The impact of new bend-insensitive single mode fibers on FTTH connectivity and cable designs

White Paper

Gerard Kuyt[1], Piet Matthijsse[1], Laurent Gasca[2], Louis-Anne de Montmorillon[2],
Arnie Berkers[1], Mijndert Doorn[3], Klaus Nothofer[4], Alexander Weiss[5]

[1 - 2]Draka Comteq Optical Fibre; [3 - 5]Draka Comteq Cable Solutions

[1]Eindhoven, The Netherlands; [2]Marcoussis, France
[3]Gouda, The Netherlands; [4]Santander, Spain; [5]Mönchengladbach, Germany

+31-40-2958705 · gerard.kuyt@draka.com

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+31-40-2958705 · gerard.kuyt@draka.com

Abstract

Reduction of bending loss has been recognized as an important aspect in optimizing single mode fibers for FTTH applications. This paper highlights some characteristics of different implementation types of bend-insensitive fiber. In addition the advantages of such fiber in connectivity and new indoor cable designs are presented.

Keywords: Single Mode Fibers; Bend-Insensitive Fibers; Bending Loss; Connectivity; Cable Designs; FTTH; G.657.

1. Introduction

In the past decades single mode fibers have been optimized for particular characteristics, strongly depending on the actual applications of that moment. With increasing data rates, for instance, Polarization Mode Dispersion (PMD) specifications became important; the introduction of Dense Wavelength Division Multiplex (DWDM) systems resulted in non-linear issues, leading to the development of optimized fibers known as Non-Zero-Dispersion Shifted (NZDS) fibers. At this moment the focus of applications is on Fiber to the Home (FTTH) networks, where reduced bend loss becomes a key feature.

For telecom networks bend loss has hardly been an issue for many years. Bending the fiber into a helical path during cabling (with bend radii well over 50 mm) is needed to create fiber over-length allowing for cable elongation during installation and a suitable temperature operating window. This requirement was met quite easily. A further requirement dealt with the storage of the fiber over-length in the splice enclosures along a route. The well-known "100 turns" requirement was created to represent the total number of fiber storage loops in a route; fiber storage radii decreased to 30 mm. A more severe tightening occurred from the increase of the operational wavelength up to 1625 nm. This resulted in 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.

First bend loss improvements were addressed in standard single mode fiber (SMF) using simple step-index core profiles. Fiber manufacturers gradually decreased the nominal mode-field diameter (MFD) at 1310 nm down to about 9 µm and increased the average cable cut-off wavelength to a value just below the lower limit of the operating wavelength window. These transitions were supported by narrowing production tolerances.

This 30 mm bend radius requirement had a big impact. In most fiber management systems it can be recognized in storage cassettes as well as in entrance and exit guides. More or less, the 30 mm radius has been considered as being a "natural law" which should not be violated. However, this situation has come to an end.

For higher level networks usually well trained installation crews are used and/or costly commissioning procedures applied. This is no longer affordable in optical access networks, where labor and productivity impacts are much heavier due to the many splitting points and the frequent network changes inherent to the nature of direct service delivery to individual end-customers. Fast, efficient and low cost installation is of high importance here. Bend-loss insensitive fibers, with tight bending specifications offer such low cost installation.

The need for such bend-insensitive SMF was recognized by operators and industry last December (more than half a year earlier than originally planned) by approving ITU-T Recommendation G.657 "Characteristics of a Bending Loss Insensitive Single Mode Optical Fibre and Cable for the Access Network" [1]. This recommendation contains two classes: class A and class B.

G.657A is fully compliant with G.652D, showing moderately improved bending specifications (about 10 times improvement compared to the macrobending specification of G.652D). G.657B does not necessarily need to be compliant to G.652D, e.g. because of small mode field diameter. Class B shows further tightened macrobending specification (about 7 to 10 times improvement compared to class A). Table 1 shows the main characteristics of the G.657A and B specifications.

In this paper we demonstrate that fibers with optimized trench-assisted step-index structures ("Trench-assisted" fibers) can advantageously replace classical SMF without any constraint [2 - 4] and a comparison will be given with other proposed implementations of bend-insensitive SMF.

Table 1. Main characteristics of ITU-T Rec. G.657 (class A and class B)

Attributes	G.657A		G.657B		
MFD 1310 nm					
Nominal range	8.6 - 9.5 µm		6.3 - 9.5 µm		
Tolerance	± 0.4 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		

Besides its optimized low macrobend loss - supporting smaller connectivity - this fiber also shows reduced microbending, introducing the possibility to develop new types of cable designs.

2. New Bend-Insensitive fiber

In the development of low bend loss SMF, we considered backwards compatibility a key requirement for network operators. Lower bend loss is realized either by using more complex core index profiles or simply by increasing the core refractive index. In this case, the increased refractive index is compensated by a simultaneous reduction of the core size. In case of a large increase of the index delta, the macro bending loss can be quite low (e.g. within the tight G.657B specification), however the resulting MFD also will be very low (6 to 7 µm), outside ITU-T Rec. G.652D and Rec.657A. This is hardly acceptable for applications in telecom networks due to the mismatch with the SMF installed base. Apart from technical problems with increased coupling losses, this solution requires precise registration of the use and stock of these cables since they should not be mixed with conventional cables. This registration results in an accompanying cost factor.

