Optical Soliton and Interaction of higher order Soliton

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(Review paper)

Abstract—In the modern world of Technology some application such as data video transmission and multimedia application require huge bandwidth. Optical fiber communication is promising technology. For such application Group velocity dispersion puts the limitation on the bit rate. Hence the different technique is used to compensate dispersion. If the power level in the fiber is increased then the nonlinear effects are generated. The power variation within the channel gives the variation in the Refractive index of fiber medium which give rise to Self phase modulation. Self Phase modulation gives positive chirp. This effect compensates the GVD if the wavelength is higher than zero dispersion wavelengths, which gives negative frequency chirp. Hence negative frequency chirp given by GVD is compensated by positive frequency chirp given by SPM. The Interaction of SPM and GVD give the pulse which maintains their pulse shape and amplitude such a wave is known as Soliton

Keywords— **SPM, GVD**

Introduction:

Light diffracts as it propagate in a medium. In linear homogeneous media (air, water),there is no physical phenomenon that restricts diffraction. However, in nonlinear media exhibiting Kerr effect, the diffraction can be controlled by a focusing effect that tries to literally squish the spatial extent of the beam .this rather special effect can be seen typically at very high intensities .According to the optical Kerr effect, the refractive index of non linear media increases proportional to the transverse intensity profile of the beam. for instance we have Gaussian profile the central part of the beam is more intense then the side, and hence the media transforms itself into a kind of a GRIN structure, whose refractive index in the central is higher than that of the edges. In other word media is transformed to a positivegradient index lens, and hence the focusing effect. If this focusing effect keeps converging a beam, the beam intensity per unit area of the non linear medium increases, and at some point this intensity goes beyond the maximumtolerable intensity level of the crystal there by physically damaging the crystal .on the other hand,when the focusing effect is matched exactly to compensate the diffraction, the beam propagates without any change in the spatial profile.

Dispersion in optical fiber:

Ideally an optical pulse with a given FWHM and amplitude, transmitted into end of fiber should arrive at the far end of that fiber with its shape unchanged however the optical pulse not only losses power but the pulse broadens as it propagate the phenomenon of broadening of pulse during its propagation through the optical fiber is known as dispersion. The widened pulse may merge into its neighbouring pulse and cause transmission errors as shown in figure 1
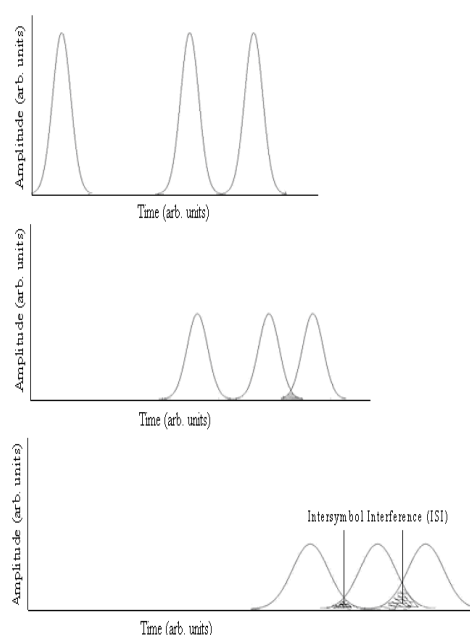

Figure 1

Chromatic dispersion:

Chromatic dispersion arises because different frequency components of light travel at different velocities in the same medium. A medium absorbs electromagnetic radiation through oscillation of bound of electrons at characteristicsresonance frequency. Hence when an optical field is incident on the dielectric medium and interacts with the bound electrons, the response of the medium depends upon the frequency of the incident optical Field. Due to this phenomenon refractive index of the medium becomes function of frequency of the incident optical field that is n(ω).this property of the medium is called chromatic dispersion Fiber dispersion plays important role in pulse propagation because different spectral components travel at different speeds, represented as c/n(ω) ,where n(ω) is frequency dependent refractive index of the fiber mathematically by using mode of Taylor series around the frequency ωo $\beta \omega = n \omega \frac{\omega}{c} = \beta 0 + \beta 1 \omega 1 - \omega 0 + \beta 2(\omega - \omega 0)^2 .1$

where n is the core refractive index, ω0 is the central frequency of the pulse spectrum and $\beta \omega = (\frac{d^m \beta}{d\omega^m})$ (m=1,2,…).1.1

$\beta 1 = \frac{d\beta}{d\omega} = \frac{1}{c}\frac{d}{d\omega}$ (nω) Where β1 is inverse group velocity vg

where ng is group index for β2 named as a GVD parameter .$\beta 1 = \frac{1}{c}(n + \frac{\omega dn}{d\omega})$ 1.2

$\beta 1 = \frac{1}{c}(n + \frac{\omega dn}{d\omega}) = \frac{ng}{c}$ 1.3

$$\beta 2 = \frac{d\beta 1}{d\omega} = \frac{1}{c}(n + \frac{\omega dn}{d\omega}) \qquad 1.4$$

