

## PMD VS. MODE COUPLING

By Francis Audet, Senior Product Manager, Optical Business Unit

Just when you thought that the polarization-mode-dispersion (PMD) world couldn't get any more complicated, along comes talk of strong-mode and weak-mode coupling by PMD test gear manufacturers. To fully grasp the impact that strong-mode and weak-mode coupling have on PMD testing and the accuracy of test instruments, the basic concepts of PMD need to be examined.

Let's begin with a basic fact: light is made of two perpendicular polarizations, commonly named electric and magnetic fields (or waves) that travel into the fiber. Add to that fact the reality that fiber is not perfect, which is caused by the core roundness, pureness, etc., or the local imperfections or stresses that can create variation in the index of refraction (which can be seen as the density of the glass). Therefore, on a given length of fiber, one path will on average have less stress than another, enabling light to travel faster; this is often referred to as the *fast axis* as opposed to the *slow axis*; note that these two axes are perpendicular. Each fiber section can have a different fast and slow axis and the length of these sections can greatly vary depending on the type and age of the fiber. Every time a section change occurs, energy transfers from one mode (fast or slow) to something else, depending on the section that follows (known as *mode coupling*), and the fibers in which this occurs are usually referred to as *strong-mode coupling*.

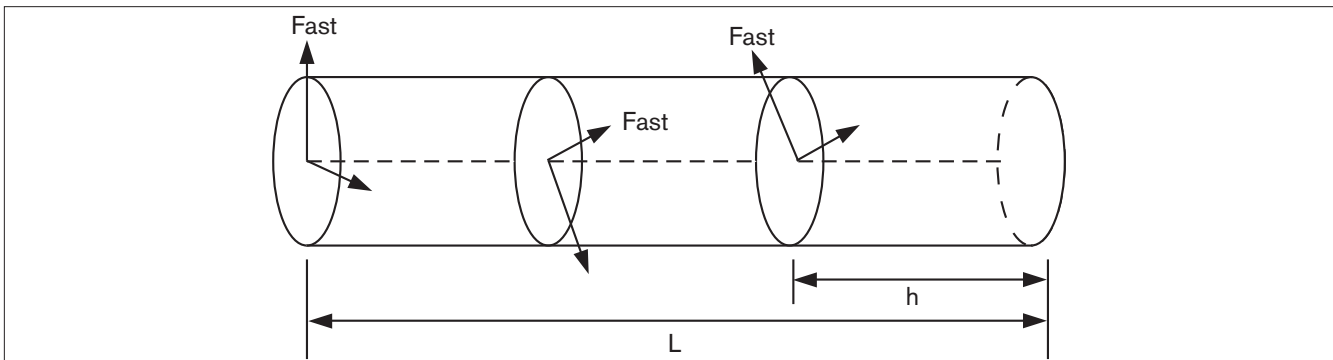


Figure 1. A length of strong-mode coupling fiber ( $L$ ) is made of several coupling sections of various length ( $h$ )

In some fibers, this randomness is eliminated by imposing a faster fiber path during production; for example, this can be achieved by creating index of refraction variations that are much greater than those that occur due to imperfections (referred to as *polarization-maintaining fibers* (PMF)). Several different PMF designs are used and most work by inducing stress in the core via a non-circular cladding cross-section or rods of other material included within the cladding. Since there is only one section with always the same fast and slow axis, these fibers are also referred to as *weak-mode coupling*.

