

## MEASUREMENTS UNITY PROVIDING FOR FIBRE-OPTICAL TRANSMISSION SYSTEMS

*V.Ye. Kravtsov<sup>1</sup>, V.N. Krutikov<sup>1</sup>, S.V. Tikhomirov<sup>1</sup>*

<sup>1</sup>All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI),  
 Moscow, Russia, [kravtsov-f3@vniiofi.ru](mailto:kravtsov-f3@vniiofi.ru)

**Abstract** —The results of design of state primary and working standards for fibre-optical systems parameters - average power, attenuation, fibre length, wavelength, chromatic and polarization mode dispersion, and also calibration chains for units transferring are described. Principles, contents and parameters of approved standards and calibration chains for units transferring traceability are considered.

**Keywords:** Calibration chain, fibre-optic transmission systems, standard, measurement unity

### 1. INTRODUCTION

Development of fibre-optic systems for information transmission (FOTS) especially with CWDM and DWDM technologies necessitates verifying and calibration of testing equipment applied.

The area under discussion falls under state oversight, according to Russian Federation laws. This necessitates the providing of certification, including tests for the purposes of type conformance for the instruments, both domestic and imported, entering them in the State Registry of Measurement Instruments of the Russian Federation, and subsequent realization of initial and periodic verification and calibration [1].

To solve the issues of measurements unity in this field the state standards, working standards, traceability chains and reference calibration and measurement methods should be developed.

In this report the results of design of standards and regulatory documentation developed for today by VNIIOFI-leading research centre and Russian National Metrological Institute in the field of optical measurements are described.

### 2. STATE PRIMARY SPECIAL STANDARDS

For the mentioned purpose the following reference standards have been developed:

**2.1. State primary special standard of units of average power and attenuation of optical radiation in FOTS, signal propagation time, optical fibre length and the wavelength for FOTS.**

The instruments included in the standard are based on the following principles:

-for optical radiation average power and attenuation units- on using calorimeter with electrical/optical substitution and precise measurement of special power meter linearity;

-for fiber length and signal propagation time units - on using precise measurements of signal delay time with electrical/optical conversion;

-for wavelength unit –on using a set of Fiso interferometers and He-Ne laser wavelength as initial wavelength.

The set of instruments for average power unit reproduction and transferring is shown in figure 1.



Fig 1 Instruments for average power unit reproduction

Basic parameters of the standard are presented in table 1.

Table 1 Basic primary Standard parameters

Reproduced unit	Average power of optical radiation, W	Optical radiation attenuation dB	Optical signal propagation time, sec	Wavelength, nm
Ranges of values	$1 \cdot 10^{-4} \div 5 \cdot 10^{-3}$	0,05÷90	$1 \cdot 10^{-7} \div 6 \cdot 10^{-3}$	600÷1700
Working wavelengths nm	600÷1700 fixed values	850 ÷ 1700 fixed values	850 ÷ 1700 fixed values	600÷1700
Expanded Uncertainty (k=2)	$0.067 \cdot 10^{-2}$ relative	$1,1 \cdot 10^{-2} \div 2,1 \cdot 10^{-1}$	$(0.80 \div 4.8) \cdot 10^{-9}$	$1,44 \cdot 10^{-7}$ relative

A specific feature of the standard is that of creating a complete system for metrological support of measurements not for individual physical quantity, but for the entire domain of application of FOTS and the use of the corresponding multiparameter passive and active components [1].

**2.2. State primary special standards of units of polarization-mode (PMD) and chromatic dispersion (CD) in optical fibre**

The primary standard for polarization mode dispersion unit in optical fiber includes the primary PMD measuring tools designed to establish the time interval between two orthogonally polarized modes of radiation that passed through the medium possessing PMD, and a complete set of PMD artifact. The primary PMD measuring tools are based on the interferometer and Stokes evaluation methods [2] and are 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÷120) ps and high measurement speed are the advantages of the interferometer (TINTY) method. The Stocks evaluation method allows precise measurements of small PMD values (0, 05÷1) ps and provides information about the second order PMD. Single-mode-fiber-pigtailed quartz plates and sets of quartz plates have been assembled as standard reference materials for the mode coupled PMD 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 calibration.

The set of instruments for PMD unit reproduction and transferring is shown in figure 2.



Fig. 2 Instruments for PMD unit reproduction

The parameters of the standard are presented in table 2.

