

Pulse Delay Chromatic Dispersion Measurements in Single Mode Fibre

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Abstract. – In recent years, there has been a rising demand for high bandwidth in long haul fibres to assist with high-speed data transmission. Chromatic dispersion limits high-speed data transmission making it essential to perform chromatic dispersion measurements. Chromatic dispersion measurements play an important role during the manufacturing processes of the optical fibre, in characterizing the different types of optical fibre, when designing optical networks and in transmission penalty estimations. In this paper, a unique laboratory setup based on the pulse delay technique was used to characterize the chromatic dispersion in a single mode fibre. The chromatic dispersion of a 6.1km long G.652 single mode fibre was measured within the 1550nm to 1553nm wavelength range. The dispersion values obtained were in the region of 15.3-20.0ps/nm.km, which compares well with the theoretical values for the G.652 optical fibre.

1. Introduction

The transmission of data over long haul optical fibre cables at speeds of 40Gbps or higher is an essential asset to the telecommunication industry as it is of valuable assistance to those making use of the Internet and its applications such as teleconferencing. Optic fibre does not only play a pivotal role in the telecommunication industry but it is also an important component in the field of medicine, where it is used in laparoscopic surgery and also in laser surgery. Other uses such as the transmitting of high power laser beams and fibre optic sensors also rely on optical fibre. However nonlinear effects, attenuation of the optical signal, polarization mode dispersion and chromatic dispersion can interfere with the high-speed data transmission. These effects are but a few detrimental factors that limit the optical fibre to perform at its peak. In this paper, chromatic dispersion is discussed and an accurate experimental method for measuring chromatic dispersion is described. This method is based on the pulse delay measurement technique. This type of measurement is important to be made as it provides a better understanding of the fibre and its characteristics when selecting the correct fibres for different network designs and during the manufacturing process of fibre.

2. Theory

Suppose an optical signal propagates along a fibre having a distinct pattern of 1's and 0's where a 1 will indicate the existence of light and a 0 indicates the lack of light as depicted in figure 1(b). The pulses denoted by a 1 can be regarded as a wavepacket consisting of several waves, where each has a distinct wavelength [1]. As it moves along the fibre some of these wavelengths will travel faster than others because of the inherent dependence of the refractive index on the wavelength. This results in the pulses spreading and overlapping into adjacent pulses as shown in figure 1(a) giving rise to bit errors [1]. This phenomenon is known as chromatic dispersion. Note that the power of the pulse in figure 1(a) equals the power of the pulse in figure 1(b). Chromatic dispersion is given as

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

where L is length of the fibre, $d\tau$ is the differential time delay and λ is the wavelength. The chromatic dispersion is expressed in ps/(nm.km) [2].

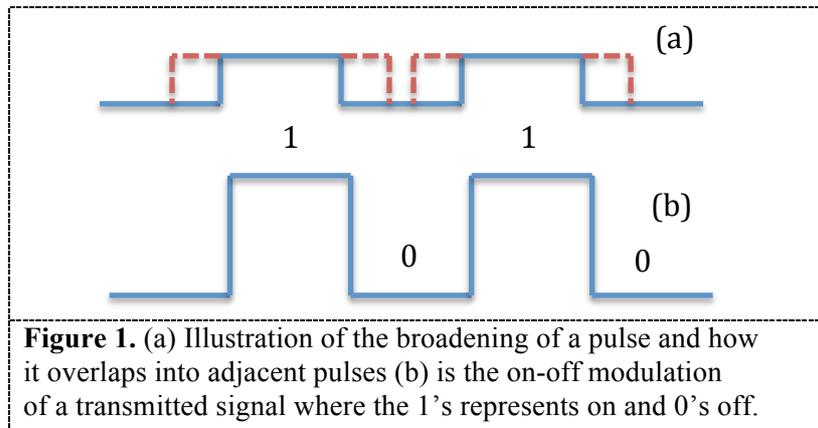


Figure 1. (a) Illustration of the broadening of a pulse and how it overlaps into adjacent pulses (b) is the on-off modulation of a transmitted signal where the 1's represents on and 0's off.

Chromatic dispersion is often considered to be the sum of material dispersion and waveguide dispersion. The chromatic dispersion curve is deterministic, has a linear trend and increases as the length of the fibre increases [1,3]. For a single mode G.652 fibre the theoretically measured value for the chromatic dispersion coefficient D is about 17ps/nm.km at 1550nm and 0 ps/nm.km at 1310nm [1,3].

