

Establishment of Fiber Optic Measurement Standards at KRISS

Seung Kwan Kim, Dong Hoon Lee, Duck Hee Lee, Han Seb Moon, and Seung Nam Park

Div. of Optical Metrology, KRISS, Daejeon 305-340, Republic of Korea

Jung-Chul Seo

Dept. of Nano-Optics, Korea Polytechnic University, Siheung-Si, Gyeonggi-Do 429-793, Republic of Korea

Abstract. We present our research activities on fiber optics metrology to establish fiber optic measurement standards at KRISS. Beginning from the fiber optic power responsivity for calibration of fiber optic power meters, we have developed optical fiber length, attenuation, and return loss standard as calibration references for optical time domain reflectometers. Chromatic and polarization mode dispersion measurements are discussed and finally optical fiber nonlinearity measurements are presented with newly obtained results.

I. Introduction

Research activities in photometry and radiometry are expanding toward new applications to meet the demanding requirement of the fast growing industries in fiber optics and optoelectronics. Many equipments, systems, modules, and components used in fiber optic communications and sensors are absolutely in need of calibration and test, but the realization of the measurement standards and their transfer into industry are relatively lower compared to other optics industries, such as lighting and display.

We began to establish fiber optics measurement standards at KRISS recently, mainly focused on the calibration of fiber optic power meter (FOPM) and optical time domain reflectometer (OTDR).

In this paper, we introduce our current research activities in fiber optics metrology to draw attention for the international collaborations to make better standards.

II. Fiber Optic Power Responsivity

Fiber optic power responsivity measurement at KRISS is based on the inter-comparison between the FOPM and the electrically calibrated pyroelectric radiometer (ECPR), that is traceable to the cryogenic radiometer. Our ECPR is calibrated at 633 nm using a highly stabilized He-Ne laser beam by directly comparing it to the silicon trap detector calibrated by the KRISS cryogenic radiometer. We evaluated the uncertainty of ECPR near infrared region to be 0.6 % ($k=2$) including the responsivity uncertainty at 633 nm and the wavelength dependence of ECPR. When we calibrate a commercial FOPM by comparing it to the ECPR, we use distributed feedback laser diodes whose wavelengths are 1310 nm and 1550 nm, respectively, collimating them in between the two fiber optic collimators so as to push in and pull out the beam chopper of the ECPR using linear translation stage. All the fiber optic connectors except for the final end to the FOPM input are FC/APCs to eliminate the unwanted Fresnel reflection. The final end is FC/PC to minimize polarization dependence.

To further increase the output power stability we use fiber optic isolators in between the components having possible backscattering. The resultant output power stability is 1.0×10^{-5} . We include the uncertainty due to input polarization dependence by finding maximum and minimum value while randomizing the state of polarization using a motorized polarization controller. The overall uncertainty of the FOPM used as our working standard including connector dependence are about 0.8 % ($k=2$) for both wavelengths (Table 1) at the power level of 0.1 mW.

Table 1. Relative uncertainty of KRISS working standard for FOPM calibration.

Uncertainty Source	u (%)	Type
ECPR	0.3	B
Source Stability	0.001	A
Repeatability	0.058	A
Polarization Dependence	0.2	B
Fiber Optic Connector	0.08	B
Combined uncertainty (%)	0.4	
Expanded uncertainty (%), $k=2$	0.8	

III. Fiber Length, Attenuation, and Return Loss

Optical fiber length, attenuation, and return loss are major parameters to be measured with OTDR. In order to calibrate optical length of OTDR, we constructed a time-of-flight measurement setup (Figure 1). We use a fiber pigtailed tunable laser diode covering both 1310 nm and 1550 nm region and make it operate in pulsed mode by current modulation. The laser is divided into two ports: one is directly led into a high speed photo-detector (PD) and the other is coupled to a fiber under test (FUT) and then led to another high speed PD. If we find the modulation frequency for the two pulses to arrive at the two PDs at the same time, we can determine the delay time of the FUT by directly counting the frequency. The frequency counter is traceable to KRISS cesium atomic clock. We certificate a fiber length reference with an uncertainty of less than 0.3 m ($k=2$) out of 13 km delay for the temperature of 23 ± 2 °C. Using this reference, we observed the optical length measured with a commercial OTDR has an offset of more than 2 m.

Optical fiber attenuation is measured directly using cut-back method [1]. Spectral attenuation can be correctly measured with the FOPM having nonlinearity less than 0.01 %. The nonlinearity of the FOPM is calibrated using the flux addition method. The uncertainty of 0.03 dB ($k=2$) has been evaluated including the repeatability of the bare fiber adaptor as well as the polarization dependence. This method can be used as a reference to calibrate not only

OTDR but also a commercial spectral attenuation measuring equipment and a simple loss meter.

