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Study of Linear Effects on Pulse Propagation in Fiber

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***Abstract*—An optical or light wave communication system is a system that uses light waves as the carrier for transmission. When the pulse travels along the fiber it experiences two linear effects such as attenuation and dispersion. Dispersion causes the pulse to broaden and attenuation causes the amplitude to decrease as the pulse travel along the fiber. This paper aims to investigate the linear effects on pulse propagation using Gaussian pulse.**

***Keywords*— Attenuation, Dispersion and Gaussian pulse.**

I. INTRODUCTION

Fiber optics are thin, long strands of very pure glass about the size of a human hair. Optical Fiber is new medium, in which information such as voice, data or video is transmitted through a glass or plastic fiber, in the form of light. Optical fiber communications typically operate in a wavelength region corresponding to one of the following windows [1]

i. The first window at 800–900 nm was originally used for short-distance transmission. However, in this region the fiber losses are in the range of 3dB/km.
ii. The second telecom window utilizes wavelengths around 1300nm for long-haul transmission where the loss of fibers is much lower about 0.4dB/km
iii. The third telecom window, which is now very widely used, utilizes wavelengths around 1500 nm. The losses of silica fibers are lowest at about 0.2dB/km

Optical fiber links are used in all types of networks such as Local Area Network (LAN) and Wide Area Network (WAN).

Optical fiber plays a very important role due to its distinct advantages

i. Long distance transmission
ii. High bandwidth
iii. No electromagnetic interference
iv. High level of security
v. Small size and
vi. Low weight.

Some of the applications of fiber optics are [2]

i. Fiber To The Home (FTTH) provide high speed internet access from a central point directly to individual buildings.
ii. Optical fiber is used in cable television companies for transmitting broadband signals, such as High-Definition Television (HDTV) telecasts.
iii. Intelligent transportation systems, such as smart highways with automated tollbooths, intelligent traffic lights and changeable message signs also use fiber-optic-based telemetry systems and they are used in most modern telemedicine devices for transmission of digital diagnostic images.
iv. Cable Television (CATV) services are supplied via a fiber optic network to an optical node, which converts and distributes the electrical signal to subscribers via a coaxial cable connection

There are two types of commonly used fiber optic cable that are Single Mode Fiber (SMF) and Multi-Mode Fiber (MMF). SMF diameters are in the 5µ to 10µ. MMF cable diameters are in the 50µ to 100µ range for the light carry component.

This paper deals with attenuation and dispersion effects of single mode fiber. The paper is further divided into different sections. Section II deals with the Gaussian pulse. Section III deals with the attenuation effects and its types. Section IV deals with the dispersion effects and its types. Section V deals with results and discussions.

II. GAUSSIAN PULSE

Gaussian pulse is a pulse that has a waveform described by the Gaussian distribution. A Gaussian function, often simply referred to as a Gaussian, is a function of the form [3]

$$g = a * \exp\left(\frac{-(t-\mu)^2}{2\sigma^2}\right) \qquad (1)$$

where

i. a is the amplitude
ii. µ is the position of the peak
iii. σ is the standard deviation and it controls the width of the bell.
iv. σ is related to the Full Width at Half Maximum of the peak (FWHM).

FWHM=$2\sqrt{2ln\,2}\sigma$=2.354σ.The graph of Gaussian is a symmetric bell shape curve.

III. ATTENUATION

Attenuation is the loss of signal power and is defined as the decrease in the light power during propagation along the optical fiber. Reduction in the intensity of light as it propagates within the fiber is called attenuation. It is a natural consequence of signal transmission over long distances. There are different types of attenuation [1]. Micro bending is the imperfection in the optical fiber which was created during manufacturing. Macro bending loses occur when fibers are physically bent beyond the point at which the critical angle is exceeded. Absorption occurs in optical fibers due to the presence of imperfections in the atomic structure of the fiber material. Intrinsic absorption is caused by the interaction of photons with the glass itself. Rayleigh scattering is the scattering of light by particles in a medium, without change in wavelength.

The following equation defines signal attenuation as a unit of length [4]

$$\alpha = -\frac{10}{L}\log_{10}\left(\frac{P_0}{Pi}\right) \qquad \text{dB/km} \qquad (2)$$

where

i. L is the length
ii. P_i is the input power
iii. P_0 is the output power.

