Effects of Macrobends on the Attenuation of Optical Signals in Multi-Mode Graded Index 62.5/125 µm Cable at 850 nm Wavelength

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Received: 14th Dec., 2011; Revised: 8th June., 2012; Accepted: 5th Oct., 2012

Abstract

In fibre optic transmissions, macrobend is a large visible bend in the optical fiber that can cause attenuation, a reduction of optical power in the glass. A relatively large- radius bend in an optical fibre may results to the degradation of the optical signal. In this paper, different magnitudes of circular macrobends in graded index 62.5/125 μm cable at 850 nm wavelength were used to determine the effect of macrobends on attenuation of signals. A special bending jig was used to produce circular bends ranging from 3mm to 200mm. The insertion method was used while attenuation (signal power loss) was measured in decibels (dB). Statistical analysis software (SAS) at a significant level of 5 per cent ($\alpha = 0.05$) and least significant difference (LSD) ranking method were used for data analysis. The findings showed that large magnitude of macrobend radii (above 40.0 mm) resulted in low attenuation (about 9.0 dB) of signals, while small size bend radii (about 3.0 mm) produced very high (about 40.0 dB) of signal losses. The research findings indicate that macrobends have significant effects on the attenuation of optical signals.

Key Words: Macrobend Attenuation, Optical Signal, Multi-Mode Fibre cable

Introduction

It is sometimes assumed intuitively that if a fibre is bent, then losses will be introduced into the transmission path. This is not true as the inside of a fibre is normally seen as a mirror to light rays, and slight bends in the fibre do not introduce losses. Losses occur only when the radius of the bend causes the light ray to be incident at an angle less than the critical angle. There are two types of bends that cause losses in optical fibers, namely microbend loss and the macrobend loss. This research investigated Effects of Macrobends on the Attenuation of Optical Signals in Multi-Mode Graded Index 62.5/125 µm Cable at 850 nm Wavelength.

A microbend, is a bend radius equal to, or less than, the diameter of the bare fibre and is generally a manufacturing problem and also due to environmental effects. A typical cause is the differential expansion of the optic fibre and the outer layers. For example if the fibre gets too cold, the outer layers will shrink and get shorter. If the core/cladding shrinks at a slower rate, it is likely to kink and cause a microbend. With careful choice of the optical fibre to be installed, microbends are less likely to be a problem compared to the macrobending losses which are caused during installation since optical fibre cables are readily available with a wide range of operating temperatures from –55°C to +85°C (Crisp, 2001).

The micro bending loss takes the form of very small sharp bends (kink) in the cable, which may be caused by imperfections in the cladding, ripples in the core/cladding interface, tiny cracks in the fibre and external forces. The external forces may be due to heavy, sharp objects being laid across the cable or caused by the cable being pinched, as it is pulled through a tight conduit. As the light ray travels through the fibre, once it meets the microbend it may strike the bend at an angle less than the critical angle and will be refracted into the cladding.

Macrobends are bends having a large radius of curvature relative to the optical fibre diameter. Figure 1 shows an exaggerated schematic drawing of a bent fibre illustrating a typical macrobend usually imposed on the fibres during installation, maintenance and general handling.

