The Behavioural Analysis of a Pulse in an Optical Fiber Over a Distance of Several Kilometers

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***Abstract*— Optical fiber telecommunication service providers prefer to increase the capacity of their existing fiber links. However, pulse broadening due to dispersion effect and frequency chirping due to nonlinear effect has become a critical factor limiting the quality of optical signal transmission over optical links. In this report, we want to balance dispersive effect and nonlinear effect by using split step Fourier method to solve non-linear Schrödinger equation. The generated ultrafast pulse has high stability and can propagate independently along the fiber. Finally, the simulation results would be shown using the MATLAB simulator.**

Keywords-dispersion effect, nonlinear effect, frequency chirping.

I. INTRODUCTION

When pulse passes through an optical fiber it disperses; with the amount of dispersion depending on the refractive index of the fiber. As a result [1] different wavelengths contained in the pulse will arrive at the fiber output at different times (resulting in pulse broadening) even though they are propagated through the same path.

Nonlinear effects which are as a result of the dependence of the pulse intensity on the refractive index of the optical fiber vary from location to location along the fiber length, which results in a variation of the refractive index. This variation in the refractive index (Kerr effect) of the fiber causes the pulse to induce its own phase shift and this phenomenon is known as Self Phase Modulation. Proper balancing of the dispersion and non-linear effects generates a very stable pulse which can be propagated through the optical fiber without distortions. This pulse can also resist perturbations in the physical medium. In this report we use split step Fourier method to solve non-linear Schrödinger equation.

This work was supported by All Nations University Ghana. The authors wish to express their sincere gratitude for their support.
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II. MATHEMATICAL MODEL

The Non-linear Schrodinger equation (NLSE) best describes the dispersion effect and nonlinear effect that occurs when an optical pulse travels through a nonlinear medium.
NLS general equation is given in [2, 3, 4] as:

$$\frac{dA}{dz}+\frac{j}{2}\beta_2\frac{d^2A}{dT^2}+\frac{\alpha}{2}A=N^2|A|^2A \qquad (3.1)$$

Where:

$$j=\sqrt{-1}$$

A = the slow varying of the envelope of the optical fiber
z = the axial distance in picoseconds
T = the delayed time in picoseconds
α = the linear attenuation factor of the fiber and accounts for the loss.
N = the nonlinear coefficient of the fiber, which accounts for the nonlinear effect.
β_2 =the second-order derivative of the propagation constant β

The fiber attenuation is assumed to be zero (i.e. α = 0 in Equation 3.1).
The simplified NLS equation is given as:

$$-\mathrm{j}\frac{\mathrm{dA}}{\mathrm{dz}}=\frac{\beta_2}{2}\frac{\mathrm{d^2A}}{\mathrm{dT}}+\mathrm{N}^2|\mathrm{A}|^2\mathrm{A} \qquad (3.2)$$

The first term on the right hand side represents the dispersion effects of the fiber.
The second term represents the nonlinear effect of the fiber.
By solving the equation numerically using Split Step Fourier transform the solution obtained is given as:

$$A(z,t) = \mathrm{sech}(t)\exp(jz/2) \qquad (3.3)$$

Sech = hyperbolic secant function
z = the axial distance in picoseconds
t = the time in picoseconds

III. SIMULATION RESULTS

The behavior of dispersion effect, nonlinear effect, and the result of balancing these two effects has been studied with MATLAB using equation 3.2 and equation 3.3 and the results are given below

ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

A. Effect of Dispersion on ultrafast pulse

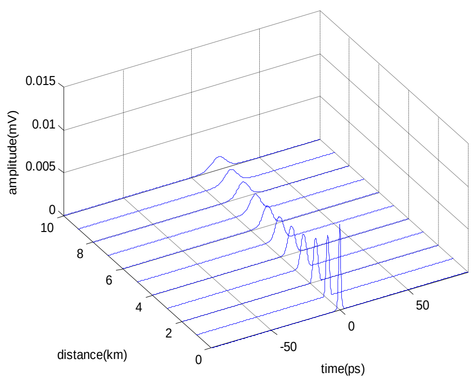

Fig 1: Pulse evolution of dispersion effect on ultrafast pulse at a distance of 10 km

