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A DESCRIPTION ON DISPERSION AS A FUNCTION OF BIT RATE AND WAVELENGTH OF SILICA CORE OPTICAL FIBER

Praveen Kumar Singh[1], Ravi Prakash[2]
1 Department of Electronics and Communication Engineering
2 Department of Electronics and Communication Engineering, UNSIET,
VBS Purvanchal University, Jaunpur, U.P. India
praveenjm15@gmail.com[1], ravirim75@gmail.com[2]

Abstract:

In this article, a description on the dispersion is studied along with the effect of bit rate and wavelength of the silica core optical fiber on the dispersion in optical communication system has been observed. In optical fiber, transmission loss is one of the major problem along with different dispersion that to be minimize. These can be dependent on the transmission bit rate and wavelength of different types of optical fiber. For getting the dispersion based on bit rate and wavelength, an optical system has been simulated. It is observed that by varying the bit rate the dispersion also varies. It has been also observed that in all the case of bit rate, it is smaller for the wave length (1.530 μm and 1.510 μm) which is nearer to the most attractive reference wave length 1.55 μm for optical communication.

Keyword: Dispersion, Bit rate, Wavelength, Transmission loss

Introduction

For smooth and sustained communication of signal, the optical fiber communication system faces a lot of challenges [1].The major issues that to be overcome different dispersion along with transmission losses which happened with in the optical fiber. Dispersion refers to the light behavior in relation to its wavelength (λ) which is travelling through refractive index medium (n).The light velocity in any medium with a eminent refractive index will be smaller due to the light velocity in a medium other than free space is expressed as the ratio of the light velocity in free space to the refractive index of the medium through which it travels. For various wavelengths, the angle of emergence (θ) can be measured when an optical beam travel through a prism. The angular dispersion of the prism may be referred as the rate of change of the emerging angle to the rate of change of the wavelength. The equation of angular dispersion contains the characteristic properties of the matter comparing the prism and indicative of the dispersion of the prism. Dispersion indicates the connection between the wavelength and refractive index. The most significant wavelength is 1550 nm for optical fiber communication, as it signifies the lowest loss [2].In different types of dispersion; material dispersion has major impact and acts as inherent property of optical fiber [3]. Material dispersion occurs due to the variation of refractive index as a function of wavelength. It is an intra model dispersion effect and taken place in single mode waveguide and Led system. The various spectral components of different mode of optical fiber will travel at different speed, depending on the wavelengths. The mode of group velocity is a function of the refractive index. The SiO_2(silica) based glasses fiber is the primarily effective option of material of optical fiber and it have a dispersion criterion and specific loss [4,5].

Calculation of dispersion and material induced dispersion:

A plane wave has been considered which is propagating in an infinitely extended dielectric medium that has a refractive index equal to the fiber core. Pulse chirping is the nonlinear change of optical frequency with time [6]. It is the instantaneous variation of the phage velocity in reference to wavelength of a plane wave which is propagating through a dielectric medium and is comprised of various frequency components. In input of the fiber, various frequency components of the plane wave has been launched that reflect different group velocities which is directly contribute to pulse chirping at the fiber output. Therefore, chirping of the pulse width may be expressed by the total group delay at the fiber output which is an inverse function of the group velocity. The group velocity can be expressed as

$$V_g = \frac{C}{(n - \lambda \frac{dn}{d\lambda})}$$

Now inverting the equation of the group velocity it can be obtain the group delay and expressed as

$$\tau = \frac{1}{V_g} \frac{(n - \lambda \frac{dn}{d\lambda})}{C}$$

Whereτ is the group delay which based on material dispersion [7, 8], V_g is the group velocity, n is the core refractive index, λ is the operating wavelength and C is the velocity of light in free space [9].

