International Journal of Computer Applications (0975 – 8887)
Volume 10– No.7, November 2010

Novel Single Mode Fiber (SMF) Ultra Low Loss Design in 1550 μM Window considering PMD, DGD and various Bending Radii

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ABSTRACT

Bend intensive single mode fibers are attractive for fiber to the home (FTTH) applications because they can lower the installation cost and improve the system performance. For in home wiring applications, bend radii in the range of 5 mm are very common [7] and bending losses must be kept minimum. Bending losses of less than 0.1 db/turn will ensure robust network performance under practical bending conditions such as tight 90^0 corners, corners under the load, excesses cable storage in tightly confined spaces. There are several approaches in designing the fibers with improved bend performance.

There are various methods for designing the fibers with improved bend performance are used, for example, reduced mode field diameter (MFD) method, depressed cladding design technique and hole assisted design.

In this paper, reduced mode field diameter method, to design and analyze the performance of single mode fiber with improved bend performance is simulated and analyzed.

General Terms

Low Loss Design, Optical Fiber, Data Rates, Bend Performance.

Keywords

Bending radius, SMF, BER, Dispersion, PMD, MFD.

1. INTRODUCTION

Light is sent down the fiber in the form of a pulse. As pulses travel down the fiber they spread out. This spreading is known as dispersion. Dispersion is undesirable because it can cause bit errors when the signal reaches the receiver. To avoid bit errors, it is necessary to condition the signal using dispersion compensation or to regenerate the signal using a repeater. The signal must be regenerated prior to the occurrence of any errors. The number of bits increases, then the performance of the system also gets affected because of the dispersion. The spacing between the optical pulses decreases due to increase in the bit rate and hence the dispersion effect increases.

In this paper, a fiber profile with less bending losses and dispersion by using reduced mode field diameter is designed and analyzed. The performance analysis of this fiber especially for the window of 1550 μm range considering PMD, MFD and bending radii is also done for error-free distance, especially for intranet applications. It also gives the various simulation results for dispersion loss analysis and fiber performance for various bending radii.

In optical fiber technology, single mode fiber (SMF) is optical fiber which is designed for the transmission of a single ray or mode of light as a carrier and is used for long-distance signal transmission. SMF are also better at retaining the fidelity of each light pulse over long distances than in multi-mode fibers. For these reasons, single-mode fibers can have a higher bandwidth than multi-mode fibers.

In 2005, data rates of up to 10 gigabits per second were possible at distances of over 60 km with commercially available transceivers [6]. By using optical amplifiers and dispersion-compensating devices, state-of-the-art DWDM optical systems can span thousands of kilometers at 10 Gb/s, and several hundred kilometers at 40 Gb/s. But as the transmission distance and data rates increased, there are several factors that affect the performance of the system in Bit Error Rate (BER). Another very important factor, which limits the data rate, is polarization Mode Dispersion (PMD).

Polarization mode dispersion (PMD) is one of the factors that limit the data rates of the optical network. PMD is a serious limitation on certain fiber links operating at 10 Gb/s. It is widely recognized that inherent challenge in providing higher data rate communication is managing the dispersion effect in a system. PMD in high data system can significantly diminish the data carrying capacity of a telecommunication network. As network data rates rise, it is becoming increasingly important to understand PMD and its potential impact on the network.

In the present paper, the statistics of Polarization Mode Dispersion (PMD), DGD and their impact on pulse broadening in optical fiber is examined .The origin and nature of PMD and birefringence and their impact on high speed transmission system and also for different fiber parameters values the effect of PMD are also examined.

Bend intensive single mode fibers are attractive for fiber to the home (FTTH) applications because they can lower the installation cost and improve the system performance. For in home wiring applications, bend radii in the range of 5 mm are very common and bending losses must be kept minimum. Bending losses of less than 0.1 db/turn will ensure robust network performance under practical bending conditions such as tight 90^0 corners, corners under the load, excesses cable storage in tightly confined spaces.

There are several approaches in designing the fibers with improved bend performance.

The various methods for designing the fibers with improved bend performance are, -

1. Reduce Mode Field Diameter (MFD)
2. Depressed Cladding Design
3. Hole assisted Design

Here, reduced mode field diameter (MFD) method to design and analyze the performance of single mode fiber (SMF) with improved bend performance is simulated and analyzed.

