# INVESTIGATIONS ON POLARIZATION MODE DISPERSION PERFORMANCE OF NON-ZERO DISPERSION FIBER RIBBON CABLES UNDER DIFFERENT STRUCTURAL AND ENVIRONMENTAL CONDITIONS

Sait Eser KARLIK [1]    Güneş YILMAZ [2]

[1,2] Uludağ University, Faculty of Engineering and Architecture, Department of Electronics Engineering,
16059, Görükle, Bursa, TURKEY    e-mail: ekarlik@uludag.edu.tr

*Key words: PMD, Nonzero Dispersion Fiber, Fiber Ribbon, Slotted Core Cable*

***Abstract-*** **Non-zero dispersion fiber (NZDF) ribbon cable has recently become a considerable alternative in long-haul high-speed network construction. Since long-distance high-bit rate transmission requires low polarization mode dispersion (PMD), it is very important to know the PMD performance of this type of optical fiber cables. In this study, we have experimentally analyzed effects of the cable structure and environmental parameters, in particular the temperature, on the PMD performance of several different types of fiber ribbon cables. Results show that typical measured PMD values are approximately 0.05 ps/km$^{1/2}$ for all cable and ribbon configurations but cable structure, ribbon thickness, positions of fibers in the ribbon and environmental temperature variations alter the PMD values of NZDF ribbon cables.**

## I. INTRODUCTION

Non-zero dispersion fibers (NZDFs) are generally used in trunk lines for long-haul network applications. Since lengths of many main communication lines exceed 400 km in these systems, PMD performance of the cable will be an important factor effecting the viability of high-bit rate communication. Previously, most common optical fiber cable structure was loose tube cable and many papers were published that reported PMD performances of these cables under various conditions [1-4]. However, because of its cost saving advantages and relatively easy upgradability to 40 Gbps transmissions, slotted core ribbon cable has recently become an important alternative to loose tube cable.

This study is aimed at experimentally examining PMD characteristics of slotted core NZDF ribbon cables. Experiments were performed on three different types of ribbon cables. Using fixed analyzer method, PMD characteristics of cabled fiber and fiber ribbons were obtained. Then, to simulate field conditions on PMD performances of cables, environmental tests -in particular temperature cycle tests- were performed.

In the following section, structures of NZDF ribbon cables used in experiments are described. Measured instantaneous PMD characteristics of cabled fibers are given in Section III. Experimental results of fiber ribbon PMD characteristics are presented in Section IV. Finally, temperature tests designed to simulate effects of field conditions on PMD performances of cables are introduced in Section V.

## II. CABLE STRUCTURE

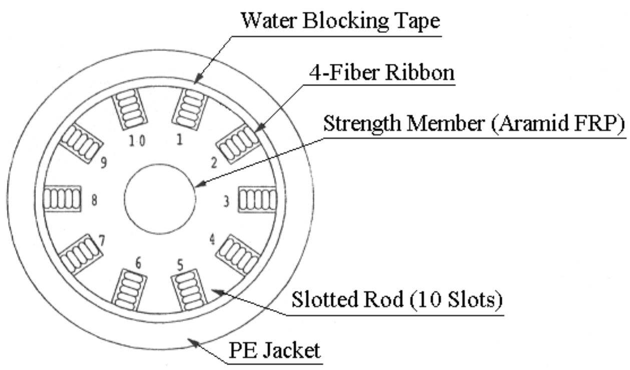
In experiments, we used a reduced slope NZDF which is optimized for high-bit rate transmission over a wavelength range of 1530 nm - 1625 nm. Some optical and geometrical characteristics of this fiber is shown in Table 1.