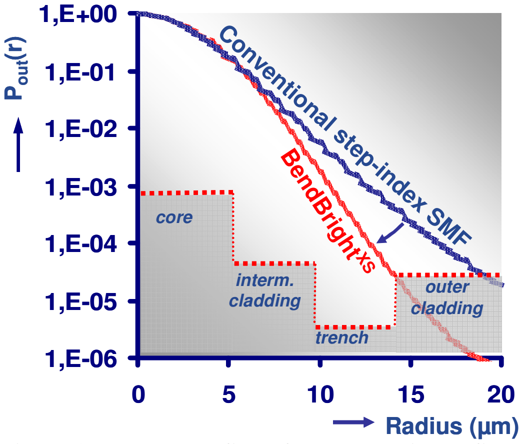


Figure 1. Index profile of trench-assisted fiber (dotted line) and modeled fundamental power (P_{out}(r) in %) propagating outside radius r for this profile and for an equivalent step-index profile (0.5% power loss corresponds with 0.02 dB)

We developed a SMF with an optical field confining trench just outside of the core, see Figure 1 and [3]. Combined with a slight reduction of the 1310 nm MFD to an average value of about 8.9 µm, the bend loss is significantly reduced. This trench-assisted SMF can easily be mixed with conventional standard SMF without violating the requirements for practical installation, maintenance or operation of the optical network.

2.1 Macrobending Loss

The described trench-assisted SMF is fully compliant with the current ITU-T G.652D Recommendation and the complementary IEC standard 60793-2-50 type B1.3. With respect to the macrobending loss requirements, it is evident this fiber shows characteristics far beyond these standards and compliant with the new ITU-T G.657 recommended bend-insensitive SMF classes. It is superior with respect to the G.657 "class A" performance and coincides with the much more stringent G.657 "class B" requirements as indicated at 1625 nm in Figure 2.

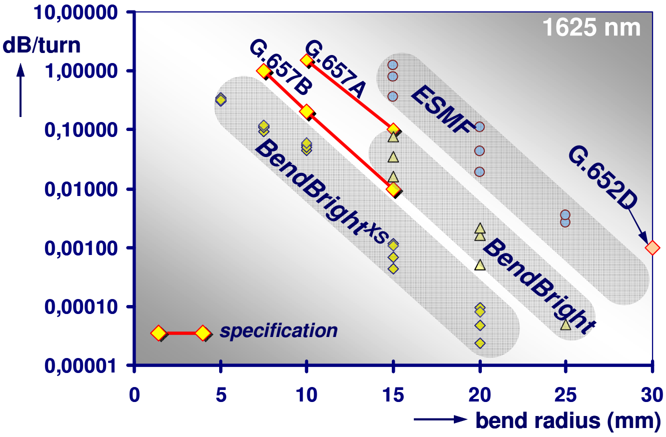


Figure 2. Bending performance of trench-assisted SMF complies with ITU-T G.657 Rec. for both class A and class B

2.2 Microbending Loss

Microbending loss is reduced with a lower fiber MAC value, i.e. the ratio MFD/Cut-off wavelength, just like the macrobending loss [5]. As extensive testing has shown, the optical field confining effect of the refractive index trench near to the core has a positive effect on microbending loss as well. Figure 3 shows spectral loss curves from fiber subjected to our internal micro-bending test. In this test, 400 m fiber is wound with high tension on a 60 cm diameter reel covered with low grain size sandpaper. The effect of the MAC value for trench-assisted fiber is shown by the two lower curves, whereas the effect of the trench alone shows from the comparison with an equal MAC value ESMF fiber test result. Note that the influence of the trench is not in the absolute height only, but also in the slope of the curve which favors the long wavelength behavior.

Microbending itself is a somewhat undefined deformation of the fiber axis for which some test methods are suggested in IEC Technical Report TR 62221. Other test methods have also been applied to evaluate the losses originating from micro-deformations as can occur in practice. Some examples are the "pin-array" test and the "kink" test. The "kink test" might give a good impression of the effects occurring in case of "stapling" or "nailing" an indoor cable. In this test, a primary coated fiber is loosely pressed against a low

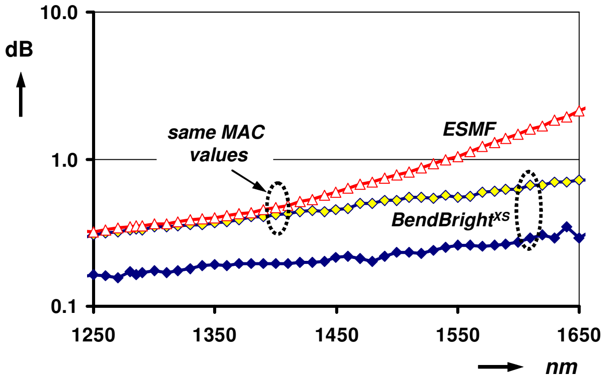


Figure 3. Spectral loss curves of microbending tests for trench-assisted and regular SMF with similar coatings

radius pin over an angle of about 45 degrees. The fiber has some free space due to the distance of about 0.7 mm between the pin surface and the pressing surface resulting in a smaller effective bend angle as is the case in usual cable structures. The test is repeated several times and the results are averaged.

