Simulation of Gaussian Pulses Propagation Through Single Mode Optical Fiber Using MATLAB

Salah Al–Deen Adnan Taha*, Mehdi M. Shellal, and Ahmed Chyad Kadhim
Department of Laser and Optoelectronics Engineering, University of Technology, Baghdad, Iraq

Abstract
Computer-aided modeling and simulation software programs are essential tools to predict how an optical communication component, link, or network will function and perform. This paper aims to investigate the various effects on pulses propagation in optical transmission systems utilizing the MATLAB program. Dispersion and Attenuation effects are explored. The simulation of Gaussian pulses propagation through single mode optical fiber, simplifies the design of optical communication system and make the design process more efficient, less expensive, and faster.
Keywords: Optical Communications, Single Mode Optical Fiber, Attenuation & Dispersion.

محاكاة لانتشار نبضات غاوس خلال كابل ضوئي احادي النمط باستخدام MATLAB

صلاح الدين عدنان طه، مهدي منشد شلال و احمد جياد كاظم
قسم هندسة الليزر والالكترونيات البصرية، الجامعة التكنولوجية، بغداد، العراق.

الخلاصة
تعتبر برامج المحاكات بمساعدة الحاسوب من الأدوات الأساسية للتنبؤ عن عمل واداء مكونات منظومة الأتصالات البصرية، خطوط الأتصال بينها ،او شبكة الخطوط. يهدف هذا البحث الى التحقق عن التأثيرات المختلفة على انتشار النبضات في أنظمة البث البصرية بأستخدام برنامج ال MATLAB . تم في هذا البحث التحري عن تأثيرات التشتت والتوهين للأشارة البصرية. لقد وجد ان استخدام المحاكات لأنتشارالنبضات الكاوسية خلال ليف بصري احادي النمط يسهل تصميم نظام الأتصالات البصرية ويجعل عملية التصميم اكثر كفاءة،اقل كلفة،وأكثر سرعة.

Introduction

An optical fiber is a thin filament of glass with a central core having a slightly higher index of refraction than the surrounding cladding. From a physical optics standpoint, light is guided by total internal reflection at the core-cladding boundary. More precisely, the fiber is a dielectric waveguide in which there are a discrete number of propagating modes. If the core diameter and the index difference are sufficiently small, only a single mode will propagate. From a transmission system standpoint, the two most important fiber parameters are attenuation and bandwidth. There are three principal attenuation mechanisms in fiber: absorption, scattering, and radiative loss. Silicon dioxide has resonance absorption peaks in the ultraviolet (electronic transitions) and in the infrared beyond 1.6 µm (atomic vibrational transitions), but is highly transparent in the visible and near-infrared [1]. On the other hand, a fiber optic system using a glass fiber is

* Email: Salahadnan9999@yahoo.com

certainly capable of carrying light over long distances. By converting an input signal into short flashes of light, the optical fiber is able to carry complex information over distances of more than a hundred kilometers without additional amplification. This is at least five times better than the distances attainable using the best copper coaxial cables. The system is basically very simple: a signal is used to vary, or modulate, the light output of a suitable source — usually a laser or a LED (light emitting diode). The flashes of light travel along the fiber and, at the far end, are converted to an electrical signal by means of a photo-electric cell. Thus the original input signal is recovered [2]. Computer-aided modeling and simulation software programs are essential tools to predict how an optical communication component, link, or network will function and perform. These programs are able to integrate component, link, and network functions, thereby making the design process more efficient, less expensive, and faster. The tools typically are based on graphical interfaces that include a library of icons containing the operational characteristics of devices such as optical fibers, couplers, light sources, optical amplifiers, and optical filters, plus the measurement characteristics of instruments such as optical spectrum analyzers, power meters, and bit error rate testers. To check the capacity of the network or the behavior of passive and active optical devices, network designers invoke different optical power levels, transmission distances, data rates, and possible performance impairments in the simulation programs [3].

