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Bend Insensitive Microstructured Optical Fibres for FTTH Deployments

Prof G Kumar
NRI Group of institutions, Bhopal, (M.P.) India

Dr R P Gupta
Radharaman Group of Institutions, Bhopal, (M.P.) India

ABSTRACT

Fiber-to-the-Home (FTTH) is becoming the main stream broadband technology of choice. Significant commercial deployment of FTTH has started only a couple of years ago in most of the countries. The main factor for the slow growth of FTTH is the higher installation costs compared to copper wires. While optical fibres have the benefits of signal capacity and immunity to electromagnetic interference, they suffer from losses due to excessive bending. When standard single-mode fiber (G.652) is used, the fiber must be installed cautiously avoiding small bends to restrict total single loss. Single Mode Fibre also has difficulty of transmitting video signals through bends tighter than about 30 mm in diameter. The bending requirement for deployment limits dimensions of hardware and imposes significant costs for FTTH installations. Hence bend insensitive single-mode fibers are attractive for FTTH applications to lower the installation costs and improve the system performance. Several fiber designs have been proposed to meet different bend loss requirements including both conventional and microstructure design approaches. This paper reviews recent progress that is reported in bend insensitive fibers.

Keyword— macrobend, FTTH, microstructure, power budget, single mode

I. INTRODUCTION

In FTTH, fibre is run from exchanges all the way to the subscriber premises up to the Termination Point (TP) on the wall of the subscriber's home. It is most cost effective to concentrate initial deployments of FTTH in densely populated areas for economical reasons. As in such dense areas the majority of subscribers either lives in multiple dwelling units or work in office premises. FTTH systems need to be optimized for such dense environments installations. In other words the FTTH industry needs optical cables that can be installed and handled in the same robust manner as copper cables. The overall objectives for an effective FTTH deployment optimization should therefore lead to a] reduction in up-front installation costs b] increase in the speed of making a subscriber connection c] reduction in life time operating costs d] and maximization of the reach & split ratio, and subscriber penetration of the network.

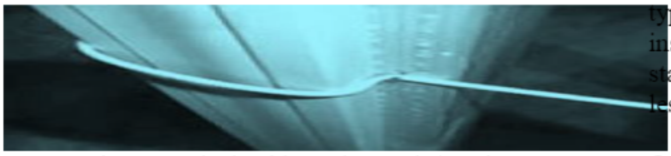


Fig.1a Optical cable under strain/tension

Fig.1b Optical cable with heavy bends

Typical FTTH installations are shown in Fig 1a and Fig1b. Optical cables routed in this manner can be subjected to tight bends, compression points in congested ducts, and stapling. In a dense environment such installation and handling practices of the optical fiber can see bends down to few mm in radius. For multiple dwelling units (MDUs) and in-home wiring applications, bend radii in the range of 5 mm are very common and hence bending losses must be kept to a minimum. Fibre macrobend loss of less than 0.1 dB/ turn at 5 mm is typically required to keep the inside wiring total loss at maximum a few tenths of a decibel. Bending losses of less than 0.1 dB/turn will ensure robust network performance under practical bending conditions, such as tight 90 corners, corners under load, fixation by stapling and excess cable storage in tightly confined spaces.

Conventional standard single mode fibres subjected to one full turn at a 5 mm bend radius would exhibit a loss in excess of 10 dB. A bend tolerant fibre compliant to the most stringent optical fibre bend standard [G.657.B] also seen to exhibit high loss in the region of 1 dB or higher. A typical bend-insensitive fibre in harsh, copper-like installation conditions with tight corners, tension, and staples should show total losses of the order of 0.2 db or less.

Optimizing the use of the available optical power budget from the central office to the dense areas of interest units needs to be exercised and that has several advantages like the ability to maximize network reach and/or to increase the split ratio. The use of a truly bend insensitive fibre helps to optimize network design and power budget. The specific power budget depends on the technology of choices like BPON [Broadband Passive Optical Networks], GPON [Gigabit Passive Optical Networks] & EPON [Ethernet Passive Optical Networks].

BPON conforms to the ITU-T G983.1 specification which is capable of 622 Mbps download and 155 Mbps upload. Each BPON fiber is split using an optical splitter to serve 16 or 32 users. GPON conforms to the ITU-T G984.1 specification. A 2.4 Gbps download speed coupled with a 1.2 Gbps upload speed is the need of the hour. Each GPON fiber is split to serve 16 or typically 32 users and next phase will support 64 users per fiber. In GPON for example the power budget from the central office to the optical network terminal (ONT) is of the order of 28 dB. Independent of the specific technology, however, it is not desirable to waste budget on inside wiring. The use of a truly bend insensitive fiber helps them optimize their network design.

