Effect of Interactions on Ultrashort Pulses Transmission

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Abstract—**Optical fiber communication has great advantages over the conventional cable communication system. The most important advantage is the availability of enormous communication bandwidth which is a measure of the information carrying capacity. Ultrashort pulses (solitons) refer to a situation where light beam propagates through a nonlinear optical medium without any change in its shape and velocity. Optical ultrashort pulses are formed due to the balance between the group velocity dispersion and self phase modulation.**

Depending upon the individual pulse width, inter pulse spacing and loss in the fiber, co-propagating ultrashort pulses do interact and share energy. Generating ultrashort pulses with the appropriate parameters is just the first step in successful ultrashort pulses communication systems. Ultrashort pulses must also be able to propagate through an optical fiber while maintaining these parameters.

Incorporating the mathematical model based on the Nonlinear Schrödinger (NLS) equation, we have conducted various simulation experiments to investigate the interaction between three adjacent ultrashort pulses of equal and unequal spacing, equal and unequal amplitude and phase variations.

Keywords- Ultrashort pulse, amplitude, spacing and interaction.

I. INTRODUCTION

Ultrashort pulses (solitons) propagation results from a special case of nonlinear dispersion compensation in which the nonlinear chirp caused by self phase modulation (SPM) balances and the temporal broadening induced by group velocity delay (GVD). Although both of these phenomena limit the propagation distance that can be achieved when acting independently, if balanced at the necessary critical pulse intensity they enable the pulse to propagate without any distortion (i.e. its shape is self-maintaining). In essence a ultrashort pulse has two distinctive features which are potentially important for the provision of high-speed optical fiber communications: it propagates without changing shape and the shape is unaffected [1].

Eventually, optical ultrashort pulses will be the ultimate candidate, which use the nonlinear self-phase modulation to counteract the group velocity dispersion (GVD). However, increased channel capacity requires the pulses to be closely spaced. After balancing the GVD and SPM, there is a need to take into consideration the relative phase, relative amplitude and the spacing between neighboring ultrashort pulses.

In this paper, various simulation experiments have been performed using Matlab to investigate the interaction between three ultrashort pulses.

II. MATHEMATICAL MODEL

The equation governing ultrashort pulse which is the Non-linear Schrodinger equation (NLSE) for an optical pulse with the field envelope A (z, τ) propagating in the optical fiber with the absence of loss and higher order dispersion is given in [2, 3, 4] as

$$j\frac{dA}{dz}-\frac{\beta_2}{2}\frac{d^2A}{d\tau^2}+\gamma|A|^2A=0 \tag{1}$$

where β_2 is the second order dispersion parameter, z is the distance along the fiber, A is the complex wave envelope, γ is the nonlinear coefficient resulting from the Kerr effect and τ is the retarded time By solving the equation numerically with the input amplitude consisting of a ultrashort pulse pair [5] we can find the effect of interaction on solitons. The solution is given as

$$A(0,t)=\mathrm{sech}(\mu+z_o)+\ \mathrm{sech}(\mu)+\ k\mathrm{sech}[k(\mu+z_o)]\exp(i\theta) \tag{2}$$

Equation (2) represents the propagation of three ultrashort pulses through a fiber, where μ is the relative amplitude; θ is the relative phase and $2z_0$ is the initial separation between neighboring solitons.

In order to achieve stability, ultrashort pulse width W_0 can be related to the bit rate as

$$B_r=\frac{1}{D_b}=\frac{1}{2z_oW_o} \tag{3}$$

where D_b is the duration of the bit slot.

$$2z_o=\frac{D_b}{W_0} \tag{4}$$

Equation (4) is the separation between neighboring ultrashort pulses. Ultrashort pulse spacing should be equal to or more than the pulse width.