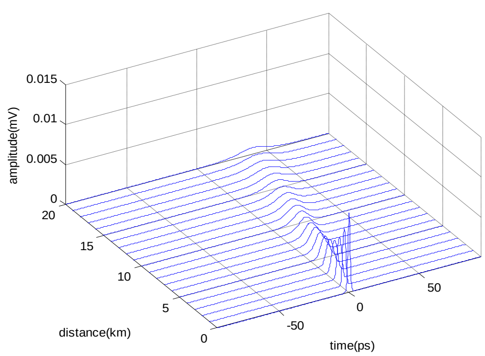

Fig 2: Pulse evolution of dispersion effect on ultrafast pulse at a distance of 20 km

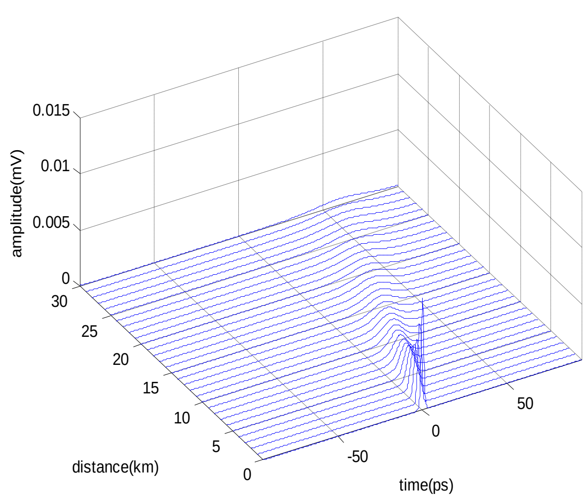

Fig 3: Pulse evolution of dispersion effect on ultrafast pulse at a distance of 30 km

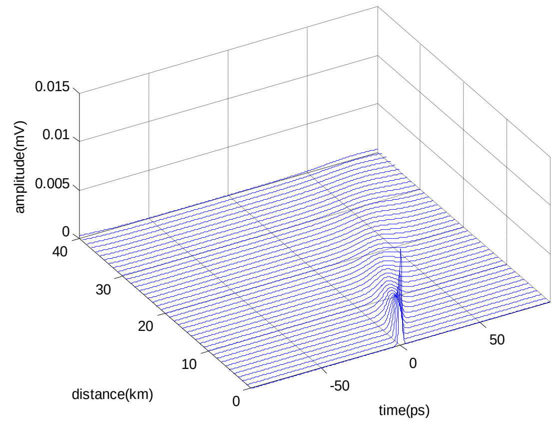

Fig 4: Pulse evolution of dispersion effect on ultrafast pulse at a distance of 40 km

Fig 1 shows the pulse evolution of dispersion effect on ultrafast pulse at a distance of 10 kilometers. The pulse amplitude varies from 0.01mV at distance 0km to 0.002mV at distance 10km. Fig 2 shows the pulse evolution of dispersion effect on ultrafast pulse at a distance of 20 kilometers. The pulse amplitude varies from 0.01mV at distance 0km to 0.001mV at distance 20km. Fig 3 shows the pulse evolution of dispersion effect on ultrafast pulse at a distance of 30 kilometers. The pulse amplitude varies from 0.01mV at distance 0km to 0.0001mV at distance 30km. Fig 4 shows the pulse evolution of dispersion effect on ultrafast pulse at a distance of 40km. The initial pulse amplitude is 0.01mv at distance 0km. At distance of 40km the amplitude of the pulse has reduced to 0mv. Initial pulse at a distance of 0 kilometer in fig 1 is having amplitude of 0.01mV. At a distance of 10 kilometer, the pulse broadening has caused the pulse amplitude to reduce to 0.002mV represent 80% decreased in pulse amplitude. Comparing fig 1 to fig 4 the pulse broadening effect is higher in the later. This shows that the longer the distance covered the greater the dispersion effect.