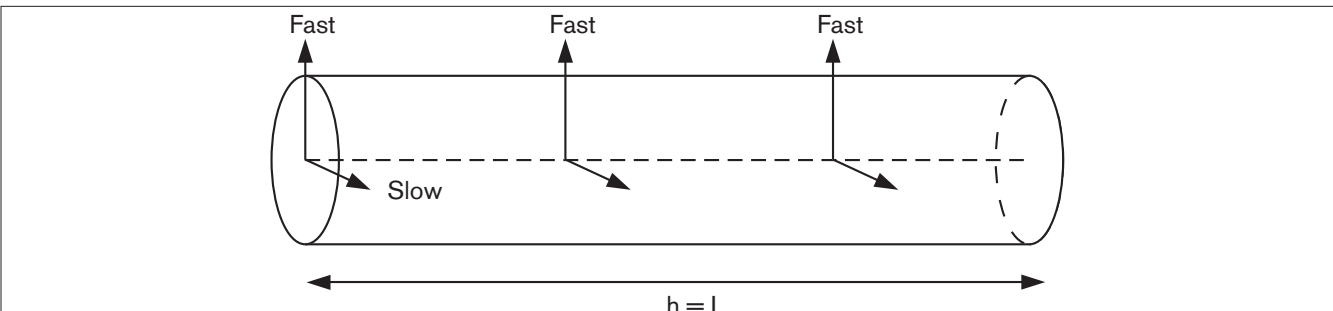
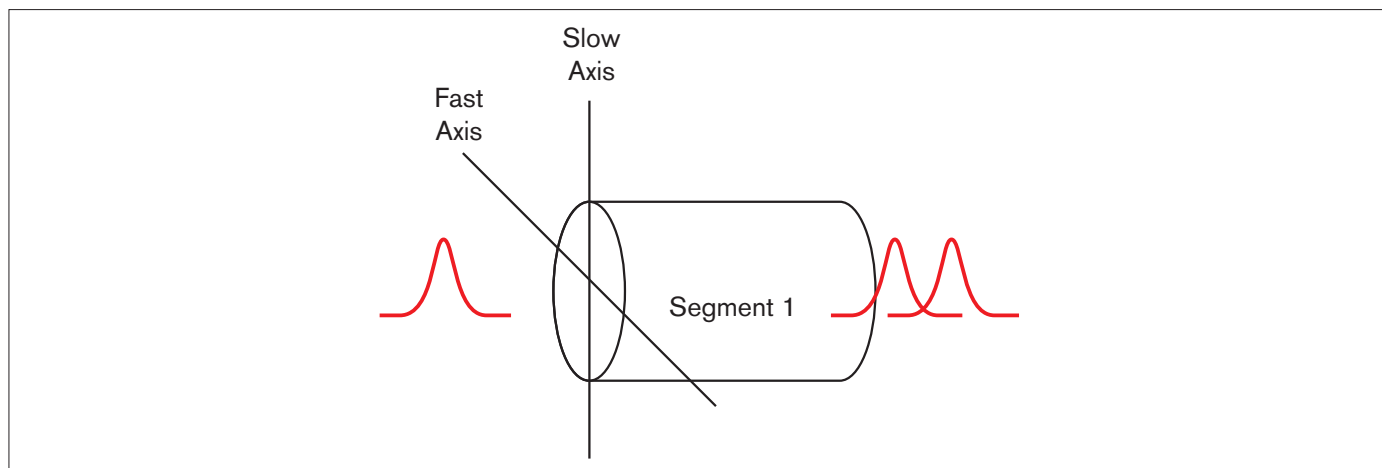


Figure 2. Polarization-maintaining fiber: A single coupling mode is imposed during manufacturing

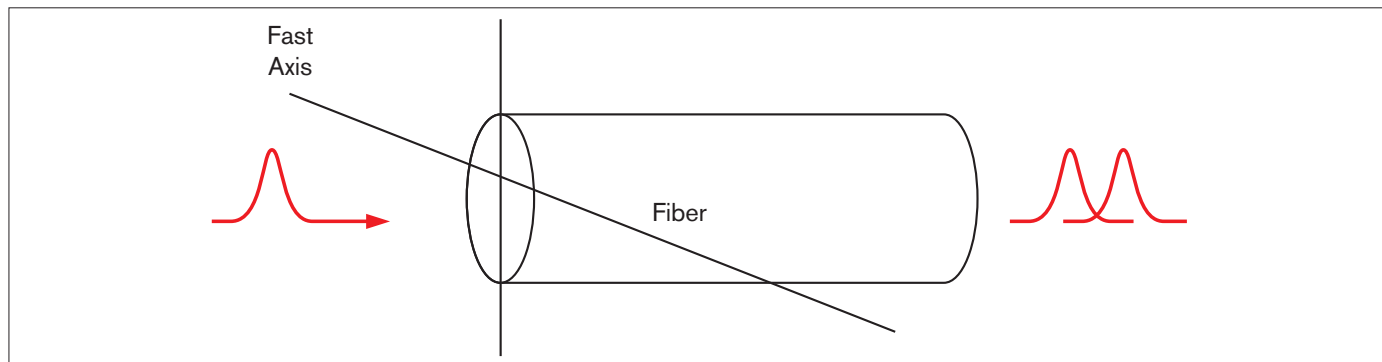
Upon closer examination of the light pulse, composed of two perpendicular polarizations, it should be noted that as this light enters a fiber that has two different propagation speeds: one of the polarizations will go faster than the other, splitting the logical "1" into two subcomponents, as illustrated in the figure below:



**Figure 3. A single coupling section divides the light pulse into two components**

## Weak-Mode Coupling

In a weak-mode coupling fiber, such as PMF, the following occurs:

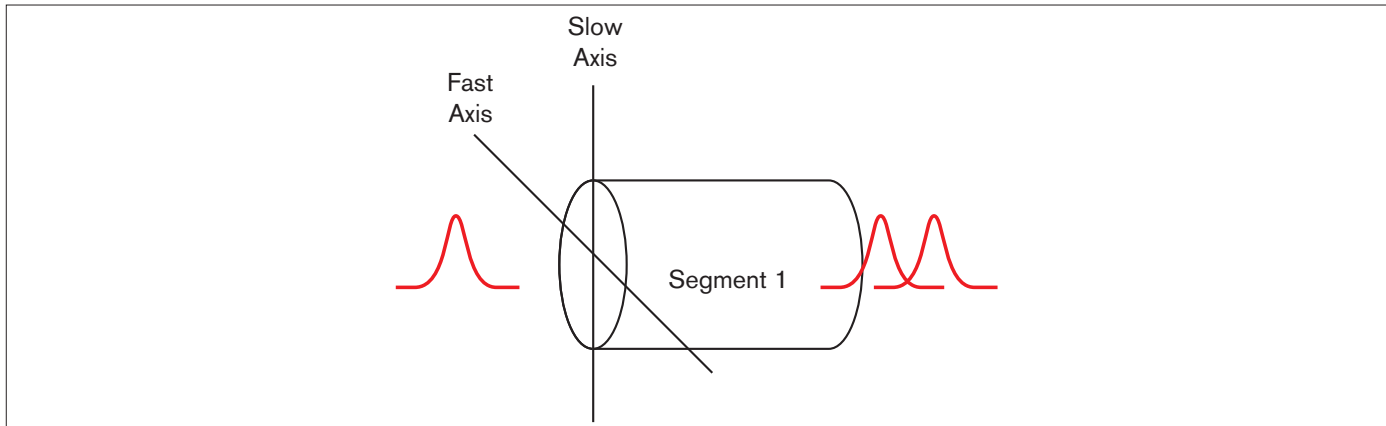


**Figure 4. Since a polarization-maintaining fiber has a single-engineered coupling mode, it is simple to predict the output**

PMD is measured as the delay at the arrival point between the two subcomponents. Since the delay is fixed and engineered in the fiber, it will not change with time and external factors, and wavelength change or the input state of polarization change will not modify the delay between the two propagation axes, making PMD measurements easily accessible while providing a high degree of accuracy.

## Non-Weak-Mode Coupling

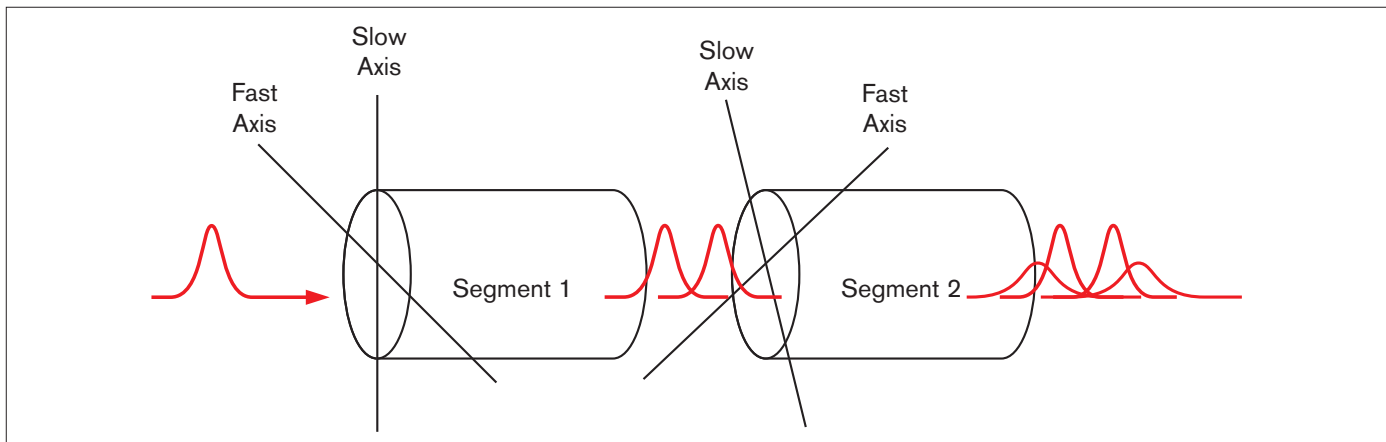
The first segment of the fiber acts as a local PMF section—it splits the pulse in two, as seen in Figure 5:



*Figure 5. A first coupling section divides the light pulse into two components*

In this case, since no speed path was engineered, there is a disturbance/imperfection/impurity a few meters after this section, and a mode-coupling change occurs, which is typical of any telecom fiber.