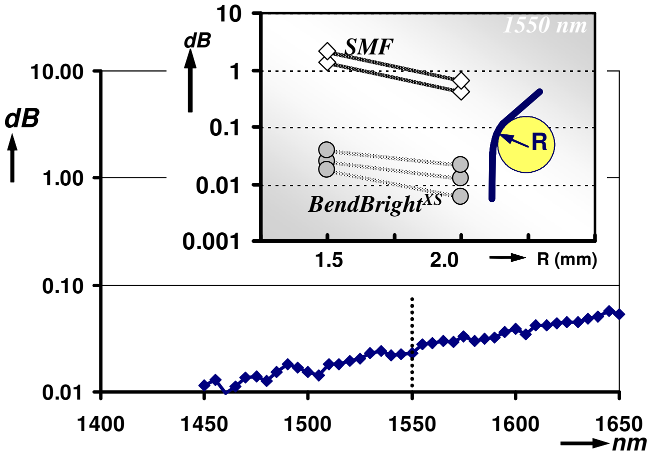


Figure 4. Spectral "kink loss" curve for a trench-assisted fiber pressed against an R=1.5 mm pin. The inset shows the losses at 1550 nm for some nominal trench-assisted fibers and regular step-index SMF fibers

In Figure 4, some test results are shown applying a 1.5 and a 2 mm radius pin. The tested fibers were nominal MAC value fibers from both the new trench-assisted and the classical step-index product line. The approximately 100-fold improvement originating from the trench is impressive. Especially for indoor cabling using stapling techniques the imprint of the staple on the cable will not cause significant attenuation increase. In case of a standard step-index SMF, the inserted loss would certainly be higher. Given this characteristic, the new trench-assisted fiber is very installer friendly and forgiving. However, this does not mean that fiber mounting should be done carelessly.

2.3 Life-Time Aspects

When deploying SMF in storage cassettes or in case of incidental bends, stress is applied to the outer circumference of the fiber causing strain in the glass material (Figure 5). Reducing the current minimum bend radius from 30 mm to 15 mm or even lower, might raise some questions on the lifetime of the fiber. For modern SMF however, there is no reason for concern.

This requirement is met by applying high quality materials and clean processes. Verification is done by proof-testing the fibers resulting in a sufficiently low number of breaks per preform pull. Meeting this requirement for a 1% strain at proof-test, insures that the fiber can withstand a permanent strain of about 1/4 to 1/3 of the proof test strain over its whole cross-section, multi-kilometer length and > 25 year lifetime. This is sufficient in all situations in a telecom network, including access networks with much more rugged environments.

2.3.1 Fiber Storage in Cassettes

When bending a fiber in a storage cassette the following main considerations apply:

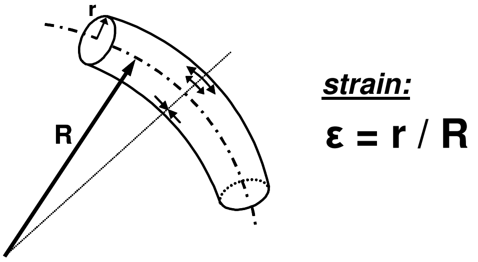


Figure 5. Strain in the outer surface of the fiber by bending the fiber axis with a radius R

1- Usually there is no axial stress on the fiber, so consequently the main cause for strain is the bending itself. By simple geometrical rules it can be calculated that a 1/3 % strain is reached at the outer circumference of a 125 µm OD fiber for a bend radius of 18.75 mm. Bending the fiber over its whole length on this diameter will not impose any additional impact on the lifetime compared with the criteria normally used for a long length of cabled fiber. The average stress in the glass fiber is even less than this 1/3 % strain, which is only present in a very small part of the fiber's outer surface.

2- The length of the bent fiber in a storage cassette is a very short section of the total fiber length only. So, the probability of failure is accordingly lower.

Both considerations apply when calculating the failure probability of a short fiber length stored in a cassette of a fiber management system. In [6] a more complete model has been described using the outside plant failure probability as indicated by network operators. With a failure probability per cassette of 0.001 % (10^{-5}) in 20 years, i.e. one single spontaneous breakage in 20 years out of 100.000 cassettes, the minimum bend radius is represented in Figure 6.

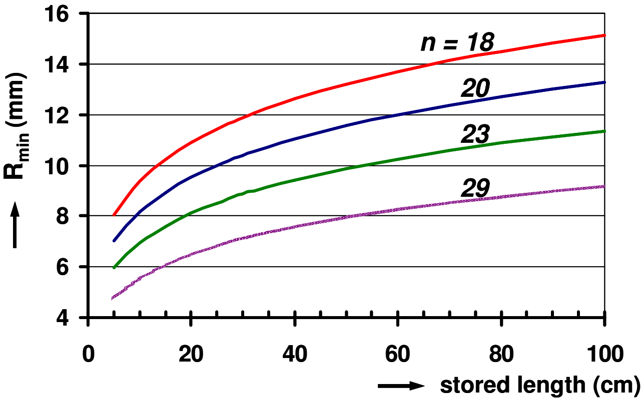


Figure 6. Minimum bending radius for fiber storage with a 20 years failure probability of < 0.001 % (10^{-5})

It is evident that this minimum radius depends on the length of the stored fiber in the cassette. The other parameter that governs the minimum bending radius is the stress corrosion susceptibility 'n' (fatigue parameter). The value of the "dynamic" susceptibility parameter for our fibers is >20 whereas the "static" value is >23.

Note that the minimum dynamic stress corrosion susceptibility coefficient is 18 according to IEC product specification 60793-2-50 and Telcordia GR-20-CORE specifications, which value might be used as "worst case". Dependent on these considerations the curves in Figure 6 demonstrate that even with the very low failure rate of 10^{-5} a storage length of, for example, 100 cm of fiber at a 15 mm radius is a safe situation.

