Simulation of short Laser Pulses Propagation Optical Fiber

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Abstract
Picosecond laser pulse propagation in monomode optical fiber is demonstrated and investigated by numerically simulation in this paper. The numerical simulation is done by nonlinear Schrödinger equation with the aid of Mathlap program. The results show that self phase modulation (SPM) leads to broadening the spectral width from 5nm to 38nm after 50m of the fiber length and accompanied by temporal broadening in the pulse width.

الخلاصة
في هنا البحث تم توضيح وفحص انتشار النبضات القصيره ضمن مدى Psec في الالياف ألبصريه أحادية النمط بوساطة المحاكاة العددية. في المحاكاة ألعدديه تم برمجه معادله شرودنكر اللاخطيه بمساعده برنامج ماتلاب . أوضحت النتائج إن تضمين الطور الذاتي يؤدي الى تعريض طيف النبضة من 5 nm إلى 38 nm بعد انتقالها في ليف بصري طوله 50 m مرافقا لها تعريض في عرض النبضة .

Introduction
The increasing demand for high data-rate fiber-optic communication systems has motivated the development of a new generation short laser pulses which are attractive sources for high-bit-rate optical data transmission. Propagation through fiber with normal group velocity dispersion (GVD) restores the pulse to nearly the original duration; there is no attempt to compensate for nonlinear effects [Atherton B. and Reed M., 1998]. The origin of the nonlinearities is the refractive index of the optical fiber, which is varying with the intensity of the optical signal. This intensity-dependent component of the refractive index includes several nonlinear effects, and becomes significant when high power is used. These nonlinear effects are characterized and influenced by several parameters, including dispersion, effective area of the optical fiber, overall unregenerate fiber length, and the degree of longitudinal uniformity of the fiber characteristic, source line width and intensity of the signal [Lamminpaa A. 2003]. Therefore, at femtosecond laser at higher transmitted power, it is important to consider the effect of the nonlinearities. SPM induced phase shift that is proportional to the optical power. It can be understood as a modulation, where the intensity of the signal modulates its own phase. A spectral analysis of the temporal self imaging phenomenon effect based on the intensity of pulse after propagation in fiber dispersive line is presented in 2006 [Chantada L., Fernandez C.,act. 2006]. In many cases it is advantageous to deliver the short pulses to the system under investigation with optical fibers [Shirakawa A.2011,Clark S.,2005 Meister S., Wu H. 2007], therefore it is very important to study the propagation of Femtosecond laser pulses in optical fibers. In this work, we demonstrate the interaction among SPM and second- and third-order dispersion for 1Psec-pulse transmission numerically and experimentally. Also the study of second order dispersion, third order dispersion and SPM effects is presented.

Theoretical Work
The study of the most nonlinear effects in optical fiber involves the use of short pulses in the range of Pecosecond or femtosecond. When such pulses propagate inside a fiber, the group velocity dispersion, third order dispersion and nonlinear effects influence their shape and spectrum. The equations for the nonlinear

propagation of short pulses in optical fibers are usually expressed in the time domain. When fields of different frequencies propagate through the fiber the common practice is to write a distinct equation for each field component. The resolution of these equations is performed either in the time domain or by spectral techniques when both time and frequency representations for the fields are necessary [Agrawal G. 2001]. The nonlinear Schrodinger equation (NLSE), modified to include higher-order dispersion, has been successful in accurately modeling pulse propagation in single-mode fibers in many diverse applications. It can therefore be employed with confidence for dispersion compensated link. In our analysis, we use the normalized NLSE[Agrawal G. 2001]

$$i\frac{\partial U}{\partial z}+i\frac{\mathrm{sgn}(\beta_2)}{2L_D}\frac{\partial^2 U}{\partial \tau^2}=\frac{\mathrm{sgn}(\beta_3)}{6L'_D}\frac{\partial^3 U}{\partial \tau^3}+i\frac{e^{-\alpha z}}{L_{NL}}(|U|^2U+is\frac{\partial}{\partial \tau}(|U|^2U)-\tau_R U\frac{\partial |U|^2}{\partial \tau}) \quad \text{----1}$$

where L_D, L_D' and L_N are the three length scales defined as

$$L_D=\frac{T_o^2}{|\beta_2|},\qquad L_D'=\frac{T_o^3}{|\beta_3|},\qquad L_{NL}=\frac{1}{\gamma P_o}$$

The parameter s and τ_R govern the effects of self-steeping and intrapulse Raman scattering, respectively, and are defined as :

$$s=\frac{1}{\omega_o T_o},\qquad \tau_R=\frac{T_R}{T_o}$$

Where U represents the normalized amplitude. P_o is the peak power of the input pulse, T_o is the input pulse width, β_2 and β_3 are the dispersion and dispersion slope parameters of the fiber respectively. and α is the fiber loss coefficient. The dispersion length L_D and the nonlinear length L_{NL} provide the length scales over which the dispersion and the nonlinear effect become important respectively. γ is the nonlinear coefficient .