2. THE REFERENCE METHOD FOR MEASURING THE MFD OF SMF

2.1 General

Mode-field diameter (MFD) is a measure of the spot size or beam width of light propagating in a single-mode fiber. Mode-field diameter is a function of basic carrier (source) wavelength, fiber core radius, and fiber refractive index profile. The vast majority of the optical power propagates within the fiber core, and a small portion propagates in the cladding near the core. The mode-field diameter is determined using Petermann's second definition of the mode-field diameter in the near field. Mismatches in mode-field diameter can affect splice loss. Fibers with varying mode-field diameters also exhibit different bend loss sensitivities.

2.2 Measurement Description

The reference measurement method for mode-field diameter is the Variable Aperture Method in the Far Field (VAMFF). This method uses a series of various-sized apertures mounted on a rotating wheel in the far field of the fiber's output. Each successive aperture restricts the far field power distribution to a specific radius. Intensity levels are measured for each of the apertures, and the data is plotted as power versus the sine of the aperture half angle (numerical aperture). Petermann's second definition of the mode-field diameter is a mathematical model which does not assume a specific shape for the distribution. This near field definition is related to the far field by the Hankel Transform. Pask's transformation of Petermann's definition of the mode-field diameter is applied directly to the two-dimensional far field data through a numerical integration routine. The Petermann mode-field diameter in the near field is calculated from the far field rms width [3, 5 and 6].

2.3 Measurement Conditions

The standard length of fiber required to measure the mode-field diameter is 2 meters deployed with an appropriate mode filter. The mode filter is used to ensure single mode operation for each single-mode product. It ensures that no higher order modes (such as LP11) will affect the measurement.

The fiber ends are stripped of coating and prepared with end angles less than 1° with near perfect mirror surfaces. Cladding mode stripping is also performed. Few of the measurement specifications are,

- Fiber Length 2 meters
- Source Spectral Width ~10 nm Full Width at Half Maximum (FWHM)
- Launch Spot Size ≥ 100 µm
- Launch Numerical Aperture ≥ 0.20
- Measurement Wavelengths 1300 nm ± 10 nm and 1550 ± 10 nm.

3. BENDING LOSS

It is a form of increased attenuation in a fiber that results from bending a fiber around a restrictive curvature (macro-bend) or from minute distortions in the fiber (micro-bend).It is also described a form of increased attenuation caused by allowing high order modes to radiate from the walls of a fiber optic cable. There are two common types of bend losses. The first type is evident when the fiber optic cable is curved through a restrictive radius or curvature. The second type is generally referred to as micro bends. It is caused by small distortions of the fiber optic cable imposed by externally induced perturbations as, for example, slip shod cabling techniques.

3.1 Macro bending loss model

The macro bending loss γ is a radiative loss when the fiber bend radius is large compared to the fiber diameter. It is defined by *P(z) = P(0) exp (-γz)*, where *P(0)* is the input power and *P(z)* is the output power at distance *z*. Two models are discussed here.

The first model uses the closed-form integral formula. It is appropriate for calculating the macro bending loss of any LP mode, both fundamental and higher-order, in arbitrary- index profile optical fibers. Using this formula the macro bending power loss coefficient is expressed as a function of the bending radius R_b in the form,

$$\gamma = \frac{\sqrt{\pi}\left(P_{clad}/P\right)}{2 s r_c\left[K_{v-1}(W)K_{v+1}(W)-K_v^2(W)\right]}\,\frac{\exp\left(\dfrac{-4\Delta W^3}{3 r_c V^2}R_b\right)}{W\left(\dfrac{W R_b}{r_c}+\dfrac{V^2}{2\Delta W}\right)^{\frac{1}{2}}}$$

Where,

$$V = k_0 r_c \sqrt{{N_{\max}}^2 - {N_{\min}}^2}$$

(the normalized dimensionless frequency)

$$W = r_c\sqrt{\beta^2 - (k_0 N_{\min})^2}$$

$$\Delta = \frac{\left({N_{\max}}^2 - {N_{\min}}^2\right)}{2{N_{\max}}^2}$$

Here, r_c denotes the fiber core radius, N_{max} and N_{min} are the maximum and minimum values of the refractive index, β is the propagation constant of the mode, k_0 is the proportionality constant in vacuum, v is the azimuthal mode number, $s = 2$ if $v = 0$ or $s = 1$ for $v \neq 0$ and K_v is the modified Bessel function of the second kind of order v.

