

**Technical protocol  
EUROMET Project 666  
Inter-comparison of Chromatic Dispersion Reference Fibres**

**Final Version**

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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 four fibres representing three of the most commonly used categories, namely G652 (standard), G653 (dispersion shifted) and G655 (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
CSIC	Pedro Corredera	<a href="mailto:pcorredera@ifa.cetef.csic.es">pcorredera@ifa.cetef.csic.es</a>
HUT	Hanne Ludvigsen	<a href="mailto:Hanne.ludvigsen@hut.fi">Hanne.ludvigsen@hut.fi</a>
NPL	Martin Wicks	<a href="mailto:martin.wicks@npl.co.uk">martin.wicks@npl.co.uk</a>
NIST	Dennis Tasshi	<a href="mailto:tasshi@boulder.nist.gov">tasshi@boulder.nist.gov</a>
METAS (pilot laboratory)	Jacques Morel	<a href="mailto:Jacques.morel@metas.ch">Jacques.morel@metas.ch</a>

NIST has been invited to participate to this project in a common agreement between all the participants. METAS leads the inter-comparison and provides the necessary reference fibres.

## 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	$\lambda_0$	nm
Dispersion slope at $\lambda_0$	$S_0$	Ps/nm <sup>2</sup>

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 $\lambda_o$ )	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 $\lambda_o = 1550$ 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 disjointed spectral segments. This calibration should be performed, whenever possible, within both the 1310 nm and 1550 nm windows. The zero dispersion wavelength  $\lambda_o$  and the dispersion slope  $S_o$  around  $\lambda_o$  will only be reported when obtained from a measurement scan that includes the zero dispersion wavelength itself; i.e. that  $\lambda_o$  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,  $\lambda_1 = 1310$ nm,  $\lambda_2 = 1312$  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. The temperature of the reference fibre will be measured during the calibration with the calibrated sensor integrated in each artefact. (See Annex 3). All laboratories will perform their calibrations at the same temperature of 23 °C. 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 $\lambda$ (nm)	$U_{\lambda}$ (nm)	Chromatic Dispersion $D$ (ps/nm)	$U_D$ (ps/nm).
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The chromatic dispersion  $D$  at the wavelength  $\lambda$  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  $\lambda$ .

The zero dispersion wavelength  $\lambda_0$  (nm) and the dispersion slope  $S_0$  (ps/nm<sup>2</sup>) around  $\lambda_0$  will be reported with their uncertainties  $U_{\lambda_0}$  and  $U_{S_0}$ .

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

Wavelength $\lambda$ (nm) of measured point	$U_{\lambda}$ (nm)	Differential Group delay $t$ (ps)	$U_t$ (ps/nm).
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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  $D$ ,  $S_0$  and  $\lambda_0$  are given in table 4.

Quantity	Description
$u_{\tau}$	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 2 <sup>nd</sup> order PMD (usually negligible)
$u_{\lambda}$	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 fibres

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. A combined temperature and humidity sensor is mounted in the centre of the reel. Access to the sensor data is provided by a RS232 serial interface (see Annex 2). The approximate dimensions of the case are 30 cm x 29 cm x 18.5 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.

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

Artefact Nr.	Fibre type	Fibre length (m) ( $\lambda = 1550 \text{ nm}$ , $n = 1.46$ )	$U$ (m)	Connectors
1	G652	20179.5 m	1.2	FC-APC
2	G653	15714.4 m	0.4	FC-APC
3	G655 (TeraLight-like)	10090.2 m	0.3	FC-APC
4	G655 (Leaf)	10130.0 m	0.6	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 and will be documented by filing in the form accompanying each artefact (see Annex 3). 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 in the same document. 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. The cleaning procedure is explained in Annex 1.

### 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. The temperature / humidity sensor will be connected to a personal computer (PC) by means of a special serial interface cable (SIC). The logging of the measured temperature and humidity will be performed by using the "METAS Logger" software. A detailed description of this system is given in Annex 2.

## 4 Organisational aspects of the inter-comparison

Each participant will calibrate four reference fibres. These fibres will circulate between the different laboratories according to a circular scheme. METAS will first prepare and calibrate the four samples that will be delivered to the first participant. After completion of the calibration, the first participant will send the four reference fibres to the second laboratory, and so on. METAS will measure once again the four reference fibres at the end of the comparison to verify their stability.

Each laboratory 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,
- A fully documented description form of each reference fibre. This document is given in Annex 3.