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III. SIMULATION RESULTS

A. *Varying the phase of ultrashort pulses with unequal amplitude and equal separation between them*

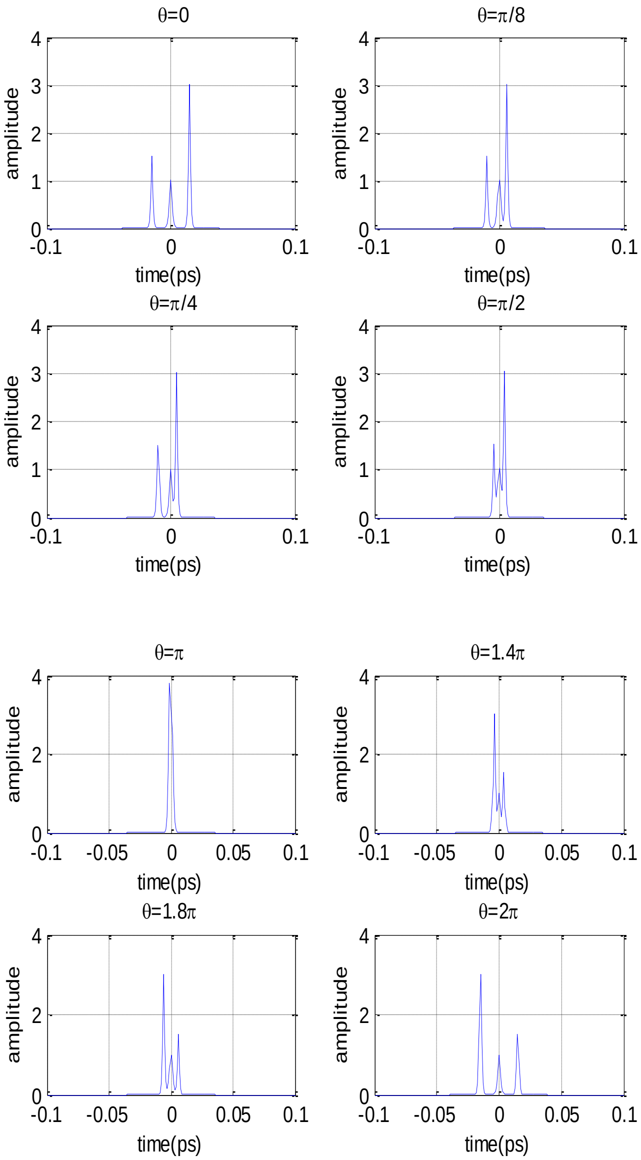

Fig.1: *Evolution of three ultrashort pulses of unequal amplitude and equal spacing with phase varying from θ = 0 to 2π*

Figure 1 shows ultrashort pulses evolution of various propagation conditions as θ varies from 0 to 2π.At θ = 0, three pulses are being launched into the fiber with unequal amplitude and equal spacing. At θ = π/8, the third pulse get attracts i.e. coming closer and joining it tail with the second pulse at θ = π/4 while the first pulse remains unchanged. Due to this attraction force, pulses merge into each other and form a single pulse with magnitude higher than the initially launched. They then continue to pass through one another and sustain the same properties they began with as if there were no interaction.

