Bilateral Comparison on Polarization Mode Dispersion between KRISS and NIST

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We made an international bilateral comparison on polarization mode dispersion between KRISS and NIST. Three mode-coupled artifacts were used for comparison. The average values of differential group delay measured by both institutes agreed well within their uncertainties.

INTRODUCTON

Polarization mode dispersion (PMD) is one of the major parameters used to characterize optical fiber and fiber optic components. It has to be accurately measured and controlled or mitigated to ensure optical signal transmission with modulation rates of more than 10 Gbps for conventional single mode fiber [1].

Demand for PMD references has been gradually increasing as the instruments of PMD measurement have been widely supplied to manufacturers of fiber optic cable and components and research laboratories in order to enhance reliability of measurement results. KRISS has been establishing a PMD measurement standard as a national metrology institute (NMI) in Korea to meet this demand [2].

However, it is generally hard to verify whether our PMD value is correct until we directly compare it with other NMIs. Therefore, we coordinated a bilateral comparison on PMD between KRISS and NIST, who pioneered to establish PMD measurement standards [3].

ARTIFACTS FOR COMPARISON

KRISS prepared the artifacts for comparison. They were fabricated by using multiple sections of polarization maintaining fiber (PMF), arc-fusion spliced with random orientation of birefringent axis [2]. If $\Delta\tau$ is a differential group delay (DGD) of each PMF section, the target PMD value becomes simply

$$PMD = \Delta\tau\sqrt{N}\ . \qquad (1)$$

Equation (1) assumes that the DGD follows the Maxwell distribution, where N is the number of PMF sections. Three PMD values were proposed for comparison, which were nominally 0.1 ps, 0.5 ps, and 1 ps. We labeled them as RM-1, RM-2, and RM-3, respectively. Since the PMF we used had a PMD coefficient of about 1.5 ps/m, the physical lengths of PMF section for the three target PMD values were determined to be 9.4 mm, 47 mm, and 94 mm, respectively, since we chose N to be 50. When the splicing of all the 50 pieces of PMF was finished, FC/PC fiber connectors were spliced onto both ends. The fibers were placed in a circular groove with a diameter of 17.5 cm in a metal case with dimension of 20 cm (L) × 24 cm (W) × 2 cm (H) and fixed with silicone glue to minimize applied stress during curing, and finally covered with a metal plate with a thickness of 1.5 mm.

COMPARISON METHODS

Both KRISS and NIST used the Jones matrix eigenanalysis (JME) method in measuring PMD. We agreed to measure DGD profiles of the three PMD artifacts at a fixed temperature of 23 °C in the wavelength range of 1520 nm to 1600 nm that the tunable laser sources of KRISS and NIST could cover. This range was useful because it included the most widely used optical communication bands, so called C-band and L-band.

In order to measure the DGD values stably, we set the three PMD artifacts in a constant temperature chamber and left them unperturbed over several hours. Separate measurements showed that the DGD of RM-2 and RM-3 at a fixed wavelength became steady after 4 hours for 4 K change in temperature.

Because the DGD values of the artifacts can be affected by the two lead fiber cables to connect them to the measurement setup, we repeated DGD measurements at least three times after changing the orientation of the lead fiber cables.

After KRISS finished measurements, the three artifacts were delivered to NIST and measured with the NIST JME setup. After NIST finished measurements, they were returned to KRISS. After the artifacts returned to KRISS, they were measured again to verify that nothing had changed significantly.

The three PMD artifacts had DGD profiles as a function of wavelength as shown in Figure 1, which were measured with the KRISS JME setup.

Based on the criterion that the product of the maximum DGD and the wavelength interval should not exceed 1.5 ps·nm for the mode-coupled case [4], we set the wavelength intervals for RM-1, RM-2, and RM-3 to be 10.0 nm, 1.5 nm, and 0.5 nm, respectively, while scanning the whole range. We obtained DGD data at every 1/5 of these wavelength intervals by repeating the scan after shifting the starting wavelength to 1/5 of the interval repeatedly.