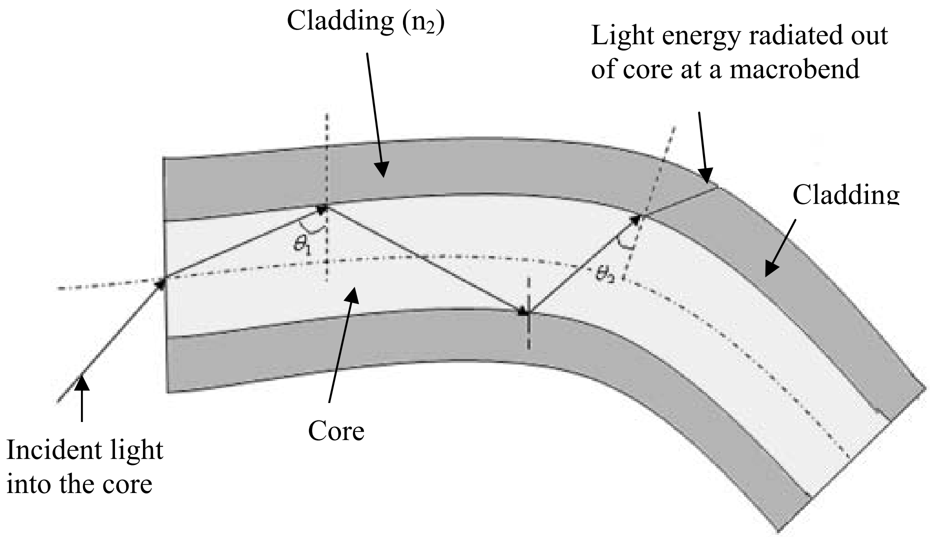

Figure 1: Light Energy Radiated Out of Core at Macrobend (Adapted from Crisp, 2001)

In the straight section of the fibre cable, the angle of incidence at the core/cladding boundary θ_1 macrobend location, the angle of incidence θ_c is less than the critical angle. Hence, the light is refracted out of the core. To reduce damage to the cable and excessive bend related losses, the minimum bend radius is always quoted in the manufacturers' specifications as a general guide during installation. Two different figures are stated, a tighter bend is allowed for long term use since the cable will no longer be under stress once installation is complete. For internal cables meant to be used indoors, the minimum bend radius is specified as about 50 mm for long term use and 70 mm during installation. For external armored cables the figures are around 175 mm and 350 mm respectively (Crisp, 2001). In this research, the effect of the bend radii which a fibre may be subjected to, by the technicians during their day to day activities in handling the optical fibre cables were investigated. These macrobend induced losses have been reduced by the use of high numerical aperture (NA), specialty bend insensitive optical fibre as recommended by ITU-T (2006). Optical signal propagation loss has been extensively studied but the losses due to macrobend and those due to the fibre surface fluctuations have not been fully evaluated in real systems using long lengths of fibre (Martelli *et al.,* 2007). Macrobend sensing is performed in a variety of ways, most of them applied to structural and civil engineering (Kuang *et al.,* 2002), physics medicine physics medicine and rehabilitation (Gibbs and Assada, (2005); Lee and Kwon, (2001) and Munoz *et al*., (1995)].

The major advantages of fibre-optic sensors are their immunity to electromagnetic interference, flexibility, low weight, sensibility in remote distances and capacity of being multiplexed (Arrue *et al*., 2001).

Although modeling results on various fibre types have been published, no generally applicable bending loss model is available to describe the loss versus bend radius behavior (ITU-T, 2009). Losses due to bending at the visible light spectrum are more apparent than losses due to other effects, such as absorption (Quino and Confessor, 2005). In this research, the wavelength used was 850 nm which is invisible to the naked eye, to study the effect of macrobends on attenuation of signals in a multimode silica (glass) fibre cables. Such a research is necessary because managing signal attenuation is critical for running a network at optimal performance. Various theoretical methods exist to predict curvature loss in optical fibre waveguides (Marcuse, 1976; Harris and Castle, 1986; Schermer and Cole, 2007)

A fibre with a lower attenuation value will allow more power to reach its receiver than a fibre with higher attenuation. If the light source and the power meter are calibrated in watts and the input power into the fibre is P_{in} while that at the output is P_{out}, then the attenuation in dB in the fibre link is given by (Young, 1992):

$$\text{Attenuation(dB)} = -10log_{10}\frac{P_{out}}{P_{in}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where:

P_{out} = measured output power level.

P_{in} = measured input power level

Attenuation is the loss of optical power usually measured in decibels (dB). Over any fixed distance, a fiber with a lower attenuation value will allow more power to reach its receiver than a fiber with higher attenuation. The attenuation in the optical link will be computed as the difference between the two power levels at a particular. Attenuation is usually expressed in dB/km. The attenuation in the optical fibre under test is the difference between the two measurements and is given by (Crisp, 2001);

$$\text{Attenuation in dB} = P_1 - P_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

where:

P_1 = Power level in dBm at the input of the fibre under test.

P_2= Power level in dBm at the output of the optical fibre under test.