IV. DISPERSION

Dispersion is a phenomenon in which the velocity of propagation of an electromagnetic wave is wavelength dependent. Different modes and different wavelengths of the optical fiber travel with different speeds and therefore have delay which is wavelength dependent. This phenomenon is called the dispersion. Dispersion is the loss of signal power due to the dispersive properties of light. This dispersive property of light is due to the fact that light can propagate inside an optical fiber only as a set of separate beams or rays. These set of light travel at distinct propagating angles ranging from zero to the critical propagation angle. Hence inside the fiber total light power is carried by individual modes so that at the output, these small portions combine producing an output beam. Since each of the mode travel at a distinct angle, they travel different distances inside the fiber producing a broadened pulse at the output. As a pulse spreads, the energy is overlapped. Dispersion is used to describe any process by which electromagnetic signal propagating in a physical medium is degraded because the various wave components of the signal have different propagation velocities within the physical medium. Dispersion is the main performance limiting factor in optical fiber communication. The performance of optical fiber communication is hampered by dispersion. When a pulse travels through an optical fiber due to dispersion it becomes broadened. The dispersion is proportional to the length of the fiber. Dispersion is a consequence of the physical properties of the transmission medium. There are different types of dispersion [1] Modal dispersion is due to the interaction among the various modes. Chromatic dispersion is caused by the fact that an individual mode includes light consisting of different wavelengths, each traveling along the fiber at a different velocity. Waveguide dispersion is a type of dispersion caused by the different refractive indexes of the core and cladding of an optical fiber. The formula for dispersion is given by [5]

$$D(\lambda) = \frac{\lambda S_0}{4}[1-(\frac{\lambda_0}{\lambda})^4] \qquad \text{ps/(nm.km)} \qquad (3)$$

where

i. S_0 is zero dispersion slope ≤ 0.092 $ps/(nm^2.km)$
ii. λ_0 is zero dispersion wavelength 1302nm $\leq$ 1322nm
iii. λ operating wavelength 1200nm $\leq \lambda \leq$ 1600nm

V. RESULTS AND DISCUSSIONS

Using (1) within the time frame $0 \leq t \leq 1$ and with μ=0.5, the Gaussian pulse is plotted as shown in Fig.1

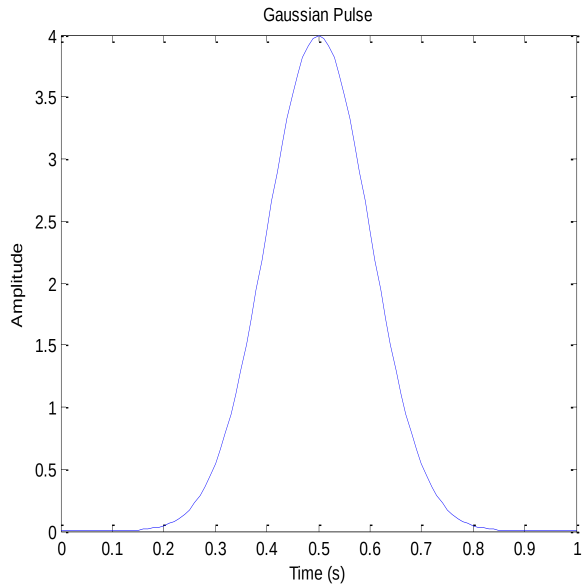

Fig.1. Gaussian pulse

The normalized Gaussian pulse is represented by Fig. 2.

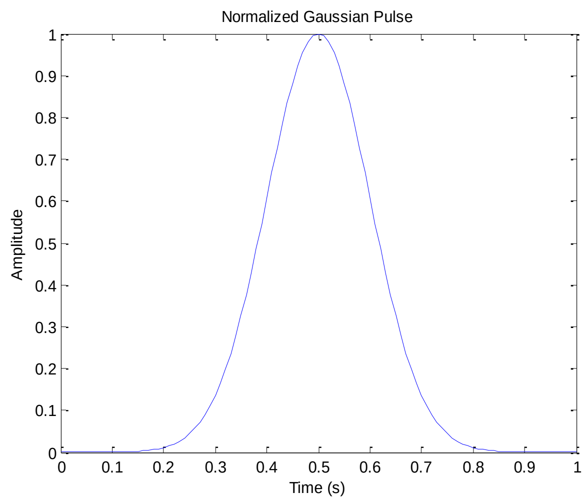

Fig.2. Normalized Gaussian pulse

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Attenuation effects are seen using (2) as shown in Fig.3. Due to attenuation the pulse amplitude goes on decreasing as the pulse travels along the distance. It is seen that attenuation effects causes decrease in the light signal during propagation along the optical fiber. As it is seen in Fig.3 for L=2km the amplitude is 1 and if the distance is increased the amplitude goes on decreasing.

