



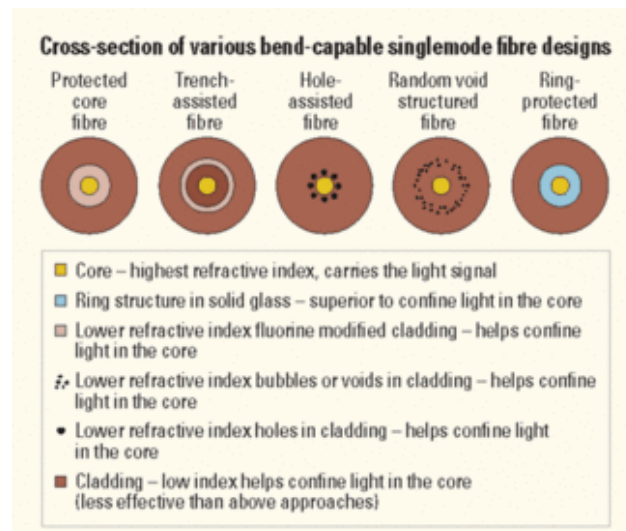
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## Bend-capable fibre variations target application needs

by John George, Peter Weimann, Ole Suhr, and Jesper Steenstrup

The current explosion in FTTX deployments has increased carrier interest in bend-capable fibres (BCFs) that greatly reduce macro-bending loss. Traditional singlemode fibres have been limited in fibre-to-the-home (FTTH) and FTTX applications by high macro-bending loss. A 1,550-nm video signal that encounters a single 10-mm radius turn will typically lose more than 60% (4 dB) of its power, likely turning off service and customers. Recently, new types of BCF have been introduced to support installation of optical drop cables in multiple-dwelling units (MDUs) and within homes without conduits or bend radius management. Understanding the various types of fibres (see Fig. 1), applications, and benefits is therefore more important than ever.



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*Figure 1. A variety of bend-capable singlemode-fibre designs have appeared since 1984. They have different properties—as well as different strengths and weaknesses.*

## History and applications

In 1984, AT&T introduced the most widely deployed BCF, known as depressed cladding fibre or protected core fibre. Protected core fibres were installed extensively in long haul, metro, access, and LANs in the 1980s and 1990s, and evolved in 2006 to a zero-water peak version that supports the full spectrum from 1,260 to 1,625 nm. In the 1980s AT&T also patented a bend-capable trench-assisted design for undersea cable applications. Trench-assisted fibres with similar designs are still used today for connectivity and in-building applications. Hole-assisted fibres (HAFs) are used by NTT for in-home applications. HAFs provide the lowest bending loss available but have substantial limitations in splicing and connectorisation.

The fundamental AT&T approach of creating a circular region around the core having a lower refractive index than the cladding is still used today in most BCF designs, including the newly announced random void structure and solid glass ring-protected fibre designs. These two designs target MDU and in-home wiring (IHW) applications. Both designs promise macro-bending loss of  $<0.1$  dB per turn at 5-mm radius, while maintaining some degree of compatibility with the installed base of conventional singlemode fibre.

However, there are significant differences in these designs and the resulting performance in splicing, connectorisation, and performance uniformity. Splice and connection compatibility between a BCF and itself, and a BCF and the installed base of fibres, is critical to help simplify installations and achieve the high optical performance required to support video and other mission-critical services. BCFs that are standard compliant to ITU-T G.652D, for example, may not necessarily splice seamlessly to other G.652D fibres due to significant mode field diameter mismatches, holes or voids in the glass, or dissimilar types of glass within the fibre structure. Designs using voids or holes may also complicate mounting and optical performance of connectors if dirt and debris stick in holes to confound polishing and cleaning processes. Another variable is potential nonuniformity of the fibre's properties along its length.

## Standards and beyond

The International Telecommunications Union Telecommunication Standardization Sector (ITU-T) has created two recommendations for BCFs targeting broadband access networks; a portion of those are shown in Table 1.

