

# Polarization Mode Dispersion

## Frequently Asked Questions

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### **What is PMD vs. differential group delay (DGD)?**

Polarization Mode Dispersion (PMD) is the average Differential Group Delay (DGD) one expects to see when measuring an optical fiber. DGD is the time separation or delay between the two principal polarization modes of the transmission link at the receiver. DGD is an instantaneous event and varies randomly with wavelength and time. This means that DGD is a statistical parameter, obeys the laws of probability theory and thus has uncertainty associated with it. PMD is the average value of a distribution of a large number of independent DGD measurements.

### **What is fiber PMD vs. cable PMD?**

Fiber PMD is PMD that is generally measured on spool, while cable PMD would be the PMD of the fibers in a cabled/installed mode. The spool measurement is not an accurate indicator of cabled and installed PMD. Many studies have found that there is no correlation between the two. Other measurement techniques such as a Low Mode Coupling (LMC) measurement have been developed to make this correlation. However, LMC is destructive and time consuming and thus, predominately performed on a sampling basis. OFS recommends that the fiber customer insist on data from the cable manufacturer that establishes this correlation and provides a Link Design Value (LDV) needed for their application.

### **What is a Link Design Value?**

Link design value (LDV) is a useful design parameter for calculating the worst-case contribution of the fiber toward the overall system PMD of a link. LDV, also referred to as  $PMD_Q$ , is a term developed in standards bodies used to evaluate the impact of fiber related PMD where cabled fibers are deployed in concatenated sections. That is, in building a network typically 2-10 km sections of cable are spliced together. The LDV is the worst case PMD of the end-to-end link made up of randomly chosen cable sections spliced together. Thus the LDV represents the worst case PMD of a fiber path in a cabled and deployed span. PMD standards indicate that LDV should be calculated from nominally 20 to 24 sections and have a maximum cumulative distribution Q of nominally 0.001 to 0.0001. This implies that 0.1% or 0.01% of all spans (made up of concatenated sections) would be above this level of PMD.

### **What is system PMD?**

System PMD is the total PMD attributed to the collection of optical components that makes up an optical link between a transmitter and a receiver. Many of these components are illustrated in **Figure 1**. Indeed, optical fiber may only be one of the components if amplification, power splitting, dispersion compensation or optical multiplexing is used in the link. With PMD performance of cabled optical fibers continuing to decrease, more emphasis will be placed on the PMD performance of the other components in the link. Typically, in a long haul system, the PMD attributed to the optical fiber itself is given half of the system PMD budget. The system PMD is calculated from the square root of the sum of the squares of each individual component PMD.

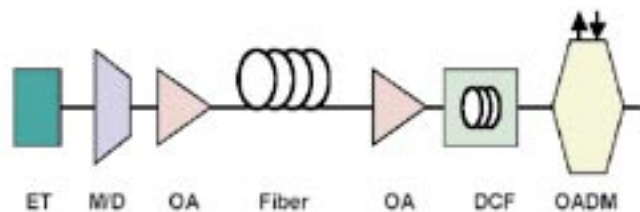
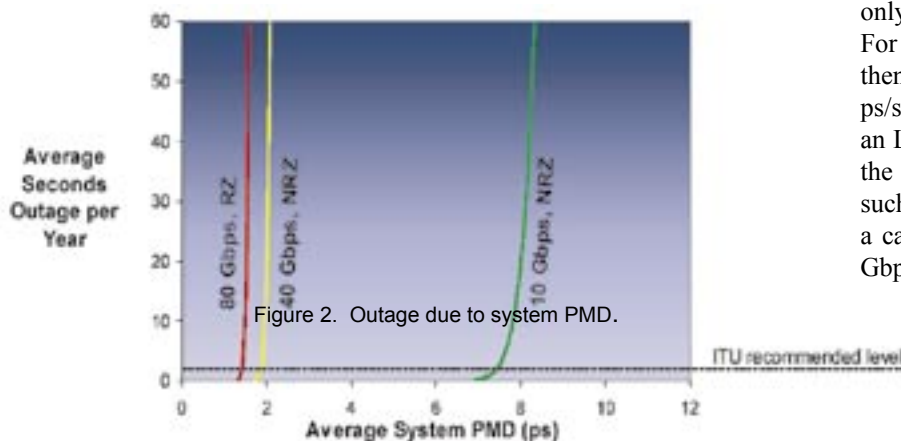


Figure 1. Optical components in a DWDM system: ET: end terminal, M/D: multiplexer/demultiplexer, OA: optical amplifier, DCF: dispersion compensating fiber, OADM: optical add/drop multiplexer