2.3.2 Incidental Bends

The curves in Figure 6 also show that for much shorter bend lengths, such as 90 degree bends in exit and entrance ports of a fiber management system, the minimum radius can be reduced. That is completely in line with the referenced lifetime model and can easily be understood because the risk of meeting a flaw in a shorter length statistically becomes smaller. As a result a higher bending stress is allowed (tighter bending). One should also understand that risky flaws (at the 1% strain or 100 kpsi level) are only present in modern fiber much less than one per kilometer.

We also calculated such incidental bends; Figure 7 shows an example of single 180° bends. Using the worst case stress fatigue parameter $n_d = 18$, one can observe that the failure risk increases 10-fold from 10^{-6} to 10^{-5} by reducing the radius from 12.6 mm to 6.7 mm. This means, one failure in 20 years assuming 100.000 incidental bends all with the indicated small radius dimension.

It is more realistic to assume only a small percentage of cassettes contain such an 180° incidental bend, e.g. 1 % of the splice cassettes. This reduces the failure risk of one 180° bend with radius of 6.7 mm to 10^{-7} (one failure per 10 million cassettes), a reassuring low number.

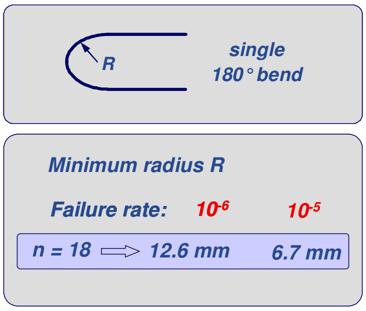


Figure 7. Calculated minimum incidental bending radius of single 180° incidental bends with 20 years failure probability of 10^{-6} and 10^{-5}

The question can be raised whether such low bend radii are identifiable with e.g. OTDR testing. Taking the least responding wavelength of 1550 nm and applying the specification for G.657B for a full turn of 7.5 mm radius, the induced bending loss is maximum 0.5 dB (certainly not zero dB). Partial bends could reduce this loss (e.g. 180° bend) but smaller bend radii quickly increase induced bend losses, see figure 2. So, long before one approaches real dangerous bending regimes trench-assisted fibers indeed show optical loss signals (some tenths of dB).

Referring to the kink loss situation as indicated in Figure 4, detailed calculations reveal that even in these cases, lifetime is not significantly affected ([2]; Fig. 9).

In conclusion it can be stated that lifetime considerations on fibers stored in short bend radius fiber management systems differ significantly from lifetime considerations of cabled fibers. For storage in fiber management systems, a higher strain may be present on short lengths, whereas for cables a lower strain and a much longer length apply. As for lifetime prediction however, similar calculation models can be applied.

2.4 Splice Results Trench-Assisted SMF

Splicing trench-assisted fibers to itself is comparable to splicing every other standard SMF in today's installation practice. Figure 8 shows an overall histogram of homogeneous splice losses at 1310 nm achieved with modern splicing machines; Figure 9 shows splice results between trench assisted fibers and various types of standard SMF. These excellent results are similar to those shown by another manufacturer of trench-assisted fibers in [7] as well as to the best results obtained for regular SMF.

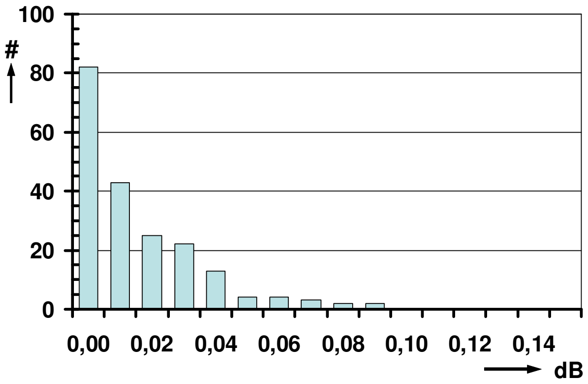


Figure 8. Homogenous splice loss results (1310 nm) of trench-assisted fibers (average loss 0.02 dB)

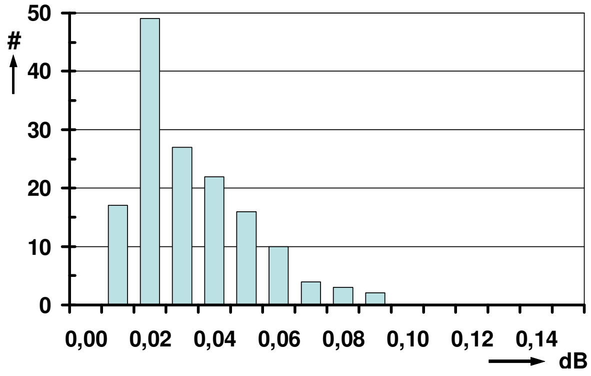


Figure 9. Splice loss result (1310 nm) of trench-assisted fiber to various standard SMF types on Fujikura FSM-30S (average loss 0.03 dB)

2.5 High Power Applications

Certain applications, like analog FTTH RF video overlay or digital DWDM solutions and certainly future Raman amplifiers in central offices could lead to high total optical power. In case of tight fiber bends the real danger exists that light stripped off from the core, due to bending, collects in the coating and could result in temperature increase well above the normal maximum of +85°C. This could result in fast aging (coating and fiber damage) and in the extreme case to fire in a central office.

