Bending Over Backwards

Bend-Improved to Bend-Insensitive Fiber for MDU Applications

Over the last few years, optical fiber manufacturers have developed single-mode optical fibers under the umbrella terminology of *bend-insensitive.* However, there are different degrees in macro-bend performance – from bend-improved, to bend-tolerant, to those fibers with truly bend-insensitive performance.

By David Velasquez and Bernhard Deutsch

Bend-improved fibers have been introduced into select cabling and hardware applications to significantly reduce the size of key Fiber-to-the-Home (FTTH) passive field equipment (e.g., local convergence cabinets), making installations of these state-of-the-art networks much easier and more cost-effective. Recent developments have led to bend-tolerant fibers with somewhat better bend performance than bend-improved fibers. However, the next generation of FTTH deployments and carriers' needs for applications such as multi-dwelling units (MDUs) or even in-home wiring will present new challenges that require truly differentiated performance levels in bending previously associated only with copper cable solutions.

It is widely accepted that the installation or deployment cost is the critical element in the business case for investment in FTTH networks – specifically in brownfield, single-family units (SFUs). It has become very clear that installations inside larger buildings such as MDUs present yet another level of complexity and challenges. Many FTTH network carriers quickly understood the value of pre-connectorized solutions for the drop cable assembly as well as in the form of pre-engineered flexible terminal distribution systems.

In addition, bend-improved fibers were used as enablers for small-form-factor enclosures such as local convergence cabinets. (See Figure 1) Their improved bend capability was combined with much better fiber management to design these splitter cabinets with approximately 40 percent less weight and approximately 75 percent smaller size, facilitating deployment and logistics savings while improving the neighborhood aesthetics and ease of permitting.

A key design requirement for these bend-improved fibers was backwards compatibility with the installed base of low-water-peak single-mode fibers in compliance with ITU-T recommendation G.652.D. This compliance allowed a seamless and transparent integration with the existing feeder and distribution networks. Recently, some manufacturers have introduced bend-tolerant fibers that exceed the bend performance of bend-improved fibers.

Figure 1. LCP Gen 2 vs. Gen 3.

Dealing With the Bends

In order to standardize the bend performance of these different categories, the ITU-T developed recommendation G.657 in late 2006 that defines two classes of single-mode fibers with enhanced bend performance:

- Rec. G.657.A defines the bend-improved fibers where the desire for backwards compatibility with G.652.D outweighs the desire to overcome bend loss limitations.
- Rec. G.657.B defines the bend-tolerant fibers where optimal bend performance is targeted without the requirement for full backwards compatibility.

The macro-bend performance is defined here as the induced attenuation at a certain number of full 360 degree turns around a specific bend diameter usually stated in dB/turn. (See Figure 2) It is also important to note that the macro-bend loss depends on the specific operating wavelength and increases for longer wavelengths. For the users of this standard, this leaves open a variety of combinations that makes it hard to compare the fiber specifications. It seems intuitive, though, when comparing bend performance to use the most common and most bend-sensitive operating wavelength of 1550 nm as well as a bend diameter that best

	ITU-T Recommendation		
	G.652.D	G.657.A	G.657.B
Industry terminology for fiber	Standard low-water peak single-mode fiber	Bend-improved single-mode fiber	Bend-tolerant single-mode fiber
Backwards compatibility with G.652.D	Naturally	Required	Not required
Bend loss at 15 mm diameter and 1550 nm	Not specified	Not specified	$\leq$0.5 dB
Bend loss at 20 mm diameter and 1550 nm	Not specified	0.75 dB/turn	$\leq$0.1 dB/turn
Bend loss at 30 mm diameter and 1550 nm	Not specified	$\leq$0.025 dB/turn	$\leq$0.003 dB/turn
Typically applied bend diameter	> 60 mm	20 - 30 mm	15 - 20 mm
Application examples	Feeder and distribution cables OSP drop cable assemblies	Small form factor Local Convergence Point cabinets	Same as or similar to 657.A

Figure 2.
Overview of typical bend performance for three single-mode fiber types, as well as key applications and terminology.

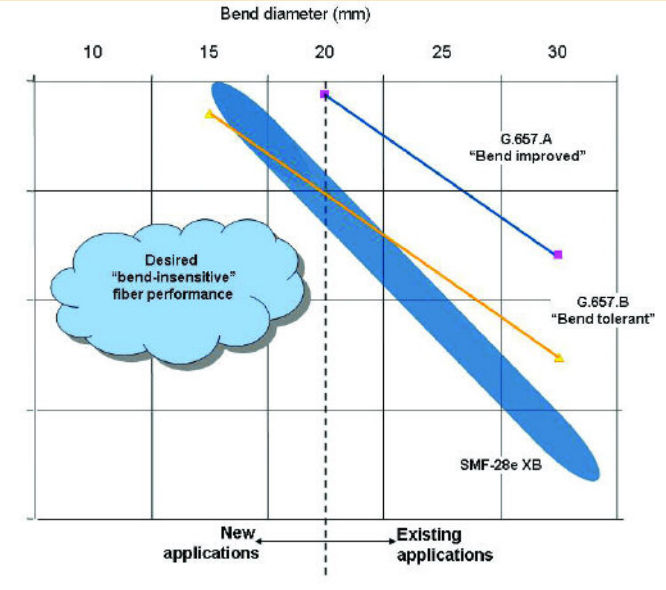

Figure 3. Bend performance.

reflects the targeted applications.