To estimate the dispersion of a fiber specimen, firstly it must fit the data of the group delay to a theoretical curve and after that differentiate the best fit curve of group delay with respect to wavelength. By selecting the option "Dispersion from file”, the dispersion data are fitted internally according to the five-term Sellmeier formula [10] namely:

$$\tau = C_1\lambda^{-4} + C_2\lambda^{-2} + C_3 + C_4\lambda^2 + C_5\lambda^4$$

where τ is the group delay and has per unit fiber length.

The dispersion coefficient D is defined as

$$D = \frac{d\tau}{d\lambda} = C_1'\lambda^{-5} + C_2'\lambda^{-3} + C_4'\lambda + C_5'\lambda^3$$

has the unit ps/(nm.km) and called ‘zero-dispersion [11]’ wavelength when it goes to zero.

Dispersion fitting according to the Sellmeier formula:

An optical beam with wavelength, passing through a medium composed of particles exhibiting a specified number of natural frequencies with relatively small amplitudes, will force additional vibrations upon the particles. The large amplitude of particle vibrations at resonance will interfere with the travelling wave, altering its velocity within the medium. The refractive-index of doped-silicahas an inflection point near 1.3 μm and follows a Sellmeier function of wavelength [12].

Thus according to the Sellmeier's equation the refractive index can be represented as

$$n^2 = 1 + \frac{C\lambda^2}{\lambda^2 - {\lambda_o}^2}$$

Where n is the refractive index, λ is the wavelength of the travelling optical beam, and λ_o is the wavelength corresponding to the natural frequency of the matter. From the above equation the unknown variable can be determined.
A more general for a series of different natural frequencies can be expressed as

$$n^2 = 1 + \frac{C_o\lambda^2}{\lambda^2 - {\lambda_o}^2} + \frac{C_1\lambda^2}{\lambda^2 - {\lambda_1}^2} + \frac{C_3\lambda^2}{\lambda^2 - {\lambda_2}^2} + \cdots$$

Where $\lambda_o, \lambda_1, \lambda_2$ ..... is the wavelength corresponding to the natural frequencies.

The delay time difference $\Delta\tau$or dispersion is the difference in transit time of a pulse relative to a reference point τ_0 through a fiber length L and can be expressed as

$$\Delta\tau = L\,D\,(\lambda_1 - \lambda_2)$$

Pulse chirping due to material dispersion at the closing stages of an optical fiber of length (L) is based on group delay. Thus the group delay resulting from material dispersion for the length of the fiber can be expressed as

$$\tau_{mat} = \frac{L}{C}(n - \lambda\frac{dn}{d\lambda})$$

Above equation indicates that pulse broadening due to material dispersion is also proportional to the length of the fiber.
Rearranging above equation yields equation as below

$$\frac{d\tau_{mat}}{d\lambda} = \frac{\lambda L}{C}\left(\frac{dn}{d\lambda} - \frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda}\right)$$

So,

$$\frac{d\tau_{mat}}{d\lambda} = \left(\frac{\lambda L}{C}\right)\left(\frac{d^2n}{d\lambda^2}\right)$$

The group delay is differentiating with respect to wavelength, the pulse speed σ_{mat} for a source of spectral width $\sigma_\lambda$has been establish and multiplying by σ_λ

$$\sigma_{mat} = \left|\frac{d\tau_{mat}}{d\lambda}\right|\sigma_\lambda$$

$$= \frac{\sigma_\lambda L}{C}\left|\lambda\frac{d^2n}{d\lambda^2}\right|$$

$$= \sigma_\lambda L|D_{mat}(\lambda)|$$

where $D_{mat}(\lambda)$ is the material dispersion.

Material dispersion depends on the fiber materials and parameters of fundamental fiber and may be reduced either by operating at longer wavelength which is optimized by system designers or by choosing sources with narrower spectral output widths.

