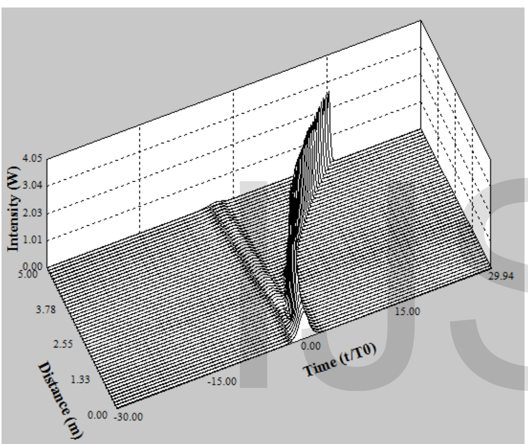

Figure.2 Soliton decay in presence of SRS for N=2 (s= 0, τ_R=0.02,β_2= -1)

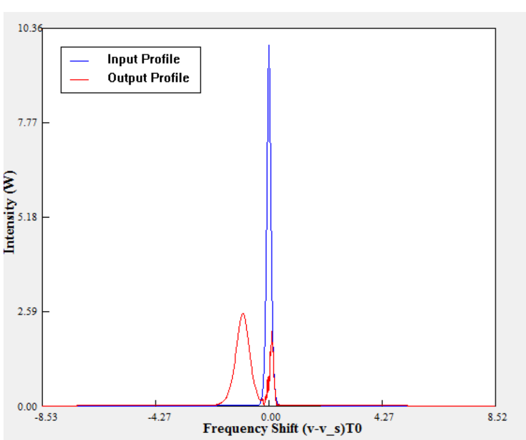

Figure.3 Pulse spectrum for parameter values identical to those of Figure.2

A comparison of Figure.1and Figure.2 gives us an idea about the similarity and the differences for two different higher order nonlinear mechanisms. A significant difference is that comparatively smaller values of τ_R compared with s can induce soliton decay over a given distance.Another important difference seen in Figure.1 and Figure.2 is that both solitons are delayed.In the case of self-steepening, whereas in the Raman case the low intensity soliton is advanced and become visible on the leading side of the incident pulse. This behavior can be understood qualitatively from Figure.3. The most striking feature is the huge red shift of the soliton spectrum. The red shifted broad spectral crest correspond to the intense soliton shifting toward the right in Figure.2, whereas the blue shifted spectral feature corresponds to the other peak moving in the direction of the left in that Figure. Since the blue shifted components travel faster than the red shifted ones, they are advanced while the others are delayed with respect to the input pulse. This is precisely what is seen in Figure.2.

Conclusion:

The soliton will propagate through the fiber without a shifting in its center; with the possibility of deformation in the form of a produced pulse, especially, in case of the higher orders of solitons. But the situation changes drastically by introducing the nonlinear effects SRS and SS.

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ISSN 2229-5518

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