



ANALYZING THE OPTIMUM LOSS AND DISPERSION OF DIFFERENT TYPES OF OPTICAL FIBERS

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Abstract: In this paper we studied the dispersion and loss characteristics of several types of optical fiber through a simulation study. The single mode step index optical fiber is the best road for a minimum dispersion. Using single mode step index fiber with proper profile the minimum dispersion and minimum loss is obtained at 1550 nm wavelength. Thus data with extremely high bandwidth can be transmitted to an enormous distance through it without any repeater or amplifier with minimum loss and dispersion.

Key words: Optical fiber, optical dispersion, attenuation, wave-guide, optical transmission

Introduction

Light is an electromagnetic wave and as such, optical communications entails just another form of electromagnetic wave propagation. The optical signals can be either transmitted in free space or through the optical fibers. The latter is termed as the guided optical signal transmission due to the fact that the fiber behaves as a wave-guide (Soleymani, 2003). The communications field has been revolutionized by the advent of optical fiber. Optical fiber now connects most of the world, carrying a vast amount of information through a very limited physical medium. The main raw material to produce optical fiber is normal sand and thus, it is cheaper than copper cable in telecommunication. The advantages of optical fibers as compared to electrical transmission media are: extremely low transmission loss, very high bandwidth, smaller size and much lighter in weight (Khan and Yesmin, 2001).

As a transmission media optical fiber is fast and almost error free thus, telecommunications and data communications using it have rapid grown into mega industries. The success of a given optical system depends directly on the choice of fiber parameters. Cross-sectional dimensions, material composition and the refractive index

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profile all influence the various linear and nonlinear phenomena, and must be carefully chosen in order to achieve optimal performance. The fiber parameters and frequency spectrum distribution keeps its shadow on attenuation and dispersion the two most important characteristics of an optical fiber, (Anon, 2000). Attenuation and dispersion determine the repeater spacings in a fiber optic communication system. Obviously, the lower the attenuation and dispersion, the greater will be the repeater spacings and therefore, the lower will be the cost of the system.

A number of mechanisms are responsible for the signal attenuation within optical fibers. These mechanisms are influenced by the material composition, preparation and purification technique, and waveguide structure. They may be categorized within several major areas which include material absorption, material scattering - linear and nonlinear scattering, curve and micro bending losses, mode coupling radiation losses and losses due to leaky modes (Dutton, 1998).

An optical ray traveling along an optical fiber, in addition to attenuation, experiences dispersion. Dispersion results in broadening of the pulses transmitted in the fiber and at a certain point results in two consecutive pulses being overlapped to the extent that distinguishing them is impossible. This effect, called Inter-Symbol Interference results in increased bit error probability and puts a limit on the maximum bit rate that an optical channel can carry. Different types of dispersion that occurs in optical fibers can be categorized into intermodal dispersion, material dispersion, waveguide dispersion and chromatic dispersion (Soleymani, 2003).

In the present study we made a simulation study on the dispersion and loss characteristics of several types of optical fiber.

Materials and Methods

In this section using the softwares "Understanding Fiber Optics on a PC", MathCAD and Matlab we made an analysis for attenuation vs. wavelength, intermodal dispersion, material dispersion and waveguide dispersion on Multi Mode Step Index Fiber (MMSIF), Multi Mode Graded Index Fiber (MMGIF), and Single Mode Step Index Fiber (SMSIF). These analyses are discussed in the following sub-sections.

Attenuation vs. wavelength λ : Attenuation is the loss of optical power into the fiber while transmitting optical signal through it. The two fundamental causes of signal attenuation in the optical fibers are absorption and scattering in the core and cladding glasses. Other sources of attenuation which may arise during fabrication are impurities in the glass (principally OH⁻ and transition metal ions), bends in the fiber and minute indentations or distortions caused by uneven pressure being applied to the fiber by the protective coating or during cabling, transverse pressure whilst in operation, etc, (Gambling, 2001). The slowly decreasing feature of the characteristic curve of attenuation up to 1550 nm in is due to Rayleigh scattering and the slowly increasing phenomenon (Fig.1).

after 1550 nm is due to infrared absorption. Moreover the peaks at about 940 nm, 1040 nm, 1260 nm and 1400 nm are due to the existence of the OH⁻ ions in the fiber. From the Fig.1 it is also found that in the optical window of 1550 nm wavelength the total loss in the fiber is minimum. If it is possible to reduce the dispersion in this region to zero, then we will be able to pull an optical fiber to an enormous distance without introducing any repeater /amplifier (Dutton, 1998).