In our simulation, we consider the second- and third-order dispersion effects and include SPM as the source of nonlinear terms. Other higher order nonlinear effects such as self-steeping, Raman contribution to the nonlinear refractive index and the shock term have been neglected. And the effect of SPM is moderate. As long as we avoid very short pulses (100 fs), the Raman effect and shock term, which are usually smaller than SPM, could be neglected but must be considered for ultrashort pulses with T_o<100 fs.

The intensity dependence refractive index of a nonlinear pulse can chirp the pulse through the phenomenon of SPM. The transmission fiber itself can be used for chirping the pulse. Frequency chirp can be divided into two components, which are often referred to as adiabatic chirp and transient chirp [Niemi T., Uusimaa M ,2001] .This prechirping approach works reasonably well at low energies, when a negative pulse propagates in a medium with a positive nonlinear index of refraction, In this case SPM compresses the spectrum and thus increases the pulse duration. For negative values of the chirp parameter, pulse spectrum at the fiber output can become narrower than that of initially unchirped pulses. The spectrum narrows rather than exhibiting broadening expected by SPM in the absence of GVD. This behavior can understood by noting that the SPM induced chirp is negative. While the dispersion induced chirp is positive for $\beta 2>0$ [Agrawal G. 2001].

Numerical Simulation Results

The natural length scale associated with dispersion is $L_D=T_o/\beta_2$, where To is the 1/e point of the intensity envelop for Gaussian pulses and $\beta 2$ is the GVD parameter. A pulse with a large bandwidth is affected more by dispersion. L_D for 1 Psec pulse propagation through single mode fiber at 1550 nm wavelength is roughly 1.3 m. For 46, 86 and 100 mW optical power, the phase nonlinear phase shifts φ_{NL} are 0.3, 0.55 and 0.9 for 50 m of the fiber length respectively. The numerical simulation of spectral results of injected Picoseconds laser pulse into 50m of single mode optical fiber are shown in the insets of figures 1, 2, and 3 for 46, 86, and 100 mW optical powers respectively. From these figures the output laser is suffering broadening due to GVD and SPM and these leads to broadening the pulse duration. The most notable feature of these figures are that GVD and SPM induced spectral broadening with accompanied by an oscillatory structure covering the entire frequency range of the laser pulse.