The Fiber Optic Transmission

In an fiber-optic transmission, an optical signal, serves as the information carrying vehicle. Both analog and digital information are supported. In operation, the light is launched or fed into the fiber. The fiber itself is composed of two layers, the cladding and the core. Due to their different physical properties, light can travel down the fiber by a process called total internal reflection. In essence, the light travels through the fiber via a series of reflections that take place where the cladding and core meet, the cladding-core interface. When the light reaches the end of the line, it is picked up by a light-sensitive receiver, and after a series of steps, the original signal is reproduced. To sum up, a video camera's output or other such signal is converted into an optical signal in an FO system. It is subsequently transmitted down the line and converted back following its Reception [4]. Calculating the performance in optical fiber communications systems in which nonlinearity plays a significant role in transmission is difficult. The difficulty is further enlarged by the complex way in which different modulation formats — such as the return-to-zero, chirped-return-to-zero, and differential phase- shift-keying — interact with modern-day receivers. The details of the optical filtering, electrical filtering, and internal nonlinearity can significantly impact the performance in even a standard receiver with hard-decision decoding. The use of forward error correction and signal processing further complicates the calculation of the performance [5].

Gaussian Pulse Response

Many optical fibers, and in particular jointed fiber links exhibit pulse outputs with a temporal variation that is closely approximated by a Gaussian distribution. Hence the variation in the optical output power with time may be described as[6].

$$P_o(t) = \frac{1}{\sigma\sqrt{2\pi}} exp - (\frac{t^2}{2\sigma^2}) \quad \ldots(1)$$

Where σ and σ^2 are the standard deviation and the variance of the distribution respectively. If t_e represent the time at which $\frac{P_o(t_e)}{P_o(0)} = \frac{1}{e}$ where $\frac{1}{e}$ pulse width. Then from equation (1) it follows that:

$$t_e = \sigma\sqrt{2}$$

Moreover, if the full width of the pulse at $\frac{1}{e}$ points is denoted by τ_e then:

$$\tau_e = 2t_e = 2\sigma\sqrt{2}$$

In the case of the Gaussian response given by equation (1) the standard deviation σ is equivalent to the root mean square (rms) pulse width.

The Fourier transform of equation (1) is given by [6]:

$$P(\omega) = \frac{1}{\sigma\sqrt{2\pi}} exp - (\frac{\omega^2\sigma^2}{2}) \quad \ldots(2)$$

The 3 dB optical bandwidth B_{opt} is defined as modulation frequency at which the received optical power has been fallen to one half of its constant value. Thus using equation (2):

$$\frac{[\omega(3\,dB\,opt)]^2}{2}\sigma^2 = 0.693$$

and

$$\omega(3\,dB\,opt) = 2\pi B_{opt} = \frac{\sqrt{2}*0.8326}{\sigma}$$

Hence

$$B_{opt} = \frac{\sqrt{2}*0.8326}{2\pi\sigma} = \frac{0.530}{\tau_e} = \frac{0.187}{\sigma}\ Hz$$

When employing return to zero pulse where the maximum bit rate $B_\tau(\max) = B_{opt}$,then,

$$B_\tau(\max) \cong \frac{0.2}{\sigma} \, bit\, s^{-1}$$

Alternatively, the 3 dB electrical bandwidth B occurs when the received optical power has dropped to $\frac{1}{\sqrt{2}}$ of the constant value giving [6]:

$$B = \frac{0.530}{\tau_e\sqrt{2}} = \frac{0.375}{\tau_e} = \frac{0.133}{\sigma} \, Hz$$

Attenuation Units

Signal attenuation (or fiber loss)is defined as the ratio of the optical output power P_{out} from a fiber of length L to the optical power P_{in} .This power ratio is a function of wavelength ,as shown by the general attenuation curve in Figure 1 .The symbol α is commonly used to express attenuation in decibel per Kilometer [7].

$$\alpha = \frac{10}{L} \log \left(\frac{Pi}{Po}\right) \quad dB/Km \qquad \ldots(3)$$

Where P_i is the optical input power, P_o is the optical output power and L is the length of fiber.