The first, G.657A, describes fibres that are compliant to the G.652D standard yet offer macro-bending loss of 0.75 dB maximum for one 10-mm radius turn at 1,550 nm, about 3× to 6× lower bending loss than conventional G.652 fibre at this radius. Compliance with G.652D is intended to ensure that properly designed G.657A fibres can be seamlessly spliced and connected to the installed base of G.652D fibres without excessive added loss. However, as noted previously, this is not always the case. For some G.657A compliant fibres, special splicing software and/or use of cladding-aligned splicing equipment may be necessary to ensure efficient splicing. End users of fibre must take care to ensure that the fibre they deploy is compatible with their splicing equipment and procedures.

Table 1. Selected ITU-T-G.657 standard data compared to 'beyond B' specification

ITU standard	Bend radius (mm)	Turns	Wavelength (nm)	ITU Max. (dB)
G.657A	10	1	1,550	0.75
	15	10		0.25
G.657B	7.5	1	1,550	0.5
	10	1		0.1
	15	10		0.03
Beyond B	5	1	1,550	~0.1 (no std.)

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The second recommendation, G.657B, describes the performance of fibres with macro-bending loss of 0.5 dB maximum for one 7.5-mm radius turn at 1,550 nm. G.657B fibre has about 15× to 30× lower macro-bending loss than conventional G.652 fibre at this radius. Yet even G.657B performance may not suffice for some in-residence optical drop applications, where installers may wish to staple and route drop cables around sharp corners without conduit or management elements. These 'beyond class B' applications in MDUs and in-home drop cables will require a macro-bending specification on the order of 0.1 dB maximum for one 5-mm radius turn at 1,550 nm—about 100× lower macro-bending loss at this radius than standard G.652D singlemode fibre.

With such standards in place, BCFs can enable installations not possible with conventional singlemode fibres. They can help decrease space requirements and improve network reliability in central offices, cable TV headends, data centres, splitter cabinets, and crossconnect cabinets. BCFs may also help carriers accommodate new, high-density equipment and apparatus that lessen the need for cable management and/or enable safe violation of traditional rules for bend radius management. More recently, service providers have desired fibre cable that can be cost-effectively and inconspicuously installed in residential environments. Given the varying requirements for bending loss, reliability, and backward compatibility for these key applications, a simple question arises: Which bend-capable optical fibre fits best with each application?

### Central offices, headends, data centres, and cabinets

Central offices (COs), headends (HEs), and data centres (DCs) typically contain hundreds and more commonly thousands of cables, and each fibre may support hundreds or thousands of businesses and residences. Thus these applications require very high reliability.

Optical fibre reliability must be viewed in terms of both optical loss and mechanical reliability. A view of mechanical reliability is shown in Fig. 2, based on classical modelling equations used by the International Electronics Commission (IEC) recommendations for optical fibre systems. With traditional rules for fibre management at large bend radii, fibre breakage has not been an issue. As fibre bend radii drop, based on improved low-bending-loss fibre designs, fibre reliability becomes an important consideration for all applications.

All of the applications discussed here share the same need for low fibre bending loss, regardless of the minimum acceptable bending radius. Additional loss beyond a few tenths of a decibel for most applications might impair or shut off video and other mission-critical services. In general

one should expect the maximum macro-bending loss of a bend-optimised cable assembly to be less than 0.2 dB for a single turn at 1,550 nm at 10-mm radius for the CO/HE/DC/cabinet applications. Below a 10-mm radius there is risk of random fibre breaks for a length of 20 cm (about three turns at 10-mm radius).

For critical applications such as these, it may be desirable that the fibres exhibit clearly measurable bending losses whenever bending radii approach the onset of the “red” area in Fig. 2 —bending radii less than 7.5 mm. A carefully designed fibre that shows bending loss in this way can identify mechanically risky bends to reduce the risk of long-term fibre breaks caused by faulty installation or the like. If such a fibre is measured after installation, and no significant added loss is found, it can readily be concluded that excessively small bending radii have not been unintentionally introduced to the fibre, thus helping to ensure its long-term reliability. For this reason, ‘beyond class B’ ultra-bend-insensitive fibres may not be appropriate for CO/HE/DC/ cabinet applications, since they will not have measurable bending loss to identify bends at radii on the order of 7.5 mm.

