Different Implementations of G.657B Bend-Insensitive Single-Mode Fibers with Ultra-Low Bend Losses, Still Compatible to G.652D

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Abstract

Single Mode Fibers (SMF) showing improved bending resistance compared with standard G.652D SMF are mandatory for the Fiber-to-the-Home deployment (cf. ITU-T G657A&B recommendation). Different profile designs allow reaching G.657B bend-losses levels while staying compatible with the legacy G.652D recommendation. They all exhibit a depressed refractive index area in the cladding layer near the core that enables improved confinement of the light to the core area.

Recently, questions have been raised concerning the bend-loss for extreme conditions; suggestions have been made to specify fiber bend radius as low as 5mm. In this paper we address this development and compare the performances of three different types of structures, as well as standard step-index fibers (i.e. without any cladding assistance) for the sake of comparison.

At last, we discuss, for the first time to our knowledge, the impact of the heterogeneity of the profile over a cross section on the fiber characteristics and in particular on the bend-loss performances.

Keywords: Single Mode Fibers; Bend Insensitive Fibers; G657; Bend Losses; FttH.

1. Introduction

Macrobend losses of single mode fibers have been optimized for classical telecommunication networks a long time ago. This ended up in the ITU-T recommendations and IEC standards with the current requirement of a maximum added loss of 0.1 dB at 1625 nm for 100 turns with a 30 mm radius.

New emerging FTTH telecommunication systems have recently induced much more challenging needs. Indeed, in this harsh environment, lower volume at the storage points is required (with radii down to 15mm), as well as increased resistance towards incidental bends originating from improper fiber deployment, sharp bent for installation in corners or also, when stapling the cable along a wall.

These needs induced the recent G.657 ITU-T recommendation. This recommendation identifies two classes (see Table 1): G657A shows slightly reduced bending sensitivity compared to already existing G.652D fibers and is fully compatible with this world wide installed fiber type. G.657B fiber show further reduced bending sensitivity, but this category contains a wider range of different fiber implementations because of which this category as a whole is not G.652D compliant. However, some implementations are compliant. The B-class version specifies fiber bend-loss levels for three different bend radii, 15, 10 & 7.5mm, and for two operating wavelengths, 1550 & 1625nm.

Table 1. Main characteristics of G.657A & G.657B fibers.

Attributes	G.657A		G.657B		
MFD 1310 nm Nominal range Tolerance	8.6 - 9.5 µm ± 0.4 µm		6.3 - 9.5 µm ± 0.4 µm		
Macrobending loss					
Radius (mm)	15	10	15	10	7.5
Number of turns	10	1	10	1	1
Max. at 1550 nm (dB)	0.25	0.75	0.03	0.1	0.5
Max. at 1625 nm (dB)	1.0	1.5	0.1	0.2	1.0
Main transmission attributes (PMD / Chrom. Dispersion)	As per G.652D		TBD		

Several refractive index profile design strategies have been proposed to produce fibers compliant with G.657A and/or G.657B recommendations. For classical step-index SMF, well-known solution to reduce bending sensitivity consists in decreasing the mode field diameter over cutoff wavelength ratio (MAC value) by increasing cut-off wavelength and/or decreasing mode-field diameter. However, bending loss levels remain significantly high when applying incidental kinks with radii in the order of 1 to 10 mm. Moreover, there is not much room to decrease the MAC value if fiber is to be kept fully compliant with the ITU-T G.657 “class A” standard. So, step-index profiles can be designed to be compliant with G.657A (small core designs) or G.657B (very small core designs) but there are no solutions to get fibers that are both G.657A&B compliant.

New types of fibers have been proposed to solve this issue. They all exhibit a depressed refractive index area in the cladding layer near the core that enables improved confinement of the light to the core area, whatever the fiber condition. We can distinguish three types of depressed-assisted profiles: Solid-Trench-Assisted [1], Random-Void-Assisted [2] and Hole-Assisted [3] Fibers structures. In the following, STAF, RVAF and HAF acronyms will be used. Figure 1 shows typical profile cross-sections of these structures.