### How much PMD can be tolerated in my system?

The level of system PMD that can be tolerated depends on data rate, distance and how much system outage one is willing to tolerate. Figure 2 indicates the average system outage as a function of system PMD for 10, 40 and 80 Gbps systems. As can be seen in this figure, as the system PMD limit for a given bit rate is approached, slight increases in PMD will cause significant increases in system outage. International standard guidelines for PMD recommend an outage probability of  $6.5 \times 10^{-8}$ , corresponding to 2 seconds of outage per year attributable to PMD.<sup>1</sup> Coupled with the 50% recommendation of system PMD that should be allocated for optical fiber, a goal for a 10 Gbps system would be a cabled optical fiber with  $\sim 4$  ps of total PMD. This drops to below 1 ps if a 40 or 80 Gbps system is envisioned operating on this fiber in the future.



The PMD requirement on your cabled fiber is now only dependent on knowing the distance of the route. For example if you have a 100 km link at 10 Gbps, then your cabled fiber should have a LDV below 0.4 ps/sqrt(km) but at 40 Gbps, this same route requires an LDV below 0.1 ps/sqrt(km). For longer distances, the LDV requirements become even more stringent such that at 1000 km, a 10 Gbps system would require a cabled fiber LDV of  $<0.13$  ps/sqrt(km) while a 40 Gbps system would need a value  $<0.03$  ps/sqrt(km).

Errors induced by PMD may be difficult to isolate. Since PMD is statistical in nature and varies with wavelength and time, errors can appear in random, frequent bursts or long durations. Errors may appear later in the life of a link as the cable plant ages and environmental factors change its performance. There are a host of external factors that can influence the PMD behavior of a link, from seasonal changes in temperature, to the effects of wind, to vibrations from proximity to railroad tracks or large building equipment.

### How do I guard against the transient nature of PMD?

The best way to guard against the transient nature of PMD is to use a fiber that has been manufactured with a process that both lowers PMD and provides PMD stability with environmental changes. OFS uses its very own, patented process to reduce PMD and help guard against destabilizing impacts of environmental changes.

### Can I fix or compensate for PMD?

Yes, but it is generally an added cost since it must be done on a per channel basis. There are two ways to compensate for PMD, optically or electronically. Optical PMD compensation is done by splitting the signal into two polarization states, actively measuring the PMD of a signal and adjusting an optical delay line to retard or advance one of the polarizations. These techniques were generally very expensive and never were widely deployed. Electronic PMD compensation can be done using adaptive processing techniques, but have limited range of compensation and are difficult to scale to higher data rates, such as at 40 Gbps. It is best to minimize your needs for compensation by installing low PMD optical fiber and components.

### Are there standards for PMD?

Yes, there are several documents that establish guidelines for everything from measurement of PMD to methods to determine LDV to how to concatenate components for a complete system view of PMD. There is the IEC 60793-3 that describes the statistical specification of PMD for optical fiber cables, the IEC 61282-3 that has guidelines for calculations of PMD in fiber optic systems and then recommended levels of PMD in cabled fiber can be found in ITU-T G.652 and ITU-T G.655 for non-dispersion shifted fiber and non-zero dispersion fiber, respectively. Typically, these are minimal requirements for PMD performance

### ***There is so much ambiguity in PMD specifications. What should I be looking for?***

The most important specification one can look for is cabled fiber link design value (LDV), also referred to as quadrature average PMD ( $PMD_Q$ ) in standards bodies, such as ITU. Purchased optical fiber is cabled, installed and concatenated with other cables along a route, so it makes sense to review a specification that best represents the PMD performance of deployed fiber. Cabled fiber LDV does just that and is straightforward to use in a system design analysis. It is the worst-case representation of the optical fiber's contribution to system PMD.

### ***What should I ask of my fiber cable supplier in terms of a PMD specification?***

OFS recommends that the customer insist on data from the cable manufacturer that establishes a correlation between fiber PMD and cable PMD and that provides a cabled fiber LDV value to meet the applications' needs. Since PMD may have some dependencies on cable construction also, we suggest PMD specifications that most closely represent the cable type of interest. Quality assurance programs must also be in place to ensure the data reported in the specifications is repeatable and therefore meaningful.

### ***Is the sensitivity to PMD, fiber design- or manufacturer dependent?***

Much of the sensitivity of a fiber to PMD effects is due to the manufacturing process. There is some variation from fiber type to fiber type due to design, but low PMD is generally achieved by quality and process control during fiber manufacturing. OFS has very tight process controls in place and uses its very own, patented process to reduce PMD and help guard against destabilizing impacts of environmental changes.