An ideal fiber would have no loss so Pout =Pin. This corresponds to a 0-dB attenuation, which is practice impossible. An actual low-loss fiber may have a 3-dB /Km average loss. This means that the optical signal power would decrease by 50 percent over a 1-Km length and

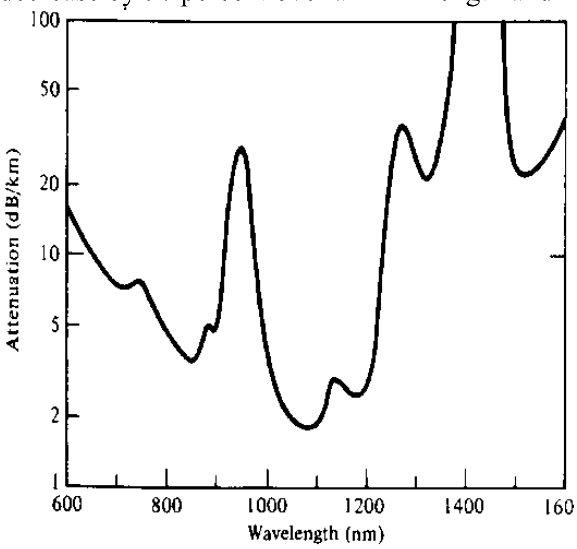

Figure 1- Attenuation –versus –wavelength curve

would decrease by 75 percent (a 6-dB loose) over 2-Km length, since loss contributions expressed in decibel are additive [7].

Dispersion Calculation

The total dispersion in single-mode fibers consists mainly of material and waveguide dispersions. The dispersion D is represented by[7]:

$$D(\lambda) = \frac{1}{L}\frac{d\tau}{d\lambda}$$

Which is expressed in $ps/(nm.km)$. The total broadening σ of an optical pulse over a length of fiber L is given by:

$$\sigma = D(\lambda)\, L\sigma_\lambda \qquad \ldots(4)$$

Where σ_λ is the wavelength spread of the source. To measure the dispersion, one examines the pulse delay over a wide wavelength range. At the zero-dispersion point the pulse delay will go through a minimum. To calculate the dispersion point the pulse delay will go through a minimum. To calculate the dispersion by D(λ) is given by [7]:

$$D(\lambda) = \frac{\lambda S_o}{4}\left[1 - \left(\frac{\lambda_o}{\lambda}\right)^4\right] ps/(nm.km) \qquad \ldots(5)$$

for $1200 \le \lambda \le 1600$ nm

Where S_o Zero Dispersion Slope≤0.092 $ps/(nm^2.km)$, λ_o Zero Dispersion Wavelength 1302nm ≤ 1322 nm and λ Operating Wavelength [7].

Computer Simulation and Results

The simulation program "MATLAB"is used to simulate signal propagation with the design of corning Single Mode Fiber (SMF -28). As example, the specifications of the corning SMF -28 single mode fiber are shown in table 1 and the transmitter and receiver have the specifications as shown in table 2 [4]:

Table 1- The specifications of the corning SMF -28

Substrate Material	Fused silica
Cladding Diameter	125 ∓ 1 μm
Core Diameter	8.3 μm
Coating Diameter	245 ∓ 5 μm
Mode Field Diameter	10.4∓ 0.8 μm
Index of Refraction core	1.4675
Index of Refraction cladding	1.4622
Refractive Index Difference	0.36%
Zero Dispersion Wavelength	1312 nm

Table 2 The specifications of transmitter and receiver.