Table 1. Optical and geometrical characteristics of NZDF

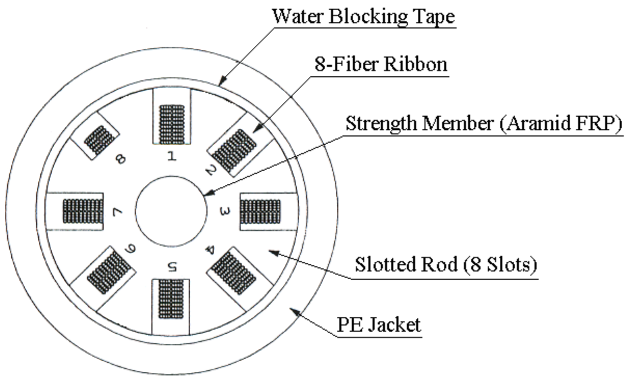
| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Chromatic dispersion (1530–1565 nm) | 2.6-6.0 ps/nm-km | Cladding diameter | 125± 1.0 μm |
| Chromatic dispersion (1565–1625 nm) | 4.0-8.9 ps/nm-km | Core/cladding concentricity error | ≤ 0.6 μm |
| MFD (at 1550 nm) | 8.4 ± 0.6 μm | Cladding non-circularity | ≤ 1.0 % |

One of the most common forms of NZDF is slotted core containing from 5 to 16 slots. Each slot comprises between 5 and 10 layers of ribbons, each of which contains 4 or 8 fibers. In experiments, we used three different types of these cables. Cable A is a 200-fiber cable with 10 slots containing 5 layers of 4-fiber ribbons in each slot. Cable B is a 600-fiber cable with 8 slots containing 8-fiber ribbons. Cable C is a 128-fiber cable with 8 slots and 2-fiber ribbons. Cables A and B have Aramid strength members while Cable C has a metallic strength member. Water penetration is prevented by water blocking tapes in Cables A and B while a filling compound is used in Cable C for water preventation.

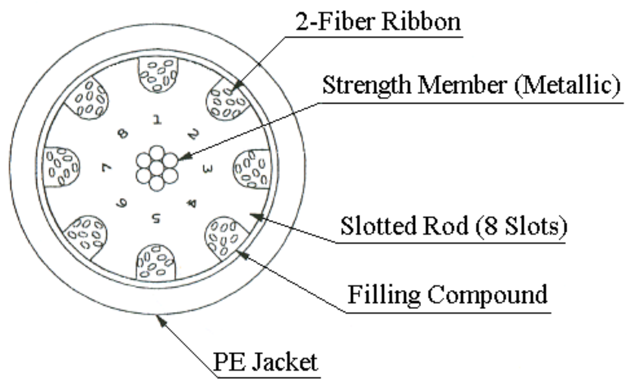
Schematic diagrams of these cables are shown in Fig. 1 and Table 2 presents the geometrical parameters.




a. 200-fiber cable with 4-fiber ribbons (Cable A)




b. 600-fiber cable with 8-fiber ribbons (Cable B)




c. 128-fiber cable with 2-fiber ribbons (Cable C)

Fig. 1. Schematic diagrams of cable structures used in our experiments

In general, optical attenuation characteristics of these types of NZDF cables are relatively low at 1550 nm and 1625 nm and are extremely stable under varying environmental and mechanical conditions and these samples are not exceptions.

Table 2. Geometrical parameters of sample cables

| Parameter | Cable A | Cable B | Cable C |
|---|---|---|---|
| Max. fiber count | 200 fibers | 600 fibers | 128 fibers |
| Ribbon type | 4-fiber | 8-fiber | 2-fiber |
| Ribbon thickness | 0.4 mm | 0.3 mm | 0.4 mm |
| Ribbon width | 1.1 mm | 2.1 mm | 0.7 mm |
| Strength member diameter | 4.5 mm (A-FRP) | 4.5 mm (A-FRP) | 7/1.4 mm (Metallic) |
| Jacket thickness | 1.5 mm | 1.5 mm | 2.0 mm |
| Cable outer diameter | 17 mm | 22 mm | 21 mm |
| Water preventation | WB tape | WB tape | Filling compound |

## III. INSTANTANEOUS PMD CHARACTERISTICS

Using the fixed analyzer method, instantaneous PMDs of sample cables were measured in the wavelength range of 1169 nm – 1696 nm. During the measurement process, cables were kept wound on wooden drums and the testing temperature was the ambient room temperature. Table 3 shows the measured PMD values of all cables.

