Analysis Of Gaussian and Rectangular Modulated Pulse in Fiber Optic Communication System

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Abstract—In this work, we study the effect of chirped Gaussian modulated non-linear effect & pulse transmission. With a single mode optical fiber with highly modulated non-linear chirped Gaussian transmission, our analysis shows better pulse broadening. In our study in this paper, we analyze for different chirped pulse values, positive and negative, the pulse broadening with distance traveled and the phase change with distance traveled with and without non-linear effect. Our analysis shows the positive non-linear chirped Gaussian modulated pulse has better pulse broadening with distance with that of negative chirped Gaussian pulse. It also shows that higher positive Gaussian pulse act as rectangular pulse.

I. INTRODUCTION

Fiber optics connects the world carrying call and data. With Bandwidth demand growing, manufacturers are working up To transmission rates, cut costs and otherwise improve product performance.

This analysis shows that the nature of pulse evolution inside an optical fiber in the presence of non-linear effect only. This situation arises when the physical length of the optical fiber is much greater than the nonlinear length but smaller than the dispersion length. This is the case when we use high optical power pulse of large width. Due to the high optical power, nonlinear effect cannot be ignored. As the pulse moves along the optical fiber, refractive indexing profile also moves along the fiber. Due to this change in refractive index within the pulse, there is also a change in the phase within the pulse. The continuous optical propagation inside an optical fiber in the presence of non-linearity is highly unstable.

The analysis of non-linearity can be analyzed using split step Fourier method (SSFM) for speed computation compares to time domain finite difference method. The major difference between time domain technique and SSFM is that the formal deals with all electromagnetic components without illuminating the carrier frequency. So pulse propagation in optical fiber is governed by NLSE.

II. Nonlinear Schrodinger Equation (NLSE)

Since the optical field that travels along an optical fiber is in fact an electromagnetic field, its behavior is governed by the well-known Maxwell’s equations.

The expression of the pulse envelope of the optical field can be derived from the Maxwell’s equations, and is governed by

\[ i \frac{dA}{dz} = -\frac{1}{2} \alpha A + \frac{1}{2} \beta_2 \frac{d^2A}{dz^2} - \gamma |A|^2 A \]

Where \( \alpha \) is the attenuation constant, \( \beta_2 \) is the group velocity dispersion parameter, \( \gamma \) is the non-linear coefficient and \( T \) is the retarded time given by \( T = t - \frac{z}{v_g} \) where \( t \) is the time, \( z \) is the distance along a fiber link and \( v_g \) is the group velocity. \( \beta_2 \) can be obtained using Taylor series expansion of the mode-propagation constant \( \beta(w) \) about the carrier frequency \( w_0 \)

\[ \beta(w) = \beta_0 + \beta_1 (w - w_0) + \frac{1}{2} \beta_2 (w - w_0)^2 + \ldots \]

The non-linear coefficient \( \gamma \) can be expressed as \( \gamma = \frac{n_2 w_0}{c \epsilon_{\text{eff}}} \)

where \( n_2 \) is the non-linear index coefficient, \( \epsilon_{\text{eff}} \) is the effective area of fiber.

The normalized form of the pulse envelope \( A(z,T) \) can be expressed as

\[ A(z,T) = \sqrt{P_0} \exp(-\frac{\alpha z}{2}) U(z,T) \]

where \( P_0 \) is the peak power of the pulse at \( z=0 \) and \( U(z,T) \) is the normalized pulse envelope. So the normalized pulse envelope \( U(z,T) \) can be expressed as

\[ \frac{dA}{dz} = \frac{\beta_2}{2} \frac{d^2A}{dz^2} - \gamma P_0 e^{-\alpha z} |U|^2 U. \]

This is the NLSE for a normalized pulse envelope \( U(z,T) \).