Transmitter	Transmission rate	2.5	Gb/s
	Output Power	0	dBm
	Spectral Width	1	nm
	Operating wavelength	1550	nm
Fiber	Zero–Dispersion Slope	0.093	Ps/nm^{2}Km
	Zero-Dispersion Wavelength	1312	nm
	Attenuation	0.2	dB/Km
Receiver	Sensitivity	-32	dBm

Attenuation Effects

Attenuation of a light signal as it propagates along a fiber is an important consideration in the design of an optical communication system, since it plays a major role in determining the maximum transmission distance between a transmitter and a receiver. The attenuation effects at varies distances are shown in figure 2, 3, 4, and 5 which are calculated using equation (3) and the values of the output against distances are shown in table 3. The simulation of optical signal propagation through SMF refers to:

When the distance increase the output power will decrease. This relation is described in figure 6.

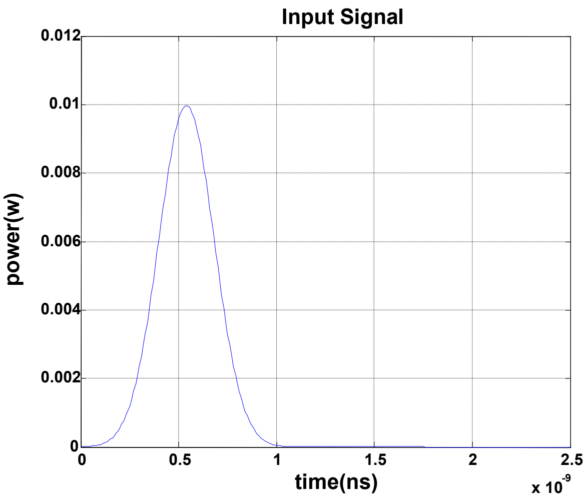

Figure 2 This Pulse represents the Input signal to the Optical Fiber from 10 mW Laser source of 1ns duration.

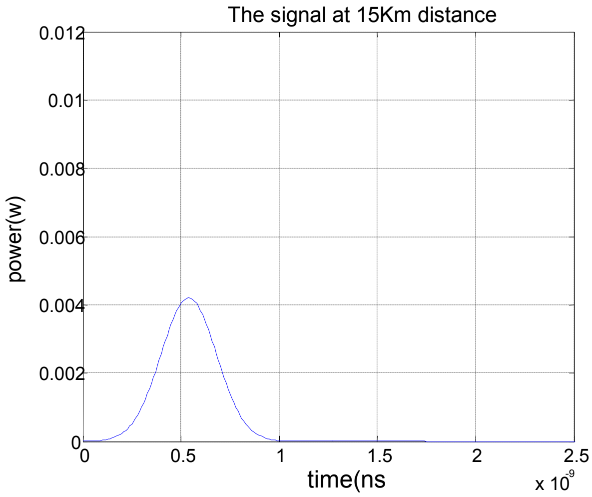

Figure 3 This signal represents the shape of source at 15 km distance. The effect of attenuation is shown on the pulse amplitude which was 4.217 mW.

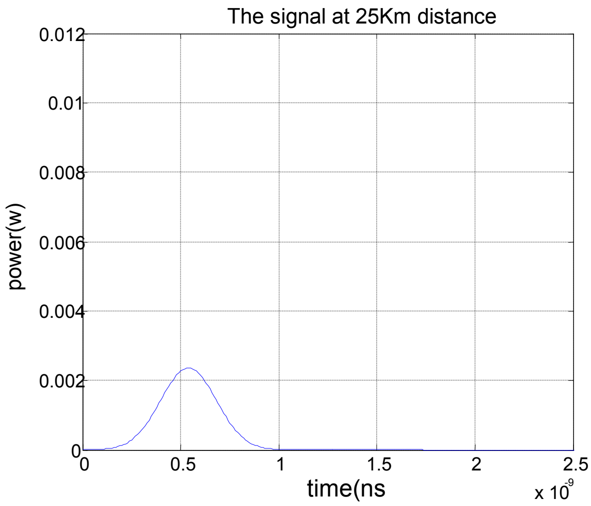

Figure 4 The source signal at 25km distance through the optical fiber where the puls is 2.211mW.