Table 3. Measured PMD values of fiber ribbons (ps/km$^{1/2}$)

| Parameter | Cable A | Cable B | Cable C |
|---|---|---|---|
| Average | 0.0443 | 0.0451 | 0.0386 |
| $\sigma$ | 0.0212 | 0.0238 | 0.0164 |
| Maximum | 0.184 | 0.161 | 0.122 |
| Minimum | 0.023 | 0.026 | 0.018 |
| Fiber count | 528 | 528 | 528 |
| Average cable length | 1.450 km | 1.410 km | 1.475 km |

Comparing the results given in Table 3, it can be said that Cable C has a slightly better PMD performance than Cables A and B. As shown in Fig. 1, Cable C has filling compound in each slot. Since PMD is a complicated function of factors, in particular the fiber birefringence and mode coupling variations along the fiber, it is more likely that the filling compound altered the stresses on the fiber and changed the above factors.

For a 1 dB power penalty, the allowable PMD has been calculated as [5]

$$L = \left[ \frac{10^3 f}{B \times PMD} \right]^2 \tag{1}$$

where $B$ is the bit-rate, $L$ is the transmission distance, $f$ is the allowable bit-period fraction. Assuming B = 40 Gbps, f = 0.1 and L = 400 km, (1) gives a maximum PMD value of 0.125 ps/km$^{1/2}$. Comparing the instantaneous PMD values with the computed value, it can be concluded that these cables will be able to support high-bit rate transmission of long-haul networks to a high extent.

## IV. PMD CHARACTERISTICS OF FIBER RIBBON

To analyze effects of ribbon thickness and fiber positions on the PMD performance of fiber ribbon, six 4-fiber ribbons were manufactured. Each ribbon was composed of fibers of the same spool. Two different ribbon thickness, i.e. 0.3 mm and 0.4 mm, were used in samples. Average ribbon length was 1.5 km and ribbons were wound on 280 mm diameter spools with a winding tension of 200 g. PMD values of ribbons were measured in a wavelength range of 1169 nm – 1696 nm with the fixed analyzer method. Measurement results are shown in Table 4 and Fig. 2.

Table 4. Measured PMD values of fiber ribbons (ps/km$^{1/2}$)

| Sample Type | | Position 1 | Position 2 | Position 3 | Position 4 |
|---|---|---|---|---|---|
| Fiber A | 0.3 mm | 0.121 | 0.240 | 0.272 | 0.108 |
| | 0.4 mm | 0.081 | 0.220 | 0.241 | 0.093 |
| Fiber B | 0.3 mm | 0.401 | 0.316 | 0.325 | 0.362 |
| | 0.4 mm | 0.348 | 0.257 | 0.229 | 0.366 |
| Fiber C | 0.3 mm | 0.133 | 0.156 | 0.132 | 0.114 |
| | 0.4 mm | 0.107 | 0.151 | 0.163 | 0.107 |

Results indicate that PMD performance was effected by the position of fiber in the ribbon. As shown in Table 4 and Fig. 2, there is a significant difference between PMD values of outside fibers (#1 and #4) and that of inside fibers (#2 and #3). It is also obvious that there is a correlation between PMD values and ribbon thickness. Generally, ribbons with 0.3 mm thickness had larger PMD than 0.4 mm ribbons.

In these experiments, each ribbon was subjected to lateral pressure due to the winding tension of 200 g. This resulted in both additional birefringence and mode coupling. However, the relative significance of these effects varied from fiber to fiber. In some fibers ( Fibers A and C), PMD increased since increased birefringence was more significant than increased longitudinal mode coupling. On the other hand, PMD of others (Fiber B) decreased, indicating that the effect of longitudinal mode coupling was more important.