Table 2. BCF application/technology matrix

Applications	Solution examples	ITU-T standard	Bending loss max. (1 turn) and projected mechanical reliability (3 turns)
CO cable, splitter cabinets, enterprise, DC, MDU riser/backbone, OSP micro-cables	Protected core fibre connectorised cables, indoor cables, OSP ZWP micro-cables	G.657A and G.652D compliant	0.2 dB 1,550 nm → (10) 0.5 dB 1,625 nm 66% lower macro-bending loss than G.657A 40 year >99.999%
CO crossconnect, OC-48, OC-192, and OC-768 systems, DWDM, high-power applications	Enhanced protected core fibre connectorised cables	G.657B G.652D compliant	0.1 dB 1,550 nm → (10) 0.2 dB 1,625 nm → (7.5) 0.5 dB 1,550 nm 1.0 dB 1,625 nm 40 year - double-strength fibre >99.999%
MDU drop cables and in-residence drop cables. Super-bendable, easy installation	Ring-protected fibre MDU and in-residence drop cables	Much better than G.657B, G.652D compatible	0.1 dB 1,550 nm → (5) 0.25 dB 1,625 nm 20 year >99.998%

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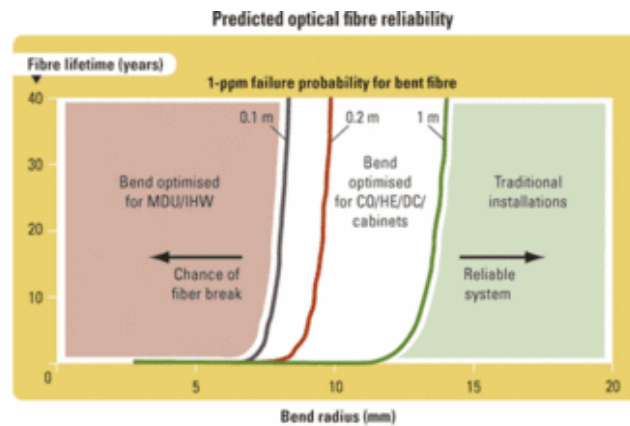
An additional concern in COs and HEs is the high optical power transmitted over fibre to support RF video or DWDM systems. Optical cable assemblies used in these applications should be able to support such high powers under bending conditions without degrading, burning, or excessive signal loss, while maintaining mechanical reliability. Again, for these applications the 10-mm minimum radius is recommended to balance these needs.

## MDU and IHW

Service providers have recently requested BCF drop cables using ‘beyond class B’ fibres that can be routed down hallways and inside residences, will conform to corners, and can be stapled in place. This type of installation promises to be less conspicuous to the customer and can help lower the cost of deployment for the service provider. The material cost savings per unit passed, for example, could be €4 to €7 per unit in addition to significant labour savings of €7 to €15 per unit.

Unlike traditional applications, MDU/IHW drop installation can involve intentionally bending the fibre to radii down to somewhere between 5 and 7.5 mm. All things being equal, mechanical reliability of the glass in sharply bent MDU/IHW cable will inherently be much lower than that in the CO/HE/DC/cabinet applications: The stress on the fibre at 5-mm bend radius is 4× higher than at a 10-mm bend radius and more than 40× higher than fibre following the traditional 32-mm bend radius fibre management upon which historical optical fibre reliability experience is

based.



