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Impact of Fiber bends in fiber optic networks

Author
Sudipta Bhaumik

Abstract
Multiple bends in fiber contribute significantly to the increase in power loss in fiber optic networks. Bending losses are influenced by different optical fiber characteristics, optical fiber cable design parameters, and installation scenarios. This application note reviews benefits of reduced macro bend loss found in Sterlite's enhanced OH-LITE®(E) optical fiber and its benefits in transmission networks.

Keywords
Optical fiber, Fiber bends, long wavelength transmission networks.

Importance of bend loss in optical transmission network

As fiber optic networks extend into longer transmission wavelengths at high data rates, the optical power budget at different wavelengths needs to be maintained. Extending optical transmission window from O-band (1260 - 1360 nm) to lower attenuation C-band (1530 - 1565 nm) and upto L-band (1565 - 1625 nm), has increased capacity of installed fiber. However, a new problem arises at longer transmission wavelengths: attenuation caused by fiber bending. In single mode fiber, as the wavelength of operation increases, the mode-field diameter (MFD) also increases and the fiber's light-guiding properties become weaker. Any tight bends in the fiber cause a greater degree of light loss at longer wavelengths, and are particularly problematic in networks that were installed solely with 1550 nm transmission in mind. Table 1 shows how bend loss challenges will increase in next generation networks. It clearly shows that next generation networks will have 2-4 times higher increase in bend loss needing low bend sensitivity fiber.

Table 1

Standard	Current Generation PON		Next Generation PON on same ODN		Approximate increase in bend loss due to wavelength
IEEE	GE-PON downstream (1000BASE-PX-D)	1490 nm	10G E-PON downstream	1577 nm	3 times
ITU-T	G- PON Downstream	1490 nm	10G E-PON downstream	1577 nm	3 times
			WDM PON	1625 nm	4 times
SCTE/ITU	RF-Video downstream	1550 nm	RFoG upstream	1610 nm	2 times

Low bend loss requirement at longertransmission wavelengths were well recognized by fiber optic industry. The key standard bodies such as the International Telecommunication Union (ITU) and the International Electro technical Commission (IEC) developed more stringent fiber standards. Macro bend loss specification was extended to longerwavelength (1625 nm), specified bend radius was lowered from 37.5 to 30 mm and maximum permissible macro bend loss with 100 turns was reduced from 0.5 to 0.1 dB at 1625 nm for single mode G.652.D category fibers.

Intrinsic parameter affecting bend loss of single mode fibers

One of the primary causes for increase in attenuation in optical fiber cables is multiple bends in fiber. Hence, it becomes very critical to understand the bend sensitivity of fiber. Bending behavior of single mode fiber (SMF) is dominated bytwo parameters:

- transmission wavelength /frequency
- bending radius

The two predominant types of bends in optical fiber, i.e macro and micro bending have significant impact on the power budget and fiber reliability in networks. If macro-bending is more predominant then, it is possible to measure the equivalent bend radius. However, if micro-bending and macro-bending co-exist, then, it may not be possible to easily determine the equivalent bend radius. In such cases, it becomes mandatory to perform various physical tests in order to determine the bend sensitivity, as it relates to various parameters such as MFD, Cutoff wavelength, MAC value and coating adhesion to glass and its properties [1, 2]. The loss due to bending can be calculated by determining the equivalent bend radius and the fiber design parameters at the desired wavelength [3].

With regard to the geometrical and optical parameters, MAC value may be defined as the ratio of MFD and cut-off wavelength. The study shows that, the MAC value can be used as a reliable parameter for the characterization of the bend sensitivity of SMF [4]. In order to reduce the micro-bending loss, low modulus, primary coating is applied directly on the glass surface. In order to assure long-term reliability in the performance of optical fibers, the coating system must adhere well to the fiber and retain adhesion during service. Adhesion of coating is greatly dependent upon the degree of cure of coating. Macro bend loss which is caused by loss of power due to radiation, increases exponentially with the radius of bending and linearly with number of turns. Below a critical bend radius, the loss becomes significant and noticeable. Bending sensitivity is greatly dependent on the fiber design in addition to the composition of glass and coating material. Critical bend radius of matched clad single mode fiber can be determined by equation 1 and is presented in graphical form in Figure 1. To get noticeable loss at 1310 nm, fiber need to be bent at 25 mm radius. ITU-T recommendations specify macro bend loss value with 30 mm bend radius and commercial fibers are expected to significantly exceed the ITU-T recommendations.

$$\text{Critical bend radius } (R_c) = 20 \times \frac{\lambda}{\Delta n^{3/2}} \times \left(2.748 - 0.996\frac{\lambda}{\lambda_c}\right)^{-3} \qquad \textbf{Eq. 2}$$