#### 4.1 Time schedule of the inter-comparison

Laboratory	Time schedule
METAS	01.04.2003 – 30.04.2003
HUT	01.05.2003 – 31.05.2003
CSIC	01.06.2003 – 30.06.2003
NPL	01.07.2003 – 31.07.2003
The fibres will be sent back to METAS in order to prepare the shipping of the artefacts to NIST	
NIST	01.09.2003 – 30.09.2003
The fibres will be sent back to METAS	
Recalibration of the reference fibres by METAS	November 2003
Draft of the final EUROMET project report submitted to all participants for discussion	December 2003
Final report submitted to EUROMET	February 2004

#### 4.2 Transportation

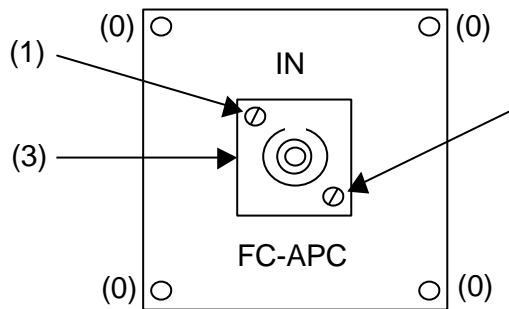
Each laboratory is responsible to organise the transportation of the artefacts to the next laboratory, according to the time schedule as stated in sect. 4.1. The four artefacts will be shipped in the provided transport case. Transport fees will be paid by each sender. Any transport damage is the responsibility of the sender. Possible costs related to transport damages will be charged to the sender. A door-to-door delivery service such as UPS will be used for the shipping. METAS provides the necessary A.T.A documents for Customs. **Please, don't forget to join this A.T.A document for the shipping to the next laboratory.** Each artefact will carry a warning label and a calibration seal stating that the artefacts shouldn't be opened. METAS will provide a full documentation of the artefacts to prevent as far as possible Customs difficulties. A detailed list of the shipping addresses is given in Annex 5.



## 5 Annex 1. Cleaning procedure for the FC-APC connectors

This procedure should only be performed when absolutely necessary and will always previously be discussed with the coordinator of the inter-comparison.

1. Remove screws (1) and (2)  
Do never remove the 4 outer screws (o)
- 2.

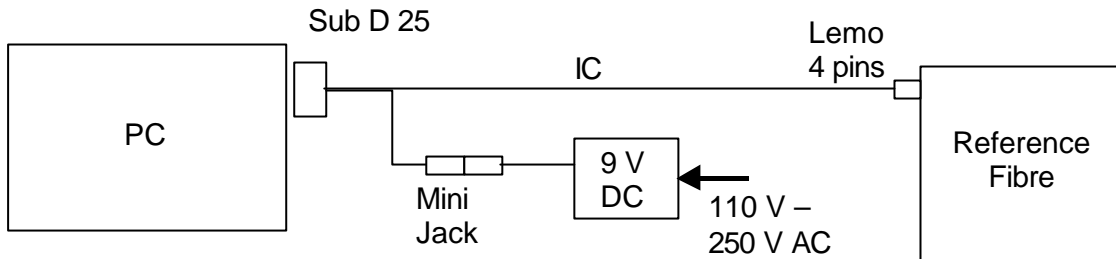


3. Gently pull the FC-APC socket (3) and the attached fibre pigtail out of the case
4. Unplug the inner FC-APC connector
5. Clean the connector ferrule with isopropyl alcohol
6. Remove any remaining alcohol trace with a soft tissue
7. Plug the FC-APC connector in the socket again
8. Gently push the assembly in the case: be careful to keep the fibre pigtail as straight as possible
9. Attach screws (1) and (2) again.

## 6 Annex 2. Interfacing the temperature / humidity probes

### 6.1 Connecting the probe to your PC

The Temperature and Humidity probe mounted in each reference fibre case is connected to one of the RS232 serial COM ports of your PC by using the interface cable (IC) as shown below.



The PC normally supplies power to the probe through the interface cable. An external 9 V DC adapter is provided for computers that doesn't provide enough voltage to the sensor. The DC supply is connected to the sensor by means of the "mini jack" plug as shown in the above figure. A Sub D25 – Sub D 9 adapter is provided for connecting the Serial adapter to a small size Sub D9 COM connector. The Interface is connected to the probe by means of a 4 pins Lemo connector.

#### Very important:

Be very careful when mating the 4 pins Lemo connectors. Align the 4 pins before plugging in the connectors. Do not rotate the connector against the chassis bulkhead in order to find the correct pin orientation. This may damage the connectors!