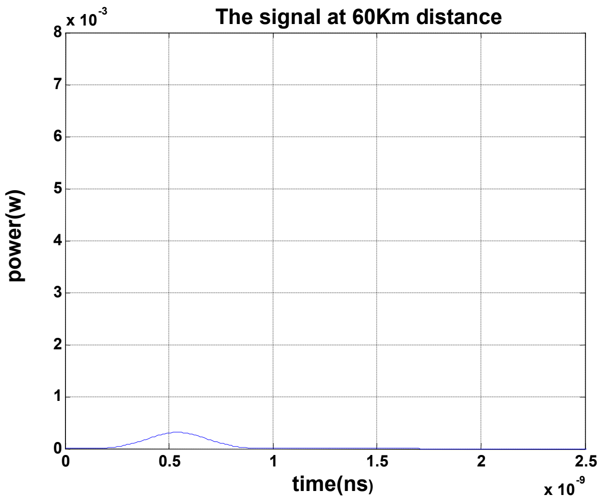

Figure 5 The pulse amplitude source is into 0.316 mW when using an optical fiber 60km in length (distance).

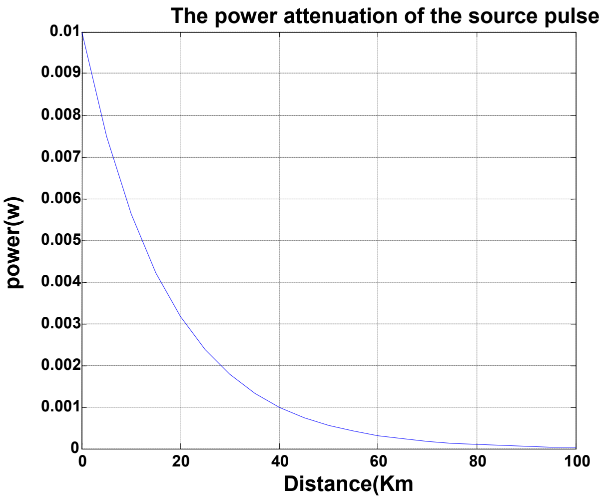

Figure 6 This curve represents the power of the source pulse travelling through an optical fiber of 100 km length (distance).

Pi=10mw, α=0.25dB/Km.

Table 3 Attenuation effects at varies distances.

Distance(Km)	5	15	30	45	60	90
Output Power (mw)	7.499	4.217	1.778	0.750	0.316	0.056
Output Power dBm	-1.24	-3.75	-7.50	-11.24	-15.00	-22.51

Dispersion

In addition to being attenuated, an optical signal becomes increasingly distorted as it travels along a fiber. This distortion is a consequence of intramodal and intermodal dispersion effects. Intramodal dispersion is pulse spreading that occurs within an individual mode and thus is of importance in single-mode fiber. In this simulation section the effects of attenuation and dispersion at the same time will described. Where the attenuation and dispersion effects are added together to the optical signal. The output of simulation program for varies distances are shown in figures 7, 8, 9, 10, and 11. The simulation result of dispersion effects refers to : when the distances increase the pulse width will increase as shown in table 4. Thus overlapping between pulses may be occur which causes distortion in information [1]. The relationship between pulse width and distances is shown in figure 12. The dispersion and total broadening σ of an optical pulse over a length of fiber L are calculated from equation (4) and (5) [1].

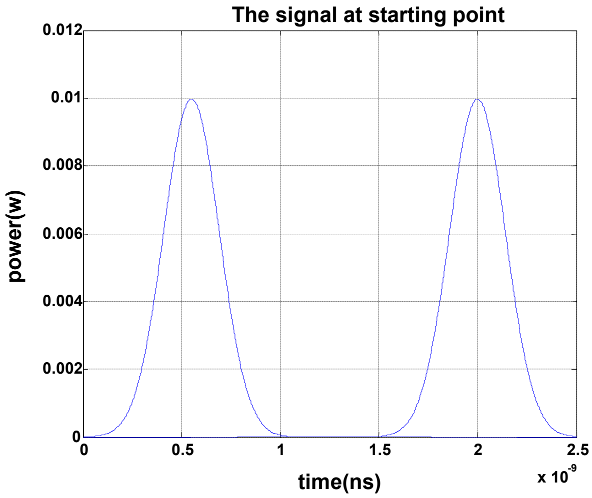

Figure 7 Two pulses of laser source at the starting of optical fiber to show the effect of pulse and attenuation .