Materials and Methods

The experimental setup for the insertion method, shown in Figure 2 was used during data collection because it is easy to use in the field and does not involve cutting the fibre and re-splicing as in the cut back method (Crisp, 2001). The multi-mode, graded index, 62.5/125 µm was used for this research. Its protruding length, which had straight tip (ST) connectors already fitted were straightened to ensure no sharp bends were present. One end of the cable was plugged into the power meter. The other end of the cable was plugged into one side of an ST-ST inline adapter. The multi-mode, graded index, 62.5/125 µm patch cord was selected and one end was then plugged into the other side of the ST-ST inline connector adapter. The other end of the patch cord was plugged into the output port of the light emitting diode (LED) light source, which had an ST connector adapter already screwed on its output port. The complete experimental setup is shown in Pate 3.1.The light source was then switched on and the transmitted signal waveform was set (using the waveform selector switch) to CW. The signal power level was adjusted (using the power adjust knob) to the maximum value, to allow for the excessive attenuation anticipated during the experiment. The power meter was switched on and the dBm power level units selected. The set of power levels, P_2 recorded were used to compute the no bend attenuations shown in Table 4.1, expected to be the lowest and thus acted as the control for the experiment.

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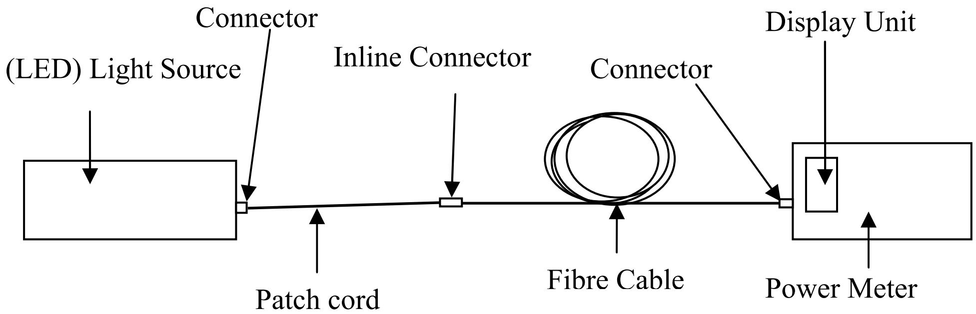
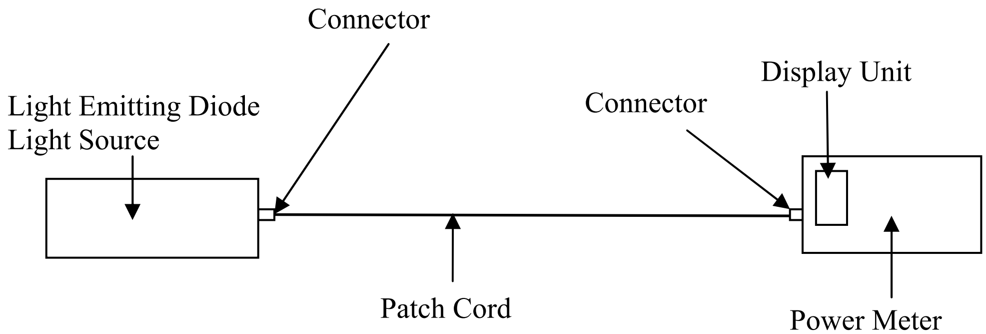


(a) P_2- Measurement Setup



(b) P1-Measurement Setup

Figure 2: Insertion Method Setup (Adapted from Bailey and Wright, 2003)

Further, the cable end next to the inline adapter was placed in the bending jig Figure 3. The bending jig was adjusted, while the diameter was read off a fixed scale rule on the frame (not shown in the sketch). The diameters ranged from 3 mm to 200 mm. Diameters smaller than 6 mm were found to break the fibre cable and hence were not used in the research. The received power level in dBm was recorded as P_2 in dBm. The procedure was repeated using the 10 mm, 14 mm, 20 mm, 26 mm, 32 mm, 38 mm, 43 mm, 56 mm, 67 mm, 73 mm, 85 mm, 98 mm, 110 mm, 161 mm, 167 mm, 190 mm and 200 mm diameters. The setup was not disturbed after the readings were recorded and the light source and power meter were then switched off and the time of switch off noted. The data collection procedure was paused for a time period of one hour. This time interval was determined from experience and was found to be enough to allow the Light source; the Power meter and the Cable under test enough time to reset to their normal rest condition. Thus, one hour after switch off, the light source and the power meter were switched on and the P_2 power level measurements were recorded a second time. The procedure was repeated in order to record four replications at each bend radius. The mean attenuation at different magnitudes of circular macrobend radii at a wavelength of 850 nm were computed (using equation 2.2) and recorded in Table 4.1