Description of design circuit for simulation:

For getting the simulated dispersion and material dispersion, a schematic diagram with different combination of components or systems is shown in Fig.1. This diagram contain following components:

S.No.	Components	Quantity
1	Pseudo Random Bit sequence Generator	2
2	NRZ Pulse Generator	2
3	CW Laser	2
4	MZ Modulator Analytical	2
5	WDM Mux 2×1	1
6	Optical Fiber Length	1
7	Optical Time Domain Visualizer	2

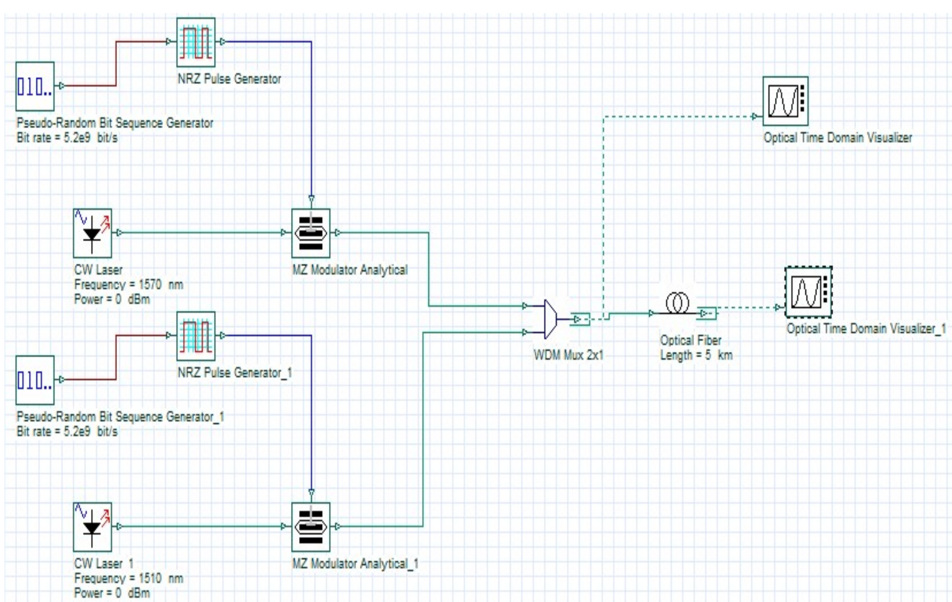

Fig. 1 A schematic simulated diagram for getting the dispersion and material dispersion

A PRBS(Pseudo Random Binary Sequence) generator has been used for generating the bit rate in binary form according to different operation modes. For approximate the characteristics of random datathe bit sequence has been designed.
The output binary signal of PRBS generator acts as the input of Non Return to Zero (NRZ) Pulse generator. Here the binary coded signal is converted into electrical signal and entered into Mach-Zehnder (MZ) modulator.

The CW (continuous wave) optical signal output of an external laser diode having a linewidthunder 10 MHz with an optical power of 0dBm, is associated to an external intensity MZ modulator. Its default value is 193.1 THz or 1550 nm.
With this CW laser it can be generate optical signal having different wavelength or frequency. In simulation process with two CW laser optical source optical signals has been generated at different wavelength or frequency.

The MZ modulator simulated with the help of an analytical model. The MZ modulator is an intensity modulator which realized on principle of interferometric. It consists of a pair of 3 dB couplers which are associated by a pair of waveguides having equal length. In the waveguide branches, an externally applied voltage may be used to fluctuate the refractive indices by means of an electro-optic effect. Depending on the applied voltage, the different paths may lead to destructive and constructive interference at the output. After that the output intensity according to the voltage can be modulated. In this modulator an electrical signal is applied as input from NRZ generator and an optical signal as a carrier from CW laser diode. The modulated optical output of both the MZ modulator acts as an input to the Wavelength Division Multiplexing (WDM) multiplexer. This multiplexer multiplexes two WDM signal channels. Its default value of bandwidth or 3 dB filter bandwidth is 10 GHz. Using an optical filter, two input signals are filtered and are combined in one signal. The optical filter can be of different types such as Rectangle, Bessel, or Gaussian optical filter. As it is observed that WDM and Dense WDM techniques are among the major applications in current scenario optical communication system.