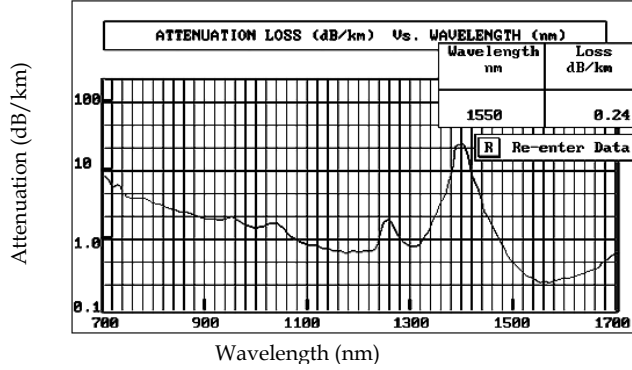


Fig.1. Attenuation (dB/km) versus wavelength (μm); lowest loss is at 1550 nm (Ghatak, Sharma and Tewari, 1994).

Intermodal dispersion: This type of dispersion, results because the wave propagates in modes and the different modes take different propagation time. It is measured by the difference of propagation time of the critical mode and zero mode (Mallick, 2001). The Intermodal dispersion that occurs in different types of fibers is now analyzed for different fiber parameters and is discussed below:

Table 1. Summary of variables used in this section.

Symbol	Definition	Value	
		MMSIF	MMGIF
c	Velocity of light	3×10^8 m/sec	3×10^8 m/sec
n_1	Refractive index of the core	1.47	1.47
n_2	Refractive index of the cladding	1.463	1.463
Δ	Normalized index difference	0.0048	0.0048
$\Delta\lambda$	Spectral width of the transmitted signal	1 nm	1 nm
a	Radius of the core	10×10^{-6} m	10×10^{-6} m
L	Length of the optical fiber	1×10^3 m	1×10^3 m
λ	Operating wavelength	$\lambda_1 = 1310$ nm $\lambda_2 = 1550$ nm	$\lambda_1 = 1310$ nm $\lambda_2 = 1550$ nm
ν	v-number or normalized frequency	$\nu_1 = 6.872$ $\nu_2 = 6.872$	$\nu_1 = 6.872$ $\nu_2 = 6.872$
$\tilde{\beta}$	Invariant, ($n_1 > \tilde{\beta} > n_2$)	$n_1 = 1.47$ $n_2 = 1.463$	$n_1 = 1.47$ $n_2 = 1.463$
q	Index defining parameter	9999	1.9726

The formulas used in this section are given below:

$$\Delta = \frac{n_1^2 - n_2^2}{2 \times n_1^2} \quad (1)$$

$$A = \frac{2}{c \times (2 + q)} \quad (3)$$

$$\tau(\tilde{\beta}) = (A \times \tilde{\beta} + \frac{B}{\tilde{\beta}}) \times z \quad (5)$$

$$V_2 = \frac{2\pi}{\lambda_2} \times a \times \sqrt{n_1^2 - n_2^2} \quad (7)$$

$$n(r) = \sqrt{n_1^2 \times (1 - 2 \times \Delta \times (\frac{r}{a})^q)} \quad (2)$$

$$B = \frac{q \times n_1^2}{c \times (2 + q)} \quad (4)$$

$$V_1 = \frac{2\pi}{\lambda_1} \times a \times \sqrt{n_1^2 - n_2^2} \quad (6)$$

$$\text{Dispersion, } \Delta\tau = \tau(n_2) - \tau(n_1) \quad (8)$$

From this analysis the values for Intermodal dispersion in MMSIF and MMGIF are found to be, 23445 ps/km-nm and 231.46 ps/km-nm, respectively.

Material dispersion: Material Dispersion is caused by the fact that the refractive index of the glass changes with the wavelength of light. In the fiber therefore some wavelengths have higher group velocities and so travel faster than others. Since every pulse consists of a range of wavelengths, it will spread out to some degree during its travel and thus material dispersion takes place.

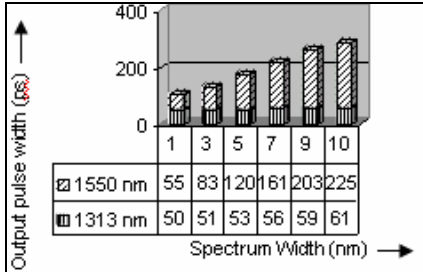


Fig. 2. Material dispersion at 1310 nm and 1550 nm wavelength for various spectral width of the signal with an input pulse of 50 ps and fiber length 1 km.

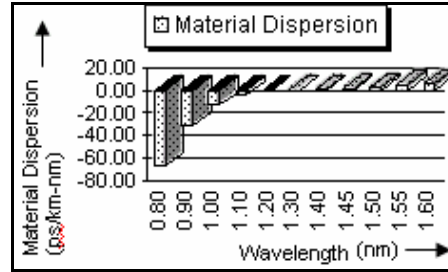


Fig. 3. Wavelength vs. Material dispersion for an input pulse width 50 ps spectrum width 1 nm and fiber length 1 km.

Waveguide dispersion: As the electric and magnetic fields that constitute the pulse of light extend outside the core into the cladding, the shape (profile) of the fiber has a very significant effect on the group velocity of the propagating wave. Moreover the longer the wavelength the further the electromagnetic wave extends into the cladding. The Refractive Index (RI) experienced by the wave is an average of the RI of core and cladding depending on the relative proportion of the wave that travels there. Thus since a greater proportion of the wave at shorter wavelengths is confined within the core, the shorter wavelengths “see” a higher RI than do longer wavelengths. Therefore shorter wavelengths tend to travel more slowly than longer ones. Thus signals are dispersed as every signal consists of a range of wavelengths. The Fig. 4 shows the waveguide dispersion at 1310 nm and 1550 nm band for signals with different spectrum width.