### ***How do I test an incoming cable or fiber for PMD?***

It is difficult to check PMD before installation. Fiber measurements on spool are notoriously unreliable. Loose coils (greater than 30 cm diameter) are one approach, though many fiber samples need to be measured before one can assess the PMD. Cable measurements present the same difficulties. Short cable lengths (less than 10 km) can be measured on-reel, but again, many measurements are required. The cable manufacturer should be able to give an estimate of the change in PMD expected when the cable is taken off the reel. It is suggested that the test set be capable of measuring a PMD value below 0.01 ps.

### ***Why is the minimum measurable PMD length dependent?***

The "PMD coefficient", with units of  $ps/km^{1/2}$ , indicates the rate at which PMD builds up along the fiber length. For a fixed length, a "PMD value", with units of ps, can be measured. Test sets have a minimum measurable PMD value. For fiber with a low PMD coefficient, a long fiber length is required for accurate measurement. For example, if a  $0.02 ps/km^{1/2}$  fiber is measured using an interferometric test set with a minimum PMD of 0.1 ps, one would require 25 km of fiber.

### ***What are the limitations to measurement of low PMD?***

It has been shown some time ago that all PMD measurement methods have an associated uncertainty depending on the bandwidth of the test set and the size of the PMD value being measured. This uncertainty, U, takes the mathematical form:

$$U = 1/(\Delta\omega \text{ PMD})^{1/2}$$

Where  $\Delta\omega$  is the instrument bandwidth and "PMD" is the correct PMD value. For the low values of PMD in fiber such as that made by OFS, this uncertainty is substantial, even for very wide instrument bandwidths ( $> 100 nm$  at 1550 nm). A simple calculation shows that with a 120 nm bandwidth (typical of the Jones Matrix Eigenanalysis test set, the IEC referenced standard and most widely accepted test method) a measurement of a 0.1 ps PMD value (corresponding to the 25 km of good fiber mentioned earlier) will result in a 33% uncertainty. This uncertainty can only be overcome by varying something other than wavelength when the measurement is made (other choices are temperature or fiber position). In any case, more than one measurement is needed if you want to measure low values with small uncertainty.

### ***What is a “low mode coupled” PMD measurement?***

Realizing that the PMD measurement of fiber on the spool or cable on the reel is very inaccurate, thought has been given to a more representative configuration that will reflect the performance of installed cable. Current standards (IEC 60793-1-48) suggest using a large diameter drum, loose coil, or flat surface for fiber or cable layout. OFS has found that the most reliable method is using the flat surface. For fibers that have little mode coupling (such as unspun fiber), all configurations involving bending, dramatically increase mode coupling and produce an erroneously low PMD value. On the other hand, fibers that are spun and highly mode coupled, tend to show higher PMD when coiled. In either case, correct answers are obtained using the flat surface.

The low mode coupled measurements have the disadvantage that only short lengths of fiber can be used. In this case, the instrument bandwidth limitations become important. For this reason, all low mode coupled measurements require some method of enhanced sampling, such as variation of fiber temperature or position in order to actually measure PMD.

### ***Is it possible to measure PMD with an OTDR?***

No, a traditional optical time domain reflectometer (OTDR) only measures loss and optical reflections. However, there are newly available polarization-OTDRs (POTDR) that can isolate and measure high levels of PMD along the length of a route.

### ***I am not running high bit rates, like 10 or 40 Gbps, now, should I be concerned about PMD?***

The timeframe for getting to 10 Gbps data rates or beyond and the length of time the fiber is expected to last, determines the need for concern over high PMD. Once fiber is purchased and installed, compensation if needed, can prove costly, complex or limiting. Many network builds are intended to be in service for well over twenty years. Over the last ten years, data rates have increased a hundred fold as personal computers have increased in processing speed. Looking forward, as Moore’s law driven improvements in microelectronics speed continue and optical transmission component costs decrease, transmission rates of 40 Gbps and beyond will be reasonable expectations and PMD will be important.

### ***Is there any correlation between chromatic dispersion and PMD?***

No, chromatic dispersion is a result of materials used in the core of the optical fiber as well as the waveguide design. PMD is a result of imperfections in the circular uniformity of the core as a result of a host of internal or external effects such as eccentricity, ovality, core/cladding defects, external bends or pressure, etc.

### ***Should I worry about PMD in a multimode fiber?***

In general, multimode fiber is only used on very short lengths (<1 km) and at lower data rates (<10 Gbps) such that PMD for these types of optical fibers is not of concern.

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<sup>1</sup> ITU-T G.652 Characteristics of a single-mode optical fibre and cable, March 2003.

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