Return loss of the optical fiber is measured with a fiber optic coupler having a splitting ratio of 50:50 [2]. We used the same FOPM as in the attenuation measurement. Owing to the polarization dependence of the splitting ratio and the fiber connection repeatability, the uncertainty is as much as 0.6 dB for up to 30 dB return loss. The higher return loss results in the larger uncertainty because of the bad repeatability. The uncertainty goes up to 1.2 dB for 60 dB return loss.

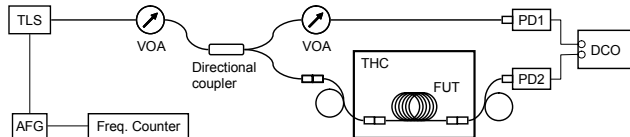


Figure 1. Schematic of time-of-flight measurement setup for optical fiber length standard. AFG, arbitrary function generator; DCO, dual channel oscilloscope; FUT, fiber under test; PD, photo-detector; THC, temperature humidity chamber; TLS, tunable laser source; VOA, variable optical attenuator.

IV. Dispersion Measurements

Chromatic dispersion (CD) and polarization mode dispersion (PMD) are essential in optical fiber specification especially for high speed and wavelength-division-multiplexing optical link.

We apply Stokes parameter evaluation technique with Jones matrix eigen-analysis as a reference method to measure PMD. Proper choice of wavelength spacing enables a repeatable measurement of PMD with an uncertainty of 3.0×10^{-4} for 1.54 ps non-polarization-mode coupled PMD. The residual PMD of our measurement setup itself was measured to be about 1 fs. In order to evaluate overall uncertainty, the uncertainty of the used fiber optic polarimeter has to be determined. With a linear polarizer having high extinction ratio (> 50 dB) and an accurate quarter-wave plate, we are going to calibrate our fiber optic polarimeter.

Regarding the CD measurement, we apply the modulation phase shift method to accurately determine zero dispersion wavelength, dispersion slope, and dispersion value as a function of wavelength. We are constructing the measurement setup at the moment and will soon be evaluating the uncertainty.

V. Fiber Nonlinearity

Nonlinear refractive index (NRI), stimulated Brillouin scattering (SBS) threshold, Brillouin and Raman gain coefficient are major parameters to be measured to characterize nonlinear effects in optical fiber.

We apply a continuous-wave dual frequency method based on self phase modulation to measure nonlinear coefficient, that is NRI divided by effective area. The major uncertainty reasons are the level accuracy of optical spectrum analyzer, CD induced error dependent on the

separation of the two wavelengths, the uncertainty of FOPM to measure incident optical power, and that of OTDR to measure effective length of optical fiber under test. These uncertainty sources result in overall uncertainty of about 5 %.

Recently we modified the measurement setup to investigate the source coherence effect that possibly affect the accuracy of the nonlinear coefficient measurement [3]. As a result, we determined that the incoherence between the two optical frequencies measure 3 % less value than the coherent dual frequencies (Figure 2).

Regarding the SBS threshold measurement, we constructed an Er-doped fiber ring laser having a stable single longitudinal mode and a narrow linewidth of less than 4.3 kHz that is tunable in 1530~1570 nm region. Except for the polarization dependence of the fiber optic coupler, we can measure SBS threshold with high accuracy using this source excluding the linewidth problem of the light source.

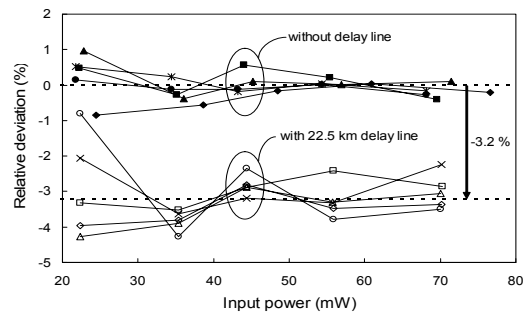


Figure 2. Relative difference of optical fiber nonlinear coefficient measured with incoherent (blank data) dual optical frequencies from that of coherent (filled data) dual optical frequencies.

VI. Conclusions

We have introduced our research activities on fiber optic metrology at KRISS. Establishment of traceability to primary standards and uncertainty evaluations enable us to provide reliable measurement and calibration services of fiber optic power meter and optical time domain reflectometer for fiber optics and optoelectronics industry. With these standards, we developed reference materials for fiber length, attenuation, and return loss as the transfer standards. We are expanding our calibration and measurement capability to chromatic and polarization mode dispersion, fiber nonlinearity, polarization dependent loss, and so forth.

References

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- [3] Kim, S. K., Moon, H. S., Seo, J. C., Coherence effect of the measurement of optical fiber nonlinear coefficient, *Opt. Lett.*, 30, 1120-1122, 2005.