# Optisystem, an Optical Fibre in Linear Regime

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**ABSTRACT:** *We have developed a package called as Optisystem which is an optical fibre in linear regime. We have studied the Gaussian pulse propagation with fibre with group velocity. The results shown the Gaussian pulse shapes in the characteristic section with velocity dispersion. Further we have presented the velocity dispersion and dispersion induced chirp with results.*

## 1. Introduction

An optical signal will be degraded by attenuation and dispersion as it propagates through the fiber optics. Dispersion can sometime be compensated or eliminated through an excellent design, but attenuation simply leads to a loss of signal [1]. Many optical fiber properties increase signal loss and reduce system bandwidth. Eventually the energy in the signal becomes weaker and weaker so that it cannot be distinguished with sufficient reliability from the noise that always present in the system, then an error may occur. Attenuation therefore determines the maximum distance that optical links can be operated without amplification. There are several component options available in fiber optic technologies that lead to particular system configurations. For longer distance optical amplifiers are needed. In general, when a system has a very wide-bandwidth used over a long distance, a single-mode fiber is used [2-4].

There are two different types of dispersion in optical fibers. The first type is intermodal, or modal, dispersion occurs only in multimode fibers. The second type is intramodal, or chromatic, dispersion occurs in all types of fibers. Each type of dispersion mechanism leads to pulse spreading. As a pulse spreads, energy is overlapped [5].

There are two types of intramodal dispersion. The first type is material dispersion. The second type is waveguide dispersion. Intramodal dispersion occurs because different colors of light travel through different materials and different waveguide structures at different speeds. Material dispersion index of the fiber core. Different wavelengths travel at different speeds in the fiber material. Different wavelengths of a light pulse that enter a fiber at one time exit the fiber at different times [3], [4], [6].

Material dispersion is a function of the source spectral width. The spectral width specifies the range of wavelengths that can propagate in the fiber. Material dispersion is less at longer wavelengths. Waveguide dispersion occurs because the mode propagation constant is a function of the size of the fiber's core relative to the wavelength of operation. Waveguide dispersion also occurs because light propagates differently in the core than in the cladding [7].

The main advantage of single-mode fibers is that intermodal dispersion is absent simply because the energy of the injected pulse is transported by a single mode. However, pulse broadening does not disappear altogether. The group velocity associated with the fundamental mode is frequency dependent because of chromatic dispersion. As a result, different spectral components of the pulse travel at slightly different group velocities, a phenomenon referred to as group velocity dispersion (GVD), intramodal dispersion, or simply fiber dispersion. Intramodal dispersion has two contributions, material dispersion and waveguide dispersion. We consider both of them and discuss how GVD limits the performance of lightwave systems employing single-mode fibers [8-11].

## 3. Effect of Group Velocity Dispersion

The equation, which describes the effect of group velocity dispersion (GVD) on optical pulse propagation neglecting the losses and nonlinearities, is [4]:

$$i\frac{\partial E}{\partial z} = \frac{\beta_2}{2}\frac{\partial^2 E}{\partial t^2} \tag{1}$$

where $z$ is the propagation direction, $t$ is the time, $E$ is the electric field envelope, and $\beta_2 = \frac{\partial^2 \beta}{\partial \omega^2}$ is the GVD parameter, defined as the second derivative of the fiber mode propagation constant with respect to frequency.

For an input pulse with a Gaussian shape

$$E(z = 0, t) = \sqrt{P_0}\exp\left(-\frac{t^2}{2T_0^2}\right) \tag{2}$$

the pulse width $T_o$, related to the pulse full width at half maximum by

$$T_{FWHM} \approx 1.665 T_0 \tag{3}$$

increases with (the pulse broadens) according to [4]:

$$T(z) = \left[1 + \left(\frac{z}{L_D}\right)^2\right]^{1/2} T_0 \tag{4}$$

and, consequently, the peak power changes, due to GVD, are given by:

$$P(z) = \frac{P_0}{\left[1 + \left(\frac{z}{L_D}\right)^2\right]^{1/2}} \tag{5}$$

In Eqs. (4) and (5):

$$L_D = \frac{T_0^2}{|\beta_2|} \qquad (6)$$

is the dispersion length. Its meaning is quite straightforward: after propagating a distance equal to $L_D$, the pulse broadens by a factor of $\sqrt{2}$.