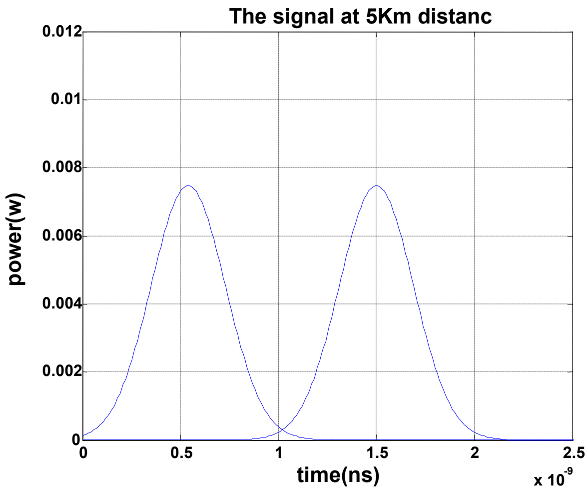

Figure 8 Attenuation and dispersion effects at 5 Km.

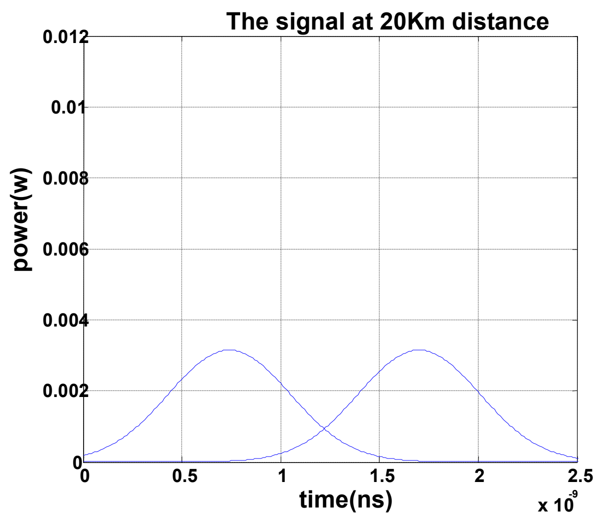

Figure 9 Attenuation and dispersion effects at distance 20 Km.

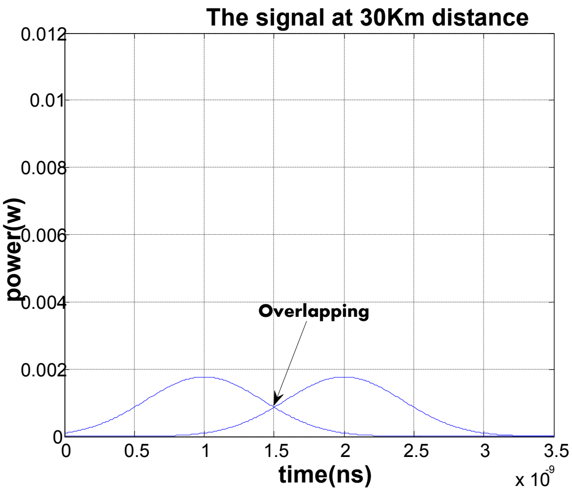

Figure10 Attenuation & dispersion effects at distance 30Km.

