

High speed transmission (160 Gb/S) in a single mode optical fiber with ultra low polarization mode dispersion

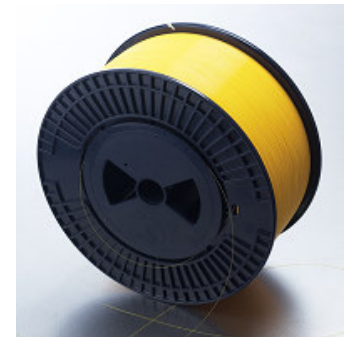
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Abstract

Very high data transmission rates impose very strict requirements on optical fiber and transmission systems installed in the field. Especially, Polarization Mode Dispersion (PMD) will be a serious limitation on links operating at speeds greater than 10 Gb/s. In view of this, this paper summarizes the root causes, importance, network cost implications of PMD and the need to push for Ultra Low PMD in an optical fiber.



Keywords

Polarization mode dispersion, birefringence

Introduction

Today's network infrastructure is now highly evolved and is required to support deployment of new triple play services like IPTV, VOD and VoIP. To support such voluminous information, each individual fiber is to be operated at very high speeds making stringent demand for ultra low polarization mode dispersion. In this paper, root causes for high PMD are discussed and then network cost advantage of having ultra low PMD is discussed.

Root cause of PMD in fiber

Polarization mode dispersion is linear average of the differential group delay (DGD) over a given optical frequency range, DGD which in turn being the time difference in the group delays of the principal states of polarization of the fiber. Factors which affect the polarization of principal states affect PMD are shown in figure 1.

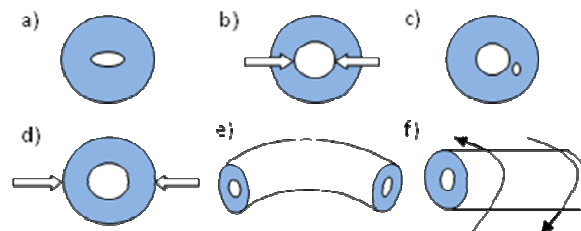


Figure 1: Major manufacturing process defects affecting PMD in an optical fiber.

Intrinsic (a, b, c) and extrinsic (d, e, f) factors due to which PMD can be deteriorated are shown in figure 1. Intrinsic being the fiber core ellipticity and internal stress. Extrinsic being the external stress arises due to bending, uneven twisting of fiber and random pulling tension fluctuations during fiber drawing. Sharp kinks in the cable or fiber cabling process also cause asymmetric stress on the fiber. Fiber core ellipticity is related core ellipticity in preform (mass blank from which fiber is drawn) which in turn is related to the symmetric and uniform deposition process (OVD, VAD, MCVD, and ACVD). Even if at preform stage the core is perfectly circular, the circularity of fiber could get deteriorated during fiber drawing.

Internal stress in fiber could be generated in the soot consolidation process, and improper annealing/cooling of fiber during drawing process. Bending and twisting of fiber which lead to the coupling of energy mostly to one of the PSPs could increase PMD, however proper and regular twisting (twist birefringence equivalent to that of beat length of fiber) could reduce PMD. Random and asymmetric voids in cladding would make the fiber cladding profile asymmetric leading to asymmetry in fiber refractive index profile thereby causing unnecessary birefringence.

Geometric birefringence and PMD

Figure 2 shows the how PMD changes when geometrical birefringence of fiber changes with core ellipticity. Since PMD is proportional to birefringence, the fiber core needs to perfectly circular along the length of the fiber for ultra low polarization mode dispersion. The fiber parameters are as follows.

Parameter	Value
n _{core}	1.44792
n _{clad}	1.44692
Wavelength	1.55 μ
Core diameter	8.5 μ

Ellipticity of core is defined as $e = 1 - a/b$, where 'a' and 'b' are the minor and major axis of the ellipse (core). Polarization mode dispersion is directly proportional to the birefringence of fiber. Even if there is no birefringence induced due to factors mentioned in section 2.1, figure 1, the geometrical birefringence is itself critical and can deteriorate PMD to large extent.

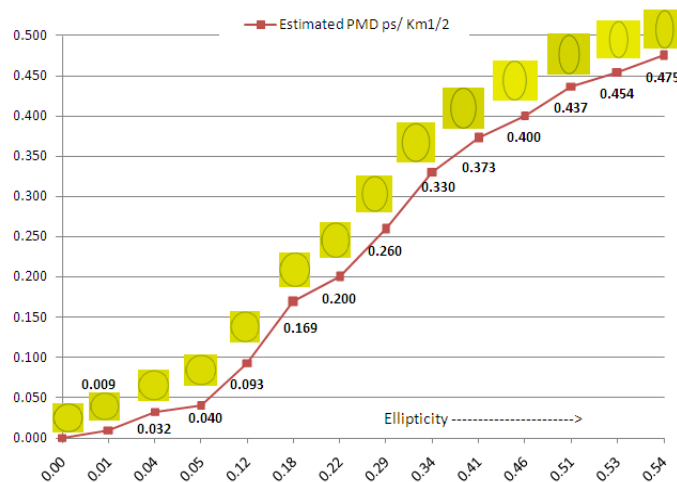


Figure 2: Fiber core ellipticity vs. PMD

Cost implication of Ultra low PMD

Network (backbone, access) wise bandwidth growth and new services deployed are different creating a different demand on the bandwidth [3]. Many of current network installations employ custom PMD mitigation components [5]. Fiber with ultra low PMD ($< 0.05 \text{ ps/km}^{1/2}$) increases the maximum link length with PMD compensators. In view of this, cost implications of using ultra low PMD vs. using PMD emulators / compensators is discussed and cost advantage is shown in this section.