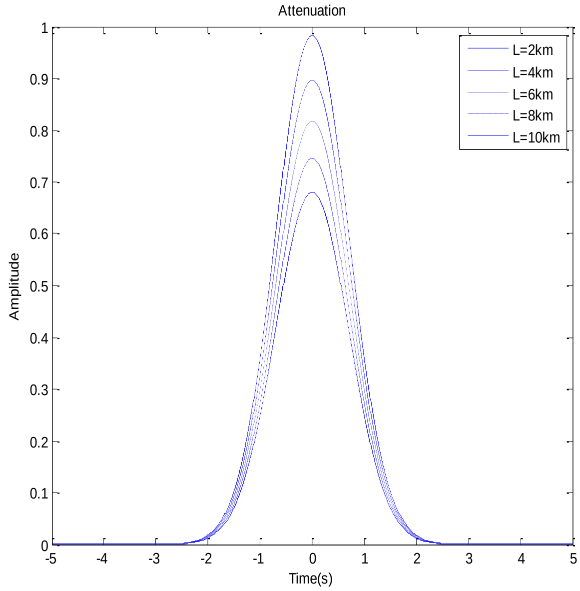

Fig.3. Attenuation plot

In Fig.3 it is seen that as the length is changed the amplitude of the pulse goes on decreasing. The decrease in amplitude as the pulse travel along the fiber is shown in Fig.4

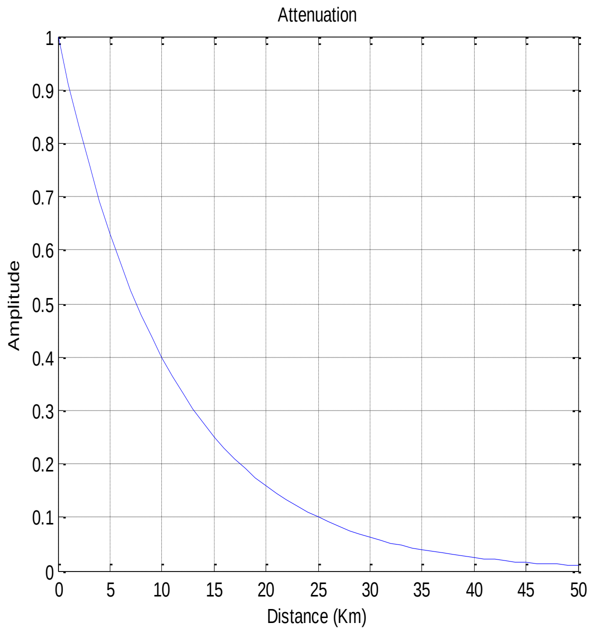

Fig.4. Attenuation v/s Distance plot

In a SMF, zero dispersion wavelength is the wavelength or wavelength at which material dispersion and wavelength dispersion cancel each other. The minimum material Dispersion occurs naturally at a wavelength of approximately 1300nm. The graph of zero dispersion is shown in Fig. 5 and is plotted using (3). In Fig. 5 it is seen that at 1300nm the dispersion is zero.

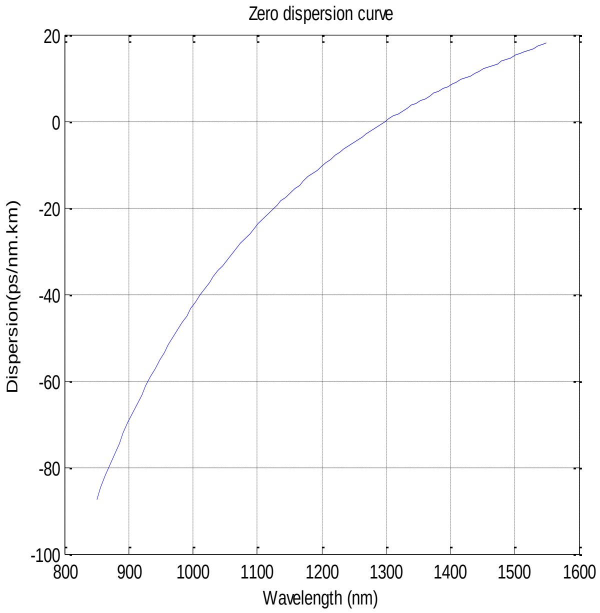

Fig.5. Zero dispersion curve

Dispersion spreads the pulse as it transmits along the fiber, this spreading of the signal pulse reduces the system bandwidth or the information-carrying capacity of the fiber. Dispersion limits how fast information is transferred. An error occurs when the receiver is unable to distinguish between input pulses caused by the spreading of each pulse. Due to dispersion when the optical pulses travel along the fiber they broaden as shown in Fig.6. As the pulses travel in the fiber due to broadening, slowly they start overlapping with each other.