Figure 3 shows the maximum limits for macro-bend loss as defined by ITU G.657 A and G.657.B for bend-improved and bend-tolerant fibers, respectively. Note that G.657.A limits are defined for 20 and 30 mm diameter while G.657.B also defines the maximum loss at 15 mm bend diameter.

The performance for most of these bend-tolerant fibers is still limited, as their fiber design is typically based on legacy processes for forming refractive-index profiles of single-mode fibers. Figure 3 also depicts the typical bend performance range of Corning's SMF-28e XB fiber. While specified as a G.657.A bend-improved fiber, its bend performance clearly exceeds the requirements for next-generation G.657.B at those bend diameters used in most of today's hardware and cabling applications. This maximizes the performance of today's generation of FTTH products.

Again, you will notice that bend-improved fibers have a performance advantage over the latest standard releases

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(G.657.B) when used with today's legacy hardware components such as terminals, closures, cabinets, pedestals etc., that have bend diameters in the 20 to 30 mm range.

More important, in order to enable hardware components and fiber optic cables for the challenging environments of today's emerging applications without increasing system loss, another level of bend insensitivity is required. Why do you need this extra bend performance beyond G.657.B? The most important reason, of course, is the specific application.

While wrapping fiber cables around a pencil or tying a knot in the fiber cable are impressive demonstrations, the primary and real concerns of most installers tend to fall into two categories: stapling of the cable, and discrete small-radius turns - both techniques used for installing copper cables. Figure 4 shows an indoor optical drop cable being stapled to the studs similar to an MDU installation. The mechanical stress is compensated for by the cable design, but the bend is still incredibly small – much smaller than G.657.B requires as illustrated in the X-ray picture shown in Figure 5. Having a series of these staples on a cable without a truly bend-insensitive fiber in such a drop cable can easily add up to several dB of incremental loss in the drop section alone.

Talk About Flexibility

There are two issues to consider when planning for deployments that will bend a fiber to the new levels we've discussed.

Issue 1: How important is backward compatibility for installers and network planners? Many commercially available fibers performing at the required bend diameters below 15 mm are also not compatible with standard single-mode fibers (ITU-T G.652) and involve significant complexity to prepare for connectorization/termination. A new technology is required to overcome this obstacle while achieving bend insensitivity in the range illustrated in Figure 2.

Issue 2: The next consideration for installers is fiber mechanical reliability at these relatively small bend diameters. For a fiber that has undergone the standard proof test stress of 100 kpsi during manufacture, it is commonly accepted that for bend diameters greater than 64 mm, the axial stress experienced by the fiber will be lower than the safe stress level

Figure 4. Attentuation.

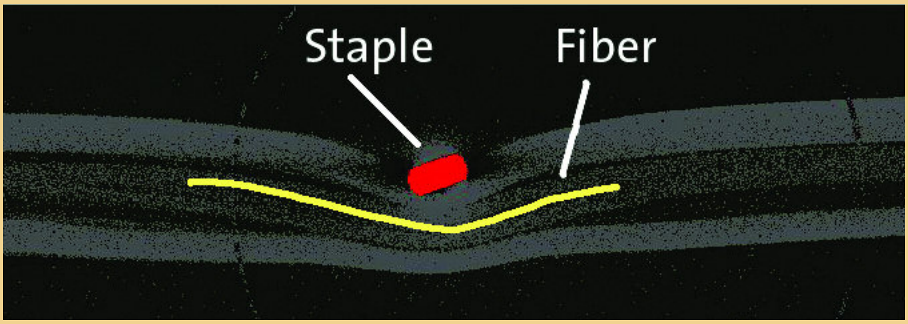

Figure 5. Stapled fiber.

(taken as 1/5 of the proof test stress), and an operator can be confident that the fiber will experience no failures due to applied stress in a 25-year lifetime. For a normal end-to-end transmission line installation of optical fiber, this 64 mm bend diameter limit is rarely exceeded. However, for FTTx network installations, the density of fiber ports in service terminals and/or the nature of indoor installation practices can drive bending of the fiber well below the 64 mm diameter limit, hence the smaller bend diameters specified in the G.657 standard. When the safe stress level is exceeded in network deployments, the fiber moves into a different regime of reliability consideration where the probability of failure during the fiber's lifetime becomes finite (non-zero).

Fortunately, the probability of failure is extremely low, even when subjected to extremely tight bend diameters of the order of 15 mm. For more than 30 years, detailed research into fiber reliability in tight bend scenarios has shown that a standard single-mode fiber when subjected to a 360 degree turn of 15 mm diameter will have only 1 ppm (one-in-a-million probability) of failure over a 25-year lifetime.

In summary, when choosing the right fiber type for applications requiring small bend diameter, it is important to differentiate between existing and new applications. For bend diameters above 20 mm, state-of-the-art bend-improved fibers can exceed even the G.657.B standard for bend-tolerant fibers while guaranteeing full backwards compatibility. However, to solve installers problems in tough environments such as MDUs where the bend diameters can go as low as 10 to 15 mm, a new technology for fiber, cable and hardware is required to ensure truly bend-insensitive performance while maintaining a high degree of reliability and enable backwards compatibility.

David Velasquez is Global Product Line Manager, Single-mode and Premises Fibers, Corning Optical Fiber, and Bernhard Deutsch, is Director of Marketing and Market Development, Corning Cable Systems. Together, they have more than 20 years of experience in the fiber optic industry. For more information, visit: www.corning.com.