In this paper, we evaluate the interest of such structures to make bend-insensitive cables under extreme conditions. In section 2, we give the fiber-design point of view, focusing on bend losses for bend radii as low as 5mm. We also discuss the impact of the heterogeneity of the profile over a cross section on the bend-loss performances. In section 3, we give the cable point of view. Two bending aspects: 90° cable bends and flat stapling of optical indoor cable, that highlights bend loss and reliability, are discussed.

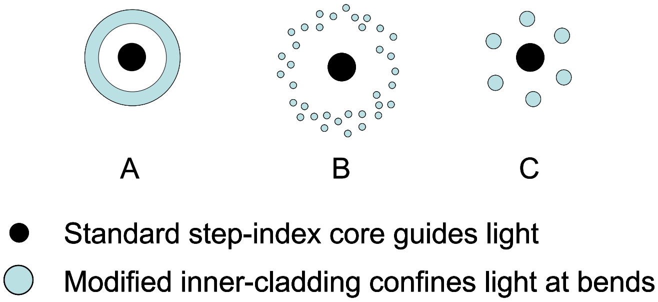

Figure 1: Solid-Trench-Assisted (A), Random-Void-Assisted (B) and Hole-Assisted (C) index cross sections.

2. Fiber Point of view

2.1 Solid-trench-assisted fibers

In 2006, we introduced solid-trench assisted bend-insensitive fibers made with our versatile Plasma Chemical Vapor Deposition (PCVD). At that time, we showed through careful design analysis of all profile parameters, that it is possible to find an optimized trench design which improves the fundamental mode confinement without reducing its mode field diameter [4]. The solid trench also improves the micro-bending sensitivity of the fibers. Combining trench-assisted profile with very low primary coating modulus remarkably reduced the micro-bending sensitivity [5]. This allows to improve low-temperature performance down to –60°C and supports new, smaller and less robust cables for use to and in homes and business [6]. We also demonstrated that solid-trench-assisted fibers offer improved safety in high-power applications ranging from 1360nm to 1625nm in case of tight fiber bends [7]. A real danger of degradation indeed exists when the power lost at the bend is absorbed by the coating and the temperature exceeds ~85°C. We estimated that solid-trench assisted fiber can withstand 1W at 1625nm for a bend radius as low as 3mm whereas the reference G.652 step-index fiber was limited to a radius of 10mm.

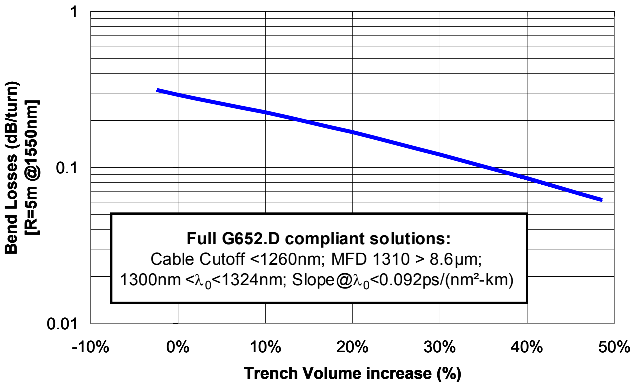

Figure 2: 5mm radius bend losses evolution at 1550nm as a function of the trench volume. 0% corresponds to our current STAF product and is taken as the reference.

All these results proved that our solid-trench fiber significantly improved bending performances of the fiber. This improvement was obtained while ensuring a full compliance with G.652 recommendation and thus full backward compatibility with the former step-index fiber generation. In this field, fusion splicing between the two types of fibers gives equivalent performance as fusion splicing between two regular step-index fibers [5], when selecting the optimum settings.

2.2 Depressed-assisted profile design addressing the 5mm radius condition

Recently, questions have been raised concerning the bend-loss resistance under extreme conditions; suggestions have been made to specify fiber bend radius as low as 5mm. This question will be addressed from the practical indoor cable point of view in Section3. Here we consider the fiber-design point of view.