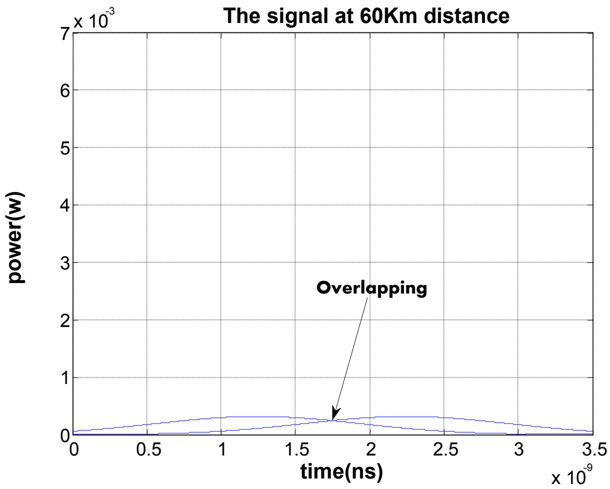

Figure 11 Attenuation and dispersion effects at distance 60 Km.

Table 4 Total broadening of an optical pulse over a length of fiber L.

Distance(Km)	5	20	30	50	60
Pulse width(ns)	1.34	2.18	2.96	4.11	4.87

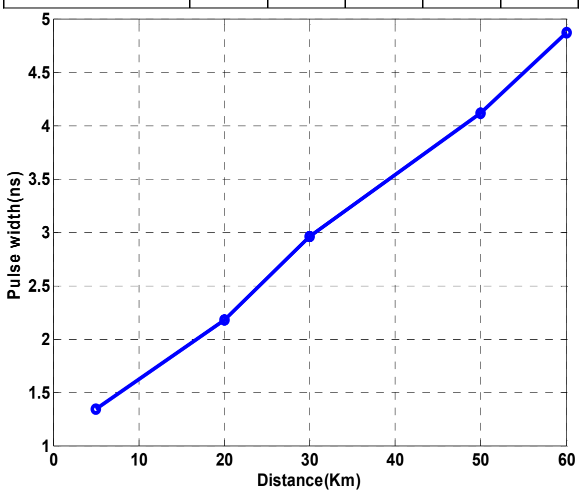

Figure12 The relationship between Distances and Pulse width.

Conclusions

In this paper, a simulation methods are presented on a single mode optical fiber, using MATLAB. The signal with wavelength of 1550 nm was used, to study the effects of attenuation and dispersion through the fiber optic length by computer simulations. The results indicate that these effects increase with increasing the distance through the fiber optic length. As propagation continues attenuation increases. Ultimately, the propagating signal is attenuated until it is at some minimal, detectable, level. At this distance the amplifiers will used to regenerate the optical signal and to eliminate the effects of the attenuation and dispersion. In practical measurements, it is not trivial to measure fiber loss because the value is low, and some precautions and a very good resolution are required to obtain a meaningful value with any degree of precision. Also to measure fiber dispersion usually implies a measurement of the propagation time. There are two avenues one can use: One is the standard procedure in industry but requires a very long piece of fiber, like 100 km. To obtain a resolution of 0.1 ps/(nm km), one needs to measure a timing differential of 10 ps/nm. With two light sources 10nm apart, this is feasible because fast photodiodes and sampling oscilloscopes easily resolve times well below 100 ps. Thus it is clear that, from the results of simulation process for attenuation and dispersion effects are more efficient, less expensive, and faster.

References

1. McGraw-Hill. **2004,** *Optical Communications Essentials*. The McGraw-Hill Companies.
2. Forestieri,E., **2005**. *Optical Communication Theory and Technologies.* Springer Science + Business Media, Inc.
3. Gerd Keiser, **1991**. *Optical Fiber Communications.* Second Edition.
4. J. Crisp, **2001**. *Introduction to Fiber Optics. John Crisp.*
5. John M. Senior, M. Yousif Jamro, **2009**. *Optical Fiber Communications Principles and Practice.* Pearson Education Limited.
6. M. Bass, Eric W. Van Stryland, **2002**. *Fiber Optics Handbook. Fiber, Devices, and Systems for Optical Communications.* The McGraw-Hill Companies.
7. Michael M. A. Mirabito, Barbara L. Morgenstern, **2004**. Applications, Policy, and Impact. *The New Communications Technologies:* Elsevier Inc.