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Federal Office of Metrology METAS

Technical protocol
Bilateral Inter-comparison METAS - VNIIOFI
Inter-comparison of
Chromatic Dispersion Reference Fibres

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1 Introduction

The aim of this project is to perform a comparison of chromatic dispersion measurements that will be carried out on two fibres types, namely G.652 (standard) and G.655 (non zero dispersion shifted). These measurements will be valuable in order to investigate the measurement accuracy that is achievable under the different measurement conditions and data processing methods that are required for each type of fibre. The results of this project will serve as a basis for the review of the CMC entries on chromatic dispersion.

2 List of participants

Laboratory	**Contact person**	**email**
VNIIOFI	Vladimir Kravtsov	Kravtsov-F3@vniiofi.ru
METAS (pilot laboratory)	Jacques Morel	Jacques.morel@metas.ch

3 Technical part

3.1 Measured quantities

The chromatic dispersion is usually defined by means of three main quantities that are summarised in table 1.

Quantity	**Symbol**	**Units**
Overall chromatic dispersion	D	ps/nm
Zero dispersion wavelength	λ_0	nm
Dispersion slope at λ_0	S_0	Ps/nm^2

Table 1

The chromatic dispersion D and the dispersion slope S_0 will be defined for a whole fibre reel and thus won't be normalised to the fibre length.

3.2 Measurement methods and data processing

The chromatic dispersion parameters will be measured by using one or several of the following measurement techniques, namely:

1. Phase shift
2. Differential phase shift
3. Spectral group delay in the time domain
4. Non linear (4 waves mixing)
5. Interferometric. Due to the length of the reference fibres (length comprised between 10 km and 26 km), this method will probably be very difficult to implement.

For calibration techniques involving the curve fitting of the differential group delay data, one of the following polynomial functions as given in Table 2 should be considered.

Fibre type	**Wavelength domain**	**Model**	**Equation**
G652	1310 nm (around λ_o)	Sellmeier 3 terms	$\tau(\lambda) = a\lambda^2 + b\lambda^{-2} + c$
	Wider range	Sellmeier 5 terms	$\tau(\lambda) = a\lambda^4 + b\lambda^2 + c\lambda^{-2} + d\lambda^{-4} + e$
G653	Around λ_o= 1550 nm	Parabolic	$\tau(\lambda) = a\lambda^2 + b\lambda + c$
	Wider range	Sellmeier 5 terms	$\tau(\lambda) = a\lambda^4 + b\lambda^2 + c\lambda^{-2} + d\lambda^{-4} + e$
G655		Sellmeier 5 terms	$\tau(\lambda) = a\lambda^4 + b\lambda^2 + c\lambda^{-2} + d\lambda^{-4} + e$

Table 2. List of the standard fitting functions

Other curve fitting models are allowed if proved that they would significantly improve the quality of the fit.

3.3 Reporting of the calibration results

The calibration of the chromatic dispersion will be performed within the largest possible wavelength range. Depending on the properties of each measurement system and on the data processing technique that will be used by each participant, the calibration will be performed in one or in several disjoined spectral segments. This calibration should be performed, whenever possible, within both the 1310 nm and 1550 nm windows. The zero dispersion wavelength λ_o and the dispersion slope S_o around λ_o will only be reported when obtained from a measurement scan that includes the zero dispersion wavelength itself; i.e. that λ_o isn't obtained from an extrapolation of the measured dispersion data.
The chromatic dispersion D will be reported for even integer wavelength values. For example, λ_1 = 1310nm, λ_2 = 1312 nm, etc.

The calibration results will include the following information:

1. Description of the measurement method
2. The traceability chain will be explained for each major parameter (wavelength, phase or differential group delay).
3. The modulation frequency used for the calibration and its uncertainty will be reported. This is mainly relevant for the phase shift and the differential phase shift techniques.
4. The spectral width of the (modulated) light source and its uncertainty will also be given.
5. All laboratories will perform their calibrations at the same temperature of about 23 °C. The effective temperature will be reported for each calibration. Humidity doesn't play an important role for this inter-comparison and will only be reported for the sake of completeness.
6. The curve fitting function used for the data processing will be given for each wavelength domain covered by the calibration
7. The number of measurement points used for the curve fitting will also be specified.

The calibration data will be reported as follows:

Wavelength λ (nm)	U_λ (nm)	Chromatic Dispersion D (ps/nm)	U_D (ps/nm).