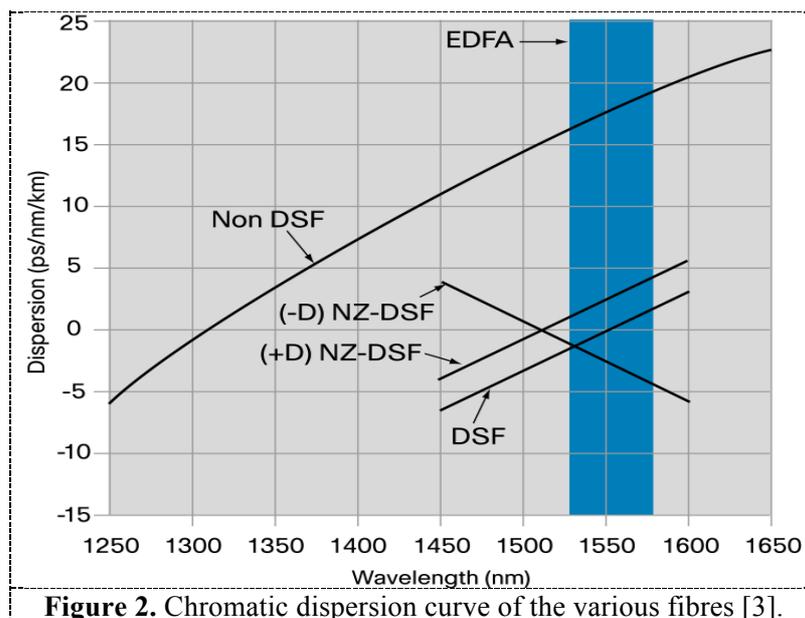


Figure 2. Chromatic dispersion curve of the various fibres [3].

Material dispersion results from the change in the refractive index of the material as a function of the optical wavelength of the light propagating through the fibre. The different spectral components of any given mode travelling through the fibre travels at different speeds depending on the wavelength of light. This occurs because the group velocity V_g of a particular mode is a function of the refractive index of the fibre [4]. Material dispersion is an intramodal form of dispersion. Waveguide dispersion arises because a single mode fibre confines 80 percent of the light to core and 20 percent of the light to the cladding. Because the light confined in the cladding travels faster than the light confined to the core, dispersion occurs within the fibre which gives rise to pulse spreading [4].

The pulse delay measurement technique, the phase shift measurement technique, the differential phase shift measurement technique and the interferometric measurement technique are the preferred methods adopted for measuring the chromatic dispersion [1,5,6]. The pulse delay method makes use of the time

of flight approach, where the time delay between two pulsed light of different wavelengths are measured. This method requires the use of a broadband laser source with high peak power. The pulse delay measurement technique has the ability to resolve a 50ps to 100ps time delay between two successive pulses. This is the smallest time delay that can be measured by this method, making it inadequate for characterizing optic fibre cables shorter than 0.5km [7].

3. Experimental Procedure

This experiment was conducted in a laboratory environment where the chromatic dispersion was measured in 6.1km of G.652 single mode fibre. The experimental measurement technique was uniquely designed and assembled using bench-top equipment and laboratory components. The technique is based on the pulse delay method and the setup is illustrated in the figure 3.