Our current STAF presents typical bend losses for such a low radius of 5mm between 0.2 to 0.3dB/turn at 1550nm, which is two orders of magnitude lower than those of a standard G.652 fiber. It is possible to find STAF solutions with better performances by increasing the trench volume, i.e. the integral of depressed index (relative to the infinite cladding) over the entire trench cross-section area. Figure 2 represents the bend loss for a 5mm radius at 1550nm as a function of the trench volume compared to our current STAF. Extensive simulations were carried out to optimize solid-trench-assisted profiles, taking the lowest possible 5mm bend loss as an optimization criterion, while ensuring full compliance with G.652 recommendation. It clearly appears in this graph that 5mm bend losses lower than 0.10dB/turn at 1550nm can be reached when the trench volume is increased to ~40%.

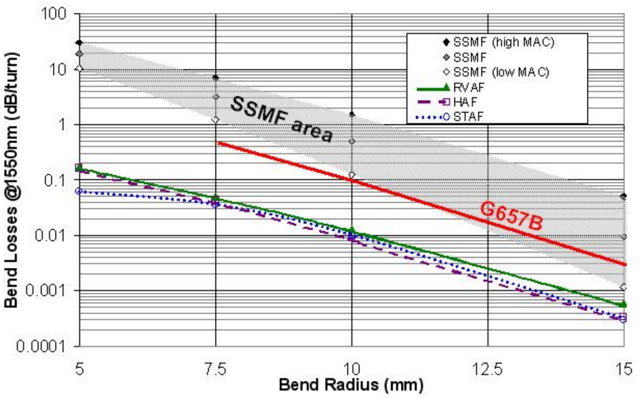

Figure 3: Bend Losses dependence with the bending radius of SSMF, Random-voids-, Hole- or Trench-Assisted Fibers (RVAF, HAF or STAF).

For random-void-assisted or hole-assisted designs, same conclusions apply. The volume of the assisting part of the cladding (solid trench, random voids or holes) is the main parameter that controls bend-loss levels for radii as low as 5mm. Note that reaching such high volumes (whatever the process and/or design used) will have an impact on the manufacturing procedures and eventually on the CAPEX. In Figure 3, bend loss dependence on bend radius is represented for the three types of structures as well as for the standard step-index fibers (i.e. without any cladding assistance) for the sake of comparison. Very small differences appear between the different fiber designs but refined optimization might lead to same performances. Note that the STAF solution is fully compliant with the G.652.D recommendation, including cable cutoff wavelengths (~1224nm), PMD link design values (to the level of standard solid step-index fibers) and chromatic dispersion attributes. This might not be the case for the other types of structures that are often presented as G.652 *compatible* fibers. For example, the RVAF studied here was slightly beyond the G.652 chromatic dispersion recommendations.

It is also important to compare the bending homogeneity of the different bend-insensitive-fiber designs. STAFs produced by the versatile PCVD process are able to guarantee an excellent homogeneity of the depressed-volume and consequently of the bending behavior. The trench internal and external interfaces are very close to perfect circular interfaces and these dimensions do not vary significantly along the fiber. Quantitatively speaking, the trench-volume variations are lower than 0.1% in the radial dimension and lower than 0.1% after 1km in the longitudinal dimension. This very good homogeneity level ensures very stable and robust bend loss performance of STAFs for indoor applications.

For the sake of comparison, we have also modeled the bend loss homogeneity in the radial dimension of the three structures. For the STAF, we have considered the worst case of 0.1% variations. For RVAF, we have considered a random distribution of voids surrounding a standard step-index core. A set of 100 voids has been defined, with centers uniformly distributed between an inner radius of 12µm and an outer radius of 18µm and angular position uniformly distributed in the [0-2π] interval. The hole diameter follows a nearly Gaussian distribution center on a 0.36µm diameter, with a 0.3µm standard deviation [8]. For HAF, diameters for the holes were chosen randomly, with typical 2% fluctuations around the mean value.