The propagation of an optical field in a fiber having single-mode is simulated by optical fiber components by means of the dispersive as well as nonlinear effects taken into account by a direct numerical integration of the modified equation of NLS (nonlinear Schrödinger) (when the scalar case is considered) and when the polarization state of the signal is random, a system of two, coupled NLS equations has been taken into account. The optical sampled signals inhabit in a single frequency band, hereafter the name of the total field. The noise bins and parameterized signals are only attenuated. This optical fiber has lower and upper calculation limit is 1200 nm and 1700 nm respectively with dispersion 16.75 ps / (nm.km) and attenuation 0.2dB/Km. In simulation process by varying the length of the optical fiber the total spread or delay time difference has been observed.
Optical Time Domain Visualizer (OTDV) allows calculating and displaying the signals of optic in the time domain. It can exhibit the signal frequency, intensity, phase along with alpha parameter for polarizations X and Y. The visualizers in the project after running a simulation generate graphs and results depended on the signal input. It may access the graphs and results

from the component viewer, from the project browser, or by double-clicking a visualizer in the main layout. The Optical Time Domain Visualizer (OTDV) is an oscilloscope for optical signals. From the simulation it can access the OTDV parameters, graphs, and results. In simulation process there are two OTDV has been used. One prior to the optical fiber and another post to the optical fiber for getting the effect of time delay or dispersion in optical signal.