B. Nonlinear effect on ultrafast pulse

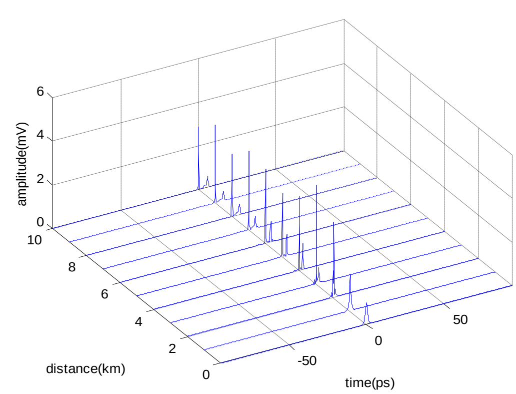

Fig 5: Pulse evolution of nonlinear effect on ultrafast pulse at a distance of 10 kilometers

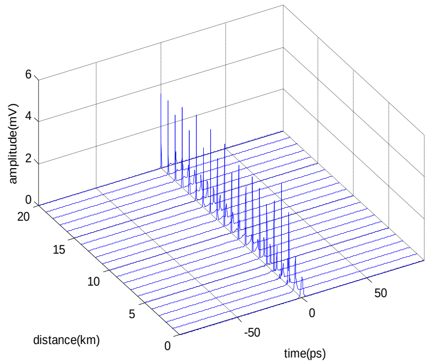

Fig 6: Pulse evolution of nonlinear effect on ultrafast pulse at a distance of 20 km

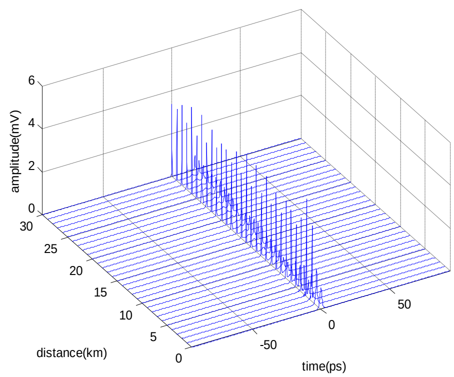

Fig 7: Pulse evolution of nonlinear effect on ultrafast pulse at a distance of 30 km

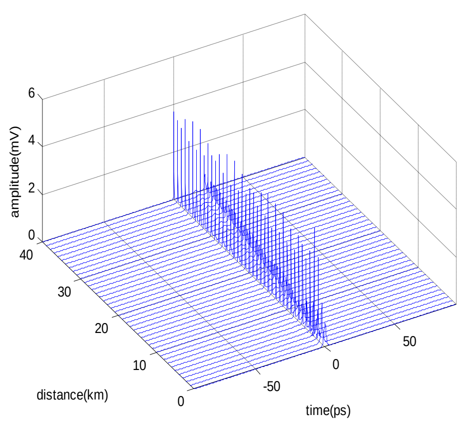

Fig 8: Pulse evolution of nonlinear effect on ultrafast pulse at a distance of 40 km

Fig 5 to 8 represent nonlinear effect that occur at various distance as the pulse travels through an optical fiber Comparing fig 5 to fig 8 it is observed that at a distance of 10km, the amplitude of the pulse is 3.25mV while at a distance of 40km the amplitude of the pulse is 4.0mV.