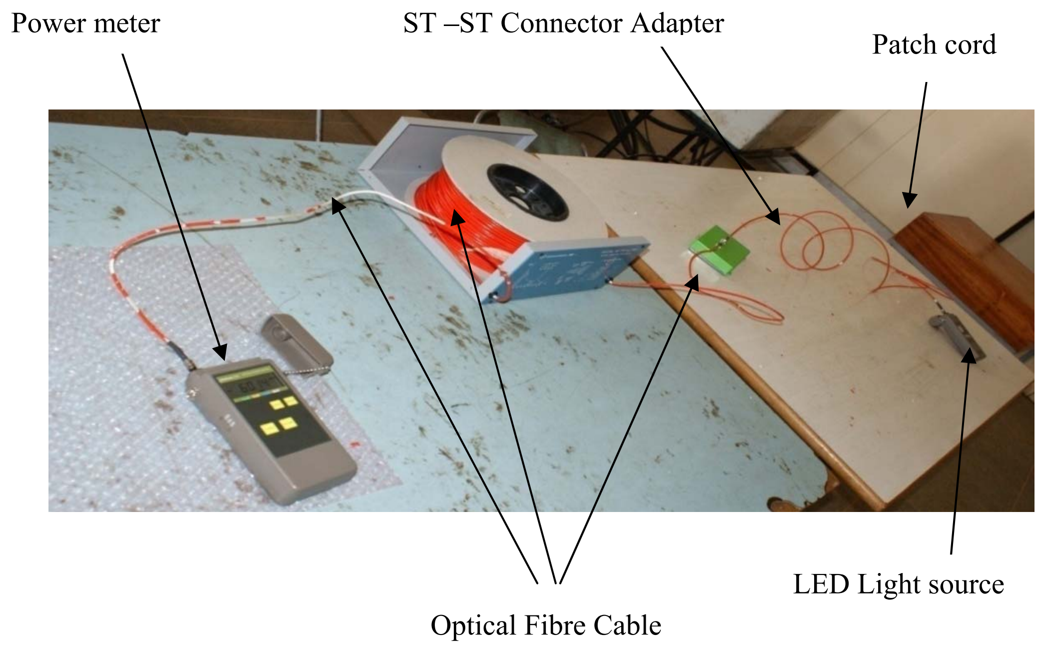


Plate 3.1 Experimental Setup for P_2 Measurement

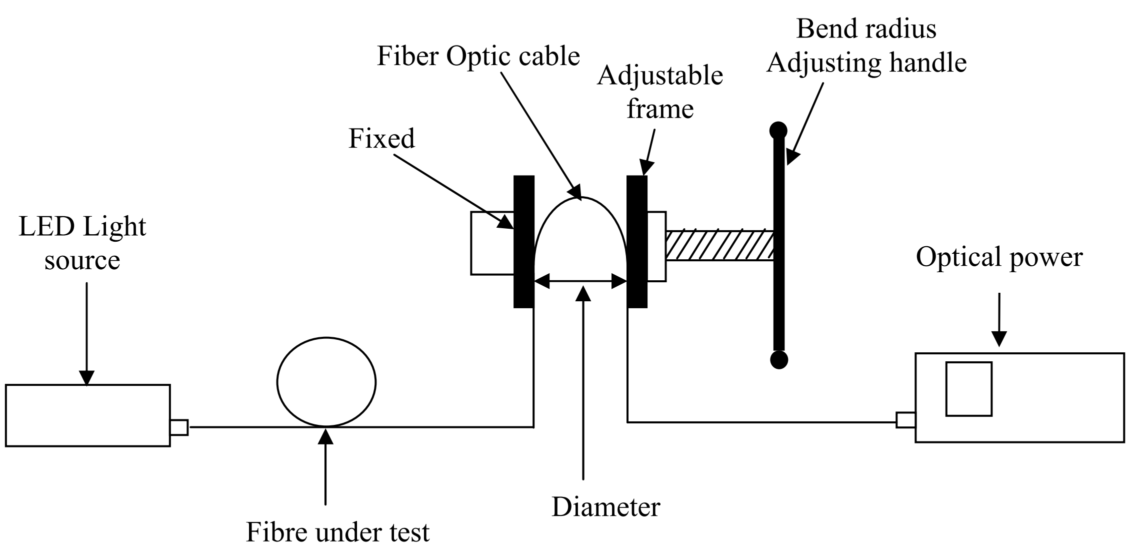


Figure 3: Experimental Bending jig

Results and Discussions

The attenuations of optical signals at wavelength of 850 nm, in a multi mode, graded index 62.5/125 μm cable versus circular macrobend radii are recorded in Table 4.1

Table 4.1: Attenuation in dB against Bend radii in mm

Radius(mm)	**Replications**				**Attenuation Mean**
	R_1	**R_2**	**R_3**	**R_4**	
3.00	37.11	37.11	37.78	37.12	37.28
5.00	24.67	24.89	25.56	24.88	25.00
7.00	16.44	16.44	17.11	16.45	16.61
10.00	13.33	13.12	13.78	13.12	13.34
13.00	11.33	11.56	12.00	11.34	11.56
16.00	10.44	10.44	11.10	10.22	10.55
19.00	10.01	10.00	10.89	10.23	10.28
21.50	9.56	9.56	10.22	9.56	9.73
28.00	9.33	9.33	10.22	9.11	9.50
33.50	9.11	9.11	10.00	8.89	9.28
36.50	8.89	9.11	10.00	8.89	9.22
42.50	8.89	9.11	10.00	8.89	9.22
49.00	8.89	9.11	10.00	8.89	9.22
55.00	8.89	9.11	10.00	8.89	9.22
80.50	8.89	9.11	10.00	8.89	9.22
83.50	8.89	9.11	1 .00	8.89	9.22
95.00	8.89	9.11	10.00	8.89	9.22
100.00	8.89	9.11	10.00	8.89	9.22

The graph in Figure 4 shows attenuation values plotted against bend radii. The bend radii ranged from the smallest value (3.00 mm) to the largest value (100.00 mm). The mean attenuation ranged from the highest value (37.28 dB) corresponding to the 3.00 mm bend radius, to the lowest value (9.22) for the 100.00 mm radius.