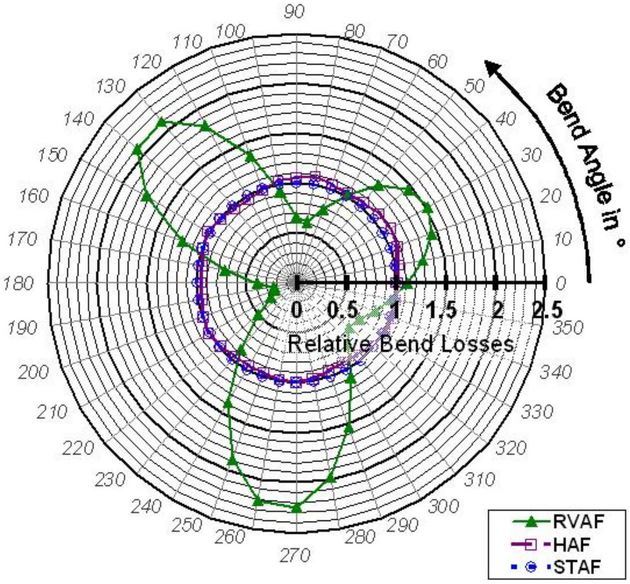

Figure 4: Bend-Loss variations as a function of the bend direction for the three type of structures.

Figure 4 illustrates this aspect for three types of fibers: the angular coordinate is the direction of the bend and the radial coordinate is the corresponding bend loss (normalized to the average bend loss for all bend directions). For the RVAF, bend-loss fluctuations are around one order of magnitude. For HAF and STAF, we estimate variations of around 1.18 (18%) and 1.004 (0.4%) respectively (this last result being in the order of the precision of our model).

Due to the random nature of the voids, approaching depressed-volume homogeneity of the order of 0.1% (both radially and longitudinally) for RVAF seems extremely difficult.

3. Cable Point of view

In the foregoing section we discussed the fiber behavior of bend loss for a radius of 5 mm. This bare fiber bend radius has been brought into discussion representing a worst case minimum fiber bending radius, which might appear in FTTH cable installation. In addition a maximum installation loss per deployment (dwelling unit) has been described of 0,25 dB. [9] [10]. In this section we address some concerns to these views focused on two bending aspects: 90° cable bends and flat stapling of optical indoor cable, highlighting bend loss and reliability.

3.1 5 mm fiber bend radius in 90° cable curves

The probability of achieving a tight 5 mm fiber bend radius is highly dependent on the cable construction and the installation method for these cables. In general indoor cables for FTTH will show enough so called “self limiting” features (robustness) because of which the indicated tight bending radii are not met, applying appropriate installation techniques. Our investigations show that even for the small size 3.0 mm indoor cable the average 90° sharp bend loss is only 0.016 dB (see Figure 5) using our current STAFs, the world first commercially available bend-insensitive G.657B fiber (and G.652D compliant). Assuming on average ten of such 90° cable bends per dwelling unit, this results in only 0.16 dB loss per deployment for a 3.0 mm indoor cable. This is well within the indicated acceptable maximum.

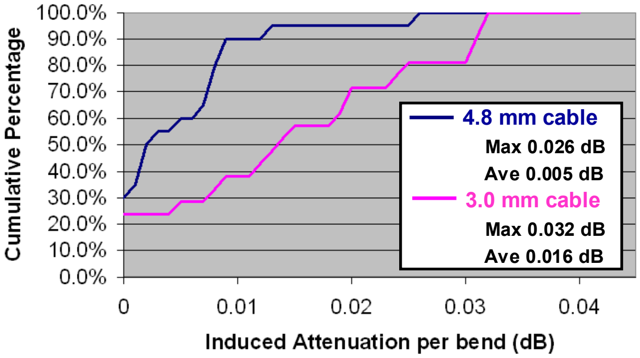

Figure 5: Induced attenuation distribution with 90° sharp bends in 4.8 mm and 3.0 mm indoor cable.

3.2 Incorrect fiber indoor cable stapling technique

Besides the cable construction itself, also the installation method is of critical importance. For economic (fast, low-cost) installations in FTTH applications, stapling techniques are proposed. In discussions concerning the minimum fiber bend radius one of the arguments for a R=5 mm specification has been the use of flat staples applied to round optical cables. This choice will automatically lead to severe cable deformation, likely resulting in small fiber bend radii e.g. of 5 mm, however with the large risk of even smaller radii. Flat stapling of round optical indoor cable should automatically be associated with highly uncontrolled installation practices.