C. The combination of nonlinear effect and dispersion effect

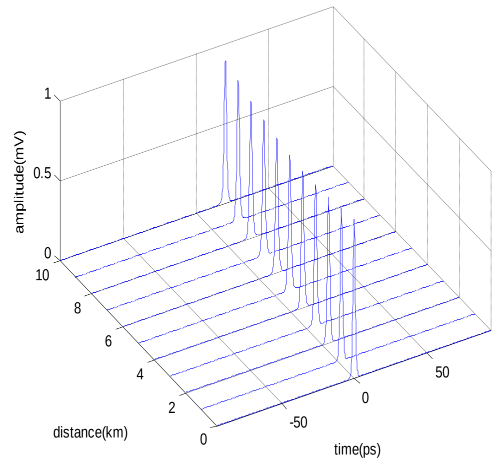

Fig 9: Pulse evolution combined effect of dispersion and nonlinear effect at a distance of 10 km

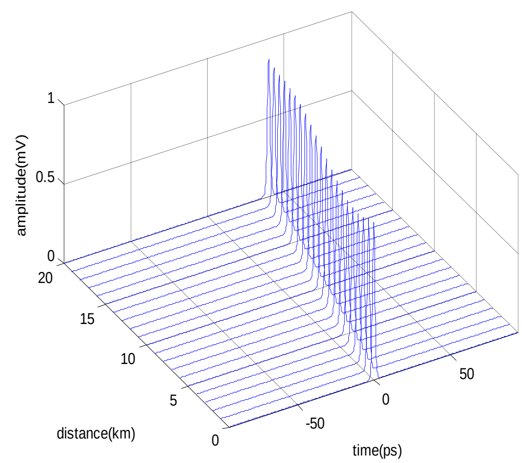

Fig 10: Pulse evolution combined effect of dispersion and nonlinear effect at distance of 20 km

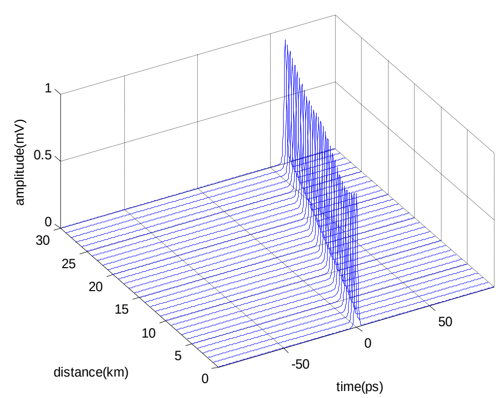

Fig 11: Pulse evolution combined effect of dispersion and nonlinear effect at a distance of 30 km

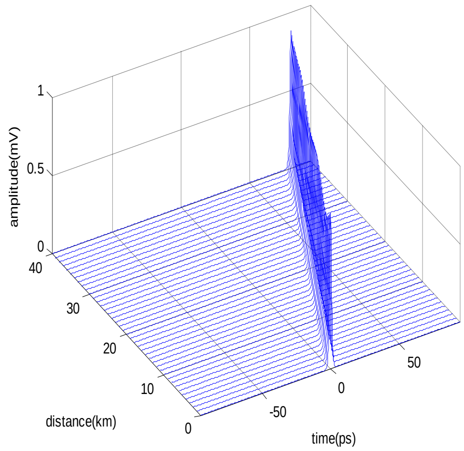

Fig 12: Pulse evolution of the combined effect of dispersion and nonlinear effect at a distance of 40 km

Fig 9 shows the pulse evolution of the combined effect of dispersion and nonlinear effect on ultrafast pulse at a distance of 10 kilometers. The initial pulse amplitude at distance 0km is 0.98mV. The pulse amplitude, phase and width remains unchanged at a distance of 10km. Fig 10 shows the pulse evolution of the combined effect of dispersion and nonlinear effect at a distance of 20 kilometers. Comparing fig 11 and fig 12, it was observed that the pulse amplitude, the pulse width and the phase of the pulse remains unchanged. This shows that the ultrafast pulse is not affected by distance.

IV. CONCLUSION

In conclusion, it was observed that for a range of distance, the dispersive effect and the pulse width increase while the amplitude decreases with the distance traversed by the pulse. However, by the use of split step Fourier method to solve the non- linear Schrödinger equation the dispersive and non linear effects can be minimized as demonstrated in this report.

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ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)