Using the second macro bending loss model the coefficient γ is expressed as,

$$\gamma = \left(\frac{\pi V^8}{16 r_c R_b W^3}\right)^{1/2}\exp\left(-\frac{4}{3}\frac{R_b}{r_c}\frac{\Delta W^3}{V^2}\right)\frac{\left[\int_0^\infty (1-f)F_0 R\,dR\right]^2}{\int_0^\infty F_0^2 R\,dR}$$

Where F_o is the radial field of the fundamental mode f , which is given as,

$$f = \frac{\left[N(R)^2 - N_{\min}{}^2\right]}{N_{\max}{}^2 - N_{\min}{}^2}$$

$$\alpha_{macro} = \frac{10}{L}\cdot\log\left(\frac{P_{in}}{P_{out}}\right) = \frac{10}{L}\cdot\log\left[\exp(\gamma L)\right] = \frac{10}{\ln(10)}\cdot\gamma$$

3.2 Micro bending loss model

Micro bending loss is a radiative loss in fiber resulting from mode coupling caused by random micro bends, which are repetitive small-scale fluctuations in the radius of the curvature of the fiber axis.

An approximate expression for the attenuation coefficient is given by,

$$\alpha_{micro} = A(kn_1 d_n)^2 (kn_1 d_n{}^2)^{2p}$$

Where, A is a constant, d_n is the near field diameter, n_1 is the core refractive index of fiber, k is the free space wave number, and p is the exponent in the power law.

4. TYPES OF DISPERSION

4.1 Material Dispersion

Dispersion in optical fibers can be categorized into three main types. The first is material dispersion which is also known as chromatic dispersion. This type of intramodal dispersion results from the fact that the refractive index of the fiber medium varies as a function of wavelength. Since neither the light source nor the fiber optic cable is 100 percent pure, the pulse being transmitted becomes less and less precise as the wavelengths of the light are separated over long distances. The exact same effect occurs when a glass prism disperses light into a spectrum.

4.2. Wave-guide Dispersion

Wave-guide dispersion depends on the shape, design, and chemical composition of the fiber core. Only 80 percent of the power from a light source is confined to the core in a standard single-mode fiber, remaining 20 percent actually propagates through the inner layer of the cladding. This 20 percent travels at a faster velocity because the refractive index of the cladding is lower than that of the core. Consequently, signals of different frequencies and wavelengths are dispersed and the pulse becomes indistinguishable. Fiber optic dispersion varies as a function of wavelength. The zero dispersion wavelength for a standard single-mode fiber is approximately 1310 nm, while a zero-dispersion-shifted fiber's wavelength at zero dispersion is 1550 nm.

4.3 Modal Dispersion

The third and final significant type of dispersion is related to the fact that a pulse of light transmitted through a fiber optic cable is composed of several modes, or rays, of light instead of only one single beam leading to modal dispersion. Since the rays of the light pulse are not perfectly focused together into one beam, each mode of light travels a different path. As a result, the modes are not received at the same time, and the signal will be distorted or even lost over the long distances. Erbium-doped fibers and wavelength-division multiplexing (WDM) effectively shift most systems to 1550 nanometer at zero dispersion. Although high-performance WDM systems have been developed from novel fiber designs, the dispersion slope and the mode-field diameter of the fiber are still producing complications. New fiber designs, such as reduced-slope fibers, have low dispersion over a very wide range because the slope of dispersion is less than 0.05 ps/nm^2-km, which is significantly lower than standard fibers.

5. RESULTS AT VARIOUS BENDING RADII AND CONCLUSIONS

5.1 Bending radius (R) = 50 mm

5.1.1 Birefringence vs Wavelength graph

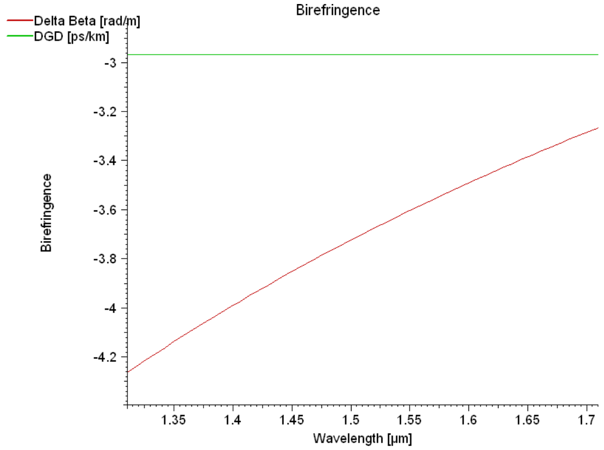
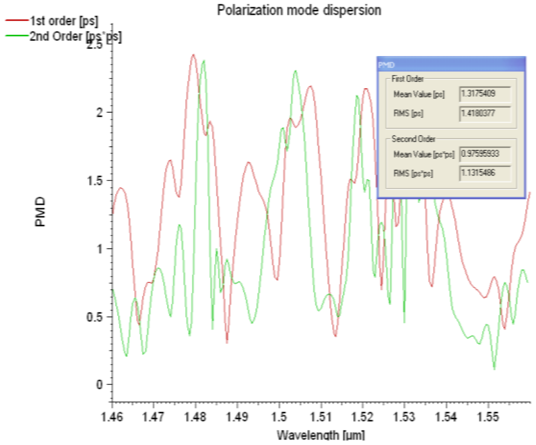