III. Nonlinearity Gaussian Pulse

The normalized pulse envelope \( U(z,T) \) used in this analysis is assumed to be Gaussian. In fact, it is not the only possible pulse shape that may be used in the variation method. A justification for using a Gaussian pulse is that an initial Gaussian pulse remains Gaussian as it propagates in a linear fiber. For this reason, the approximate solution of the NLSE obtained from the variation method is actually exact linear fiber with a Gaussian input pulse. By continuity, the approximation is still valid when then the non-linearity is not too large. In practice, the approximation holds because effective nonlinearity decreases with the increase in distance \( z \) when \( U(z,T) \) is a Gaussian pulse with chirp, it is governed by
U(z,T) = G(z)exp[-T^2(\frac{1}{2a^2} b(z))]\\
Where G(z) is the complex pulse amplitude with G(0)=1, a(z), is a pulse width and b(z) is the chirp parameter at a distance z .\\
\[ L_D = \frac{a_0^2}{\beta_2} L_{NL} = \frac{1}{\gamma_{NL}} (2a_0^2) \frac{L_D}{L_{NL}} C^2 = -2a_0^2 b_0 \]

Where \( L_D \) is the dispersion length, \( L_{NL} \) is the non-linear length, \( N^2 \) is a nonlinearity parameter, \( C^2 \) is the initial normalized chirp. If \( N^2 \ll 1 \), the dispersion is dominant effect, whereas \( N^2 \gg 1 \) the nonlinearity is dominant over the dispersion.

With higher positive value of \( C \) it will act as rectangular pulse.

c. \( L \ll L_{NL} \) and \( L \gg L_D \). This Non-linear regime. In this case we get a phenomenon called the self-phase modulation. The pulse spectrum expands but the pulse in time domain remains unchanged. Since the non-linearity length is inversely proportional to the pulse power, for high power but for not so narrow pulses this condition prevails.

d. \( L \gg L_{NL} \) and \( L \gg L_D \). In this situation both, the dispersion and non-linearity play a role in pulse propagation, and there is possibility of canceling the two effects giving what is called the Soliton.

IV. Optimum Chirp

In a fiber optic communication system, it is desirable that the broadened. The most desired is that the output pulse width is equal to input pulse width. So the optimum chirp can be expressed as \( C_{opt} = -\text{sgn}(C) \frac{Z}{L_D} \pm \sqrt{\left(\frac{Z}{L_D}\right)^2 - 1 + \text{sgn}(C) N^2 Z^2} \)

Where the + and - sign corresponds to the normal and anomalous dispersion regimes, respectively. This is because the sign of \( C \) to be opposite to \( \text{sgn}(C) \) in order to obtain the pulse compression effect. The maximum distance can be defined as \( Z_{max}^2 = \frac{\frac{L_D^2}{1 + \text{sgn}(C) N^2 Z_{max}^2}}{\sqrt{2}} \)

We take \( D= 0.7ps/(km.nm) \), which corresponds to \( \beta_2 = 0.895p s^2/km \) at \( \lambda_0 = 1.552 \mu m \) given a dispersion of length \( L_D = 87 \) km furthermore the single mode optical fiber used in the numerical evaluation has \( A_{eff} = 70 \mu m^2 \cdot \alpha = 0.2 \) dB/km.

V. SIMULATION ANALYSIS OF CHIRPED GAUSSIAN PULSE (\( C = -2, -1, 0 \))

There are 4 types of pulse propagation that can be analyzed. They are:

a. When the fiber length \( L \) is such that \( L \ll L_{NL} \) and \( L \ll L_D \) where \( L_{NL} \) is the non-linear fiber length: In this case neither the dispersion nor the non-linearity plays a role in pulse propagation and the fiber is merely a medium of energy transport.

b. \( L \gg L_{NL} \) and \( L \ll L_D \) this is Dispersive regime. It broadens as it propagates on the fiber. Since dispersion length is proportional to the square of the pulse width, for narrower pulses, the dispersion length is smaller and dispersive effect is considered.
C=3

VI. Conclusion

Here we can conclude that with higher positive chirped Gaussian pulse it has higher pulse broadening for higher modulated pulse with longer transmission which is being determined with mat lab simulation of Gaussian pulse compared to negative chirped Gaussian pulse. Higher positive chirped Gaussian pulse act as rectangular pulse. So rectangular pulse can more effect for pulse broadening rather than negative chirped Gaussian pulse.

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References


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