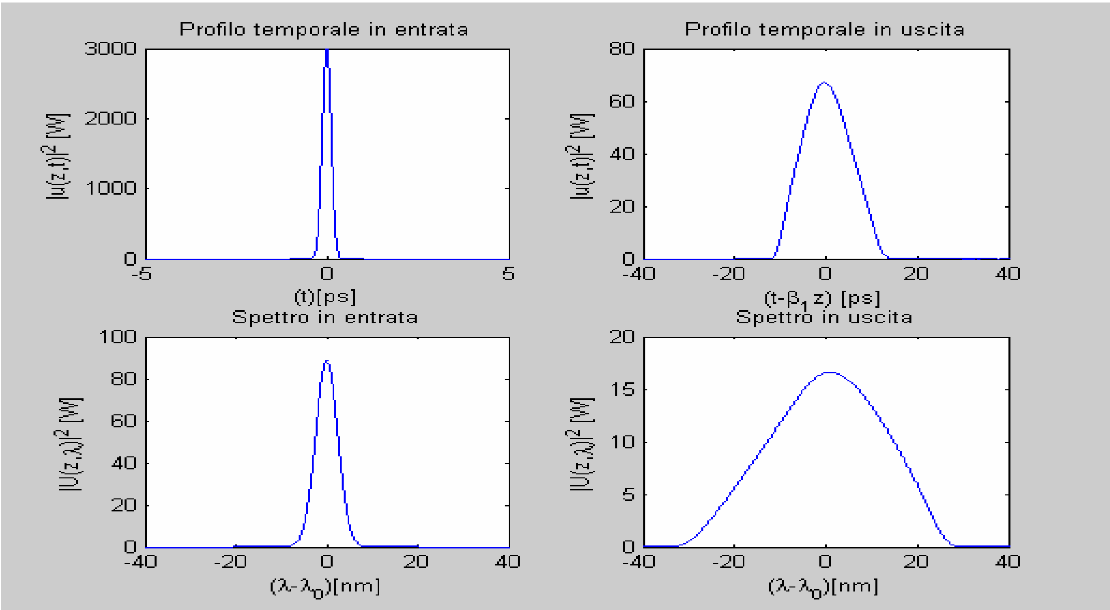

Figure 1: Input and output optical pulse when P_{in}= 46 m W. Initial Spectral Width [nm] = 5.703. Final Spectral Width [nm] = 24.5644 , Output Pulse Width [ps] = 10.2224

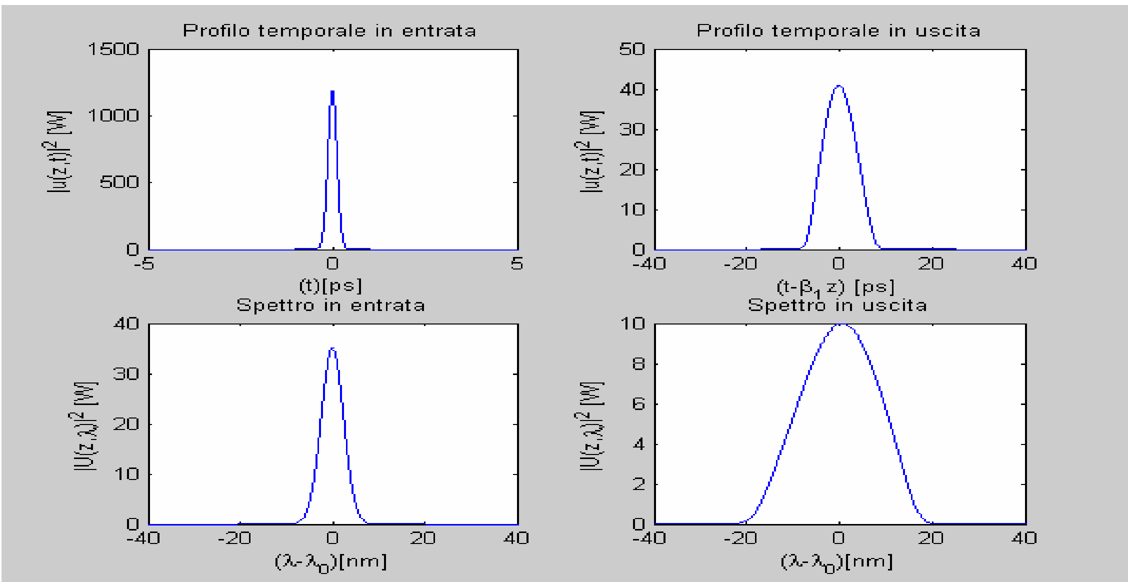

Figure 2: Input and output optical pulse when P_{in}= 86 m W. Initial Spectral Width [nm] = 5.703 , Final Spectral Width [nm] = 32.7170. Output Pulse Width [ps] = 13.7661

