B.1.2.2 Wavelength selection

A wavelength selector is used to select the wavelength at which the group delay is to be measured. Optical switch, monochromator, dispersive devices, optical filters, optical coupler, connectors etc. may be used, depending on the type of light sources and measurement set-up. The selection may be carried out by switching electrical driving signals for different wavelength light sources. The wavelength selector may be used either at the input or at the output end of the fibre under test.

B.1.2.3 Detector

The light emerging from the fibre under test, the reference fibre or the optical divider etc., is coupled to a photo detector whose signal-to-noise ratio and time resolution are adequate for the measurement. The detector is followed by a flow noise amplifier if needed.

B.1.2.4 Reference channel

The reference channel may consist of electrical signal line or optical signal line. A suitable time delay generator may be interposed in this channel. In certain cases, the fibre under test itself can be used as the reference channel line.

B.1.2.5 Delay detector

The delay detector shall measure the delay time or the phase shift between the reference signal and the channel signal. In the case of sinusoidal modulation, a vector voltmeter could be used. In the case of pulse modulation, a high speed oscilloscope or a sampling oscilloscope could be used.

B.1.2.6 Signal processor

A signal processor can be added in order to reduce the noise and/or the jitter in the measured waveform. If needed, a digital computer can be used for purposes of equipment control, data acquisition and numerical evaluation of the data.

B.1.3 Procedure

The fibre under test is suitably coupled to the source and to the detector through the wavelength selector or the optical divider etc. If needed, a calibration of the chromatic delay of the source may be performed. A suitable compromise between wavelength resolution and signal level must be achieved. Unless the fibre under test is also used as the reference channel line, the temperature of the fibre must be sufficiently stable during the measurement.

The time delay or phase shift between the reference signal and the channel signal at the operating wavelength are to be measured by the delay detector. Data processing appropriate to the type of modulation is used in order to obtain the chromatic dispersion coefficient at the operating wavelength. When needed, a spectral scan of the group delay versus wavelength can be performed; from the measured values a fitting curve can be completed.

The measured group delay per unit fibre length versus wavelength shall be fitted by the three-term Sellmeier expression:

$$\tau(\lambda) = \tau_o + \frac{S_o}{8}\left(\lambda - \frac{\lambda_o^2}{\lambda}\right)^2$$

Here τ_o is the relative delay minimum at the zero-dispersion wavelength λ_o. The chromatic dispersion coefficient $D(\lambda) = d\tau/d\lambda$ can be determined from the differentiated Sellmeier expression:

$$D(\lambda) = \frac{S_o}{4}\left[\lambda - \frac{\lambda_o^4}{\lambda^3}\right]$$

Here S_o is the zero-dispersion slope i.e., the value of the dispersion-slope $S(\lambda) = \frac{dD}{d\lambda}$ at λ_o.

Note 1 - These equations for $\tau(\lambda)$ and $D(\lambda)$ are sufficiently accurate over the 1270-1340 nm range, but are less accurate in the 1550 nm region. Because the dispersion in the latter region is large, the reduced accuracy may be acceptable; if not, it can be improved by including data from the 1550 nm region when performing the fit. However, it should be noted that this may reduce the accuracy in the 1300 nm region.

Note 2 - Alternatively the chromatic dispersion coefficient can be measured directly, for example by a differential phase shift method. In this case, the differentiated Sellmeier equation shall be fitted directly to the dispersion coefficient for determining λ_o and S_o.

B.1.4 Presentation of results

The following details shall be presented:

a) Test set-up arrangement

b) Type of modulation used

c) Source characteristics

d) Fibre identification and length

e) Characteristics of the wavelength selector (if present)

f) Type of photodetector

g) Characteristics of the delay detector.

h) Values of the zero-dispersion wavelength and the zero- dispersion slope

If the frequency domain technique is used, the time group delay t will be deduced from the corresponding phase shift ϕ through the relation $t = \phi/(2\pi f)$, f being the modulation frequency

i) Fitting procedures of relative delay data with the used fitting wavelength range

j) Temperature of the sample and environment conditions (if necessary)

FIGURE B-11/G.652

Typical arrangement of the test apparatus

B.2 Alternative test method for chromatic dispersion coefficient measurement: the interferometric test method

B.2.1 Objective

The interferometric test method allows the chromatic dispersion to be measured, using a short piece of fibre (several metres). This offers the possibility of measuring the longitudinal chromatic dispersion homogeneity of optical fibres. Moreover, it is possible to test the effect of overall or local influences, such as temperature changes and macrobending losses, on the chromatic dispersion.

According to the interferometric measuring principle, the wavelength- dependent time delay between the test sample and the reference path is measured by a Mach-Zehnder interferometer. The reference path can be an air path or a single-mode fibre with known spectral group delay.