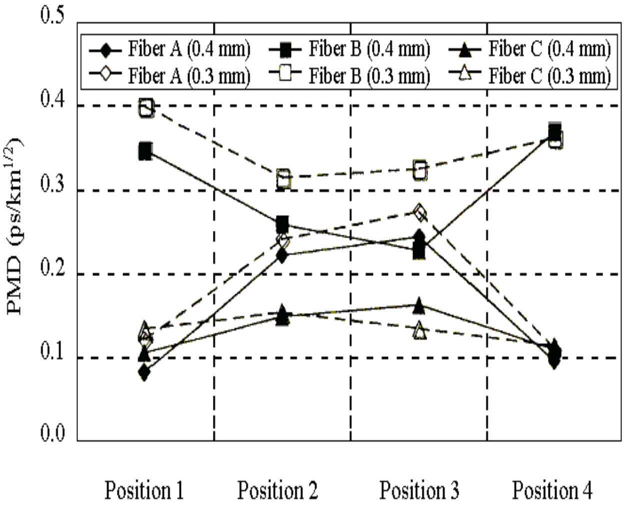



Fig. 2. Fiber ribbon PMD values

## V. TEMPERATURE TESTS

The optical fiber is subjected to various environmental factors in the field. In this work, we mainly focused on effects of temperature variations on PMD performance of optical cables. PMD is generally measured under static hold conditions, i.e. constant environmental temperature. However, temperature in the field is not static and can change rapidly and randomly. Therefore, under field conditions birefringence and mode coupling distribution along the cable length are constantly and randomly changing. This results in that time variability of PMD might be greater than the values obtained in static temperature tests.

To observe this effect, we formed two separate loops from Cable A, which was wound on a wooden drum with an approximate length of 1 km, using the outside fibers (loop 1) and inside fibers (loop 2). Each loop length was about 47 km. We measured the PMD on both loops at 30-minute intervals using the fixed analyzer method in the range of 1386 nm – 1694 nm. During the measurement process, we varied the temperature from 10 °C to 60 °C. The results of this experiment are shown in Fig. 3 and 4.

Figures 3 and 4 indicate a slight variation of PMD with the changing temperature. PMD variation of loop 1 was found to be 14.2 % while that of loop 2 was 10.7 %. The reason for the difference in PMD performances of loop 1 and loop 2 is that loop 1 consists of outside fibers that are in close contact with the slotted core of the cable. Therefore, it is more likely to be effected by fiber/cable interactions than loop 2 which is formed by inner fibers buffered from such effects by outside fibers. Consequently, birefringence and mode coupling along the cable length will be greater in loop 1.

In order to clearly understand PMD performance of cable under actual field conditions, we performed three additional temperature tests - controlled room temperature test, uncontrolled room temperature test and simulated field temperature test - that gradually expanded the range and variability of the ambient temperature.

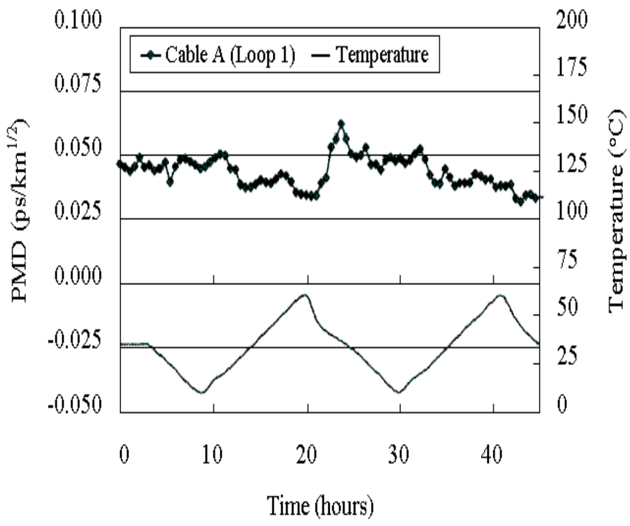



Fig. 3. Variation of PMD with the changing environmental temperature (loop 1 of Cable A)

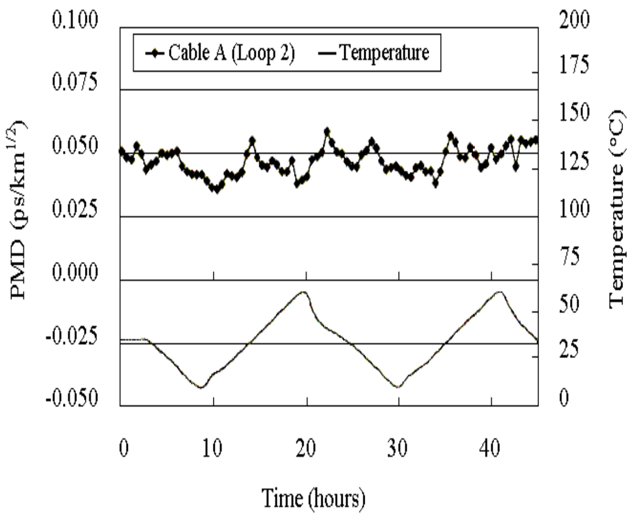



Fig. 4. Variation of PMD with the changing environmental temperature (loop 2 of Cable A)

In the controlled room temperature test, the spooled fiber sample was kept at a well controlled 23 °C for 24 hours and PMD of this sample was measured at 30-minute intervals using the fixed analyzer test set with 1550 nm light source. As expected, PMD was found to be very stable with a very small variation of 2.2 %.