Key issue in applying the stapling technique is the adaption of the staple form to the cable shape. An industry-wide accepted practice is to use round staples in combination with round cables (both for copper and for optical cables). With good reason, such installation techniques have been standardized:

- ISO/IEC 14763-2, Cable installation:

"When installing cables appropriate techniques shall be applied"
"Prevent pressure marks (e.g. through improper fastening or crossovers) on the cable sheath or the cable elements"
"Prevent optical fiber within cables experiencing direct stress following installation".

- EN50174-3, Cable installation:

"Proper installation practices shall be observed for cabling to ensure performance of the cabling system over its life cycle".
"Minimum bend radii shall never be less than those specified by the manufacturer/supplier"
"No forces shall be allowed that cause damage (e.g. through improper fastening or crossovers) to the cable sheath or the cable elements"

Optical fiber indoor cable installation should be performed in similar ways as is common practice for copper cables (CAT5/6 or coax). These techniques (using round staples or cable clamps) have been developed for fast and economic installation, even by lower skilled installers, without introduction of severe deformation of copper cables. Installation of optical fiber indoor cable should not be performed with worse techniques then applied for copper cables.

Using ruggedized MDU Cable, we investigated the stapling effect using 4.8 mm and 3.0 mm indoor cable equipped with our current STAF, applying the correct installation techniques, see Figure 6. In all cases the total induced attenuation stayed within 0.25 dB.

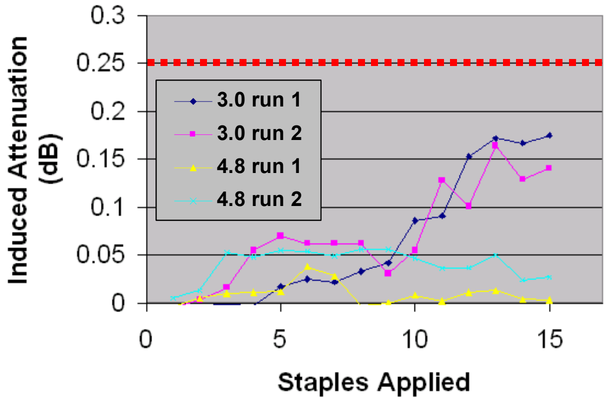

Figure 6: Induced attenuation of installed ruggedized MDU cable (3.0 mm and 4.8 mm) equipped with regular STAF applying minimum 10 bends and using round staples.

Another cable installation investigation is shown in Figure 7, with combined stapling / cable bending using a 4 mm diameter indoor cable. Applying 89 round staples and 15 cable bends of 90°, a total installation loss of only 0.05 dB was observed at 1550 nm applying our STAF.

3.3 Fiber reliability at 5 mm (or smaller) bend radius

Another argument against a too tight and uncontrolled installation method using flat staples is the mechanical reliability. A 5 mm radius places fiber in a strain condition above the standardized 100 kpsi prooftest value, see Figure 8, increasing the probability of fiber breakage.

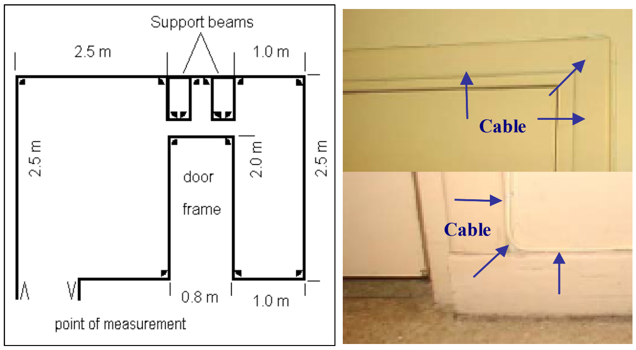

Figure 7: Stapling test indoor cable (89 staples, 15 angles 90°) that induces 0.05dB max @1550nm with regular STAF.