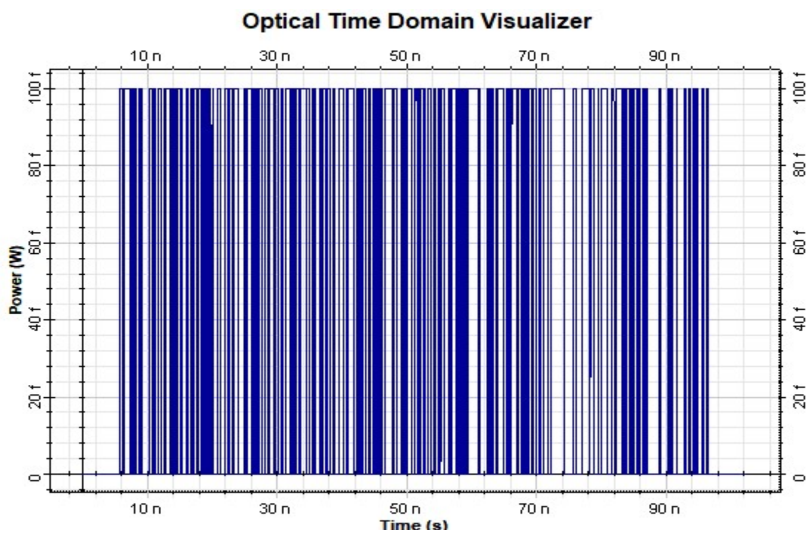

Fig.2. OTDV before the optical cable

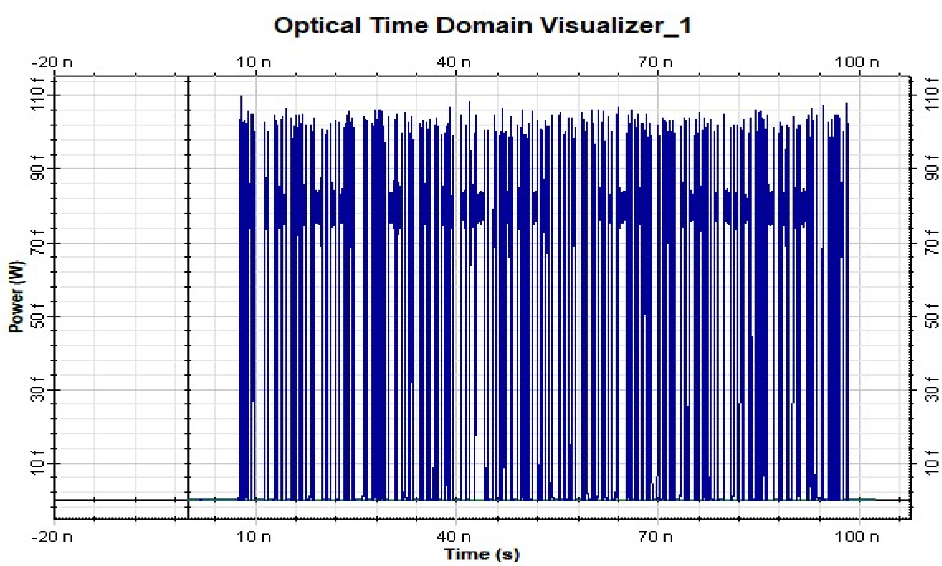

Fig.2. OTDV after the optical cable

Table-1: Observation of time spread

Bit Rate	Wavelength	Distance (Km)	Total Spread ($\Delta\tau$)	Dispersion ($\Delta\tau_x - \Delta\tau_0$)
2.5e9	$\lambda_1 = 1570$ $\lambda_2 = 1510$	0	0.771	-
		5	0.775	0.004
		10	0.776	0.005
		15	0.791	0.020
		20	0.791	0.020
	$\lambda_1 = 1530$ $\lambda_2 = 1510$	0	0.781	-
		5	0.784	0.003
		10	0.785	0.004
		15	0.786	0.005
		20	0.786	0.005
5.2e9	$\lambda_1 = 1570$ $\lambda_2 = 1510$	0	4.643	-
		5	4.671	0.028
		10	4.713	0.070
		15	4.715	0.072
		20	4.715	0.072
	$\lambda_1 = 1530$ $\lambda_2 = 1510$	0	4.645	-
		5	4.668	0.023
		10	4.692	0.047
		15	4.712	0.067
		20	4.713	0.068

Result and discussion:

In this research, it is simulated for getting the delay time or time spread,delay time difference and dispersion at different bit rate of Pseudo Random Binary Sequence (PRBS) generator as binary signal. In simulation process to generate a continuous wave (CW) optical signal as carrier for MZ modulator, CW laser has been used having different wavelength. The used wavelengths are 1570 nm, 1530 nm and 1510 nm. The observation of the time spread at different optical fiber length with different combination of wavelength is shown in Table-1.

This table also showing the dispersion at different optical fiber length with combination of wavelength. Fig. 2 shows the OTDV of multiplexed optical signal before the optical fiber. Fig.3 shows the OTDV of the multiplexed optical signal after the length of the optical fiber. OTDV shows the optical signal in terms of power vs. time where power is in 'W (Watt)' and time is in 'ns (nano second)'. By varying the bit rate of the PRBS and varying the wavelength of the CW laser along with variation of length of the optical cable, the total time delay with the help of OTDV which is placed before and after the optical cable has been observed.

From the table 1, it is observed that by varying the bit rate the dispersion also varies. It has been also observed that in both the case of bit rate, it is smaller for the wave length (λ_1=1530 nm and λ_2=1510 nm) which is nearer to the reference wave length.

Conclusion

In optical fiber communication system, dispersion and transmission loss is the major problem that to be minimize. These can be dependent on the transmission bit rate and wavelength of different types of optical fiber. So, a description on the dispersion has been studied as well as the effect of bit rate and wavelength of the silica core optical fiber on the dispersion in optical communication system has been observed. An optical system which is the combination of different components like pulse generator, random bit sequence generator, modulator analyzer, WDM multiplexer, optical fiber, optical visualizer has been simulated for getting the dispersion based on bit rate and wavelength. By varying the bit rate, it is observed that the dispersion also varies. It has been also observed that in all the case of bit rate, it is smaller for the wave length (1.530 µm and 1.510 µm) which is nearer to the most attractive reference wave length 1.55 µm for optical communication. These observations can be useful for minimization of dispersion in optical communication system.

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