All-Solid G.652.D Fiber with Ultra Low Bend Losses Down to 5 mm Bend Radius

Louis-Anne de Montmorillon (1), Frans Gooijer (2), Nelly Montaigne (3), Stef Geerings (2), David Boivin (1), Lionel Provost (1), Pierre Sillard (1)

(1) Draka Communications, Route de Nozay, 91460 Marcoussis, France, email: louis_anne.de_montmorillon@draka.com
(2) Draka Communications, Zwaanstraat 1, 5651 CA Eindhoven, The Netherlands, email: frans.gooijer@draka.com
(3) Draka Communications, 644 boulevard Est, 62138 Billy Berclau, France, email: nelly.montaigne@draka.com

Abstract:
We demonstrate the feasibility of all-solid G.652.D fibers that exhibit bend losses 10 times lower than ITU-T recommendation G.657.B and 0.05 dB/turn at 5 mm bend radius at 1550 nm.

OCIS codes: (060.2430) Fibers, single-mode; (060.2400) Fiber properties

1. Introduction

The emergence of Fiber-to-the-Home (FttH) networks subject to harsher environments than long-distance networks has spurred the development of bend-insensitive fibers. In this context, the ITU-T recommendation G.657 identifies two fiber classes (see Table 1): G.657.A shows slightly reduced bending sensitivity compared to the well-known G.652.D and is fully compliant with this worldwide installed fiber type; G.657.B shows further reduced bending sensitivity with specifications given at three different bend radii (15, 10 and 7.5 mm), but its compatibility with G.652.D is not mandatory.

Standard step-index G.652.D fibers cannot comply with this B class. As a result, new types of index profiles have been proposed. They all exhibit a depressed index area in the cladding near the step-index core that allows for better light confinement, whatever the fiber condition. In 2006, we introduced a solid Single-Trench-Assisted bend-insensitive Fiber (STAF) [1]. This fiber is fully compliant with both ITU-T recommendations G.652.D and G.657.B, and exhibits bend losses two orders of magnitude lower than those of standard step-index G.652.D fibers.

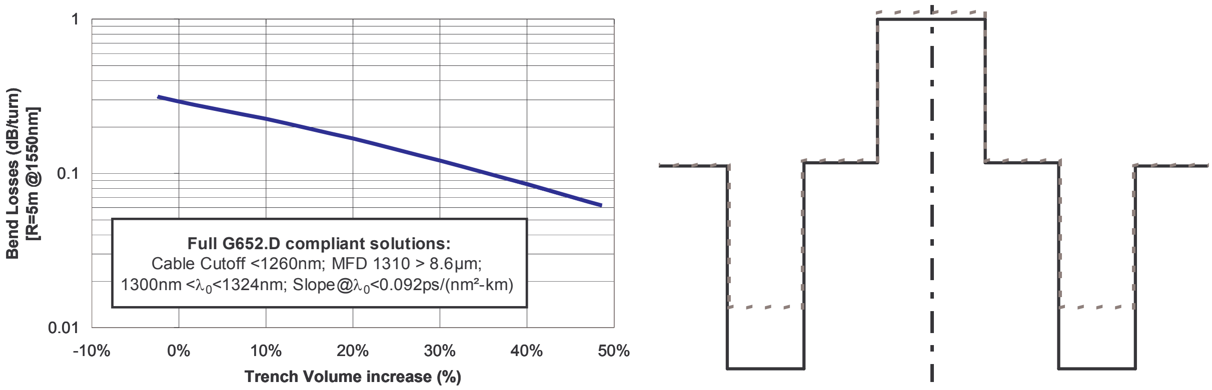
Recently, questions have been raised concerning bend losses for extreme conditions and suggestions have been made to specify bend radius as low as 5 mm. Random voids have been presented as an alternative to solid trenches and samples with 0.03 dB/turn bend losses at 5 mm bend radius at 1550 nm have been reported [2]. A solid ring-assistance concept has also been proposed and bend losses below 0.07 dB/turn at 5 mm bend radius at 1550 nm have been demonstrated [3]. This latter concept utilizes a resonant mechanism that improves the cutoff versus bend loss trade-off, but it requires tight controls of the parameters of a quite complex profile.

In this paper, we demonstrate that equivalent bending performances can be obtained with simple and robust solid STAFs, compatible with all G.652.D attributes and with mature manufacturing processes.

2. Single-Trench-Assisted Fiber Design

It is possible to find solid STAF designs with better bend losses at 5 mm bend radius by increasing the trench volume, i.e. the integral of the trench index (relative to the optical cladding) over its cross-section, and by carefully choosing its position. Fig.1(a) represents the modeled bend losses at 5 mm bend radius at 1550 nm as a function of the trench volume compared to that of the solid STAF of Ref. [1]. Our model solves the full-vectorial wave equation with the finite-element method. Extensive simulations have been carried out to optimize solid STAF profiles, taking the lowest possible bend losses at 5 mm bend radius as an optimization criterion, while ensuring full compliance with all G.652.D attributes. Fig.1(a) shows that bend losses lower than 0.10 dB/turn at 5 mm bend radius at 1550 nm can be obtained when the trench volume is increased by ~40%.

Such solid STAFs, produced with the mature Plasma Chemical Vapor Deposition (PCVD) process, exhibit very good homogeneities of the trench parameters. The trench internal and external interfaces are very close to perfect circular interfaces and these dimensions are almost constant along the fiber. Quantitatively speaking, the trench-volume variations are lower than 0.1% in both radial and longitudinal (after 1 km) dimensions, which ensures very stable and robust bend-loss performances for FttH applications. We estimate bend-loss fluctuations lower than 0.4% for the worst case of 0.1% radial variations (this result being in the order of the precision of our model).