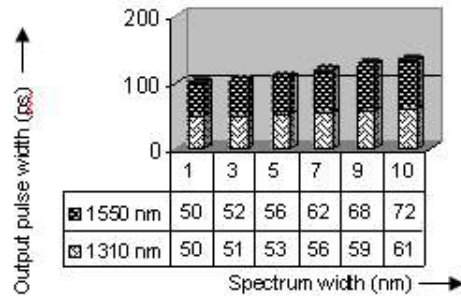


Fig. 4. Waveguide dispersion at 1310 and 1550 nm wavelength for various spectral width of the signal with an input pulse of 50 ps, fiber length 1 km and core diameter 3 μm.

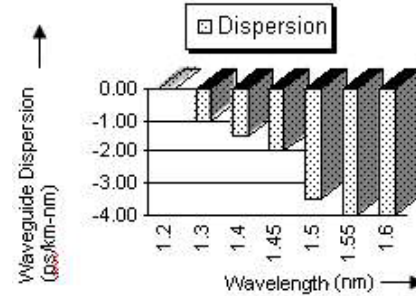


Fig. 4. Wavelength vs. waveguide dispersion for an input pulse width 50 ps, spectrum width 1 nm, fiber length 1 km and core diameter 3 μm.

The good news is that the two forms of dispersion (Material and Waveguide) have opposite signs (as can be visualized from Fig. 3 and 5 as well), so they tend to counteract one another. As a result total dispersion due to this two at a wavelength of 1310 nm, becomes zero. Thus if the signal is sent at 1310 nm, dispersion will be minimized. Moreover as we know the empirical formula for waveguide dispersion for step index fibers is $\tau_w \cong -\frac{1}{40c} \frac{\lambda_0}{n_2 a^2}$ (Ghatak, 1990), waveguide dispersion

always be negative. So it is possible to design a fiber with required profile by controlling the radius (as $\tau_w \propto \frac{1}{a^2}$), so that the zero dispersion point will shift at 1550 nm. As a result using SMSIF with proper profile at 1550 nm will be the best solution to achieve minimum attenuation as well as minimum dispersion.

Results

With the analyses it is found that optical fibers have minimum loss and dispersion at 1550 nm and 1310 nm wavelength accordingly. From Fig. 2 and Fig. 4 it is also found that with the increasing input spectrum width the dispersion increases rapidly. Moreover the analysis of dispersion for a SMSIF shows that dispersion becomes zero at 1310 nm wavelength region as this fiber operates with an input signal of minimum spectral width.

Discussion

From Table 2 it is obvious that SMSIF has enormously less dispersion than that of MMSIF or MMGIF. Moreover we also found that in a good designed fiber the material dispersion and waveguide dispersion can be canceled out to achieve zero dispersion in the region of 1550 nm optical window instead of 1310 nm window (Fig. 6). As a result optical fibers with optimum dispersion and loss at 1550 nm wavelength are possible to design controlling the fiber profile.

Table 2 Dispersions for different types of fibers (considering 50 ps pulse width and 1 ns spectrum width for the input).

Fiber type	Type of dispersion km ⁻¹				Total dispersion km ⁻¹		
	Intermodal	Material		Waveguide		1310 nm	1550 nm
Spectrum		1310 nm	1550 nm	1310 nm	1550 nm	1310 nm	1550 nm
MMSIF (ps)	23445	0	5	0	-3	23445	23447
MMGIF (ps)	231.46	0	5	0	-3	231.46	233.46
SMSIF (ps)	0	0	5	0	-3	0	2

In the normal dispersion region the long wavelengths travel faster than the short ones and in the anomalous dispersion region the short wavelengths travel faster than the long wavelengths (Dutton, 1998).

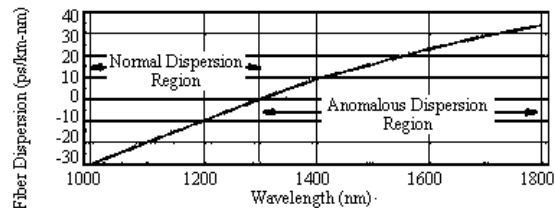


Fig. 6 Total dispersion (Material and Waveguide) at 1310 nm in a SMSIF.

Conclusion

As fiber attenuation is the lowest at 1550 nm band, Erbium Doped Fiber Amplifiers and Wavelength Division Multiplexed systems are operated in this band to save power. It has been found that by using SMSIF with proper profile we can optimize the attenuation and dispersion at 1550 nm wavelength. Thus the fibers can be used for a long distance

without any splicing or amplifier at 1550 nm. As a result data with extremely high bandwidth can be transmitted to an enormous distance through it without any repeater or amplifier.

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