B. *Varying the phase of ultrashort pulses with unequal amplitude and unequal separation*

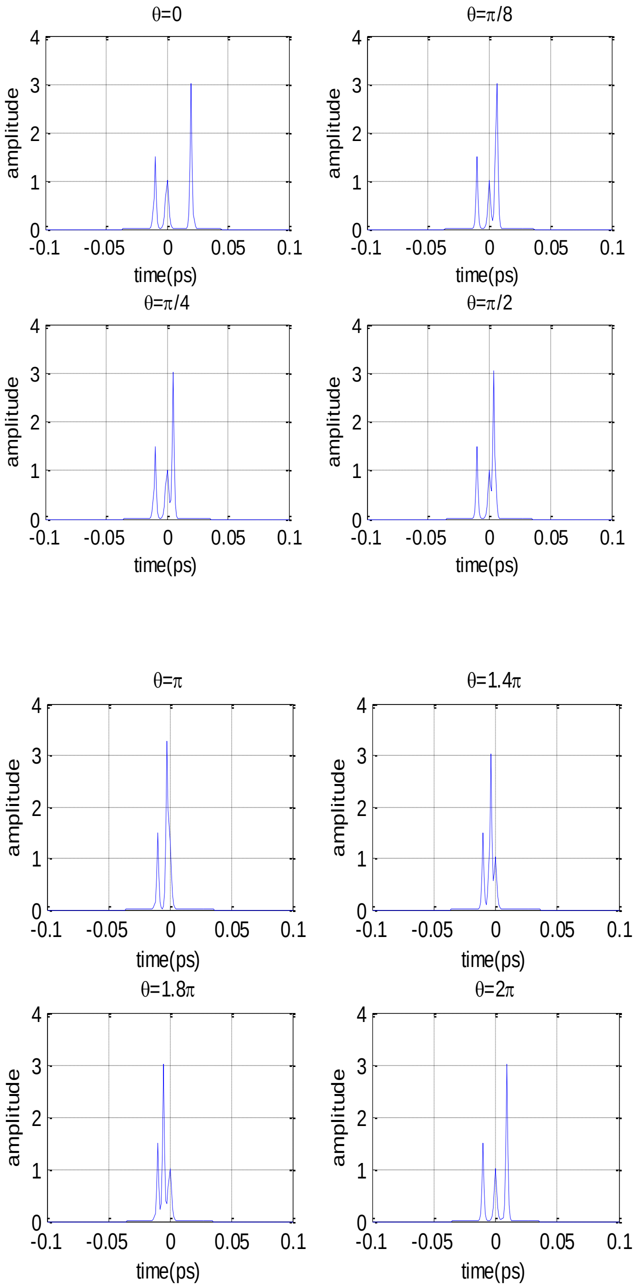

Fig.2: *Evolution of three ultrashort pulses of unequal amplitude and equal spacing with phase varying from θ = 0 to 2π*

In Fig. 2 shows ultrashort pulses of unequal amplitude and equal spacing with changing phase from θ = 0 to 2π. At θ=π/8, the third pulse gets closer to the second pulse while the first pulse shape is the same. They then begin to interact and form a giant pulse having amplitude higher than their initially launched. They then walk through each other and separated after interaction as if there was no interaction at all.

C. Varying the phase of ultrashort pulses with equal amplitude and equal separation

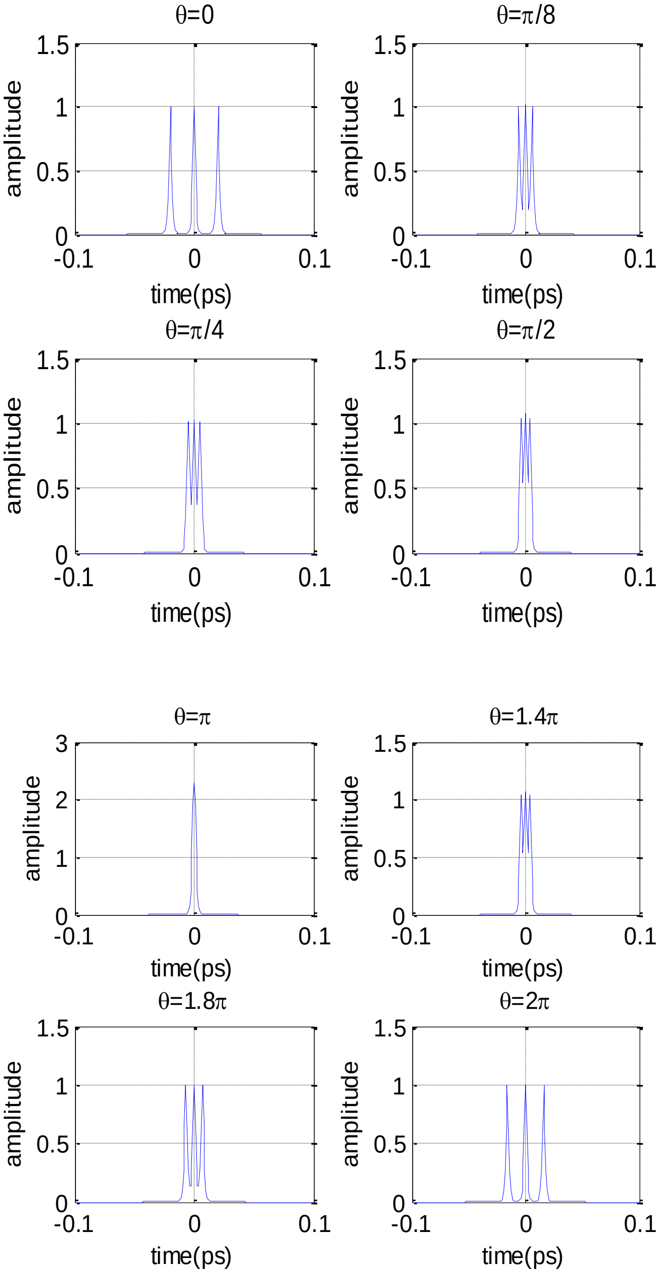

Fig 3: *Propagation of ultrashort pulses with equal amplitude and spacing.*

In Fig. 3, both the amplitude and the spacing is kept equal at θ = 0. These pulses begin their interactions i.e. coming closer and joining their tails respectively. They then form a giant pulse after their collision with their amplitude higher than the initially launched. After collision, they continue to pass through one another and sustain the same properties they began with.