Bend-insensitive fiber offer the advantage that less optical power is collected in the coating when tightly bending the fiber. Assuming similar coatings, this can be translated in higher acceptable optical launch power, as is shown in figure 10, where our trench-assisted fiber is compared with a regular G.652 fiber [8]. In this figure different failure definitions have been applied [9]:

R1: catastrophic failure of the glass fiber mimicking a fiber break;
R2: catastrophic damage to the fiber coating;
R3: accelerated ageing of the coating.

Fibers showing the lowest bending loss offer the highest safety in high power applications. For that reason the trench-assisted fiber, with G.657B bending performance, offers increased safety in high power applications compared to regular G.652 and to G.657A type fibers.

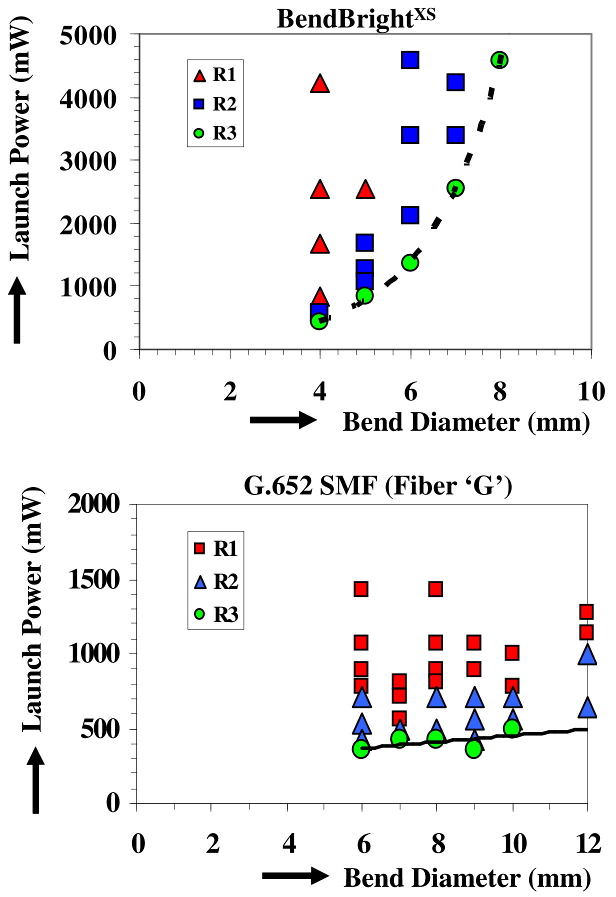


Figure 10. Launch power (1480 nm) for different failure regimes (R1 – R2 – R3), tested in 180 degree 2-point bends.

Top: Trench-assisted fiber withstands up to about ten times higher launch power (R3) at 8 mm diameter compared to G.652 fiber (bottom)

2.6 Characteristics of Different Implementation Types of Bend-Insensitive Fiber

In the market several implementations of G.657 fibers can be observed. As described in section 2, one type is based on a higher refractive index of the core, compensated by a reduced core diameter. For extreme small core diameters this results in very low mode field diameters, typically 6 to 7 µm, complying with G.657B, including the tight bending specification. The large offset in mode field diameter compared to the installed base G.652 fibers makes practical use with standard single mode fibers very difficult, yielding high splice losses.

A moderately reduced core diameter design brings the mode field diameter 1310 nm just on the limit of G.657A (nominal 8.6 µm), with only moderately improved bending performance compared to G.652D. Such reduced mode field diameter fibers will not cause high splice losses, however still OTDR issues are present in the form of loosers (exaggerated loss) and gainers (negative loss) in single direction OTDR testing, when combining these fibers with the installed base G.652D.

Another design is a matched or depressed cladding fiber with almost normal mode field diameters (e.g. 8.9 µm nominal); again the bending performance is only moderately improved according to G.657A. Based on their specifications these fibers - when used in a compact fiber management system with a storage radius of 15 mm – cannot guarantee low losses at 1625 nm (e.g. two times 1 meter of stored fiber is equivalent to two times 10 turns with maximum loss according to G.657A of two times 1 dB).

The trench-assisted fiber is the only full-silica fiber design available at this moment offering the unique combination of almost normal mode field diameter (nominal 8.9 µm) and yet offering the most tight bending specification according to G.657B. This fiber is the only implementation (still compatible to G.652D) offering real potential in reducing the size of fiber management systems down to 15 mm radius without higher losses at 1625 nm (for two times 1 meter of fiber maximum loss would be 2 times 0.1 dB).

Table 2 offers an overview of application oriented issues for the indicated different fiber implementations. In addition to the items discussed above, the following issues are summarized:

Installation issues:

- (Easy) splicing to installed base fiber. Extreme small core designs will show the issue of high splice loss due to MFD mismatch.
- One way OTDR testing < 0.3 dB. Extreme small core and small core designs will show sensitivity for "loosers and gainers", again due to MFD mismatch.

Reliability issues:

- Identify unsafe bends network testing >0.2 dB.
- Guaranteed lifetime of the glass fiber, though standard test methods.
- The ability to withstand high power resistance (best for G.657B fibers).
- Proof testing coloured fiber (avoiding risks in off-line coloring).

Based on an objective comparison (figures and facts) the trench-assisted single mode fiber is regarded as the best choice in FTTH applications. This is further supported by the low spectral attenuation of this fiber, see section 3 (Production Results).