Fig. 1: Birefringence Vs Wavelength at R = 50 mm

5.1.2 PMD Vs Wavelength graph



First Order
Mean Value [ps] 1.3175409
RMS [ps] 1.4180377
Second Order
Mean Value [ps*ps] 0.97595933
RMS [ps*ps] 1.1315486

Fig. 2: PMD Vs Wavelength at R = 50 m

5.1.3 Fiber Confinement

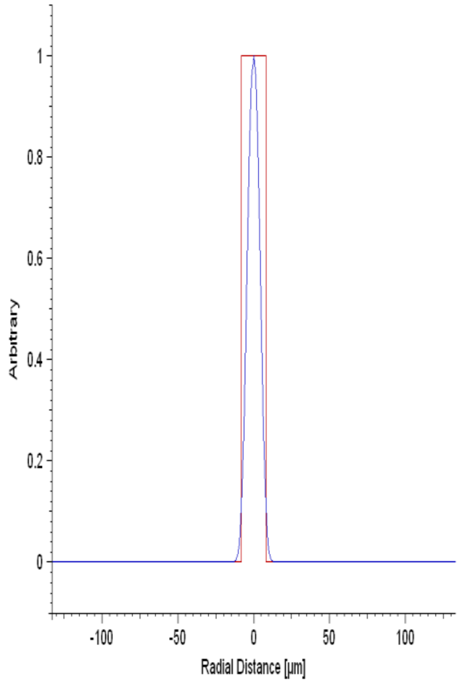


Fig. 3: Fiber Confinement

5.1.4. Fiber Profile

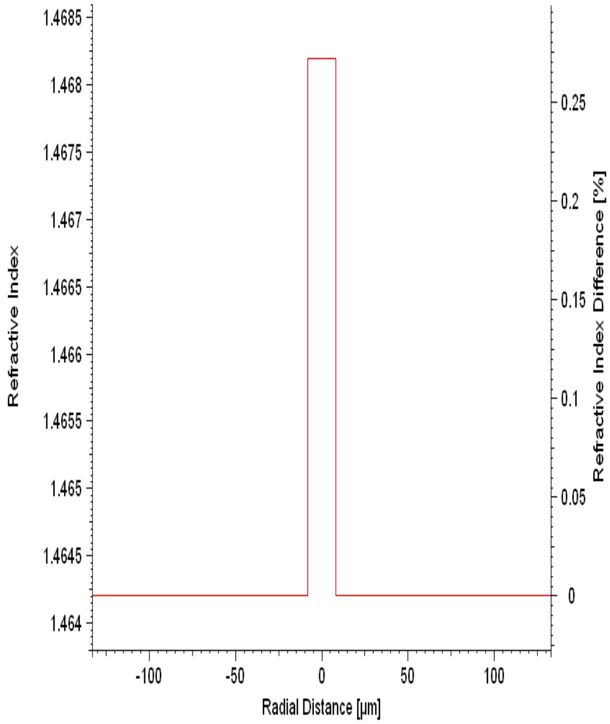


Fig. 4: Fiber Profile

5.1.5 Fiber Effective MFD

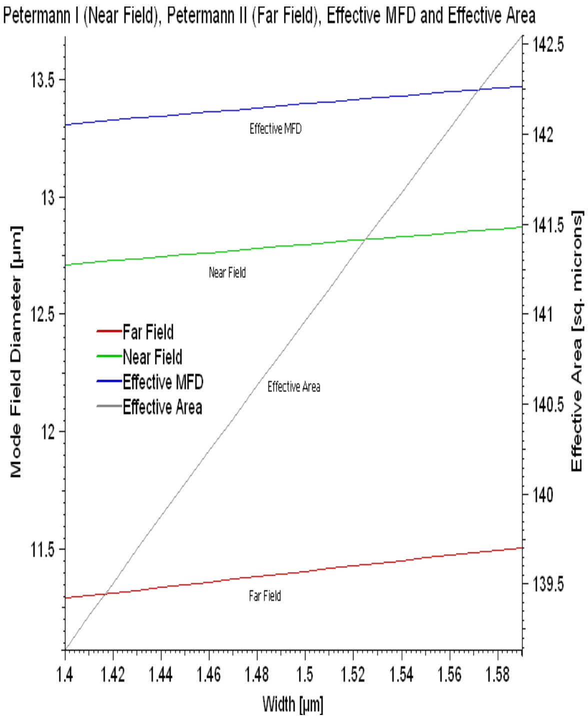


Fig. 5: Fiber Effective MFD

5.1.6 Fiber Bending Loss