Effect of GVD on the Gaussian pulse is analyzed in the software OptiSystem [12]. Characteristics of the system include: bit rate signal is 40 Gb/s, bit duration 25 ps, the width of the Gaussian pulse is 0.5, and the power of 0 dBm (1 mW).
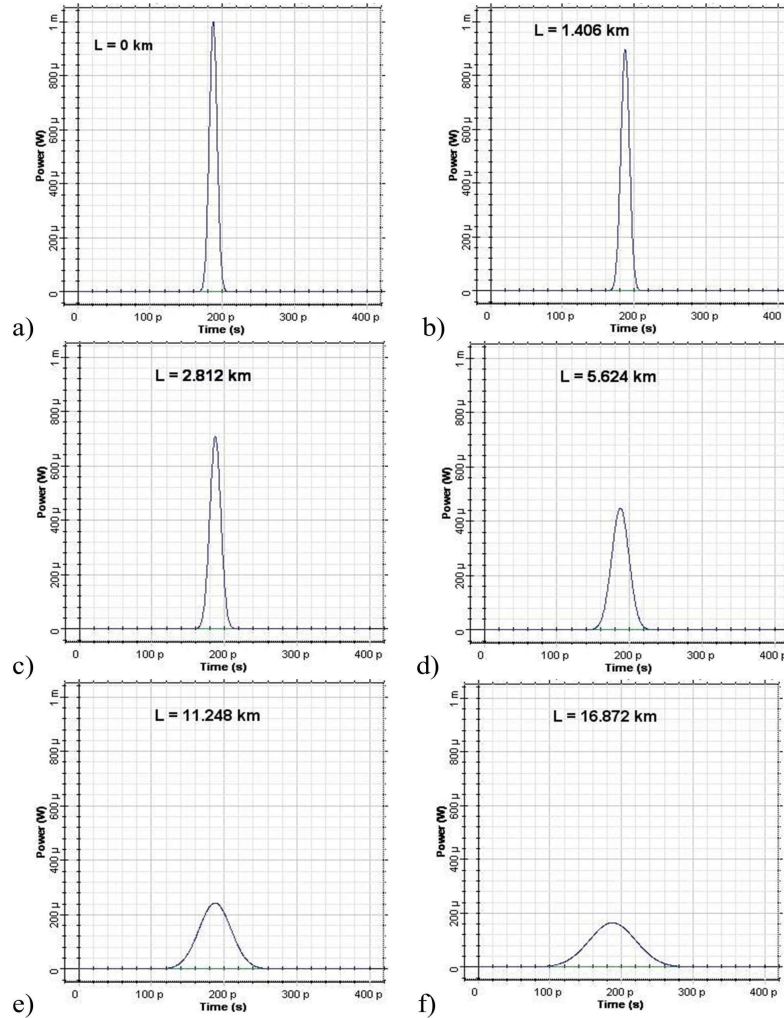


Figure 1. Gaussian pulse on optical fiber length of: a) $L = 0$, b) $L=0.5L_D$, c) $L=L_D$, d) $L=2L_D$, e) $L=4L_D$, f) $L = 6L_D$

The system is observed at wavelengths 1.55 μm. Value of GVD parameter is $\beta_2 \approx -20 \left( ps \right)^2/km$ on 1.55 μm for singlemode fiber.

Based on Eqs (3) and (6) and the values of the parameters observable system we obtain values $T_0 = 7.5$ ps and $L_D = 2812$ km.

Figure 1 shows the Gaussian pulse at the output of the transmitter ($L = 0$) and after transmission through an optical fiber length, $L=nL_D = 0.5, 1, 2, 4, 6$.

From Figure 1 we can see that with the increase of the length of the distance is to spread the impulse and to reduce its power. The peak power decreases in accordance with Eq. (5).

The origin of pulse broadening can be understood be looking at the instant frequency of the pulse, namely the chirp. Whereas the input pulse is chirpless, the instantaneous frequency of the output pulse decreases from the leading to the trailing edge of the pulse. The reason for this is GVD. In the case of anomalous GVD ($\beta_2 < 0$), the higher frequency components of the pulse travel faster than the lower frequency.

### 3. Effect of Initial Chirp with Group Velocity Dispersion

If the input pulse is frequency modulated (i.e. chirped), Eq.

$$E(z=0,t) = \sqrt{P_0}\exp\left(-\frac{1+iC}{2}\frac{t^2}{T_0^2}\right) \tag{7}$$

and the expression for the dependence of the pulse width on $z$ is:

$$T(z) = T_0\left[\left(1+\frac{C\beta_2 z}{T_0^2}\right)^2 + \left(\frac{\beta_2 z}{T_0^2}\right)^2\right]^{1/2} \tag{8}$$

The pulse broadens monotonically with $z$ if $\beta_2 C > 0$, however, it goes through initial narrowing when $\beta_2 C < 0$. In the latter case, the pulse width becomes minimum at distance [4]:

$$z_{\min} = \frac{|C|}{1+C^2}L_D \tag{9}$$

and is given by:

$$T(z_{\min}) = \frac{T_0}{\left(1+C^2\right)^{1/2}} \tag{10}$$

where $C$ is chirp parameter.