Table 2. Main application oriented issues for different G657 fiber implementations

Issue	Description	Extreme small core design	Small core design	Matched / Depressed cladding design	Trench-assisted design + ColorLock
Connectivity compared to G.652D	MFD 1310nm	6 to 8 µm	8.6 µm nominal	8.9 µm nominal	8.9 µm nominal
G.65x compatibility		G.657B	G.652D (limit) & G.657A	G.652D & G.657A	G.652D & G.657A & G.657B
Bending performance	1 turn R=10 mm @1550 nm	0.1 dB	0.75 dB	0.75 dB	0.1 dB
Compact fiber management @1625 nm	2 * 1 m fiber R=15 mm (2 * 10 turns)	0.2 dB	2 dB	2 dB	0.2 dB
Installation	Easy splicing to installed base	No, MFD mismatch	No, MFD mismatch	Yes	Yes
	One way OTDR testing (0.3 dB limit)	No MFD mismatch	No MFD mismatch	Yes	Yes
Reliability issues	Identifying unsafe bends with >0.2 dB of loss during network testing	????	Yes	Yes	Yes
	Guaranteed lifetime reliability, through standard test methods	Yes	Yes	Yes	Yes
	High Power resistance	Yes	Average	Average	Yes
	Proof testing colored fiber	No	No	No Yes CL coating	Yes ColorLock coating
Overall bend optimization design	Choice in FTTH applications	Average	Average	Average Good	**Best**

3. Production Results of Trench-Assisted SMF

After its announcement (autumn 2006) our trench-assisted fiber, compliant to ITU-T Recs. G.652D, G.657A and G.657B, has been produced in substantial volumes. Figure 11 shows the attenuation distributions for 1550 nm, 1625 nm and 1310 nm.

Figure 12 shows as an example the distribution of the bending loss at 1550 nm for a radius of 15 mm. Both aspects show the excellent low loss and low bending-sensitivity over a broad wavelength for this fiber design.

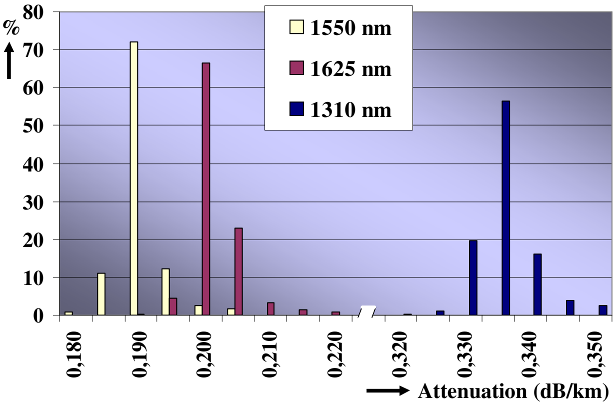


Figure 11. Trench-assisted SMF spectral attenuation distribution at 1550 nm, 1625 nm and 1310 nm

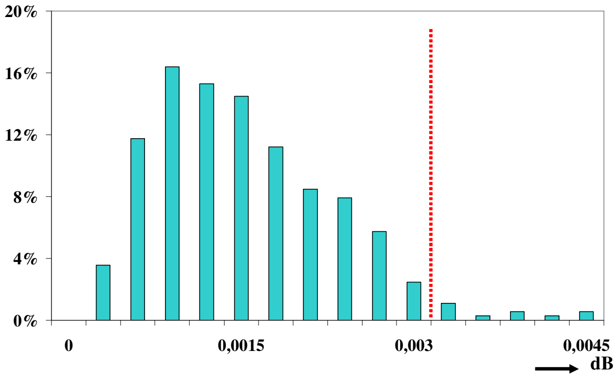


Figure 12. Trench-assisted SMF bending loss distribution at 1550 nm and radius of 15 mm

4. Impact of Bend-Insensitive Fiber on Connectivity Products

The use of bend-insensitive fibers in connectivity products like Optical Distribution Frames (ODF), underground splice closures, wall boxes and termination boxes, offers three major advantages:

- Reduction of the component space, which is very important in FTTH networks with its high fiber densities.
- Use of single circuit fiber management instead of single element fiber management (so avoiding potential disturbance during maintenance operation on cabinet).
- Lowering actual installation cost due to the robust character of the fiber (less re-work after installation).

4.1 Reducing the Size of Components

Smaller size network components are achieved by using the lower installation bend radius of the bend-insensitive fiber in splice trays, pigtails and patch cords. Presently commercially available splice trays are designed for a minimum fiber bend radius of 30 mm, resulting in splice trays with a smallest diameter of 60 mm. New G.657 fibers and in particular G.657B fibers (for use up to 1625 nm) can be used with a minimum bend radius as small as 15 mm, offering a four times smaller component surface.

4.1.1 ODF Drawers

Bend-insensitive fiber allows the use of a reduced size ODF drawer by applying smaller splice trays. In this way completely new layouts, sizes and capacities of ODF drawers can be obtained.

A further space reduction can be achieved by using bend-insensitive fibers in patch cords on the front of the patch panel and pigtails on the back of the patch panel, allowing smaller bending radii. This volume reduction has a high impact on the cost of ownership (size of telecom offices / POPs).

4.1.2 Splice Closures, Wall and Termination Boxes

Also in these components the small size splice trays will reduce the size of the casing of the component or increase the fiber splice capacity of the component. As an example two wall mounted splice boxes (3M company) with comparable splice capacities are shown in Figure 13 and 14.