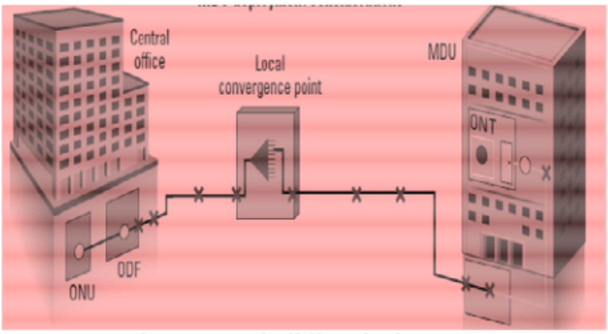


Fig.2 Dense building deployments

ODF - OPTICAL DISTRIBUTION FRAME
ONU - OPTICAL NETWEORK UNIT X SPLICE POINTS
ONT - OPTICAL NETWOTK TERMINAL
MDU - MULTIPLE DWELLING UNITS [OR OFFICES]

More bends during installation in buildings can give raise to unexpected additional losses. Those bend may disturb power budget or could deplete the repair and maintenance margin. Additionally cabling installations in such dwelling units or even in multi-complex offices are more exposed to unwanted public intervention than any other part of the network, increasing the possibility of network outages due to bends.

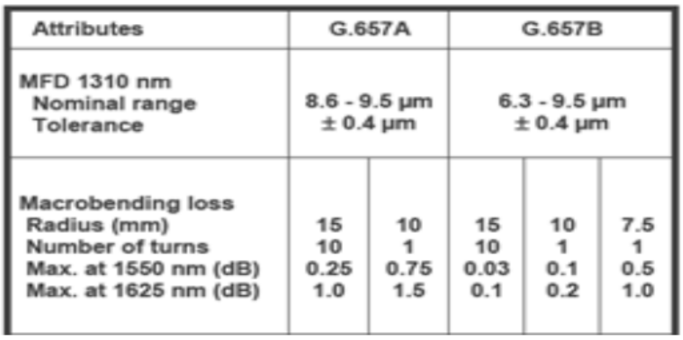
II. THE CHALLENGES IN FIBRE DESIGN AND DEPLOYMENTS

Improving the bend performance of an optical fibre presents an interesting challenge. There are several fibres designs or technologies that can significantly reduce the macrobend loss. However, the fibre industry must address the macrobend problem keeping in mind the compatibility with telecom industry requirements.

The first challenge is to reduce the bending loss at 1550 nm to less than 0.1 dB/turn at a bend radius of 5 mm to meet the requirements of harsh, copper cable-like handling conditions in MDU applications. As a reference point, the bend loss of standard single-mode fiber at1550 nm is typically 20 dB/turn at 5 mm bend radius. Hence a bend loss reduction factor of over 200 is required which is very difficult to achieve using conventional fiber designs. The second challenge is to meet the requirements of backward compatibility with the standard single-mode fibers imposed by the telecom industry standards. This requires a fibre that meets ITU-T G.652 standards for mode filed diameter, cable cut-off wavelength, attenuation and splice loss.

Single Mode Fibers (SMF) showing improved bending resistance compared with standard G.652D SMF are mandatory for the Fiber to-the-Home deployment (ITU-T G657A&B recommendation). Different profile designs allow reaching G.657B bend-losses levels while staying compatible with the legacy G.652D recommendation. The applicable industry standards and recommendations are displayed in Table 1, below.

Table 1



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

These recommendations identify two classes: 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. Recently, questions have been raised concerning the bend-loss for extreme conditions and suggestions have been made to specify fiber bend radius as low as 5mm.

III. VARIOUS POSSIBLE DESIGNS

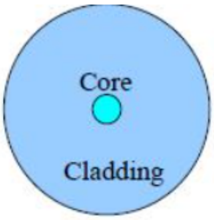


Fig.3a

Fig. 3(a) is a reduced mode field diameter (MFD) design with a simple step index profile. The reduction in the MFD can improve the bending performance, but will change other fiber parameters like cutoff wavelength, zero-dispersion wavelength, and dispersion slope and splice/connector loss significantly. Keeping in mind the bending performance and the backward compatibility, the MFD at 1310 nm can be reduced to about 8.6 m compared to about 9.2 m in typical standard single-mode fiber. With the reduced MFD, the 1550 nm bend loss is lowered to close to 2 dB/turn at a bend radius of 5 mm, which is still well above the bend loss requirement for MDU applications.

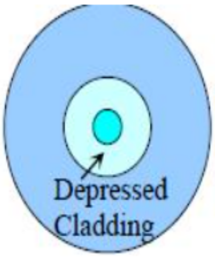


Fig.3b

The addition of a low index layer around the core as shown in the depressed cladding design in Fig. 3(b) helps in tuning the fiber zero-dispersion wavelength in the 1310 nm window. However, with backward compatibility constraints to the fiber design, the bending performance and other optical parameters that can be achieved with the depressed cladding design are essentially the same as the simple step index design with reduced MFD.