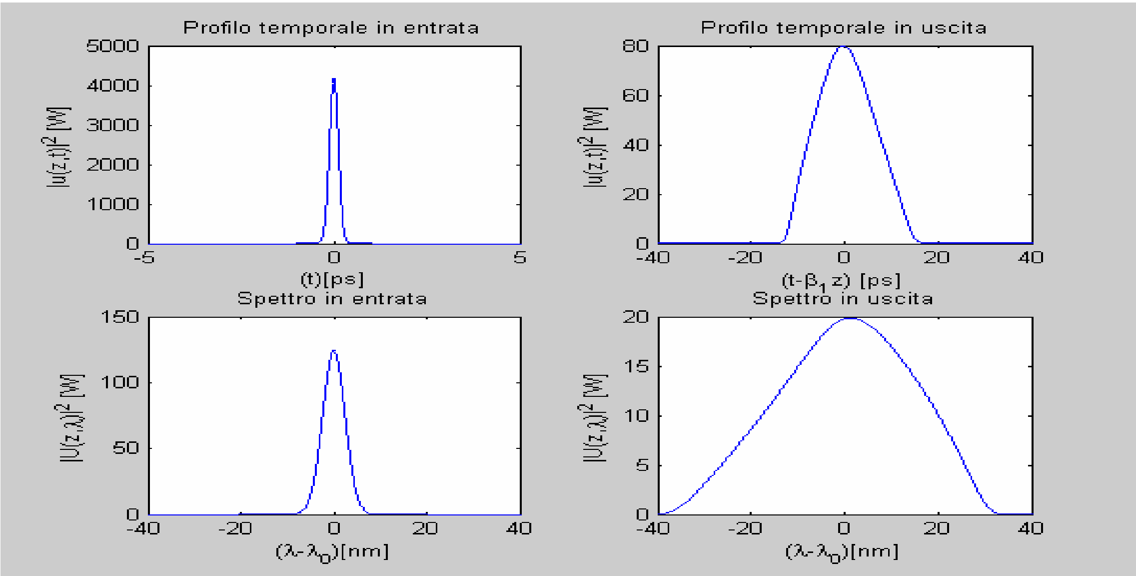

Figure 3: Input and output optical pulse when P_{in}= 100 m W. Initial Spectral Width [nm] = 5.703 , Final Spectral Width [nm] = 38.1544. Output Pulse Width [ps] = 16.1921.

The spectral broadening are arises from the optical nonlinearities which generate a phase shift compensation through the SPM by the optical Kerr effect. While GVD depends on the wavelength, its effect on signal distortion increases in pulse with spectral width of the laser diode. This distortion is arises from the variation of the refractive index of the core as a function of wavelength. The resultant effects of the input power on the laser spectral width and pulse duration from simulations are shown in Figures 4 and 5 respectively, in both cases the higher input power gives a larger spectral width broadening and pulse duration due to the nonlinear effects. The dots in these figures represent the numerical results while the straight line represent the linear fitting of numerical results**.** The origin of the oscillatory structure is temporal variation of SPM induced phase shift and frequency chirp of Gaussian pulse, where the time dependence of the SPM induced frequency chirp differs across the pulse from its central value**.**

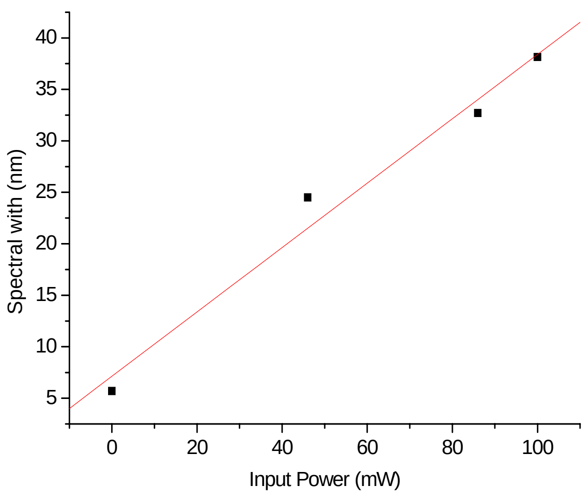

Figure 4: Spectral width as a function of input power

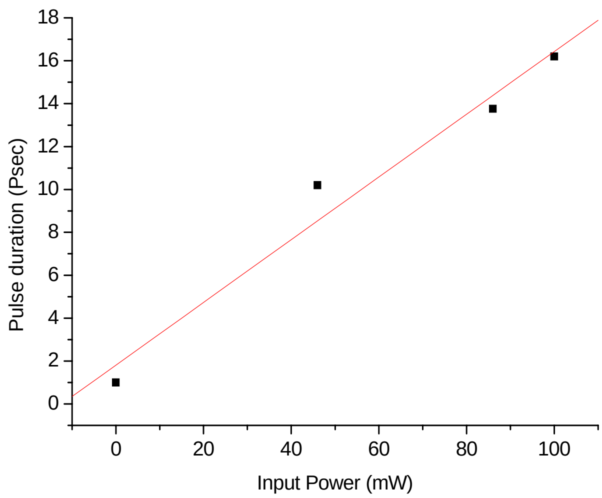

Figure 5: Pulse duration as a function of input power

Conclusion

An analysis of the performance of the Psec laser pulse that propagates in standard single mode fiber has been presented. Uniform spectral narrowing, accompanied a temporal broadening is achieved by propagation of different optical power in 50 m of the fiber length with an effective nonlinear length that is significantly longer than the dispersion length.

The results show that the fiber length and the injected optical power are affected during our procedures. The spectral broadening from 5 nm to 38 nm with broadening in the pulse duration from 1Psec to 16 Psec is achieved when the optical power is 100 mW and fiber length of 50 m.

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