

Electromagnetic Metrology

Measurement of Chromatic Dispersion in Single-Mode Optical Fibres

Chromatic dispersion is a measure of how the time, τ , taken by an optical pulse to travel along a fibre varies with the wavelength, λ , of the light making up the pulse. Chromatic dispersion is one of the main factors limiting the information carrying capacity of single-mode optical fibre. The variation of propagation time with wavelength, $d\tau/d\lambda$, is known as the dispersion or dispersion coefficient. It arises from the wavelength dependent properties of the fibre materials and guiding structure. As the sources used in communications systems typically emit pulses made up of a range of wavelengths, an optical pulse broadens as it propagates down a fibre. This limits the minimum usable pulse length and spacing and hence the information carrying capacity of the fibre. The figure below shows the dispersion characteristics of three types of fibre.

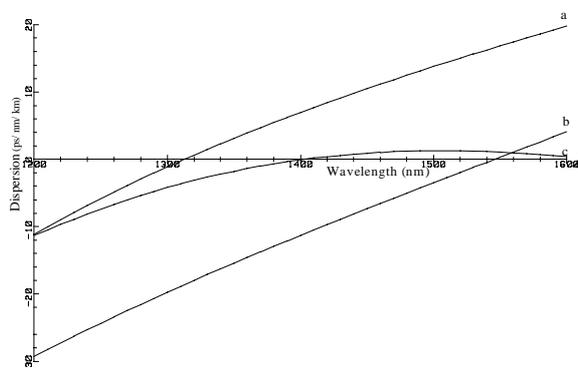


Figure 1. Dispersion coefficient vs. wavelength for standard dispersion(a), dispersion shifted (b) and dispersion flattened (c) fibres.

Because of its importance as a fibre parameter, chromatic dispersion is routinely measured by optical fibre and cable manufacturers and a number of commercial test sets are available. For a number of years NPL has provided a calibration service for the measurement of chromatic dispersion in single-mode optical fibres with a typical accuracy (at 95% confidence) of ± 0.5 nm in zero dispersion wavelength, λ_0 , and $\pm 2\%$ in dispersion. The uncertainty in λ_0 has recently been reduced to 0.1 nm in both the 1300 nm and 1550 nm windows.

The notes that follow draw on NPL's experience of chromatic dispersion measurement and are intended

to point out potential sources of error in dispersion measurements and to provide advice on how to make the best use of NPL calibrated reference fibres. The notes are particularly applicable to measurements using phase shift or differential phase shift techniques but most of the observations are also relevant to pulse or interferometrically based measurement systems.

Air or Vacuum Wavelength?

The difference between a wavelength measured in air and in vacuum is approximately 0.4 nm at 1550 nm. Changes in atmospheric pressure temperature and humidity can result in changes in air wavelengths of up to 0.04 nm. This change is small compared to the uncertainties quoted on NPL certificates based on LED measurements which quoted air values for all wavelengths. With the introduction of calibrations based on measurements using tuneable laser systems with uncertainties in λ_0 of 0.1 nm the variation in air wavelengths becomes important. Therefore from certificate number DIS138 all wavelength values quoted are vacuum values. To convert air values on older certificates to vacuum values the following formulae should be used: For λ_0 add 0.35 nm for standard dispersion fibres and add 0.40 nm for dispersion shifted fibres. For dispersion $0.03 \text{ psnm}^{-1}\text{km}^{-1}$ should be subtracted from a dispersion value at a given air wavelength to give the dispersion value at the same vacuum wavelength for both standard dispersion and dispersion shifted fibres. For example if the dispersion quoted on a certificate at 1280 nm (air) was $-3.33 \text{ psnm}^{-1}\text{km}^{-1}$ then the dispersion at 1280 nm (vacuum) would be $-3.36 \text{ psnm}^{-1}\text{km}^{-1}$. If the dispersion quoted at 1550 nm (air) was $16.19 \text{ psnm}^{-1}\text{km}^{-1}$ then the dispersion at 1550 nm (vacuum) would be $16.16 \text{ psnm}^{-1}\text{km}^{-1}$. The use of these formulae will result in an increase in the uncertainties in the values λ_0 and dispersion of less than 10%. The value of S_0 changes by less than 0.1% in changing from air to vacuum wavelengths.

Temperature

The absolute temperature affects the value of λ_0 , typical values for the temperature coefficient of λ_0 are $+0.025 \text{ nm } ^\circ\text{C}^{-1}$ for standard dispersion fibre and $+0.030 \text{ nm } ^\circ\text{C}^{-1}$ for dispersion shifted fibre.

Temperature has no significant effect on the value of the dispersion slope at λ_0 , S_0 .

Temperature changes during measurement can introduce errors and fibres should be allowed to reach thermal equilibrium in the measurement environment before measurements are attempted. Avoid making measurements in locations subject to significant temperature fluctuations. For example a temperature change of the fibre of $+0.1 \text{ } ^\circ\text{C}$ during a measurement covering a 100 nm wavelength range would introduce an error of about -0.4 nm into the value of the zero dispersion wavelength. Any errors due to temperature drift can be minimised by placing fibres in insulated enclosures where possible and by making measurements in a short time span (e.g. as happens in differential phase shift systems).

Polarisation Mode Dispersion and Winding Tension

Polarisation mode dispersion, PMD, does not appear to introduce errors into chromatic dispersion measurements made on normal telecoms fibre wound on shipping reels because of mode coupling effects.

Measurements of λ_0 and dispersion made on the same fibre wound at tensions between 20 g and 100 g showed no significant variation. Therefore the gradual relaxation of a fibre should not introduce measurement problems.

Reflections

Optical reflections in a measurement system can introduce measurement errors due to wavelength dependent interference effects causing anomalous phase shifts. This can be a particular problem when highly coherent lasers are used as light sources. Reflections should be kept below -30 dB and all connectors cleaned as the measurement system is assembled.

Data Fitting Equations

The IEC recommended fitting equations should be used; three term Sellmeier for the 1300 nm window, quadratic for the 1550 nm window and five term Sellmeier for dual window fits. It is important in single window measurements to fit data over a wavelength range symmetrical about λ_0 in order to obtain reliable values for λ_0 . The optimum wavelength range for single window measurements is 60 - 80 nm subject to the symmetry condition and noise limitations.

NPL uses the five term dual window fit when producing certificates based on measurements carried out with its LED system. Within the uncertainties quoted this gives the same values for λ_0 , S_0 and dispersion as the recommended single window fits for 1260 nm to 1360 nm for standard fibres and 1500 nm to 1600 nm for dispersion shifted fibres.

Use of Calibrated Reference Fibres

Calibrated fibres, for example fibres measured at NPL, can be used to verify the operation of chromatic dispersion measurement systems. The quoted value for λ_0 can be used to check the wavelength scale of the measurement system and dispersion values also provide a check of the time scale of the system. If a system is to be used for both 1300 nm and 1500 nm measurement windows, it should be checked with two fibres, one with λ_0 in the 1300 nm window and one with λ_0 in the 1550 nm window. Reference fibres should be of a similar length to those routinely measured.

Fibre Length

The optimum length of fibre to measure for maximum accuracy results from a trade off between the greater time delay and the reduced light transmission as fibre length increases. Typical optimum lengths are 13 km at 1300 nm and 22 km at 1550 nm for normal production fibres. Accuracy of results for very short or very long fibres will be reduced by time resolution and noise limitations respectively.

Further Information

For further information on this and the rest of NPL's comprehensive range of fibre optic measurement services please contact
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