The peak power of the pulse in this case is:

$$P(z_{\min}) = P_0\left(1+C^2\right)^{1/2} \tag{11}$$

Table 1 provides the values of the length of the optical fiber in which the minimum pulse width and peak power at that point for different values of the chirp parameter.

Figs. 2 and 3 shows the Gaussian pulse in the characteristic points for chirp parameter $C = 1$ and $C = 5$, respectively.

With the given figure can be seen under the influence of chirp leads to increase peak power and reduce the pulse width to the point $L = z_{\min}$, where it reaches its maximum power and a minimun width. After a distance $z_{\min}$ comes to a sharp decline of peak power and a significant expansion of impulse. These effects are much more expressed for higher values of chirp parameter $C$.

### 4. Conclusion

Initial narrowing of the pulse for the case $\beta_2 C < 0$ can be explained by noticing that in this case the frequency modulation (or

| C | $z_{min}$ [km] | $P(z_{min})$ [mW] |
|---|---|---|
| 1 | 1.406 | 1.414 |
| 2 | 1.125 | 2.236 |
| 3 | 0.844 | 3.162 |
| 4 | 0.662 | 4.123 |
| 5 | 0.541 | 5.099 |
| 6 | 0.456 | 6.083 |
| 7 | 0.394 | 7.071 |
| 8 | 0.346 | 8.062 |
| 9 | 0.309 | 9.055 |
| 10 | 0.278 | 10.05 |

Table 1. Values of $Z_{min}$ and $P(Z_{min})$ For Different Chirp Parameter
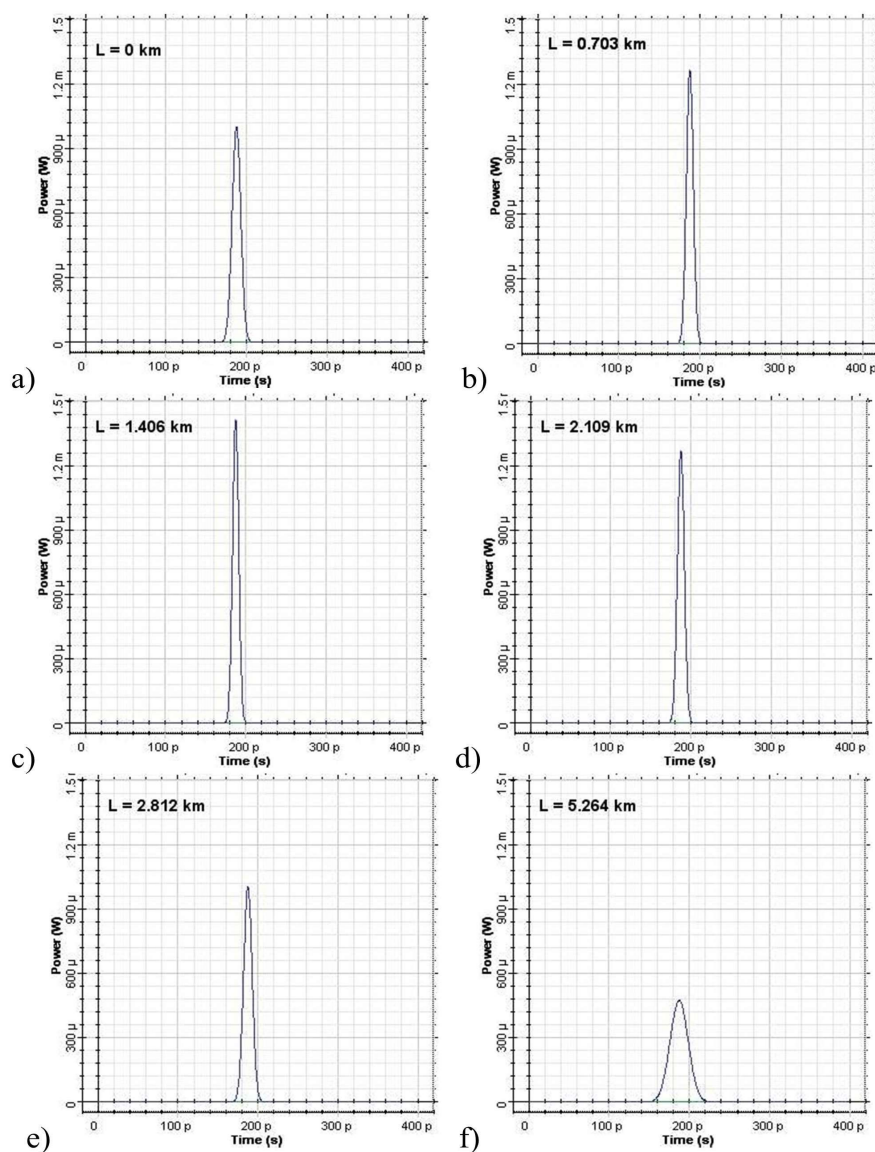


