Standards and traceability for measurements of chromatic and polarization mode dispersion in optical fiber

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The results of chromatic dispersion (CD) and polarization mode dispersion (PMD) state standards development are presented. The results of metrology research of said standards and traceability chain project are described. The results of CD preliminary international comparison are shown.

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1. Introduction

Nowadays VNIIOFI has State Standard of the main metrology parameters (average power, distance, attenuation and wavelength) of optical fiber transmission systems (OFTS) [1]. Dynamic development of OFTS with CWDM and DWDM technologies necessitates verifying dispersion characteristics of transmission medium. The chromatic dispersion (CD) and the polarization-mode dispersion (PMD) effects become one of the main limiting factors in modern high-speed OFTS. These forms of dispersion degrade the modulation-phase relationships in lightwave signals reducing information-carrying capacity through the pulse broadening. Chromatic dispersion results from a variation in propagation delay with wavelength. Polarization mode dispersion caused by splitting of a polarized signal into two orthogonal polarization modes with different speeds of propagation. PMD becomes a limiting factor in single mode fiber when CD is sufficiently reduced. Designers of OFTS must estimate CD and PMD of fiber, components and installed transmission paths. Information about dispersion characteristics of old fiber links makes it possible to upgrade these systems with higher speeds. To resolve the CD and PMD measurement task in OFTS, a number of types of measuring instruments are currently used in Russia. Generally, CD and PMD analyzers of such companies as EXFO, Anritsu and JDSU are used within the country. This task, in turn, requires development of reference measurement methods and instruments enabling verification, calibration and testing of the measuring instruments of such types. In effort to meet this goal VNIIOFI developed reference apparatuses allowing ensuring the uniformity of CD and PMD measurements. The apparatuses developed were approved as the state primary standard of CD and PMD units in optical fiber. In the course of creating reference CD and PMD measuring instruments, working standards of CD and PMD units were created. The calibration chain regulating traceability of CD and PMD units was built.

2. Chromatic dispersion state reference standard. Methods and design

The primary standard of CD unit in optical fiber includes the reference CD measurement setup designed to establish the phase difference between optical signals with different wavelengths passed through the CD medium, and a set of CD standard reference artifacts. The reference Phase-shift method (MPS) with reference optical signal is used [2,3]. Detailed analysis of reference methods defined such advantages of the MPS, as: high wavelength resolution of phase difference measurements due to reference optical signal with fixed wavelength scheme implementation; high accuracy and repeatability of phase differences measurements; simple design of the measurement setup. The design of CD measurement setup contains clock generator, electro-optical modulator, tunable laser source, reference optical sources block, precision phase meter, optical-electronic converter, dual heterodyne conversion transducer, reference laser radiation wavelength meter, CD reference artifact and PC. Light from the tunable laser with wavelength λ_1 (test signal) and reference optical source with wavelength λ_0 (reference signal) comes to the electro-optical modulator. Modulation frequency f=150 MHz is used. After that modulated test signal goes through the CD reference material and incidents into the optical-electronic converter. Modulated reference signal comes to the converter immediately. Precision phase meter measures phase difference between test and reference signals. Temperature-controlled reels with different types (G.652, G.653, G.655) of single-mode fiber are used as CD reference artifact. Table 1 contains uncertainties of the CD measurement reference setup including artifact uncertainties at the range -400 ÷ +400 ps/nm (wavelength range 1260 ÷ 1650 nm).

Table 1. CD measurement uncertainties

Uncertainty type	Uncertainty value, [ps/nm]
Standard uncertainty u_A	0,1
Standard uncertainty u_B	0,31
Combined standard uncertainty u_C	0,33
Expanded uncertainty $U=2u_C$	0,66

Two CD artifacts were chosen for the preliminary bilateral comparison between VNIIOFI and METAS (The Federal Office of Metrology, Switzerland). METAS is a pilot of the EUROMET intercomparison project 666 (Inter-comparison of Chromatic Dispersion Reference Fibres). Spools with single-mode fiber G.652 and G.653 were used. The result of the measurements (table 2) shows good agreement of received uncertainties values.

Table 2. Measurement results for CD artifact with G.652 fiber

λ, nm	D, ps/nm	Deviation, ΔD, ps/nm	Comparison uncertainty $U_{\Delta D}$, ps/nm (k=2)
1510÷1516	183.353÷187.925	0.901÷0.750	0.786÷0.720
1518÷1570	189.449÷228.676	0.709÷0.694	0.711÷0.700
1572÷1640	230.161÷278.899	0.718÷1.225	0.700÷0.806

3. Polarization mode dispersion state reference standard. Methods and design

The primary standard of PMD unit in optical fiber includes the reference PMD measuring tools designed to establish the interval of time between two orthogonally polarized modes of radiation that passed through the medium possessing PMD, and a complete set of PMD reference artifact. The reference PMD measuring tools are embodied based on the interferometry and Stokes evaluation methods [4, 5] and additionally equipped with a supporting measurement channel with a stabilized wavelength single-frequency source of radiation. Wide PMD range measurements with appropriate uncertainties of large PMD values (1÷100 ps) and high measurement speed are the advantages of the interferometry method. Stocks evaluation method allows precise measurements of small PMD (0,05÷1 ps) and provides an information about second order PMD. PMD measurement reference setup based on inerferometry method (TINTY) contains polarized optical source, polarizer and fiber-optical Michelson interferometer with photo-detector. Mirror movement is controlled by the fringe of the reference laser radiation. Wavelength of the reference laser is calibrated by the reference wavelength meter. PMD measurement reference set up based on Stocks parameter evaluation method (JME) contains tunable laser source, polarization controller and polarimeter. Single-mode-fiber-pigtailed quartz plates and sets of quartz plates have been assembled as standard reference materials for mode coupled PMD (applied for frequency domain PMD measurement instruments) and non mode coupled PMD. The spool of single-mode fiber is used as a comparator for mode coupled PMD applied for all types of PMD analyzers. Table 3 contains uncertainties of described PMD measurement reference setups. At the present time a preliminary intercomparison of some PMD artifacts is in the process.

Table 3. PMD measurement uncertainties

Uncertainty type	Uncertainty value, [ps]	
	Stocks parameter evaluation method (0,05÷0,5 range)	Interferometry method (0,5÷120 range)
Standard uncertainty u_A	0,002	$0{,}005\times\Delta\tau$
Standard uncertainty u_B	0.003	0,004
Combined standard uncertainty u_C	0,0036	0,005 for $\Delta\tau = 0{,}5$
Expanded uncertainty $U=2u_C$	0,0072	0,01 for $\Delta\tau = 0{,}5$

$\Delta\tau$ – PMD measurement value, [ps]

As a result state verification chains based on state standards of PMD and CD were built. The chains are trimetric (state standard – industrial standards – working measuring tools) for simple application.

4. Conclusions

The results of primary CD and PMD standards development have allowed creating a calibration chain regulating traceability of listed units as state paper standard. Received uncertainties values of standards are comparable with ones of such metrological centers as NPL and METAS. The preliminary international comparisons of CD unit were made between VNIIOFI and METAS to approve measurement uncertainties. Based on CD and PMD reference artifacts investigation working standards of CD and PMD units were created.

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