In the uncontrolled room temperature test, Cable A was wound on a 1 meter drum and fibers were spliced to form a loop that is about 50 km in length. The sample was placed in a storage room where temperature varied by +/- 4 °C. Measurements were performed with the same method in the controlled room temperature test. Resultant PMD variation (9.7 %) was greater than the one in controlled room temperature test.

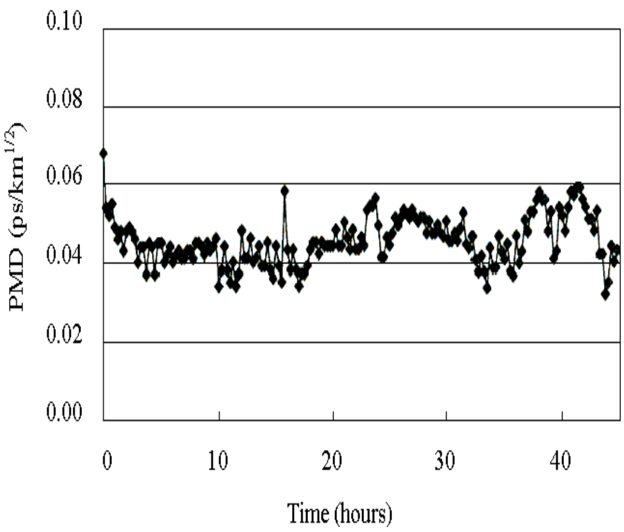



Fig. 5. PMD variation under simulated field conditions

To simulate field conditions, the fibers of Cable B were spliced together to form a 60 km loop and the cable was exposed to sunshine and ambient temperature variations for 48 hours in the third test. Measurements were performed with the same test set used in previous tests. The environment temperature range was about from 13 °C to 25 °C. Results of this experiment are shown in Fig. 5. From these results, the PMD variation under simulated field conditions was found to be 13.4 %. This result is similar to the results obtained in temperature tests performed on inner and outer loops of Cable A.

## VI. CONCLUSION

Effects of cable structure and environmental temperature variations on the PMD performance of three different types of NZDF ribbon cables have been experimentally analyzed.

Results show that the most significant factor effecting PMD characteristics of fiber ribbon cables is the environmental temperature variability. The slotted core cable structure is sensitive to this effect because of the fiber/cable interactions. Instantaneous PMD seemed to depend mainly on the cable design since existence of the filling compound in each slot slightly lowered the PMD values of the sample cable with respect to other samples that did not contain the filling compound. Moreover, a correlation between ribbon thickness and PMD performance was observed. Thinner ribbon showed larger PMD than thicker ribbon. Also, a significant difference was found between PMD values of outside and inside fibers of the same ribbon. This indicates that PMD performance can be effected by the location of the fiber in the ribbon.

In addition, when compared with the maximum allowable PMD, experimental results show that each of the three types of slotted core cable is suitable for use in long-haul high bit-rate transmission networks

## REFERENCES


[1] N. Gisin, J. P. von der Weid and J. P. Pellaux, "Polarization mode dispersion of short and long single-mode fibers", J. Lightwave Tech., vol. 9, pp. 821-827, 1991.

[2] J. Cameron, L. Chen, X. Bao and J. Stears, "Time evaluation of polarization mode dispersion in optical fibers", IEEE Photonics Technol. Lett., vol. 10, pp. 1265-1267, 1998.

[3] J. Cameron, X. Bao and J. Stears, "Field measurements of polarization mode dispersion", Fiber & Integ. Optics, vol. 18, pp. 49-59, 1999.

[4] S. E. Karlık and G. Yılmaz, "Analysis of polarization mode dispersion of optical fiber under adiabatic and isothermal conditions", Proceedings of ELECO'2002, vol. 2, pp. 246-251, 2002 (in Turkish).

[5] S. A. Jacobs, J. J. Refi and R. E. Fangmann "Statistical estimation of PMD coefficient for system design", Electronics Lett., vol. 33, pp. 619-621, 1997.