D. Varying the phase of ultrashort pulses with equal amplitude and unequal separation

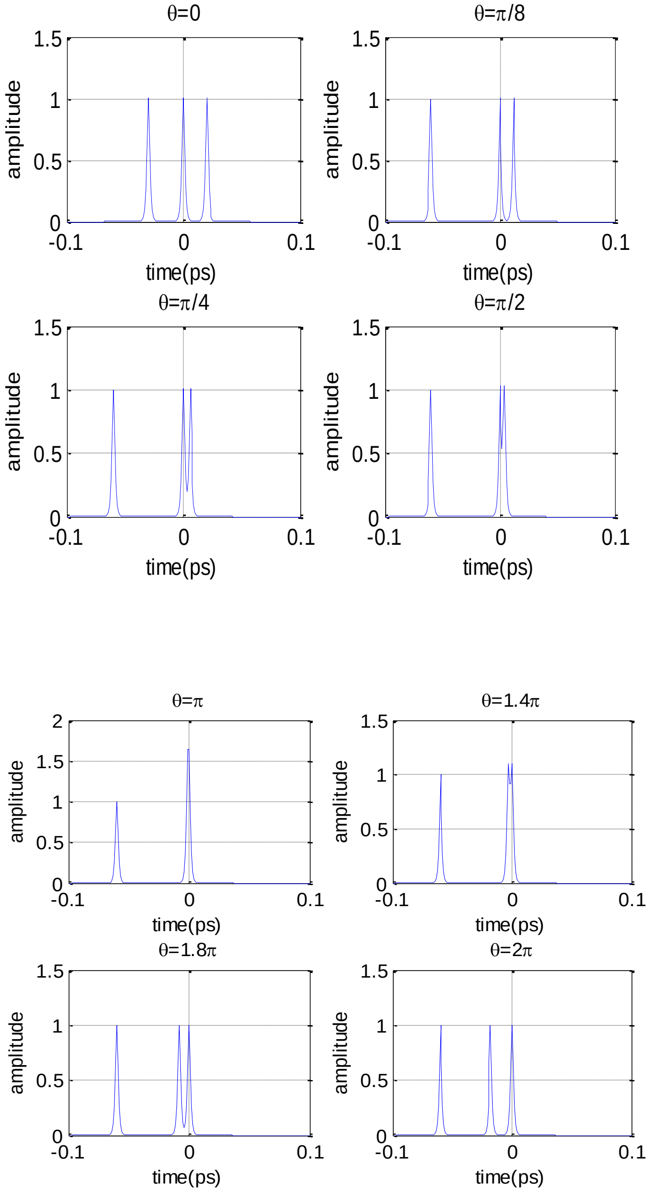

Fig 4: *Evolution of three ultrashort pulses of equal amplitude and unequal spacing with phase varying from θ = 0 to 2π*

Fig. 4 shows ultrashort pulses of equal amplitude and unequal spacing at θ = 0.The third pulse begins it interaction i.e. coming closer and joining it tail with the second pulse while the first pulse remains unchanged i.e. do not interact, due to wider separation. The third and second pulses form a single pulse having magnitude higher than their initially launched. They then continue to pass through one another after their collision and sustain the same properties they began with.

IV. CONCLUSION

In this paer, the effect of varying the parametrs i.e. phase, amplitude and spacing between ultrashort pulses are analyzed. The paper reveals that the choice of amplitude causes interaction and also the choice of spacing between ultrashort pulses plays an important role in transmission. The wider the spacing the lesser the interaction. In order to avoid interaction, the phase, the choice of amplitude and spacing should be taken into consideration since interaction reduces the efficiency of soliton transmission.

REFERENCES

[1] A. Antwiwaa and S. Prince, “Effect of interaction caused by relative phase, amplitude and spacing on neighboring soliton pulses,” in Lecture Notes in Engineering and Computer Science: *Proceedings of World Congress on Engineering 2012*, 4-6 July, 2012, London, U.K., pp 944-947.
[2] G.P. Agrawal, *Fiber-optic Communication Systems*, John Wiley and Sons, NY, 1997.
[3] C. R. Menyuk, G. M. Carter, W. L. Kath and R. M. Mu, ‘Dispersion managed solitons and chirped return to zero: what is the difference?’, in I. P. Kaminow and T. Li (Eds), Optical *Fiber Telecommunications IVB*, Academic Press, pp. 305–328, 2002.
[4] Optical solitons theory and experiments edited J.R.Taylor.
[5] A. Hasegawa, Y. Kodama, Solitons *in Optical Communications*, in Clarendon Press, Oxford (1995).