Table 2 Basic PMD primary Standard parameters

Range of values, ps	Working wavelengths, nm	Expanded uncertainty (k=2), ps
0,05÷120	1310, 1550	0,005÷0,3

The CD standard is based on the reference phase-shift method. The parameters of the standard are presented in table 3. The primary standard for chromatic dispersion (CD) unit includes the primary 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 modified phase-shift method with optical signal is used. Temperature-controlled reels with different types (G.652, G.653, G.655) of single-mode fiber are used as a CD reference artifact. The parameters of the standard are presented in table 3.

Table 3 Basic CD primary Standard parameters

Range of values, ps/nm	Working wavelengths, nm	Expanded uncertainty (k=2), ps/nm
-400 ÷ +400	1260 ÷ 1650	0,66

The set of instruments for CD unit reproduction and transferring is shown in figure 3.



Fig. 3 Instruments for CD unit reproduction

The described primary standards are the tops of corresponding calibration chains that have been developed to provide instruments calibration and verification. Each

calibration chain for mentioned units consists of three steps: primary standard - working standard – working instrument.

### WORKING STANDARDS

Calibration processes are carried out by means of following working standards with parameters preliminary defined by primary standards:

- Working standard of average optical radiation power and attenuation units for FOTS for calibration of power meters, attenuators, optical testers, etc. This standard is based on photoelectric and calorimetric detectors and includes the apparatus to measure photodetectors spectral responsivity.

The working standard view is shown in figure 4.



Fig. 4 Working standard for power meters calibration

- Working standard of distributed attenuation, length and transmission time units for calibration of optical reflectometers-OTDRs. This standard is based on active method of OTDR length and attenuation scales calibration. It includes special optoelectronic generator which direct several optical pulses with known time delay and amplitude differences to the OTDR input. It allows estimating both OTDR scales.

The working standard view is shown in figure 5.



Fig. 5 Working standard for OTDR calibration

- Working standard of wavelengths unit for FOTS of for calibration of optical spectrum analyzers (OSA) is based on the set of gas cells with several absorption lines.

The working standard view is shown in figure 5.



Fig. 5 Working standard for OSA calibration

- Working standard of chromatic dispersion unit for calibration of CD analyzers is based on the set of thermostabilized optical fibers.

- Working standard of PMD unit for calibration of PMD analyzers is based on the set of optical fibers and optical crystals samples.

- Working standard of unit of optical return loss in optical fibre (for calibration of ORL measuring instruments) is based on photometer and special fibreoptical designs with known reflectance.

The samples of working standards described have been manufactured at VNIIOFI and are applying now in different metrological centers in Russia.

The results of design of verification chains and working standards for described units provide traceability for basic parameters of FOTs in Russia.

The bilateral and supplementary comparisons on units of average optical radiation power (APMP and COOMET projects) [4] and chromatic dispersion of optical fibre (EURAMET project) [5] gave good results and confirms the standards characteristics.

### 3. CONCLUSIONS

The results of standards and documentation design allow providing metrological support of most important parameters in this field.

Nowadays the research on metrological support of digital fibre-optical systems parameters is in process.

### ACKNOWLEDGEMENTS

We would like to express sincere gratitude to colleagues of the VNIIOFI fiber optics systems metrology Lab for their work on the standards, to Dr. I. Vaishenker, NIST, to Dr. J. Morel, METAS, to Dr. S.K. Kim, KRISS, to Dr. S. Kück,

PTB, and to Dr. A. Galygo, Belgim, for their support of intercomparison works.

## REFERENCES

- [1] Glasov A., e. a. Reference apparatuses for metrological support of measurements of the parameters of optical fiber transmission systems // Proc. IZMTII. 2009. V. 3. P. 98 – 102.
- [2] V.V. Grigoriev, V.Ye. Kravtsov, A.K. Mityurev, A.B. Pnev, S.V. Tikhomirov «Reference apparatuses for metrological support of instruments measuring polarization mode dispersion in optic fibre», *Proceedings of ISMTII-2009*, Vol. 3, pp. 295-297, 2009.
- [3] S.V. Tikhomirov, A.I. Glasov., M.L.Kozatchenko, V.E Kravtsov., A.B Svetlichny, I. Vayshenker., T.R Scott., D.I Franzen., *Metrologia*, 37, pp. 347-348, 2000.
- [4] A. Svetlichny, V. Kravtsov, S.Kück, H. Hofer and A. Galygo, Final Report on COOMET Supplementary Comparison on Fiber Optic Power Responsivity COOMET.PR-S6.2012, 2014 *Metrologia* **51** 02003.
- [5] Morel J., V Kravtsov and V Grigoriev: Final report on EURAMET.PR S3: Bilateral intercomparison of measurements of chromatic dispersion reference fibres between METAS and VNIIOFI, *Metrologia* 50, 2013, Tech. Suppl. 02001