Where,

λ = Transmission wavelength

Δn = Index difference between core and clad ?tc

λ_c = Cut-off wavelength

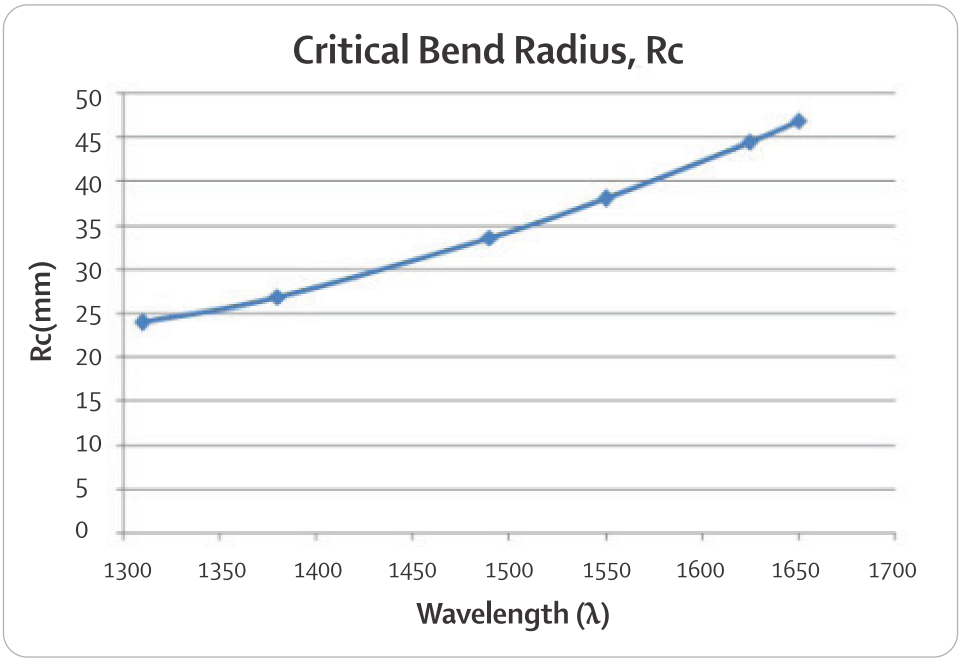

Figure 1: Wavelength vs Critical Bend Radius

Although fibers produced in a well-controlled drawing process are axial, non-uniformities of the fiber sheath, a non-uniform lateral pressure applied to it or a differential expansion or contraction due to environmental effects can cause microscopic deviations of the fiber axis. These microscopic random deviations are called “micro bends”. Micro bend losses are dependent on number of modes and wavelength [5]. Although micro bend effect can be observed at all the commonly used wavelengths (1310, 1550, 1625 nm), rapid increase in bend loss has been predicted at wavelengths above 1550 nm [6].

Despite their small diameter, the glass in SMF exhibits a very good resistance to deformation due to their high Young’s Modulus. This property is more effective against deformations at shorter wavelengths [7]. More specifically, a fiber with a radius ‘r’ and modulus ‘Ef’ embedded in a soft jacket (coating) of modulus ‘E: will resist deformations with frequencies higherthan

$$=\frac{1}{r} x \left[\frac{4}{\pi} x \frac{E_j}{E_f}\right]^{1/4} \qquad \textbf{Eq. 2}$$

Extrinsic parameters affecting bend loss of single mode fiber

An installed fiber optic cable has several situations where fiber bends occur, both by design and by accident. Various bending scenarios are

1. Low Lay Length Cable
Fibers (in loose tube) inside the cable itself are wrapped helically around a central strength member. Some cables, however, are designed for a specific use and may have to trade off fiber bending performance against the parameters required for a particular application like cable tensile strength. For example, low-lay (pitch)-length cabling used in all dielectric metal-free aerial cables. The bending situation arises from the helical winding of fiber round a central element. The resulting cable has an equivalent bending radius (EBR) that depends on the lay length of the winding. If this lay length falls below about 60 mm, it is likely that very low bending radii may occur, resulting in added power loss. Designing cables with low EBR demands enhancement in macro bend loss property of uncabled fiber and sometimes it need to be exceed G.652.D ITU-T recommendations.

2. Fiber bends inside the splice tray
During cable installation, it is a common practice to splice fiber ends. Fiber bend occurs when excess fiber is stored in loops inside the splice tray after splicing. This loss is considered in ITU-T G.652 recommendation here minimum bend radius of 30 mm is specified to reflect typical splice tray dimensions, and 100 turns represents total excess fiber from all the splice enclosures between repeaters, and a maximum 0.1 dB loss towards macro-bending is allocated in the power budget.