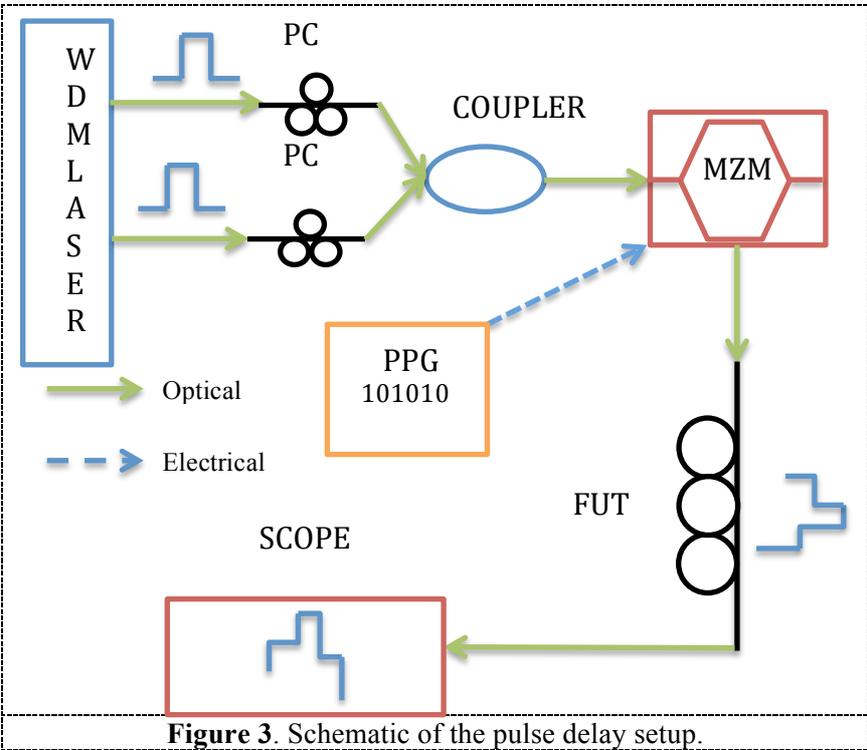


Figure 3. Schematic of the pulse delay setup.

An eight-channel wavelength division multiplexer (WDM) laser source, provided continuous light. A Mach-Zehnder modulator (MZM) modulates the intensity of the light, which generated the optical light pulses transmitted through the 6.1km long G.652 single mode fibre. The pulse adopted a specific sequence of 1's and 0's set by a pulse pattern generator (PPG). The Mach-Zehnder modulator (MZM) is polarization sensitive. Hence manual polarization controllers were used to adjust the state of polarization of the input signal. This was done in order to maximize the efficiency of the Mach-Zehnder modulator. The chromatic dispersion in the fibre under test (FUT) can then be determined as a function of wavelength from pattern collected on the oscilloscope as described below.

4. Results and Discussions

The question presented was, what actually happens as the two pulses of different wavelength travels through the fibre? Due to the difference in propagating speeds of the input pulses, the individual pulse combine to form a broadened and disfigured pulse as indicated in figure 4. The solid lines denote the delay experienced between the two pulses as a result of the different propagation speeds.

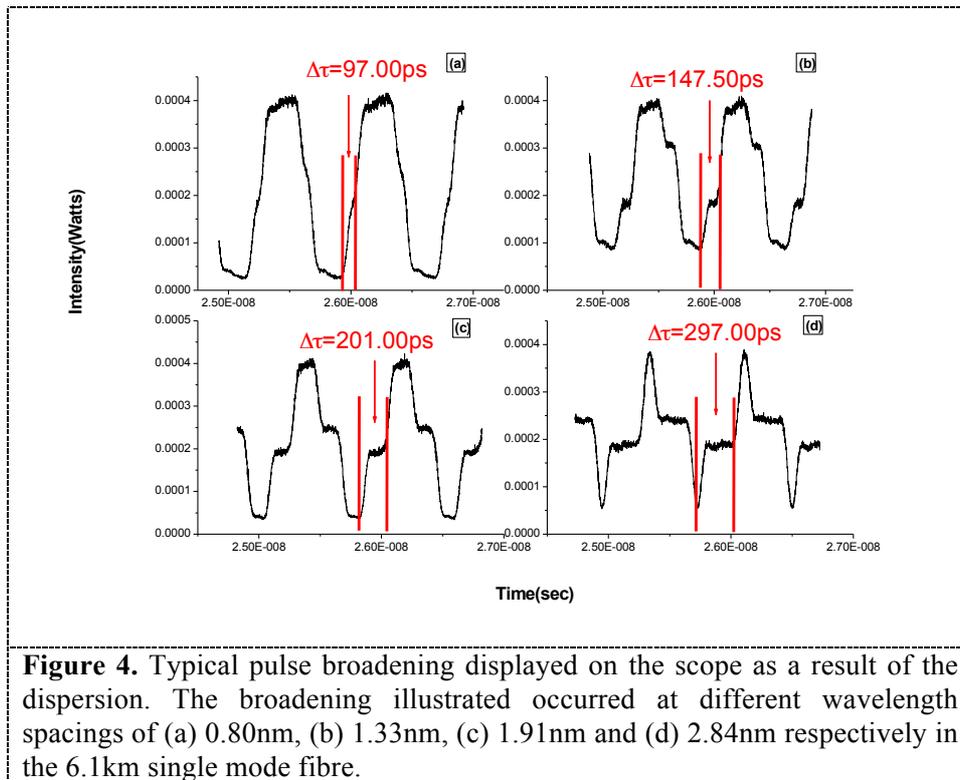
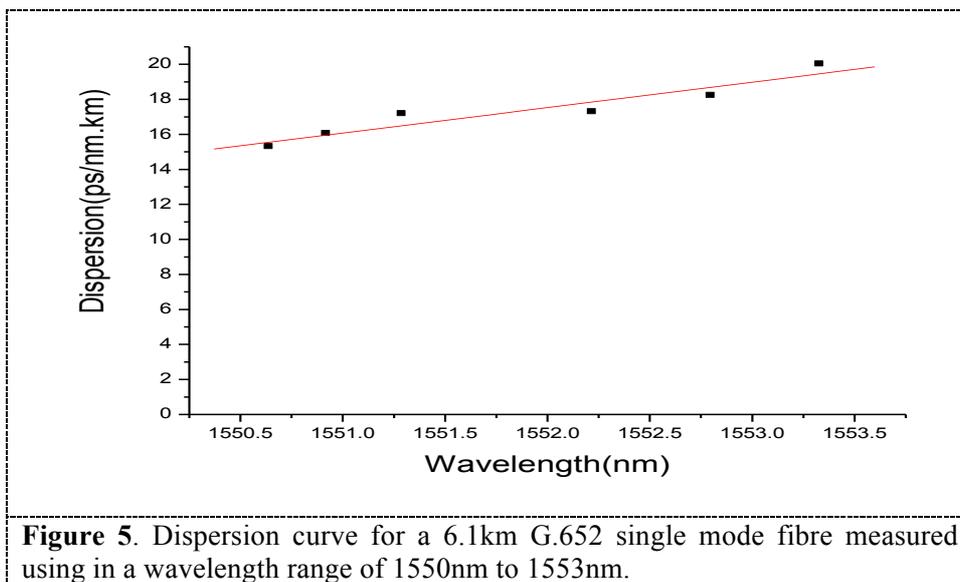