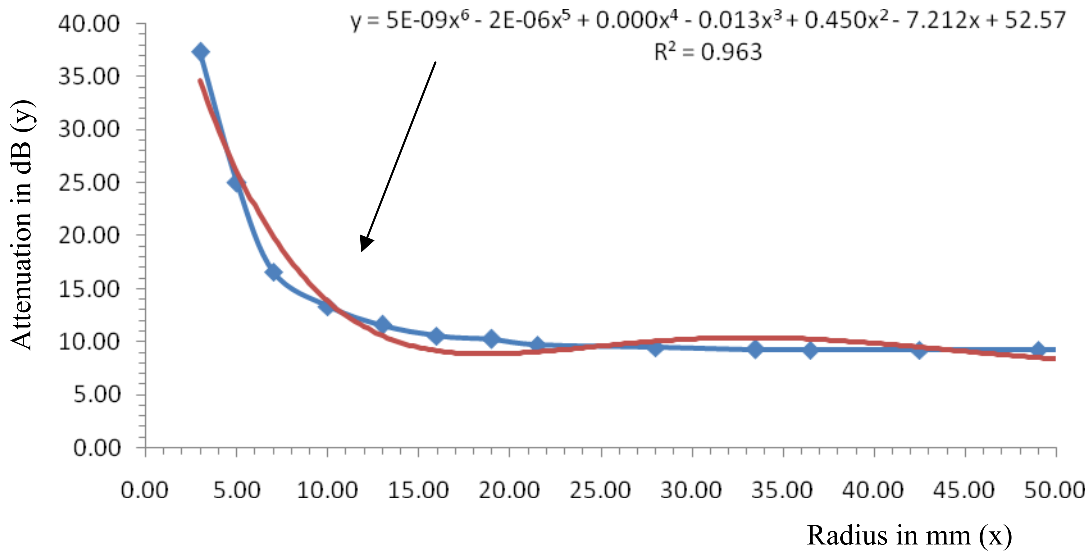


Figure 4: Attenuation against Circular bend Radius

Figure 4 shows that, attenuation remained unchanged (at 9.22 dB) as the radius was decreased from 100.00 mm to 36.50 mm, giving a horizontal plot. The radius axis was therefore truncated as indicated. The attenuation gradually increased from 9.22 dB mm to 16.61 dB as the bend radius was reduced from 36.50 dB to 7.00 mm respectively. The power loss was observed to rise steeply from 16.61 dB to 37.28 dB as the bend radius was reduced from 7.00 mm to 3.0 mm respectively. The trend line superimposed on the curve shows that the attenuation versus macrobend radii could be represent by a polynomial of order 6 Correlation coefficient $(R^2 = 0.963)$ is quite high. This is an indication of very good correlation of the collected data.

The data analysis [using Statistical analysis software (SAS, 2008) at a significant level of 5% (alpha, $\alpha = 0.05$)] results, in Table 4.2, show that at a least significant difference (LSD) of 0.04.

Table 4.2: Mean Attenuation against circular macrobend radii

Radius(mm)	Attenuation
3.00	37.28 [a]
5.00	25.00 [b]
7.00	16.61 [c]
10.00	13.34 [d]
13.00	11.56 [e]
16.00	10.55 [f]
19.00	10.28 [g]
21.50	9.73 [h]
28.00	9.50 [i]
33.50	9.28 [j]
36.50	9.22 [k]
42.50	9.22 [k]
49.00	9.22[k]
55.00	9.22[k]
80.50	9.22[k]
83.50	9.22[k]
95.00	9.22 [k]
100.00	9.22 [k]
LSD	0.04

Means with the same letter in the column are not significantly different at a level of significance of 5%.

The implication of the above findings is that large bend radii (above 36.00mm) have no significant effect on signal power loss. This means that the optical fibre cable may be bent round circular bends having radius of curvature above 36.00 mm with no danger of signal deterioration. Therefore, bend radii above 36.00 mm may be assumed to be equivalent to a straight cable. This agrees well with the manufacturer's choice of the drum of 195 mm diameter for coiling the sample fibre cable in Plate 3.1. It can also be deduced that due to the gradual rise of signal power loss from 9.22 dB at 36.50 mm to 16.61 dB at 7.00 mm the bend radii smaller than 36.00 mm have a significant effect on the signal attenuation. The larger the bend radii the lower the resultant power loss while the smaller the radii the higher the resultant attenuation. The bend radii between 36.00 mm and 7.00 mm could be used when laying the optical fibre cable, but the network planning engineer specification should be strictly adhered to so as to avoid excessive signal degradation. The steep rise of attenuation from about 16.61 dB at 7.00 mm bend radius to beyond 37.00 dB at 5.00 mm radius indicates that the optical fibre should not be bent to bend radii smaller than 7.00 mm if reliable communication system is to be maintained. The critical bend radii for this cable should be 7.00 mm. This suggestion compares well with other findings (Quino and confessor, 2005; Schermer and Cole, 2007; Martelli *et al*, 2007).

Conclusions

The findings show that macrobends, wavelengths and type of optical fibre cables have significant effects on power loss of signals. It was found out that large magnitude circular macrobends (above 36.00 mm have no effect on attenuation of signals whereas small magnitude macrobends (smaller than 36.00 mm) have a significant effect on signal attenuation. However macrobends radii in the range 36.00 mm to 7.00 mm could be allowed with consultation with the network planning engineers. The critical bend for this cable was found to be 7.00 mm. This implies that circular bends of 7.00 mm or less should never be applied on a telecommunication cable in service.

Recommendations

The research output would recommend bend radii equal to or larger than 40 mm to be used while negotiating corners in buildings. This may benefit the implementation of the Fibre-to-the-desk (FTTD), Fibre-to-the-home (FTTH), applications if ordinary multimode graded index 62.5/125 will be used.

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