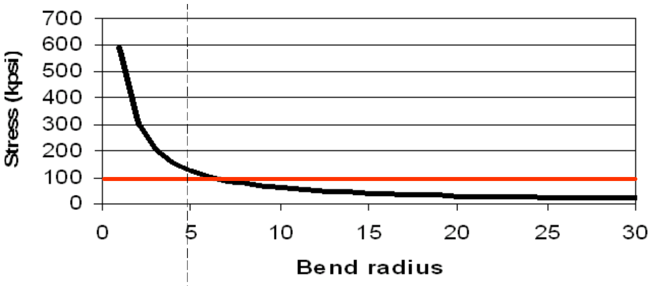

Figure 8: Bend induced stress in a 125µm fiber.

Stapling related factors influencing the loss and mechanical reliability are:

- Staple Type (Round vs. Flat)
- Staple Gun age (Force applied)
- Operator factors
- Wood finish
- Wood density

In no way it can be claimed that using flat staples, the minimum radius will be limited to 5 mm. Because of this uncontrolled technique (due to e.g. operators / staple gun / wood characteristics) even smaller fiber bend radii are very well possible, resulting in unreliable installations (uncontrolled mechanical reliability and potential higher bend losses).

Introducing a tight fiber bend radius of 5 mm based on the allowance of flat stapling techniques for round optical indoor cable is in fact an invitation of bad installation practices.

4. Conclusion

It has been shown that solid-trench-assisted fibers can meet tighter bending specifications (R=5mm). However, it should be realized that tight bend-radius (R=5mm) specified fiber implementations – whatever the production process – will lead to higher CAPEX compared to regular bend-insensitive fibers fulfilling the present G.657B (and G.652D) specification.

The new proposed 5 mm fiber radius specification is superfluous when applying appropriate (and standardized) cable installation techniques, both from a bend loss as well as from mechanical reliability aspect. Acceptation of this specification will be an invitation to poor and unreliable cable installation, which is not in the best interest of our industry.

When industry accepted practices are followed, our installation investigations indicate minimal induced attenuation from (round) staples applied to indoor cables equipped with STAF and no significant reduction in mechanical performance.

Regular solid-trench-assisted fiber produced by the mature PCVD process, show the best overall performance for presently required FTTH applications, taken into account low bend loss, low attenuation, low splice losses and low CAPEX.

5. References

[1] G. Kuyt et al., "The impact of new bend-insensitive single-mode fibers on FTTH connectivity and cable designs", Proc. 56th IWCS Conference, pp 363-371, November 2007.

[2] M.-J. Li, "Ultra-low bending loss single-mode fiber for FttH", Proc. OFC/NFOEC Conference, PDP10, March 2008.

[3] K. Ieda et al., "Transmission Characteristics of a Hole-Assisted Fiber Cord for Flexible Optical Wiring", Proc. 54th IWCS Conference, pp 63-68, November 2005.

[4] L.A. de Montmorillon et al., "Bend-Optimized G.652D Compatible Trench-Assisted Single Mode Fibers", Proc. 55th IWCS conference, pp 342-347, November 2006.

[5] L. Provost et al., "Cabling and installation aspects of full-silica bend-insensitive single-mode fibres", Proc. Optical Cabling and Infrasructure (OC&I) conference, Krems, Austria, July 2008.

[6] B. Overton et al., "Microbending –Resistant Fiber", IWCS 2008.

[7] M. Bigot-Astruc et al., "High-power resistance of bend-optimized single-mode fibers", Proc. OFC/NFOEC conference, paper JWA2, February 2008.

[8] D. Bookbinder et al., "Microstructured optical fiber and its manufacturing method", Application WO 2007/055881, May 2007.

[9] David Z. Chen et al., "Requirements for Bend Insensitive Fibers for Verizon's FiOS and FTTH Applications", OFC/NFOEC conference, paper2-26, February 2008.

[10] Bernhard Deutsch et al., "New technology provides breakthrough for MDU fiber installation", Lightwave, October 2007.

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