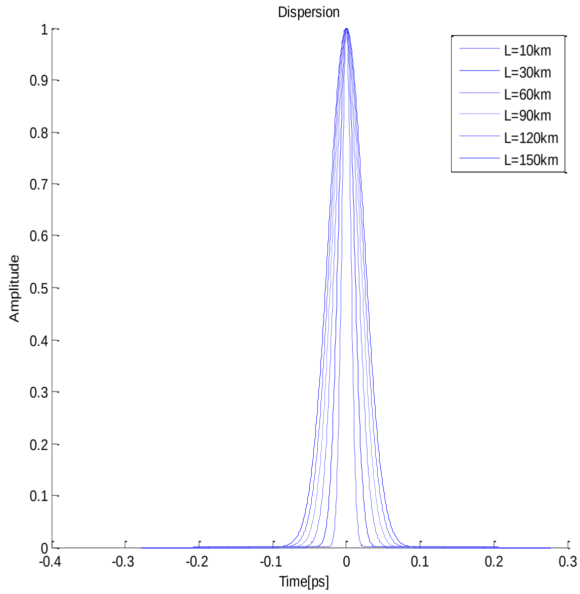

Fig.6. Dispersion along the fiber

For better understanding of the pulse broadening, 3D graph is plotted as shown in Fig. 7.

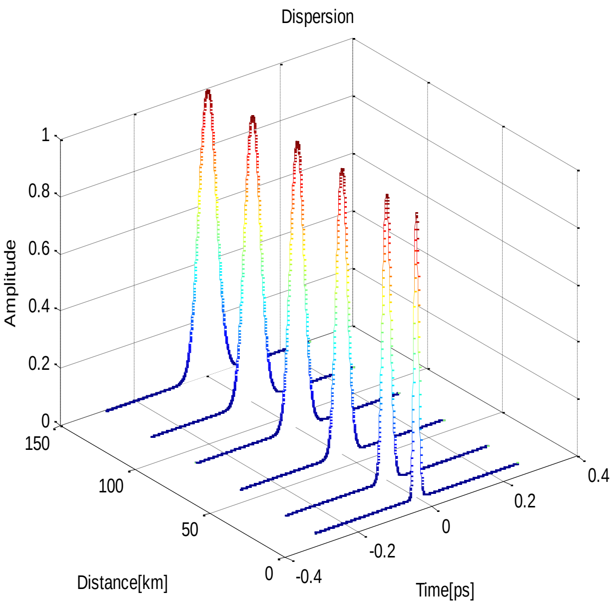

Fig.7. 3D plot to show dispersion effects

TABLE I. TOTAL BROADENING OF AN OPTICAL PULSE OVER A LENGTH OF FIBER L.

Distance(km)	Pulse Width(ps)
10	1.8604
30	3.2223
60	4.5571
90	5.5812
120	6.4446
150	7.2053

When two pulse travel along the fiber, the pulse broadens and overlaps with the other pulse as shown in Fig.8