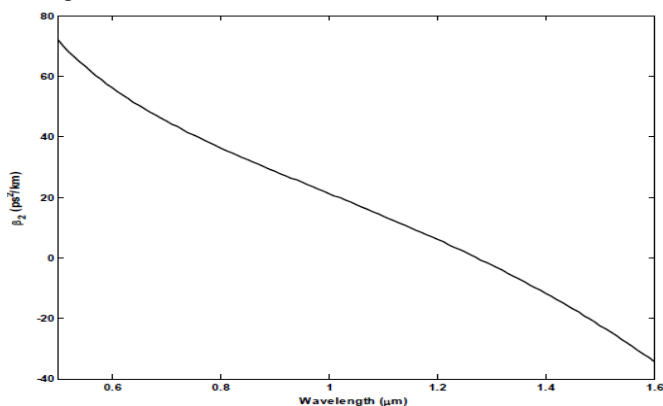Figure 2 shows the variation of β2 with wavelength around the region of interest

Figure2

From the figure it is clear that for the wavelength of 1.27um denoted as λd, the effect of β2 vanishes. The values of β2 are positive for wavelength less than λd, while they become negative for wavelength greater than λd. the region for β2 > 0 is called normal dispersion regime while the region for β2< 0 is known as anomalous dispersion regime

Generation of optical Soliton

If the relative effect of SPM and GVD are controlled just right, and the appropriate pulse shape is chosen the pulse compression resulting from SPM can exactly offset the pulse broadening effect of GVD.Depending On the particular shape chosen, the pulse either does not change its shape as it propagates. The family of pulse that do not change in shape are called fundamental solitons, and those that undergo Periodic shape changes are called higher order solitons.

Frequency chirp

When a high intensity optical pulse is coupled to a fiber, the optical power modulates the refractive index seen by the optical excitation .This induces Phase fluctuations in the propagating wave thereby producing a chirping effect in the pulse.
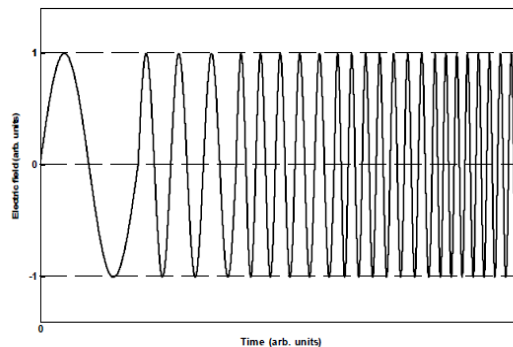

Figure 3

When a narrow high intensity pulse traverse a medium with a negative GVD parameter for the constituent frequency GVD counteracts the chirp produced by SPM. Now, GVD retards the low frequency in the front end of the pulse and advances the high frequency at the back .The result is that the high intensity sharply peaked soliton pulse changes neither its shape nor its spectrum as it travel along the fiber.

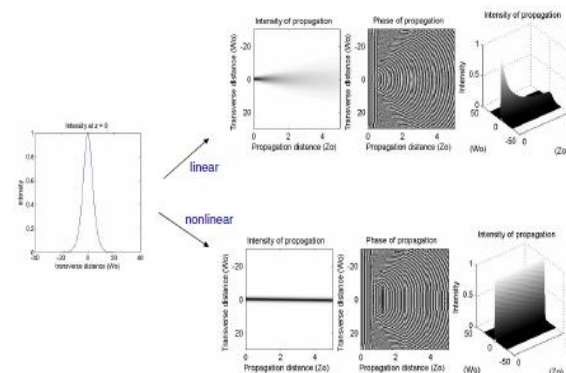## Pulsepropagation in linear and non linear medium

Figure3

The intensity image clearly shows the energy spreading out as Sech propagate in Z direction. The Phase shows expanding spherical wavefront. The three apparent vertical discontinuities in the phase plot are not real .The 3D intensity plot shows the intensity draining out as it propagates .when pulse propagates through the non linear medium there is no spreading of pulse energy as the sech propagate the 3D Intensity plot of spectrum is shown in above
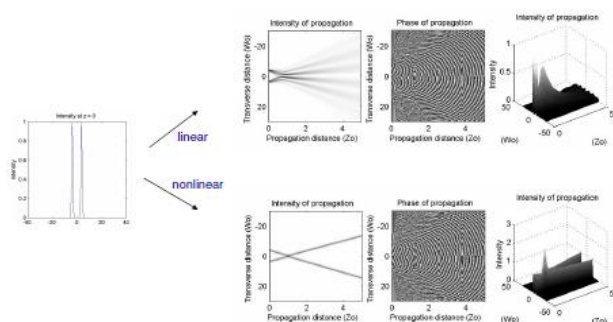
Soliton Interaction