Figure 2. Gaussian pulse for $C = 1$ at distance: a) $L = 0$, b) $L = 0.5z_{min}$, c) $L = z_{min}$, d) $L = 2z_{min}$, e) $L = L_D$, f) $L = 2L_D$
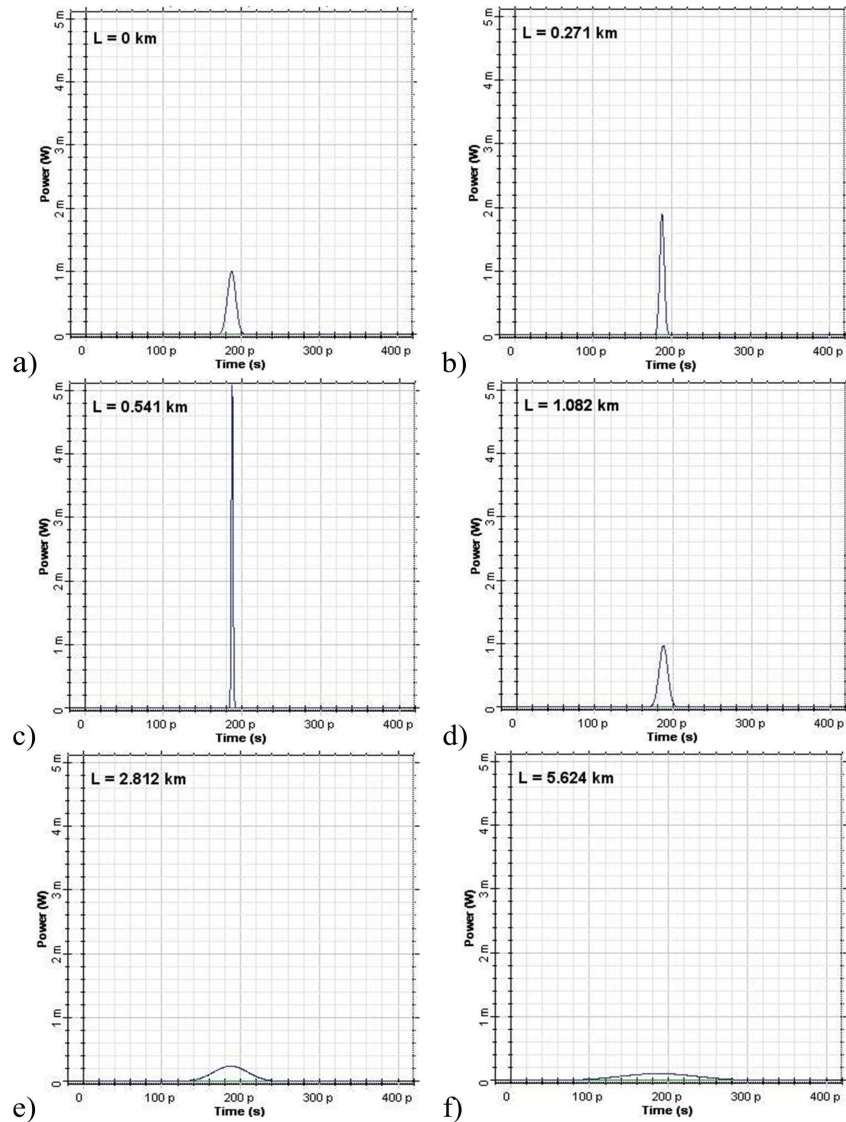
Figure 3. Gaussian pulse for C=5 at distance: a) $L = 0$, b) $L = 0.5z_{min}$, c) $L = z_{min}$, d) $L = 2z_{min}$, e) $L = L_D$, f) $L=2L_D$

"chirp") is such that the faster frequency components are in the trailing edge, and the slower in the leading edge of the pulse. As the pulse propagates, the faster components will overtake the slower ones, leading to pulse narrowing. At the same time, the dispersion induced chirp will compensate for the initial one. At $\bar{L}=z_{min}$, full compensation between both will occur. With further propagation, the fast and the slow frequency components will tend to separate in time from each other and, consequently, pulse broadening will be observed.

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