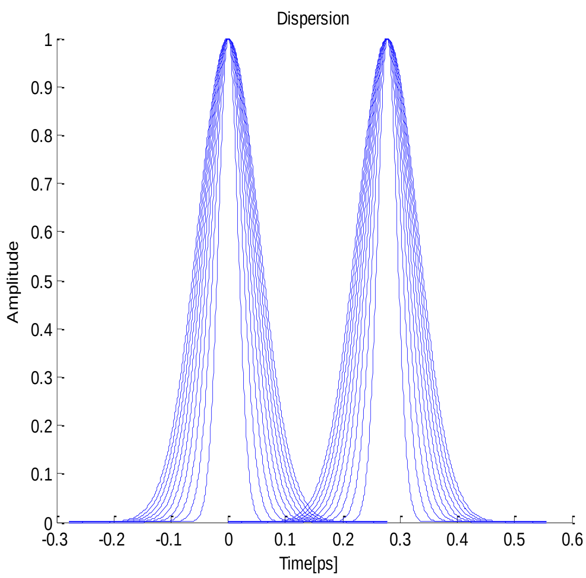

Fig.8. Dispersion of two pulses along the fiber

The 3D plot of pulse broadening travelling along the fiber is shown in Fig.9

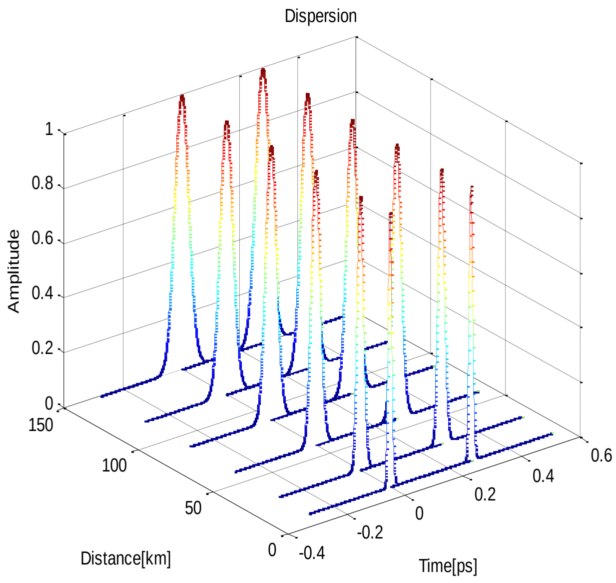

Fig.9. 3D plot of dispersion of two pulses

In fiber different wavelength components will propagate at different speeds eventually causing the pulse to spread. When the pulses spread to the degree where they collide it causes detection problems at the receiver resulting in errors in transmission. This is called Intersymbol Interference (ISI) [6].Dispersion is a limiting factor in fiber bandwidth, since the shorter the pulses the more susceptible they are to ISI.The effects of attenuation and dispersion at the same time is shown in Fig.10, where the attenuation and dispersion effects are added together to the optical signal. The result of dispersion effects shows that when the distances increase the pulse width will increase. Thus overlapping between pulses may occur, which causes distortion in information. The distortion of information becomes very difficult for the receiver to detect. The 3D plot showing both the linear effects is shown in Fig.11

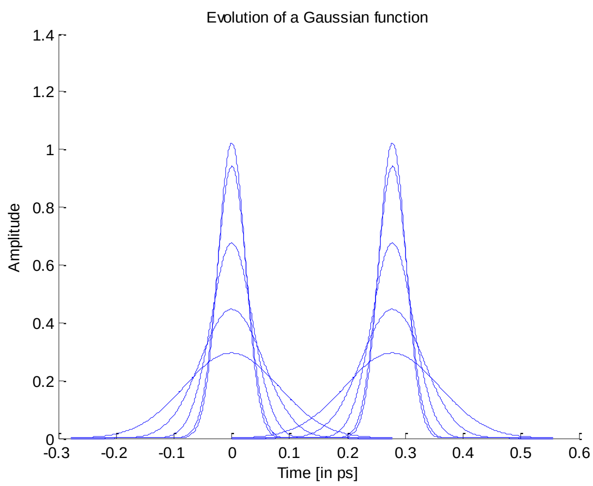

Fig.10. Attenuation and dispersion effects

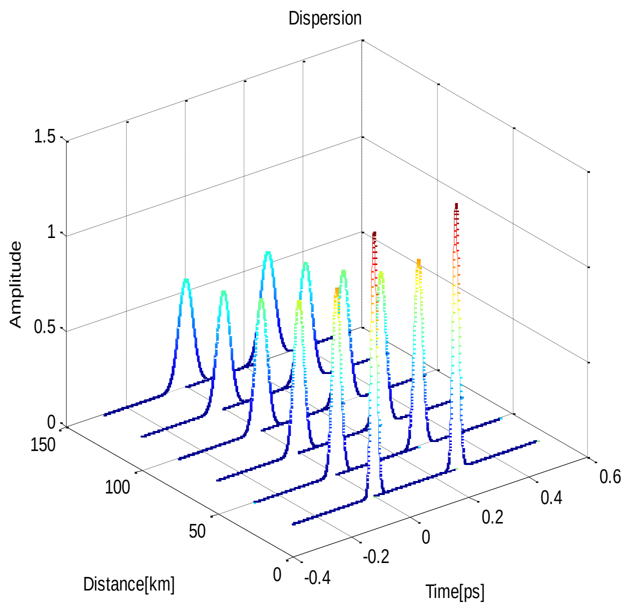

Fig.11. 3D plot of attenuation and dispersion effects

VI. Conclusion

Signal with wavelength of 1550 nm was used, to study the effects of attenuation and dispersion. The results indicate that these effects increase with increasing the distance through the fiber length. Attenuation increases as the pulse travels along the fiber. The propagating signal is attenuated and undergoes broadening until it is at some minimal, detectable level. At this distance the amplifiers will be used to regenerate the optical signal and to decrease the effects of the attenuation and dispersion.

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