Allowable PMD

According to International telecommunication standard G691, for the case in which probability of PMD of a link exceeding DGD_{max} is 4.2×10^{-5} , the safety factor is 3, i.e. the link PMD should be maximum $1/3 (DGD_{max})$. Since DGD_{max} is 30 % of bit period T_B , the maximum allowable PMD is $1/10$ of bit period [1, 2]. Figure 3 shows the maximum allowable PMD_{coeff} for two different link lengths at various transmission speeds on individual fiber, showing the importance of requirement of Ultra low PMD coefficient as networks scale to higher speeds.

PMD < 0.1 T_B (1)

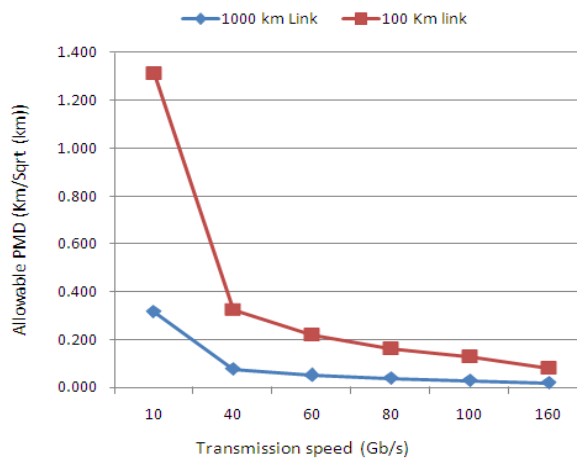


Figure 3: Allowable PMD for a given transmission speed and link length.

Speed (Gb/s)	Allowable PMD coeff (ps/km ^{1/2})	
	100 km link	1000 km link
2.5	4.000	1.265
10	1.000	0.316
40	0.250	0.079
60	0.167	0.053
80	0.125	0.040
100	0.100	0.032
160	0.063	0.020

Table 1: Allowed PMD values at various speeds and link lengths with maximum allowable PMD being one third the pulse width.

Ultra low PMD vs. PMD compensation

A 1000 km fiber link is considered for calculating the normalized cost (NC) of a network with various link PMD designs and transmission speeds. It is assumed that a PMD compensator compensates for 1 ps delay. For each set transmission speed, for various link PMD design values, the delay is calculated. If the delay is less than the maximum allowable delay (Eq. 1.), there is no need for compensation, adding no cost to the network. For every 1 ps additional delay than the allowed delay, one compensator is to be added. Thus extra cost incurred for installing compensator is equivalent to the extra delay. No additional delay is considered to contribute, other than that of PMD and so this calculation is independent of type of network.

- For every link design PMD_{coeff}, delay (T_d) is calculated. If delay exceeds the threshold ($0.1 * T_B$), then a compensator is added.
- Assuming, each compensator is for 1ps delay, number of compensators (N_c) is calculated in the following way.
 - $N_c = 0$; if $T_d < 0.1 * T_B$
 - $N_c = (T_d - 0.1 * T_B)$, if $T_d > 0.1 * T_B$ (Rounded off to an integer on higher side)
- Assuming unit cost for compensator, values are normalized to maximum of all combinations.

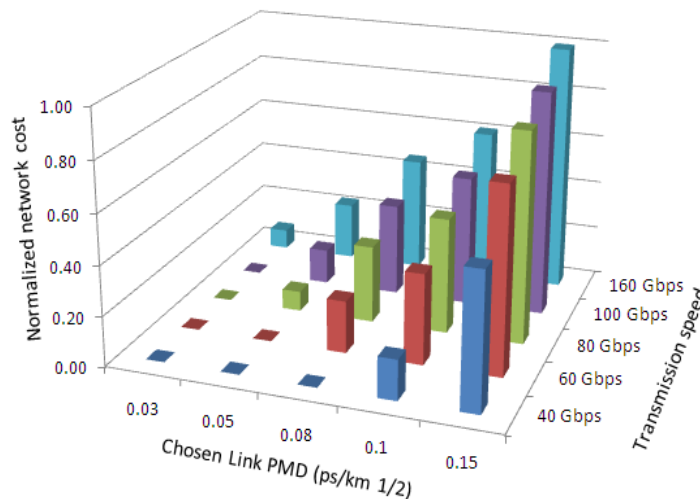


Figure 4: Normalized network cost for various link designs.

Conclusion

Clearly the advantage of ultra low PMD (< 0.05 ps/km^{1/2}) is seen from figure 4. For the given link length, when the link PMD design value is less than 0.05, no compensation was required even till 100 Gb/s operation and least cost even at 160 Gb/s operation, thus putting a stringent requirement on fiber to have very low polarization mode dispersion.

References

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