For example,
In case of, 70 km typical span length between repeaters and 4 km cable length, number of splice points will be 17. So number of fiber loop per splice enclosure will be maximum 6 which is equivalent to 1,1 meter. offiber.

Sterlite’s OH-LITE® (E) optical fiber is an enhanced version of ITU-T G.652.D fiber. OH-LITE® (E) offers a maximum 0.03 dB loss at 1625 nm for 100 turns at a 30 mm radius which is significantly better than ITU-T G.652 recommendation and additional specification of maximum 0.03 dB losses at 1310 and 1550 nm for 100 turns at 25 mm radius. These improved bending characteristics can enable optical transmission well into the L-band without any network performance degradation due to the fiber. One thing is certain: when this extra bandwidth is needed, the networks will be ready and able. Stringent bend characteristics at 25 mm radius will allow using smaller size splice tray in case of any space constraint during cable installation.

3. Accidental Bend

The cable installation may experience accidental unwanted low radius kinks, for example, a situation where fiber enters or leaves an enclosure over a sharp edge especially for the low diameter micro or mini cable which is flexible enough to bend easily to low radius. Most of the accidental bend situations are developed near or inside the splice enclosure (Figure 2), and therefore, it is often mischracterized as splice loss or 'bad splice'. Very tight bends can disrupt optical signal transmission completely at higher wavelengths. However, for moderate bend situations, induced bend loss at 1550 nm may be negligible, but can be noticeable at 1625 nm and can be confused as 'bad splice'.

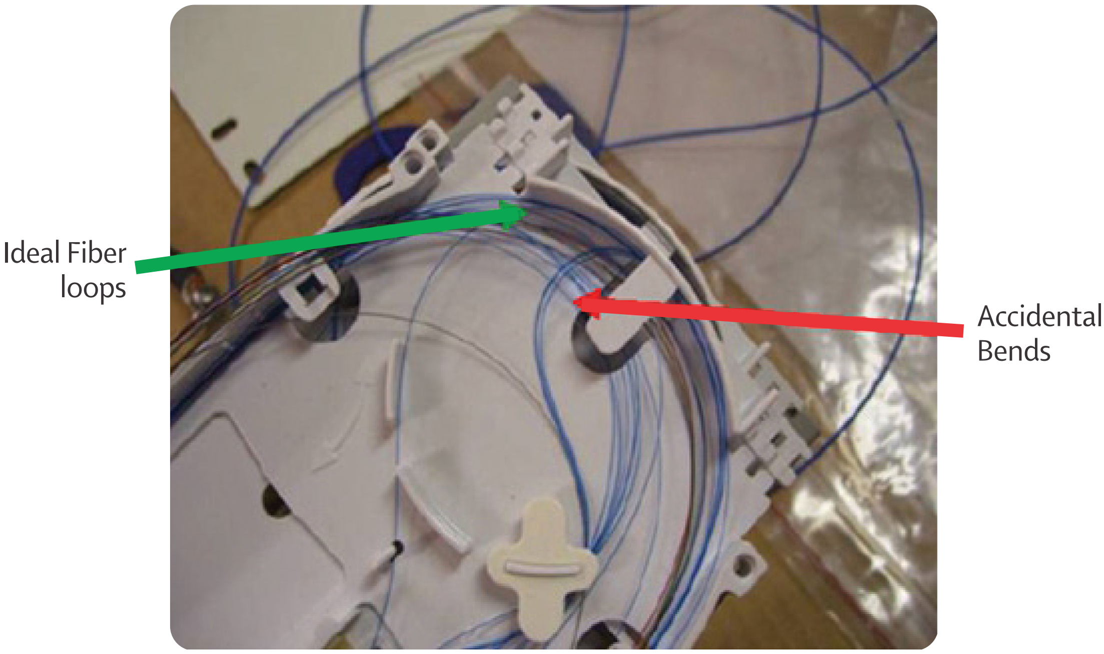

Figure 2: Fiber inside splice closure tray

When the installed cable route is commissioned, the total power loss is checked by testing every fiber link by an Optical Time-Domain Reflectometer (OTDR). The splice enclosure is generally opened for re-splicing if high splice loss is detected which takes time and adds an expense and should be avoided. Splice loss, in contrast to bend loss, is almost independent of transmission wavelength. But because most OTDRs cannot distinguish between losses originating from poor splices, stored fiber loops inside the splice enclosure, and accidental short bends, testing splice loss both at 1550 nm and 1625 nm provides useful information which will help in taking decision for re-splicing.

The improved bend characteristics of Sterlite's OH-LITE® (E) optical fiber make the fiber less vulnerable to accidental bends, allowing faster and harsher installation, and reduces network costs.

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