Figure 13. Standard wall mountable 3M box with dimensions (*HxWxD*): 290x255x86 mm

Figure 13 shows the standard solution, a box with dimensions *(HxWxD)* 290x255x86 mm; Figure 14 shows a wall box with the same functionality using the advantages of the bend-insensitive fiber. This new developed box has dimensions of only 130x125x30 mm , giving a vast reduction in both wall space and mounting depth.

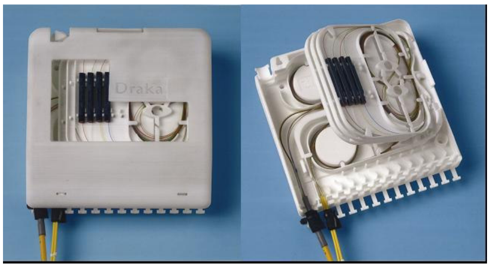


Figure 14. Prototype wall mountable 3M box for trench-assisted fiber with dimensions (*HxWxD*): 130x125x30 mm

4.1.3 Single Circuit vs. Single Element Fiber Management

FTTH network designs can be divided in two different approach scenarios:

- Installation of the total passive FTTH network with customer connection cables to all houses.
- Installation of a basic FTTH network, adding customer fiber connections on demand. In this last option, also known as the grow-with-the-market scenario, customer connections are added to the initially installed basic network.

Single element splice trays for ODF drawers, closures and wall boxes in FTTH networks introduce a high potential risk: when new fiber splices are installed in a splice tray that already contains spliced and active fiber connections, the transmission through the active fibers can be disturbed.

Use of bend-insensitive fibers allows applying reduced size single circuit fiber management with none or limited extra space compared to the standard single element components.

5. Cable Development

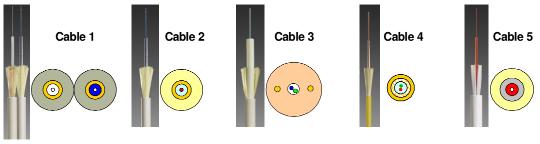
For application in FTTH networks several different cable designs are suitable, including constructions based on indoor, outdoor or indoor/outdoor cables. Bend-insensitive fibers offer the maximum benefit particularly in indoor areas, where the possible advantages in bend radii and small connectivity equipment is essential. Requirements for such small FTTH cables designs are high mechanical strength and allowance of low bending radii; a HFFR jacket is mandatory.

Preferably they shall be applicable as FTTH as well as FTTD cables, where fiber count is limited; for most applications a maximum of 4 fibers is sufficient. Different cable designs to fulfill these requirements are presented.

The indicated application area adds some additional requirements to the properties mentioned above which are not met by common cable types. For easy on-wall indoor installation, the new indoor cables should be "staple-able". Therefore high mechanical strength regarding impact resistance is mandatory. In addition a HFFR sheath is necessary in order to safely allow indoor or combined indoor/outdoor use. A completely dry design is possible, too.

Our new bend-insensitive fiber allows lower bending radii which cannot be reached by regular single mode fibers. Using this fiber type, cable constructions can be developed which are generally not possible using conventional single mode fibers. Figure 15 shows an overview of some cable designs, including central tube and fig-8 cables.

Figure 16 shows bend loss test results at 1550 nm using cabled standard SMF and trench-assisted fiber [10].



Application	Interconnect, Stapling, Clamping, Glueing	Interconnect, Stapling, Clamping, Glueing	Duct, Stapling, Clamping, Glueing	Microduct, Duct, Glueing, Clamping	Duct, Stapling, Clamping, Glueing
Buffer type	Tight Plastic	Tight Acrylate	Dry Loose	Fibre Unit	Semi-Tight
Fibre count	2 x 1	1	2(4)	2(6)	1
Diameter	2.8mm x 5.7mm	2.8mm	3.5mm	1.8mm	2.8mm

Figure 15. Overview of new cable designs, based on trench-assisted fiber, including central tube and fig-8 cables

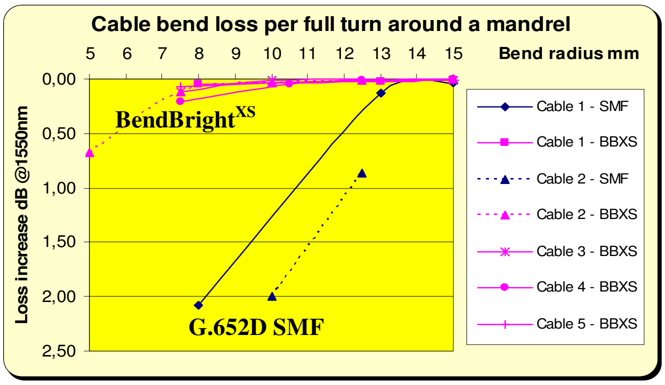


Figure 16. Bend loss test results at 1550 nm using cabled standard SMF and trench-assisted fiber.

This approach delivered flame retardant cables with very high impact and crush resistance, at quite small dimensions, being suitable for on-wall installation. The flame retardancy offers additional safety in indoor areas.

The new indoor cable designs – based on the described trench-assisted fibers – allow installation using regular tackers and staples for fixing of the cable without damaging it. This technique may induce some small imprints of the staple into the cable and cause some small kink type deformations of the fiber. As discussed in section 2.2 Microbending, such kink type of bends do not cause attenuation increase in trench-assisted G657B fibers, see also Figure 4. For further test results on cables see also [11].