### 6.2 Installing the METAS Logger software

The "METAS logger" is a Run-time Labview application allowing the recording of the temperature and humidity inside the reference fibre case. The application is installed on your PC by double-clicking on the "setup" application that is located in the "METAS Logger folder" (see "METAS Logger" CD). The Labview Run-time kernel will be installed meantime with the application itself. An application shortcut will be installed in the start-programs menu.

### 6.3 Configuring and using the application

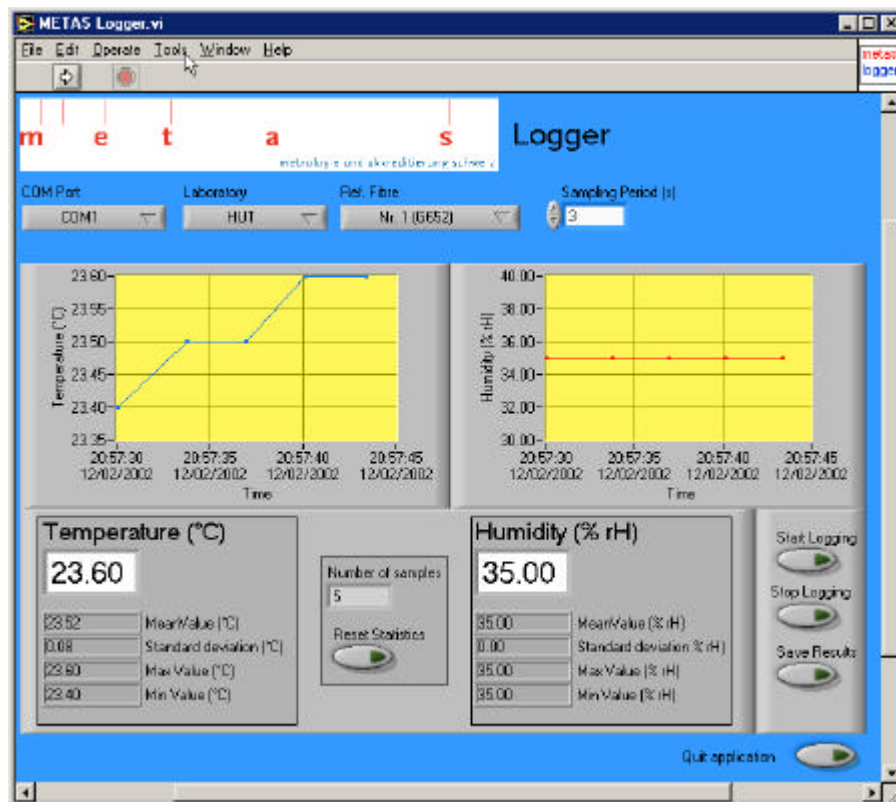
1. Start the application by clicking on the arrow that is located on the top left corner of the front panel.
2. Select the correct COM port, laboratory name and artefact number by popping up on the corresponding controls. The serial communication parameters (bitrate, parity, ...) are automatically configured by the "METAS Logger" application and do not require any extra manual configuration of your COM ports.
3. Set the sampling period to the desired value. The default value of 3 seconds should be used for the calibration
4. Start the data logging by clicking on the "start logging" button

5. Stop the data logging by clicking on the “stop logging” button. The data are then stored by clicking on the “save results” button. Please note that this button only appear after completion of the stopping process.
6. The data will be stored into an ASCII file at the end of each calibration. Please specify a filename including the name of the reference fibre.
7. The application displays the mean, max, min and standard deviation for the temperature and humidity. The statistics is calculated over the number of measured points that is also displayed on the front panel. The “reset” button allows to erase all the measured points and to start a new analysis.
8. The “Quit application” button allows stopping the application.

#### 6.4 Troubleshooting

If the application returns the message ““Probe Error or wrong COM port selected” after starting an acquisition, please verify the following points:

1. Make sure that the selected COM port is free (not reserved for any other application)
2. Verify that the 4 pin Lemo connector was properly inserted into the sensor (connector on the left hand side of the case)
3. Connect the extra 9V DC power supply to the sensor as explained in section 6.1.