Figure 4 describes the progression of pulse broadening as the pulse propagates along the fibre at different wavelength spacing's. It is clear that as the wavelength spacing increases, $\Delta\tau$ increase as well. This is a direct result of the difference in the propagation speeds between the two individual pulses. A larger wavelength spacing between to pulses implies that pulse 1 has a greater velocity than pulse 2, yielding a greater time delay between the two pulses. The resolution is limited by the challenge to distinguish the dispersion between two pulses with narrow wavelength spacing. It can be concluded that, material dispersion could be the primary form of dispersion due to the wavelength dependence on the refractive index being such a major contributing factor to the chromatic dispersion.



From figure 4, it can be seen how pulse broadening increases the errors when distinguishing between 1's and 0's. The dispersion curve obtained for the wavelength range selected, 1550nm to 1553nm, in figure 5 is in close agreement with the theoretical dispersion curve displayed in figure 2 for the same wavelength range. A dispersion of 15.9ps/nm.km to 20.0ps/nm.km was measured, again this is in close agreement to the theoretical dispersion values. Table 1 displays the dispersion coefficients D obtained at their corresponding wavelength value in the 6.1km single mode fibre. The experimental results obtained for the dispersion coefficients do not entirely agree with the theoretical standard of 17ps/nm.km at the 1550nm wavelength region found in the relevant literature. This can be related to the poor resolution displayed by the pulse delay method, however the measurement technique described above can be utilized for characterizing the chromatic dispersion in single mode fibres.

Table 1. Chromatic dispersion coefficients at their respective wavelengths.

Wavelength (nm)	Time Delay (ps)	Dispersion (ps/nm.km)
1553.33	97.5	20.0
1552.80	147.5	18.2
1552.22	201.0	17.3
1551.29	297.0	17.2
1550.92	313.5	16.0
1550.64	325.0	15.3

5. Conclusion

A method has been proposed for measuring the chromatic dispersion in a 6.1km long G.652 single mode fibre. The dispersion coefficients obtained for the 1550nm to the 1554nm wavelength range is in agreement to those found in the relative literature. Furthermore, it is required that additional chromatic dispersion measurements be undertaken in lengths of fibre exceeding 6km, in order for one to see if the dispersion coefficient improves as well as the resolution. The measurement technique described above can be utilized for characterizing the chromatic dispersion in G.652 single mode fibre.

6. Acknowledgements

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