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Research Paper

PRINCIPLE OF SOLITON AND EFFECT OF MODULATION INSTABILITY ON SOLITONS PROPAGATING IN NONLINEAR MEDIA

PHYSICS

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ABSTRACT

A soliton is a localized wave that propagates without change through a nonlinear medium. In soliton kerr effect cancel the dispersion effect and thus pulse shape is maintained. Soliton are narrow and high intensity pulses which can retain their shape by compensating the effects of SPM and GVD Mechanisms.

INTRODUCTION:

The soliton wave concept was suggested by John Scott-Russell [4] which can travel rapidly and unattenuated over very long distance even thousands of kilometers maintaining its shape and size. They interact with other soliton as normal waves but unlike normal waves after interaction emerge out by retaining their shape and amplitude with phase change (or) splits into two solitary waves with the same shape and velocity as before.

Properties associated with soliton:

Normal wave merge or combine but in case of soliton waves of two different size, small wave is overtaken by large wave and soon splits in to two separate wave again of small and big size waves.

These waves can travel large distances and are stable retaining their shape and size.

Solitons are found in nature will be building blocks in future especially in the field of optical devices [3].

Temporal solitons are classified in to two types

1) Bright temporal solitons
2) Dark temporal solitons.

Pulses of light which represent a local increase in wave amplitude is called bright soliton and dark solitons[6] represent a decrease in wave amplitude and the amplitude dropping to zero which is experimentally observed in number of system but not in water.

In solitons group velocity dispersion effect and kerr effect mechanisms[4] acts in opposite direction (or) one cancels the effects of other and vice versa and thus maintains the pulse shape and size while propagation and such pulses which are propagating and maintain the size and shape are called temporal soliton pulses[5].

Results and Discussion:

1.2.1: Effect of Self Phase Modulation mechanism in soliton:

Self phase modulation (SPM) [2] solitons are narrow and high intensity pulses that maintains its shape by balancing the pulse compression occurring by SPM and pulse broadening occurring by GVD (group velocity dispersion).

The root cause of SPM(self phase modulation)[6] is the change in frequency which is in turn changes by the phase difference introduced (or) developed by the refractive index of fiber which in turn depends on the intensity.

Different parts of travelling pulse have different intensity suffer different phase shift and this results in frequency change (or) also called as frequency chirping. The phase introduced by the fiber after travelling a fiber length L is given by equation

$$\ddot{O} = \frac{2\eth}{\ddot{e}}(n\acute{e} + n_{n\acute{e}} I)\, L_{eff} \qquad (1.1)$$

The first term of above expression gives the linear portion of phase and second term gives the non linear phase constant.

As phase is varying with time it leads to frequency variation also called as chirping frequency due to SPM.

As phase is varying it leads to change in frequency spectrum or broadening of a pulse due to self phase modulation [1].

1.2.2 Effect of GVD mechanism in soliton:

The effect of GVD [6] is the overlapping of neighboring pulses which is caused by the group velocity of the signal. Due to overlapping error occurs at the receiver.

The group velocity is given by $u_g = c\left(\frac{d\beta}{dk}\right)^{-1}$.

And the delay difference over a length L is given by

$$\delta\tau = \frac{d\tau_g}{d\omega}\delta\omega = \frac{d}{d\omega}\left(\frac{L}{u_g}\right)\delta\omega = L\left(\frac{d^2\beta}{d\omega^2}\right)\delta\omega$$

Where $\hat{a}_2 \equiv \frac{d^2\hat{a}}{d\grave{u}^2}$ is called the GVD parameter.

1.2.3 Wave equation (NLSE) of soliton:

A wave is represented by a wave equation mathematically. For example, matter wave is represented by Schrodinger wave equation which may be time dependent (or) time independent. Similarly, non linear Schrodinger equation (NLSE) is used to describe the propagation of solitons in optical fiber [9]

It is given by

$$i\left(\frac{\partial u}{\partial z}\right) - \frac{s}{2}\left(\frac{\partial^2 u}{\partial t^2}\right) + N^2|u|^2 u + i\left(\frac{\acute{a}}{2}\right)u = 0$$

The solution can be written as

$$u(z,t) = \sec h(t)\exp(\dot{z}\ /2) \qquad (1.10)$$

Here sech (t) represents the hyperbolic secant function. This is a bell-shaped pulse used for soliton pulses. The first term of NLSE equation gives the GVD effects in which dispersion tends to broaden pulse. The second term gives non-linear factor which shows the relationship between refractive index of the fiber and intensity of light [5].

This leads to broadening of frequency spectrum of pulse through self phase modulation (SPM).

The third term gives the alternation or amplification in other words the loss or gain of energy respectively.

Also, from NLS equation, it is derived that the dispersive and nonlinear terms are complementary phase shifts and upon integration leads to phase shift but maintains its shape and size.

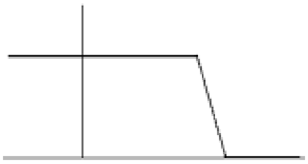

Figure 1: Nonlinear term (steepen).

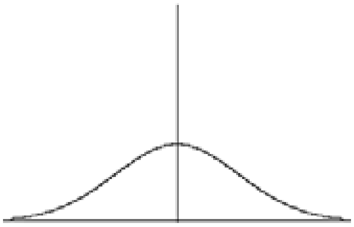

Figure 2: Dispersion term (flatten).

In the experiments a laser (λ = 0.6328 mm) was passed through a variable beam splitter and a system of two cylindrical lenses. The beam was directed into a photorefractive crystal. The beam was placed about 0.2 mm in front of the crystal so that the input beam in the crystal was diverging. A variable dc voltage was applied and images of the intensity distribution were recorded.

Figure:3 shows the near-field distributions of the input (*a*) and the output (*b*), (*c*), *d*), (*e*), (f) beam for different values of the applied voltage (different values of the nonlinearity).

Under transient conditions the transverse modulation instability was clearly seen breaking up of two-dimensional bright spatial solitons propagating in nonlinear medium due to transverse modulation instability [3].

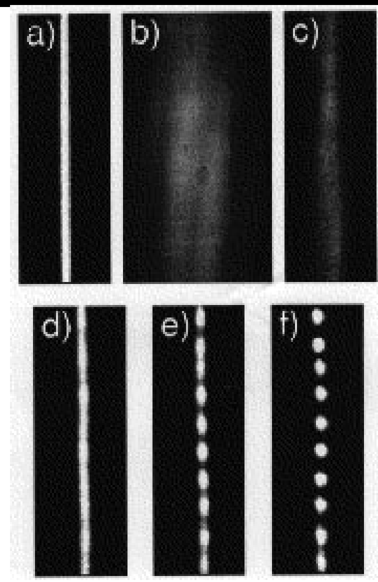

Figure.3: Break-up of two-dimensional bright spatial solitons propagating in nonlinear medium due to transverse modulation instability.

CONCLUSIONS:

If a wave is in motion, the compression of pulses occurs by SPM

and broadening of pulse occurs by GVD .

Optical solitons pulses which can preserve their shape by balancing the mechanism called self phase modulation (SPM) resulting from the Kerr non- linearity and pulse broadening effect of GVD (Group velocity dispersion). This is important, because to any pulse travelling through a nonlinear media is affected by both the Kerr nonlinearity effect and group velocity dispersion effect. Also, under transient conditions the transverse modulation instability was clearly seen which gives break-up of two-dimensional bright spatial solitons propagating in nonlinear medium due to transverse modulation instability.

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