6. Conclusions

A new bend-insensitive single mode fiber has been developed to fulfill the demanding requirements of FTTH applications. ITU-T Recommendation G.657 describes improved bending characteristics of such fibers in two classes: class A describes moderately improved bending compared to standard G.652 fibers, while much tighter bending loss is described in class B of Rec. G.657.

We developed a unique bend-insensitive trench-assisted fiber entirely compatible with Rec. G.652D for compatibility with the installed base, and with bending characteristics compatible to G.657 class B. This fiber also shows reduced microbending and kink loss. Fiber lifetime is not a concern even at the lower fiber storage radii around 15 mm.

Only this trench-assisted fiber design offers real potential in reducing the size of fiber management systems and use up to 1625 nm, offering reduced cost of ownership to operators. Based on a number of installation criteria, trench-assisted fibers are regarded as the best choice for use in FTTH applications.

The feasibility of HFFR drop cables using this bend-insensitive trench-assisted fiber has been demonstrated. Designs with fiber counts up to 4 fibers were developed and qualified. Flame retardancy and mechanical properties allow easy installation as well as safe and simple handling.

The combination of high mechanical strength, flame retardancy and bend-insensitive trench-assisted fibers is perfectly suited for the intended indoor application.

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8. Pictures of Authors

Gerard Kuyt (1950) received his B.Sc degree in Electrical Engineering at the The Hague University in 1973. In the same year, he joined the Philips Research Laboratories in Eindhoven, in a new group on optical transmission. In 1981 he joined Philips Optical Fibre, now Draka Comteq Optical Fibre, starting in the measurement & applications department. From 1992, he changed position to the Sales & Marketing group; currently he is Product Line Manager. He is active in standardization e.g. CENELEC, ITU-T and IEC (Convenor of IEC 86A/WG1). E-mail: gerard.kuyt@draka.com

Pieter Matthijsse graduated in Electrical Engineering at the Eindhoven Technical University in 1971. After his PhD study in Fourier Optics at the Leuven University he joined KPN Research in 1976 where he worked on optical cables and network technology. In 1985 he joined Philips Optical Fibre where his main task was on PCVD fiber production process development. In 1991 he returned to KPN where he worked on access and transport systems and outside plant development. From 2001 on, he is with Draka Comteq Optical Fibre, currently as Product Line Manager. He is active in the ITU-T SG 15 where he is rapporteur on Q 10: “Cable and fibres for the access network”. E-mail: piet.matthijsse@draka.com

Laurent Gasca (1968) graduated in science from the Ecole Supérieure de Physique et Chimie Industrielles de Paris and in business from the University of Pantheon-Sorbonne Paris. He joined ALCATEL in 1993 to work on new processes for optical fibers. He has been involved in the development and production of specialty fibers, taking the lead of this group in 2000. He has been elected as Distinguished Member of the Alcatel Technical Academy and reviewer of the OAA conference. He authored or co-authored more than 30 patents and several international papers. He is presently working in Draka Comteq Optical Fibre as a Product Line Manager.
E-mail: laurent.gasca@draka.com

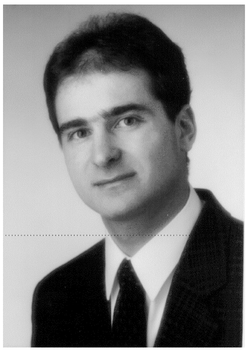
Louis-Anne de Montmorillon received an engineering degree in Optics from the Ecole Supérieure d’Optique in Orsay in 1993. He received his Ph. D. degree in Physics from the university of Paris-Sud in 1997 for a work pursued at the Institut d’Optique, devoted to photorefractive ultrasonic detection. He then joined Alcatel Cable in the fiber optic R&D unit, Conflans Sainte-Honorine and is now within Draka Comteq Optical Fibre in the Marcoussis product R&D group.
Email: louis_anne.de_montmorillon@draka.com

Arnie Berkers received his M.Sc. degree in Electrical Engineering in 1987 at the University of Eindhoven. In the same year he joined Draka Comteq Telecom, in Delfzijl, The Netherlands, responsible for the development of fiber optic cables. Presently he is working at Draka Comteq Optical Fibre as Product Manager.
E-mail: arnie.berkers@draka.com

Born in 1953, **Mijndert Doorn** graduated in Telommunications Science from the Hogere Technische School Hilversum. He joined NKF Kabel B.V. in 1977 and held different positions in development of telecommunication cables, product engineering, general sales support cables & connectivity. He is now working in Draka Comteq Telecom as Manager Development & Engineering Network Solutions.

E-mail: mijndert.doorn@draka.com

Klaus Nothofer (1956) received his Dipl.-Ing. degree in Telecommunications and joined AEG-Kabel (now Draka Comteq) in 1981. From 1984 he held various management positions in O.F. cable manufacturing, development, and marketing in Alcatel Europe. He is now Manager Development and Engineering for Optical Fiber Cables in Draka Comteq Cable Solutions EMEA.
E-mail: klaus.nothofer@draka.com



Alexander Weiss obtained his D.Sc. in chemistry of the University of Tübingen in 1990. In the same year he joined AEG (now Draka Comteq). He held various management positions in manufacturing and development of optical fiber cables and is currently Manager Materials of Draka Comteq Cable Solutions EMEA in Moenchengladbach, Germany.

E-mail: alexander.weiss@draka.com.