## **7 Annex 3. Reference Fibre Check Form**

Form available on next page

### Reference Fibre Check Form

<b>Laboratory name</b>	
<b>Reception date (dd/mm/yy)</b>	
<b>Reference fibre Nr.</b>	

**Visual controls :**

<ul style="list-style-type: none"> <li>• <b>Case</b> Please, report any defect or degradation of the reference fibre case</li> </ul>	
<ul style="list-style-type: none"> <li>• <b>FC-APC connectors</b></li> <li>• <b>Please, do not dismount connectors for control</b> Please, report any defect or degradation of the optical connectors</li> </ul>	
<ul style="list-style-type: none"> <li>• <b>Input connector cleaned? (Yes/No)</b> <b>please, contact coordinator before cleaning</b></li> </ul>	
<ul style="list-style-type: none"> <li>• <b>Output connector cleaned? (Yes/No)</b> <b>please, contact coordinator before cleaning</b></li> </ul>	

**Optical controls:**

<b>Does light goes through the fibre?</b>	
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**Temperature / Humidity sensor**

<p><b>Is the sensor operational?</b> This test will be performed by connecting the sensor to the serial port of a personal computer and by testing the communication with the "METAS Logger" software</p>	
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**Other Remarks**

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## 8 Annex 4. Packing list

Quantity	Description
1	Transport case, size 60 cm x 40 cm x 44 cm (weight: 19 Kg), containing:
	<ul style="list-style-type: none"> <li>1 Case: Reference Optical Fibre Nr. 1 (G652)</li> <li>1 Case: Reference Optical Fibre Nr. 2 (G653)</li> <li>1 Case: G655 Reference Optical Fibre Nr. 3 (G655, TeraLight)</li> </ul>
	<ul style="list-style-type: none"> <li>1 Accessories box, including                             <ul style="list-style-type: none"> <li>1 RS232 Serial adapter (cable length: 2m) with 1 Lemo 4 pins connector</li> <li>1 9 V DC power supply (110V – 250 V AC)</li> <li>1 German Wall Plug adapter for the 9V DC power supply</li> <li>1 UK Wall Plug adapter for the 9V DC power supply</li> <li>1 US Wall Plug adapter for the 9V DC power supply</li> <li>1 CD “METAS Logger” software</li> <li>1 Sub D25 –Sub D 9 adapter</li> </ul> </li> <li>2 Lock keys for Reference Optical Fibre Cases</li> <li>1 Full documentation, including 16 Reference Fibre Check Forms</li> </ul>
1	Transport case, size 40 cm x 30 cm x 35 cm (weight: 6.5 Kg) containing:
	<ul style="list-style-type: none"> <li>1 Case: G655 Reference Optical Fibre Nr. 4 (G655, Leaf)</li> </ul>

## 9 Annex 5. Shipping Addresses

Laboratory	Shipping Address
HUT	<p>Helsinki University of Technology                      Metrology Research Institute                      Dr. Tech Hanne Ludvigsen                      Otakaari 5 A                      FIN-02150 Espoo                      Finland</p> <p>Phone : +358 9 451 22 82                      Fax : +358 9 541 22 22                      Email : <a href="mailto:hanne.ludvigsen@hut.fi">hanne.ludvigsen@hut.fi</a></p>
CSIC	<p>Centro De Tecnologias Fisicas Leonardo Torres Quevedo                      Instituto de Fisica Aplicada                      Dr. Pedro Correderas                      Calle Serrano, 144                      28006 Madrid                      Espana</p> <p>Phone : (91) 561 88 06                      Fax : (91) 411 76 51                      Email : <a href="mailto:pcorredera@ifa.cetef.csic.es">pcorredera@ifa.cetef.csic.es</a></p>
NPL	<p>National Physical Laboratory                      Centre for Electromagnetic and Time Metrology                      Dr. M. Wicks                      Building 95                      Queens Road,                      Teddington, Middlesex, TW11 0LW                      United Kingdom</p> <p>Phone : +44 20 894 36 6787                      Fax : +44 20 894 36 6098                      Email : <a href="mailto:martin.wicks@npl.co.uk">martin.wicks@npl.co.uk</a></p>
METAS	<p>Swiss Federal Office of Metrology and Accreditation (METAS)                      Dr. J. Morel                      Lindenweg 50                      3003 Bern-Wabern                      Switzerland</p> <p>Phone : +41 31 32 33 350                      Fax : +41 31 32 33 210                      Email : <a href="mailto:jacques.morel@metas.ch">jacques.morel@metas.ch</a></p>
NIST	<p>National Institute of Standards and Technology                      T. Dennis, Ph.D.                      Optical Fiber and Components Group                      Optoelectronics Division                      325 Broadway, 815.03                      Boulder, Colorado 80305                      USA</p> <p>Phone : +001 (303)497-3507                      Fax : +001 (303)497-7621                      Email : <a href="mailto:tasshi@boulder.nist.gov">tasshi@boulder.nist.gov</a></p>