(a) (b)

Fig.1: trench volume impact. (a) Bend losses at 5 mm bend radius at 1550 nm as a function of the trench volume (0% corresponds to the solid STAF of Ref. [1] and is taken as reference). (b) Schematic of the profiles of Ref. [1] (dashed grey lines) and of an optimized set point for low bend losses at 5 mm bend radius (dark full lines).

3. Experimental results

We have developed such a solid STAF with an increased trench volume of 50% compared to that of the STAF of Ref. [1] (see Fig.1(b)). Results of typical samples are presented and compared to those of the Ref. [1] in Table 1.

Table 1: Propagation characteristics of the newly-developed fiber (STAF[2008]) and of the fiber of Ref. [1] (STAF [2006]).

Sample	STAF [2006]		STAF [2008]	
Cable Cutoff (nm)	1210		1250	
MFD (μm) at 1310 nm at 1550 nm	8.9 10.0		8.6 9.6	
$\lambda 0$ (nm)	1318		1316	
Slope at $\lambda 0$ (ps/nm²-km)	0.089		0.088	
PMD (ps/km$^{1/2}$)	0.02		0.02	
Loss (dB/km) at 1550 nm at 1625 nm	0.188 0.200		0.188 0.201	
Macrobending loss Wavelength (nm) = (dB/turn)	*1550*	*1625*	*1550*	*1625*
5 mm radius	*0.2*	*0.6*	0.05	0.14
7.5 mm radius	*0.08*	*0.2*	0.01	0.05
10 mm radius	*0.01*	*0.04*	0.004	0.01
15 mm radius	0.001	0.005	0.0003	0.001

These newly-developed fibers are all fully compliant with ITU-T recommendations G.652.D, G.657.A and G.657.B, including mode-field diameter, dispersion, PMD and cutoff attributes. Concerning this latter parameter, it has been shown that with cable cutoff wavelengths below 1260 nm, such solid STAFs exhibit multi-path interference values below -40dB in all harsh field deployment scenarios, yielding sufficient margins for FttH applications [4]. They also exhibit attenuation levels lower than 0.201dB/km over the entire C- and L-bands, ranging from 1530 to 1625 nm. At last, bend losses are more than 10 times lower than those of ITU-T recommendation G.657.B and 0.05 dB/turn at 5 mm bend radius at 1550 nm have been obtained (see Fig.2).

Concerning splicing, these new solid STAFs have same performance as that of the STAF of Ref. [1] for standard fusion splicer equipment [5]. For core alignment-based fusion splicing, average splice losses of 0.02dB are obtained when splicing STAFs with themselves, while splicing STAFs with standard step-index G.652.D fibers result in average losses of 0.04dB. No specific tools or procedures are required for connectorization aspects. This demonstrates the full backward compatibility of STAFs with the most commonly installed G.652 fibers.

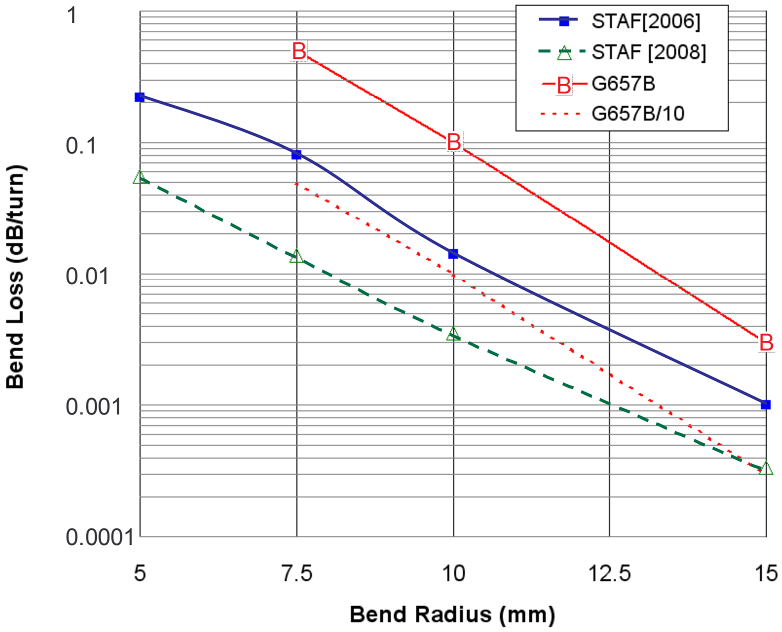


Fig.2: bend losses as a function of bend radius for the newly-developed fiber (STAF[2008]) and for fiber of Ref. [1] (STAF [2006]).

5. Conclusion

We have demonstrated the feasibility of solid single-trench-assisted fibers that are fully compliant with standard step-index G.652.D fibers and that exhibit bend losses more than ten times lower than those of the most severe G.657.B bend-insensitive fibers. In addition, bend losses of 0.05 dB/turn at 5 mm bend radius at 1550 nm have been obtained. Note that for such tight bends, poor cable installations might become an issue, especially regarding long-term mechanical reliability.

This simple and robust concept is compatible with mature manufacturing processes such as the versatile PCVD process. This opens the door to extremely compact sub-components and makes all-solid G.652.D fiber a good candidate for future home networks.

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7. References

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