It should be noted that extrapolation of the chromatic dispersion values derived from the interferometric test on fibres of a few metres length, to long fibre sections assumes longitudinal homogeneity of the fibre. This assumption may not be applicable in every case.

B.2.2 Test apparatus

Schematic diagrams of the test apparatus using a reference fibre and an air path reference are shown in Figures B-12/G.652 and B-13/G.652 respectively.

B.2.2.1 Optical source

The source should be stable in position, intensity and wavelength for a time period sufficiently long to complete the measurement procedure. The source must be suitable, e.g. a YAG laser with a Raman fibre or a lamp and LED optical sources etc. For the application of lock-in amplification techniques, a light source with low-frequency modulation (50 to 500 Hz) is sufficient.

B.2.2.2 Wavelength selector

A wavelength selector is used to select the wavelength at which the group delay is measured. A monochromator, optical interference filter, or other wavelength selector may be used depending on the type of optical sources and measurement systems. The wavelength selector may be used either at the input or the output end of the fibre under test.

The spectral width of the optical sources is to be restricted by the dispersion measuring accuracy, and it is about 2 to 10 nm.

B.2.2.3 Optical detector

The optical detector must have a sufficient sensitivity in that wavelength range in which the chromatic dispersion has to be determined. If necessary, the received signal could be upgraded, with for example a transimpedance circuit.

B.2.2.4 Test equipment

For the recording of the interference patterns, a lock-in amplifier may be used. Balancing of the optical length of the two paths of the interferometer is performed with one linear positioning device in the reference path. Concerning the positioning device, attention should be paid to the accuracy, uniformity and stability of linear motion. The variation of the length should cover the range from 20 to 100 mm with an accuracy of about 2 µm.

B.2.2.5 Specimen

The specimen for the test can be uncabled and cabled single-mode fibres. The length of the specimen should be in the range 1 m to 10 m. The accuracy of the length should be about ± 1 mm. The preparation of the fibre endfaces should be carried out with reasonable care.

B.2.2.6 Data processing

For the analysis of the interference patterns, a computer with suitable software should be used.

B.2.3 <u>Test procedure</u>

1) The fibre under test is placed in the measurement set-up (Figure B-12, B-13/G.652). The positioning of the endfaces is carried out with 3-dimensional micro-positioning devices by optimizing the optical power received by the detector. Errors arising from cladding modes are not possible.

2) The determination of the group delay is performed by balancing the optical lengths of the two interferometer paths with one linear positioning device in the reference path for different wavelengths. The difference between position x_i of the maximum of the interference pattern for wavelength λ_i and position x_o (Figure B-14/G.652) determines the group delay difference $\Delta t_g(\lambda_i)$ between the reference path and the test path as follows:

$$\Delta t_g(\lambda_i) = \frac{x_o - x_i}{c_o}$$

where c_o is the velocity of light in the vacuum. The group delay of the test sample is calculated by adding the value $\Delta t_g(\lambda_i)$ and the spectral group delay of the reference path. Dividing this sum by the test fibre length then gives the measured group delay per unit length $\tau(\lambda)$ of the test fibre.

From the individual group delay values of the fibre under test an interpolation curve can be derived. The measured group delay per unit fibre length versus wavelength shall be fitted by the three-term Sellmeier expression:

$$\tau(\lambda) = \tau_o + \frac{S_o}{8}\left(\lambda - \frac{\lambda_o^2}{\lambda}\right)^2$$

Here τ_o is the relative delay minimum at the zero-dispersion wavelength λ_o. The chromatic dispersion coefficient $D(\lambda) = d\tau/d\lambda$ can be determined from the differentiated Sellmeier expression:

$$D(\lambda) = \frac{S_o}{\ }\left(\lambda - \frac{\lambda_o^4}{\ }\right)$$

4 ╗ ╪^{3} ┘

Here S_o is the zero-dispersion slope, i.e., the value of the dispersion-slope

S(╪) = dD

— at ╪$_o$. d╪

Note - These equations for τ(╪) and D(╪) are sufficiently accurate over the 1270-1340 nm range, but are less accurate in the 1550 nm region. Because the dispersion in the latter region is large, the reduced accuracy may be acceptable, if not, it can be improved by including data from the 1550 nm region when performing the fit. However, it should be noted that this may reduce the accuracy in the 1300 nm region.

B.2.4 Presentation of results

The following details shall be presented:

a) Test set-up arrangement

b) Source characteristics

c) Fibre identification and length

d) Characteristics of the wavelength selector (if present)

e) Type of the photodetector

f) Values of the zero-dispersion wavelength and the zero-dispersion slope

g) Fitting procedures of relative delay data with the used fitting wavelength range

h) Temperature of the sample and environmental conditions (if necessary).