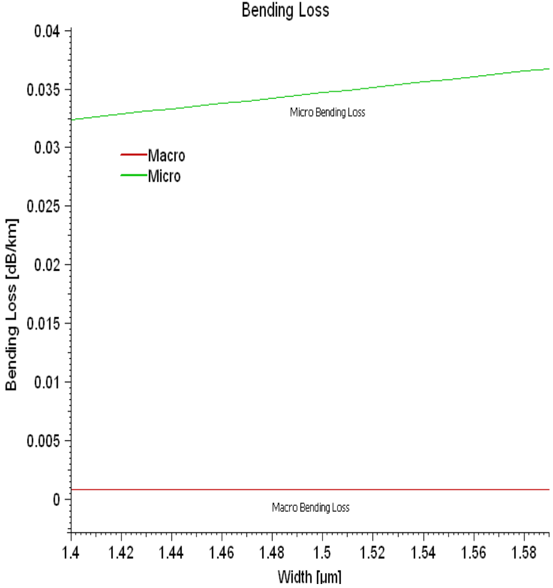


Fig. 6: Fiber Bending Loss

As Seen from these graphs feon Fig. 1 through Fig. 6, PMD has maximum values at 1480 nm, 1500 nm, and 1520nm. The Value of PMD here for the given wavelength is found to be 1.31409 ps. For R= 10mm, the value of PMD is found out to be 31.2146 ps. Here, in the graph, R = 50 mm and PMD is 1.31409 ps, which is very less.

5.2. Bending Radius (R) = 200 mm

5.2.1 Birefringence Vs Wavelength Graph

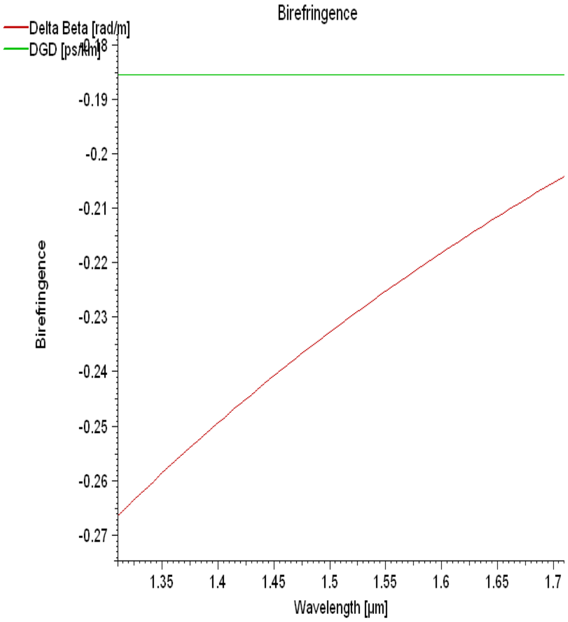
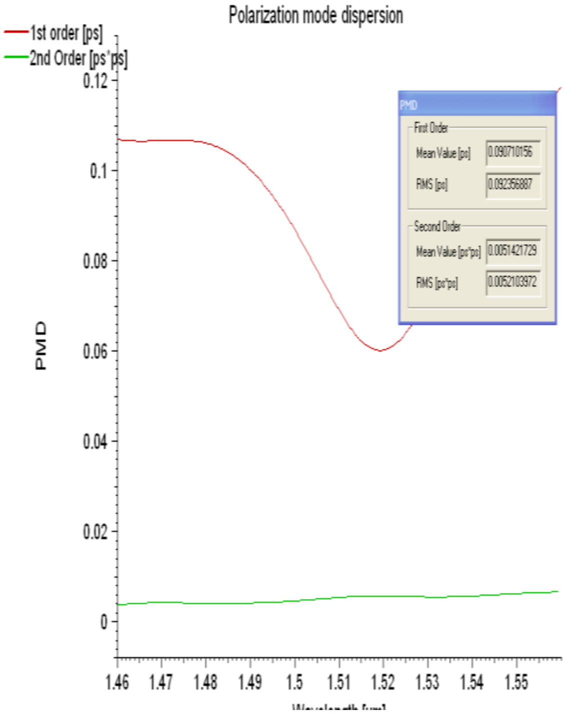