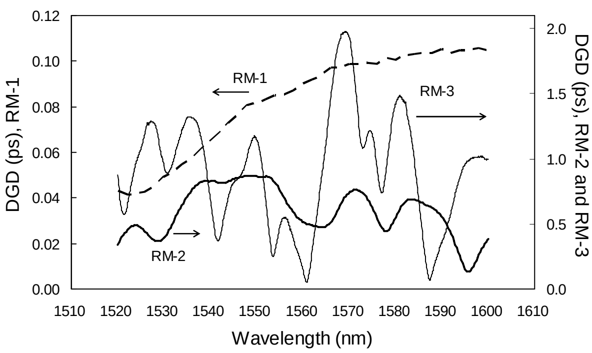

Figure 1. DGD profiles of PMD artifacts.

COMPARISON RESULTS

Our results are summarized in Table 1 and Table 2. The λ_{start} and λ_{stop} in the tables mean the wavelength of first DGD and last DGD, respectively, in the range between 1520 nm and 1600 nm. The *U* in the tables means expanded uncertainty with a coverage factor of 2 for the confidence level of 95 %. The deviations between the PMD values measured by KRISS and NIST were 0.4 fs, 2.3 fs, and 5.7 fs for RM-1, RM-2, and RM-3, respectively.

Table 1. Measurement results with KRISS JME setup. The mean temperature was 23.1 °C.

	λ_{start} [nm]	λ_{stop} [nm]	*PMD* [ps]	*U* [ps]
RM-1	1522.00	1598.00	0.0830	0.0027
RM-2	1520.30	1599.80	0.5980	0.0069
RM-3	1520.10	1599.90	0.909	0.012

Table 2. Measurement results with NIST JME setup. The mean temperature was 23.2 °C.

	λ_{start} [nm]	λ_{stop} [nm]	*PMD* [ps]	*U* [ps]
RM-1	1522.55	1597.48	0.0834	0.0044
RM-2	1520.53	1599.57	0.6003	0.0046
RM-3	1520.24	1599.88	0.9035	0.0049

In Figure 2, we plotted the PMD values and the expanded uncertainties of all the three artifacts measured by KRISS and NIST after normalizing the PMD values and the expanded uncertainties with the average PMD value of KRISS and NIST for each artifact. The deviations of PMD values from average, that is 1.00 in Figure 2, were 0.26 %, 0.20 %, and 0.32 % for RM-1, RM-2, and RM-3, respectively, well within the combined uncertainties of KRISS and NIST.

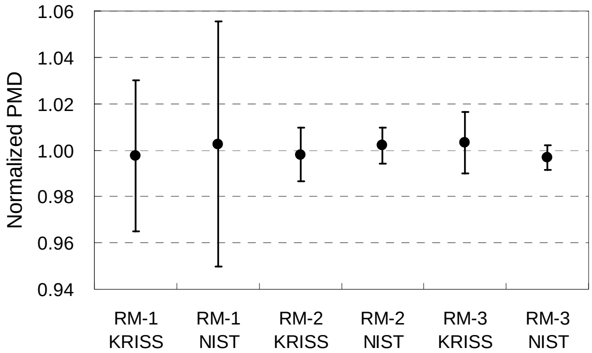

Figure 2. Normalized PMD with expanded uncertainty of the three artefacts measured by KRISS and NIST.

CONCLUSION

The measurement results between KRISS and NIST showed good agreement within their combined uncertainties.

In fact, the DGD profiles are a function of temperature and shifted toward shorter wavelength by ~0.9 nm/°C. It can be expected from Figure 1 that RM-1 and RM-2 are more robust under temperature change than RM-3 in our wavelength range selection. Therefore, RM-3 had larger relative deviation than others.

RM-1 had a slightly higher relative deviation than RM-2 because the mismatches in start and stop wavelengths between KRISS and NIST were larger in RM-1 than RM-2 as shown in Table 1 and Table 2.

REFERENCES

1. P. Hernday, Dispersion Measurements, Fiber Optic Test and Measurement ed. by D. Derickson, 475-518, Prentice Hall, New Jersey, 1998.
2. S. K. Kim, S. C. Gil, B. W. Lee, S. N. Park, Development of Certificated Reference Materials for Polarization Mode Dispersion, Proc. of SPIE Vol. 6351 63510F1-8, 2006.
3. P. A. Williams, “Mode-coupled artifact standard for polarization-mode dispersion: design, assembly, and implementation,” Appl. Opt. 38, 6498-6507, 1999.
4. P. Williams, PMD measurement techniques and how to avoid the pitfalls, J. Opt. Fiber Commun. Rep. 1, 84-105, 2004.