The chromatic dispersion D at the wavelength λ will normally be calculated by differentiating the best-fit function of the differential group delay data $\tau(\lambda)$, and by calculating its value at the wavelength of interest λ.

The zero dispersion wavelength λ_o (nm) and the dispersion slope S_0 (ps/nm^2) around λ_0 will be reported with their uncertainties $U_{\lambda o}$ and U_{S0}.

The Differential Group Delay and its uncertainty will also be reported for each measured wavelength as follows:

Wavelength λ (nm) of measured point	U_λ (nm)	Differential Group Delay τ (ps)	U_τ (ps).

Referencing the differential group delay data to any measurement point is allowed. These data will only be used to help to understand potential discrepancies in the calibration results that could arise from the different data processing techniques used by each participant. These data won't be integrated in the final report of this inter-comparison.

3.4 Uncertainty budget

Relevant parameters for the calculation of the uncertainty budget depend on the measurement and on the data processing techniques that will be used by each laboratory. Some of the most relevant parameters that may be considered to calculate the combined uncertainty associated to D, S_o and λ_o are given in table 4.

Quantity	**Description**
u_τ	Uncertainty in the determination of the differential group delay due to the measurement system
u_T	Uncertainty due to thermal drifts
u_{fit}	Uncertainty due to the curve fitting
U_{PMD2}	Uncertainty due to the 2nd order PMD (usually negligible)
u_λ	Uncertainty in the determination of the wavelength associated to each measurement point
u_A	Type A uncertainty

Table 4. Most relevant parameters for the calculation of the uncertainty budget.

The uncertainty of each quantity will be reported as the combined standard uncertainty multiplied by a coverage factor *k* = 2, estimated according to the ISO guide.

The measurement uncertainty will contain contributions originating from the measurement standards, from the calibration method, from the environmental conditions and from the artefacts being calibrated.

3.5 Reference fibre

Each reference consists of a single-mode fibre reel with a typical length of 10 km up to 26 km. The fibre is mounted in a carrying case providing a good mechanical and thermal protection (see Fig. 1). Two FC-APC connectors that are mounted in the front of the case provide access to the fibre. The approximate dimensions of the case are (41 x 33 x 1) cm.

Fig. 1. Reference Fibres mounted in a thermal enclosure.

The case will remain locked during the whole inter-comparison in order to keep the fibre properties as stable as possible.

Two different fibres will be calibrated by each laboratory, as summarised in Table 3.

Artefact Nr.	Fibre type	Fibre length (m) (λ= 1550 nm, *n* = 1.4682)	Connectors
1	G.653	12528.7 m	FC-APC
2	G.652	12814.1 m	FC-APC

Table 3. List of the reference fibres used for the comparison

3.6 Pre-check of the artefacts

A visual inspection of the cases will be performed upon arrival of the material. A visual check of the FC-APC connectors will be done without dismounting the FC-APC sockets. Results of this pre-check will be reported. A cleaning of the FC-APC connectors will only be performed when absolutely necessary and will always be previously discussed with the coordinator of the project.

3.7 Preparation of the reference fibre for the calibration

After initial check, the reference fibre will be kept at the temperature of calibration for a least one day before performing the measurements.

4 Organisational aspects of the inter-comparison

Each participant will calibrate two reference fibres. VNIIOFI will first prepare and calibrate the two samples that will be delivered to METAS. After completion of the calibration METAS will immediately send the fibres back to VNIIOFI who will perform a subsequent stability check of the artefacts.
VNIIOFI will send all the calibration results and their related documents to the coordinator not later than one month after completion of the measurements. The following documents should be delivered:

- A full description of the calibration method, traceability chain, and calibration results, as defined in Paragraph 3.3,

4.1 Time schedule of the inter-comparison

Laboratory	Time schedule
VNIIOFI	September 2011
METAS	November 2011
The fibres will be sent back to VNIIOFI	December 2011
Data Analysis and preparation of the first draft of the inter-comparison report	February 2011
Preparation of the final report	March 2012

4.2 Transportation

Each laboratory is responsible to organise the transportation of the artefacts to the next laboratory, according to the time schedule as stated in sect. 4.1.

5 Annex 1. Shipping Addresses

Laboratory	Shipping Address
VNIIOFI	All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI, Russian Federation) Dr. V. Kravtsov Ozernaya str., 46 119361 Moscow Russia Phone : +7 495 781 45 86 Fax : +7 495 437 40 77 Email: kravtsov-F3@vniiofi.ru
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