Fig 7: Birefringence Vs Wavelength at R = 200 mm

5.2.2 PMD Vs Wavelength Graph



First Order
Mean Value [ps] 0.090710156
RMS [ps] 0.092356887
Second Order
Mean Value [ps*ps] 0.0051421729
RMS [ps*ps] 0.0052103972

Fig 8: PMD Vs Wavelength at R = 200 mm

5.3 Fiber Bending Radii Vs Macro Bending Loss

Macro bending losses at various fiber bending radii are obtained and are shown below,

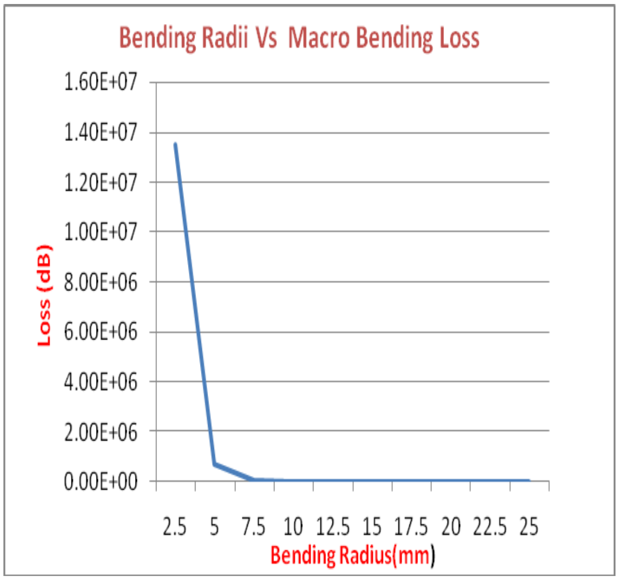


Fig 9: Macro Bending Losses at various Bending Radii

5.4 Fiber Bending Radii Vs Micro Bending Loss

Micro bending losses at various fiber bending radii are obtained and are shown below,

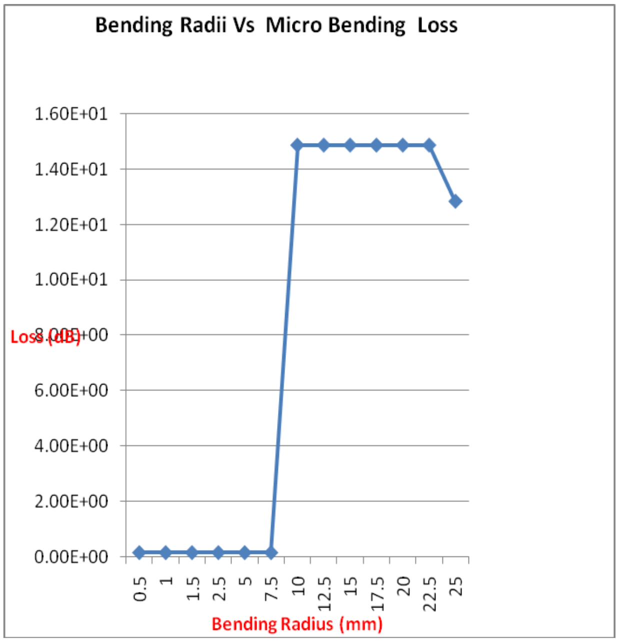


Fig 10 : Micro Bending Losses at various Bending Radii

For bending radii between 5mm to 10 mm, we get ultra minimum bending loss in the given fiber at 1550 nm wavelength. PMD and MFD analysis also show the same. Such fibers, when used for the specified wavelength and bending radius, BER suitable to the present industry standard is possible to achieve. Intranet applications are possible with higher bandwidth and much higher data rate.

6. REFERENCES

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