Figure 4

The Above figure illustrate the collision of two sech beams in a linear medium interference fringes can be seen the far field. we now implement a two soliton collision .the intensity image clearly shows that the soliton remain unchanged after collision. It is interesting to see an on axis amplitude null exactly when the two solitons collide .The solitons destructively interfere in that region .Due to the on axis null , there's an on axis phase discontinuity in the phase plot .
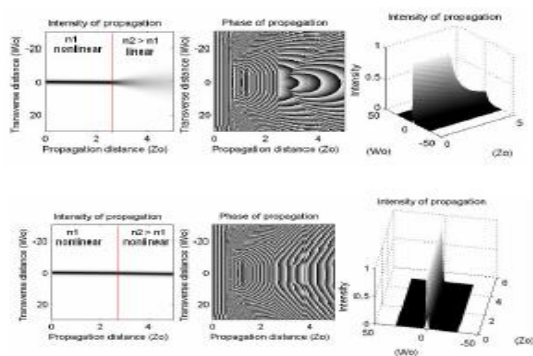
Soliton through boundaries

Figure 5

When pulse propagates through boundaries having different refractive index n1and n2 where n1 is non linear refractive index and n2 is linear refractive index. At the boundary of linear and nonlinear the phase of pulse gets dispersed as shown in figure 5 When the pulse propagates through non linear medium where n1 and n2 refractive index are nonlinear the spectrum of the pulse remain unchanged as shown in figure 5.

Effect of loss for high order Soliton

In order to see the effect of loss on high order solitons,thepropogation of the first and second order soliton is simulated for a distance of 69 km with a loss of 0.5dB/km. As it can be seen from the figure the second order soliton compresses to the one fourth of the initial pulse width at the half period and then return to initial pulse width at the half period and when the propagation of the second order soliton under the effect of the loss which is shown in figure 6a and 6b
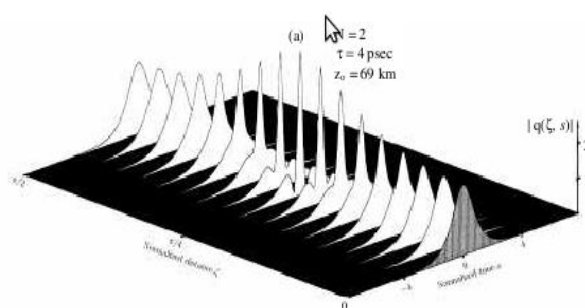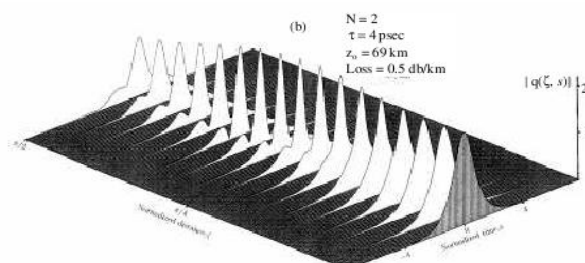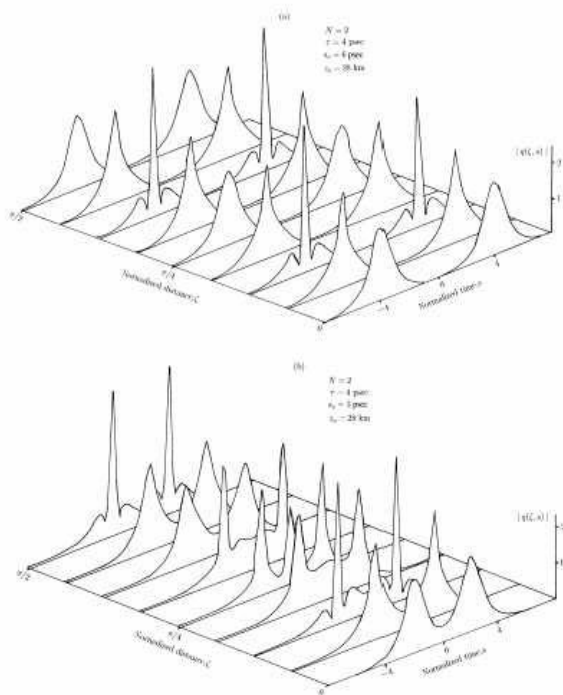

Figure 6a

Figure 6b

Figure 7 represent the propagation of two second order soliton through 28km lossless optical fiber.The time between the pulses is taken as 12psec in fig a and 6psec in fig b since the time between the pulse is much longer in fig a, there is no interaction between solitons and they propagate the same. As in fig a and figb.when the time between the pulse is reduced to 6psec as shown in fig b the interaction of soliton starts.

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Conclusion :

Due to shape preserving property of soliton.Itwas considered as a candidate carrier for long distance and a high bit rate optical communication. The result obtained from computer simulation of the twosecond order solitonpropagation through the optical fiber shows that soliton interact with each other depending on the time between the pulses if the loss of the optical fiberneglected. It is also found that loss of optical fiber increases this interaction. It is observed that the interaction of the soliton can lead to lose the properties of the soliton