The two output pulses above are once again split in two and lead to the following result:



*Figure 6. Each added coupling section subdivides the pulse further and in random ways*

As the length of the fiber continues, this process is repeated a number of times, which results in a pulse that is much broader with a random distribution, as illustrated below:

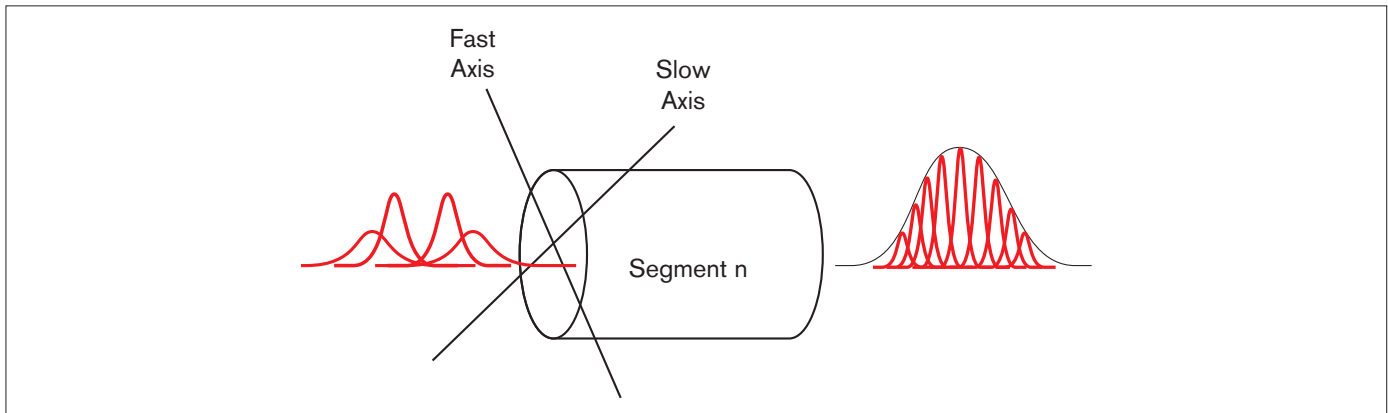


Figure 7. After  $n$  segments, the light pulse is randomly spread

PMD is defined from the root mean square (RMS) or average width of the spread. Each wavelength will see different fast and slow axis, which will change with variations in temperature, time and the input state of polarization. This results in significant variations in the overall output shape of the pulse over time. The model defined in the standards calls for infinite coupling with a perfectly distributed pulse shape at the end, but the reality is that telecom fibers can be made from anything from two to an infinite amount of sections, and they are completely unpredictable.

Some test equipment makes this assumption (infinite coupling); i.e., instruments based on the fixed-analyzer method, as well as those based on the traditional interferometric method (TINTY), which can lead to potentially large errors. Even for test equipment that goes past these assumptions (i.e., the general interferometric method and the SOP scrambling analysis method), measuring a value that is an average or the RMS of several varying and random parts is much more challenging, yet this challenge needs to be addressed since it is a real-world issue.

## Conclusion

All telecom fibers—whether standard fibers, non-zero dispersion-shifted fibers (NZDSFs), bend-insensitive fibers etc.—are all strong-mode coupling fibers. Their type, length, age and environment dictate the amount and distribution of the coupling sections and ratios, making it more challenging to test the fiber for PMD. Some test equipment vendors base their accuracy specifications on weak-mode coupling, a condition never seen in network scenarios and that is extremely easy to measure and qualify. An accuracy value based on a test scenario that will never be seen in the field cannot guarantee anything on real-world fibers. Some other test equipment vendors tackle the challenge and specify accuracy with strong-mode coupling. This accuracy is often not as good as the values quoted on weak-mode coupling, but it is a usable number and certainly has a true accuracy rate that is much higher than those specifying only weak-mode coupling values, which are in reality focusing on a specification rather than an application.

**EXFO Corporate Headquarters** > 400 Godin Avenue, Quebec City (Quebec) G1M 2K2 CANADA | Tel.: 1 418 683-0211 | Fax: 1 418 683-2170 | info@EXFO.com

Toll-free: 1 800 663-3936 (USA and Canada) | [www.EXFO.com](http://www.EXFO.com)

<b>EXFO America</b>	3701 Plano Parkway, Suite 160	Plano, TX 75075 USA	Tel.: 1 800 663-3936	Fax: 1 972 836-0164
<b>EXFO Europe</b>	Omega Enterprise Park, Electron Way	Chandlers Ford, Hampshire S053 4SE ENGLAND	Tel.: +44 2380 246810	Fax: +44 2380 246801
<b>EXFO Asia</b>	151 Chin Swee Road, #03-29 Manhattan House	SINGAPORE 169876	Tel.: +65 6333 8241	Fax: +65 6333 8242
<b>EXFO China</b>	No. 88 Fuhua, First Road, Central Tower, Room 801 Futian District	Shenzhen 518048 P.R. CHINA	Tel.: +86 (755) 8203 2300	Fax: +86 (755) 8203 2306
	Beijing New Century Hotel Office Tower, Room 1754-1755 No. 6 Southern Capital Gym Road	Beijing 100044 P.R. CHINA	Tel.: +86 (10) 6849 2738	Fax: +86 (10) 6849 2662