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*Figure 2. Attention to predicted optical fibre reliability metrics can help installers determine which fibre type is best suited for a specific application.*

The optical cable design is a key to preserving optical and mechanical reliability in these demanding deployment conditions. Deployment of optical cables in a manner similar to that used for copper telephone wire leads to new questions for the industry: Is the reliability risk associated with these intentional sharp bends acceptable in MDU/IHW applications, given the first-cost benefits of using ultrabendable cables? One consideration with the MDU or single-family residential application is that only one subscriber is supported for each optical drop cable. Is it acceptable in this case to lower the reliability expectation? Is the reliability of nanovoid types of fibres the same or lower than that of solid glass fibres? This is unexplored territory in practice and one that the industry will study in the coming months as the market desire for ultrabendable cables intensifies. Preliminary studies in OFS laboratories suggest that the combination of bending strain and installation tension in these aggressive installations may have a significant impact on fibre lifetime.

### **Smaller outdoor cables lower costs**

New low-diameter cables, known as micro-cables, can pack powerful fibre-optic bandwidth in a small package. The benefit of this micro-cable override approach becomes apparent as providers increasingly attempt to place cables in existing duct instead of disrupting both budgets and the environment by digging to bury new ducts. Micro-cable overrides can reduce installation costs by more than 50% compared to direct burying of new duct.

A benefit of some types of BCFs is further reducing the diameter of micro-cables. Protected core fibre has bending loss properties that enable the packaging of 96 fibres in the same diameter that can hold only 48 or 72 fibres of conventional G.652D full-spectrum fibre. As a result, a further reduction of up to 50% in installation cost is possible by using protected core fibre micro-cables compared to conventional micro-cables.

BCFs provide significant value to many applications (see Table 2). These benefits include lower labour installation, smaller packaging (for example, plug-and-play terminals are now available for distributing up to 12 drop cables from a backbone cable to subscriber units), and protection of the many long-wavelength applications used today and coming in the future for video, data, and voice applications. Three bend-capable technologies were described that are optimised for key application spaces. By choosing the fibre optimised for the application, one can achieve the best balance of reliability and optical performance in bending challenged systems.

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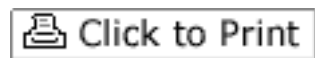
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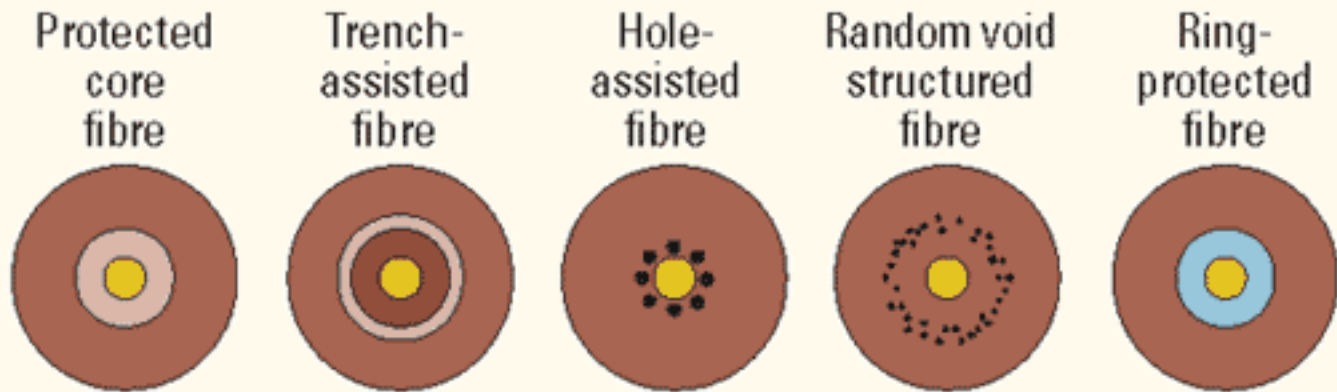
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## Cross-section of various bend-capable singlemode fibre designs







- Core – highest refractive index, carries the light signal
- Ring structure in solid glass – superior to confine light in the core
- Lower refractive index fluorine modified cladding – helps confine light in the core
- Lower refractive index bubbles or voids in cladding – helps confine light in the core
- Lower refractive index holes in cladding – helps confine light in the core
- Cladding – low index helps confine light in the core (less effective than above approaches)

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### Predicted optical fibre reliability