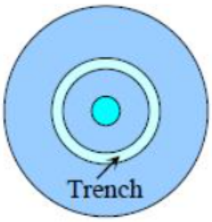


Fig.3c

The trench fiber design shown in Fig. 3(c) may offer the best approach among the conventional fibre designs. The low index trench reduces the power in the cladding region outside the trench, thus improves the bend loss. However, in order to keep the cable cutoff wavelength below 1260 nm required by the standards, the trench volume, which is defined as the product of the area and the relative refractive index change of the trench, has to be small enough to allow the mode to tunnel into the cladding. Typical bending performance of this trench fiber is about 0.5–1 dB/turn at 1550 nm with a bend radius of 5 mm. All of these conventional designs have similar limitations and cannot deliver the desired bending performance without compromising the other optical parameters required by the standards.

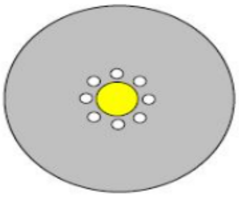


Fig.3d

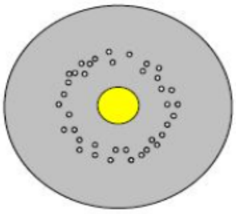


Fig.3e

A very different type of design approach is to use air holes in a hole assisted fiber design shown in Figure 3.d] & 3.e]. Such microstructured fibres can be either with random holes or periodic. The bending performance that can be achieved with this type of design is very good due to effective confinement of light. But maintaining compatibility with standard single-mode fibers has proven to be very difficult. The cable cutoff wavelength of this type of fibers is well above the 1310 nm and manufacturing in large volume is little involved as of date.

Recently, a new fiber design using the nano Structures technology [Ref 5] has been proposed by Corning to overcome the difficulties encountered in conventional designs. This novel technology enables new fiber designs having superior bend performance that meets the FTTH requirements and, at the same time, maintaining compatibility with large scale manufacturing, legacy fiber plant and existing field installation equipment and procedures.

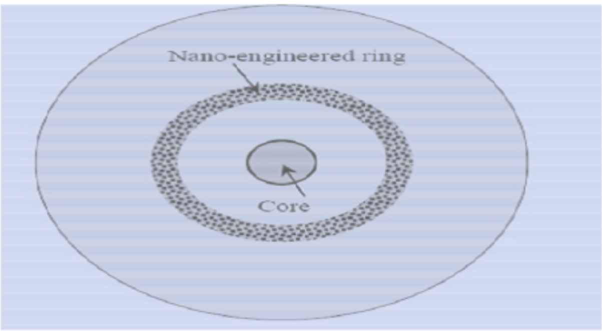


Fig.4 Bend insensitive optical fibres with nano rings

Figure 4 shows a schematic of the fiber design. It consists of a germanium-doped core and a nano-engineered ring in the cladding. The ring consists of nanometer-sized gas filled voids that are incorporated in the glass during the fiber processing. These voids are non-periodically distributed in the ring cross-section. The cross-sections of the voids are circular. They have diameters ranging from several dozens to several hundreds of nanometers. The void fill fraction can be designed to be between 1 to 10 percent depending on the ring dimension. The voids are sealed and non-periodically distributed along the fiber with void lengths ranging from less than one meter to several meters.

The refractive index of nano-engineered glass has much stronger wavelength dependence than that of fluorine doped glass. The index change for nano-engineered glass increases with wavelength, while the index change for fluorine doped glass is nearly flat in the wavelength range of interest. This feature maximizes bend performance in the 1550 nm window while maintaining a cable cutoff wavelength below 1260 nm. Second, large negative index changes can be made with nanometer sized features. A relative index change as high as several percent can be achieved by using a nano-engineered design. Such a high index change is very difficult to realize using the conventional fluorine doping technology. Third, the scattering property of a glass having nanometer sized voids also has strong wavelength dependence. Light at shorter wavelengths has higher scattering losses than at longer wavelengths, which facilitates the suppression of higher order modes. These new features allow fiber designs with much better bending performance and with other optical parameters compliant with the FTTH standards.

IV. CONCLUSION

Bend insensitive fibers are a key enabling component for low cost FTTH installations. The objective for a bending optimized fiber should be meeting the key requirements for successful FTTH deployment like a] Compatibility with the existing base of single-mode fiber b] Easy splicing and connector mounting c] Full spectrum performance d] Reliability. The advancements in macrobend performance reported brings significant technical and economic benefits to FTTH installations by enabling optical fiber cables that can be handled and installed like copper, with no requirements for avoidance of bends and staples. Operators avoid significant amounts of installation rework that is caused by bend induced power loss and associated power budget failure. As a result, network operators are seeing significantly high potential for bend-insensitive fibers to reduce the first installed cost of an FTTH network, in particular in the dense environment, by accelerating subscriber connection and reducing the probability of failure during the network's lifetime through protection of the power budget.

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